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EARLY CRETACEOUS HIGH LATITUDE MARINE REPTILE ASSEMBLAGES FROM SOUTHERN AUSTRALIA

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ABSTRACT

The Lower Cretaceous (Aptian-Albian) southern high latitude deposits of Australia have yielded a diverse range of marine reptile fossils. Ichthyosaurs and at least five distinct plesiosaur taxa have been recorded. Most of the current marine reptile specimens are derived from the predominantly Aptian Bulldog Shale and Wallumbilla Formation. These units, famous for producing opal, represent shallow epicontinental marine depositional environments. Fragmentary plesiosaur remains have also been recovered from high latitude non-marine deposits of the Wonthaggi, Eumeralla, and Griman Creek formations. These are Aptian to middle Albian in age, and comprise fine-grained fluviatile/estuarine sediments laid down in inland rift valleys and coastal flood plains near the Cretaceous southern polar circle. Estimates of palaeolatitude place most of southern Australia at around 60º to 80º S during the late Early Cretaceous. Sedimentary structures, fossils, isotope data, and climatic modeling indicate highly seasonal cool-cold conditions possibly with winter freezing. This contrasts markedly with climate regimes typically tolerated by modern aquatic reptiles, but suggests that some Mesozoic forms may have possessed adaptations to cope with low average water temperatures.

INTRODUCTION

Australian marine reptile fossils are common although currently poorly documented. At present, most of the described material is derived from extensive Early Cretaceous epicontinental marine rocks in northeastern Australia (Kear 2003). In recent years however, a number of fragmentary specimens have been recovered from Lower Cretaceous marine/non-marine sequences in the southern part of the continent (Figure 1). These fossil-producing strata include – 1) the Aptian-Lower Albian Wonthaggi (Gippsland Basin) and Eumeralla (Otway Basin) formations, southern Victoria; 2) Aptian Wallumbilla Formation (Eromanga Basin), White Cliffs, New South Wales; 3) Lower Aptian-Lower Albian Bulldog Shale (Eromaga Basin), northern South Australia; 4) Lower-middle Albian Griman Creek Formation (Surat Basin), Lightning Ridge, New South Wales/Surat region, Queensland. Interestingly, these units were deposited in an Early Cretaceous high latitude zone (60º-80º S), subject to highly seasonal cool to cold conditions and months of winter darkness near the southern pole.

Several previous reports have discussed Australian Early Cretaceous high latitude marine reptile fossils (e.g. Rich et al. 1988; Kear 2003, 2004, 2005, 2006). Despite this, relatively few specimens have been thoroughly described. It is therefore the purpose of this article to present an up to date summary of the Australian record and assess its palaeobiological/palaeoecological implications; this is intended as a companion for more detailed studies currently being undertaken by BPK (see Kear 2003).

Abbreviations—AM, Australian Museum, Sydney, NMV, Museum of Victoria, Melbourne, SAM, South Australian Museum, Adelaide.

GEOLOGICAL AND PALEOENVIRONMENTAL SETTING

The Wonthaggi Formation (Strzelecki Group) and middle Eumeralla Formation (Otway Group) comprise finely laminated sandstones and mudstones with locally abundant horizontally stratified fossiliferous claystone/mudstone conglomerates. The deposits were laid down by meandering to braided river systems in a mid-Cretaceous rift valley flood plain, which formed as

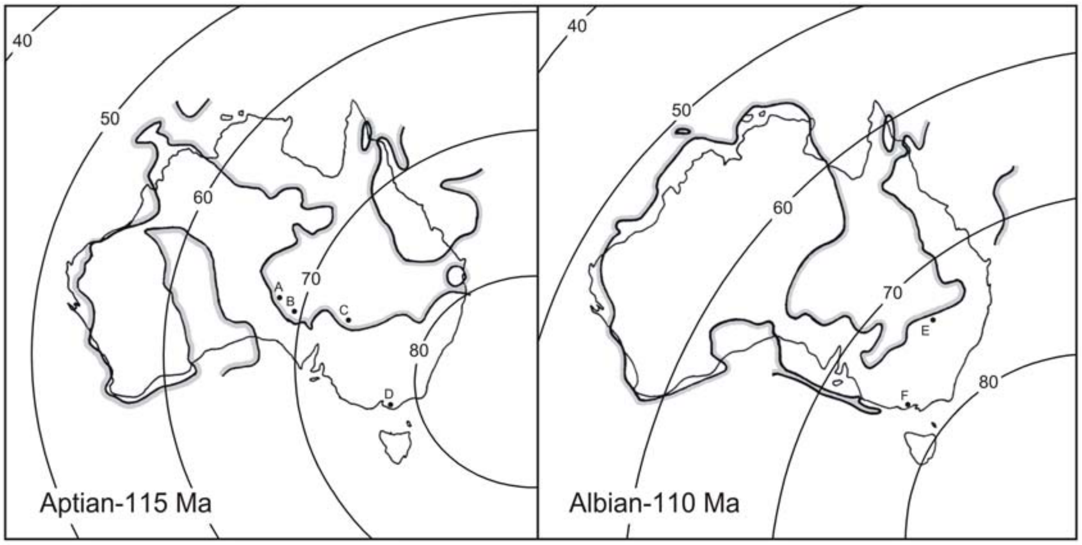

FIGURE 1. Maps showing Australian Early Cretaceous high latitude marine reptile localities (A-F) with paleoshorelines (bold) and paleolatitudes (from Embleton 1984) for Aptian and Albian stages. A, Coober Pedy, South Australia (Bulldog Shale); B, Andamooka, South Australia (Bulldog Shale); C, White Cliffs, New South Wales (Wallumbilla Formation); D, Inverloch and Cape Patterson, southern Victoria (Wonthaggi Formation); E, Lightning Ridge, New South Wales (Griman Creek Formation); F, Cumberland River and Dinosaur Cove, Cape Otway, southern Victoria (Eumeralla Formation).

a result of the onset of rifting between Australia and Antarctica (Veevers 1984; Mutter et al. 1985). Age estimates place the Wonthaggi Formation within the Aptian upper *Cyclosporites hughesii* spore-pollen Subzone, and Eumeralla Formation within the Late Aptian-Early Albian *Crybelosporites striatus* spore-pollen Subzone (Wagstaff and McEwan Mason 1989).

The stratigraphically contemporaneous epicontinental marine deposits of the Bulldog Shale (Marree Subgroup) and Wallumbilla Formation (Rolling Downs Group) are currently the most productive sources for Australian Early Cretaceous high latitude marine reptile fossils. These laterally equivalent units comprise finely laminated mudstones and claystones (commonly pyritic and carbonaceous) laid down under transgressive coastal shallow marine conditions (Krieg and Rogers 1995). Rich macroinvertebrate (Ludbrook 1966) and palynomorph (Alexander and Sansome 1996) assemblages have been used to determine an Early Aptian-Early Albian age: *Cyclosporites hughesii*, *Crybelosporites striatus* spore-pollen zones/ *Odontochitina operculata*, *Diconodinium davidii*, *Muderongia tetracantha* dinoflagellate zones (Helby et al. 1987). However, at some localities including Coober Pedy, Andamooka and White Cliffs, severe weathering has destroyed most microfossil remains. Nevertheless, an Aptian age can be suggested on the basis of key macroinvertebrate index taxa (see Ludbrook 1966; Burton and Mason 1998).

The Griman Creek Formation (Rolling Downs Group) is dominated by lithic glauconitic sandstones, siltstones and mudstones. Characteristic molluscan fossils, cross-bedding, plant root impressions and vertebrate taphonomy indicate a coastal plain fluviatile/estuarine depositional setting (Dettmann et al. 1992). Burger (1980) determined the age of the Griman Creek Formation as Early-middle Albian, corresponding to the *Coptospora paradoxa* spore-pollen Zone of Helby et al. (1987).

Estimates of paleolatitude place southern Australia near the southern polar circle (about 60º-80º S, Embleton 1984) throughout much of the Jurassic-Cretaceous. Palaeoclimatic indicators suggest highly seasonal cool-very cold (possibly with winter freezing) conditions during deposition of Aptian-Early Albian sequences (Douglas and Williams 1982; Frakes and Francis 1988, 1990; Gregory et al. 1989; Frakes et al. 1995; Constantine et al. 1998; De Lurio and Frakes 1999). Younger middle-Late Albian sediments, however, are thought to correspond to a much warmer temperate climatic period (Dettmann et al. 1992).

SUMMARY OF LOCALITIES AND REPRESENTATIVE TAXA

Wonthaggi Formation/Eumeralla Formation

Major Localities—Inverloch and Cape Patter-son, southern Victoria (Wonthaggi Formation); Cumberland

River and Dinosaur Cove, Cape Otway, southern Victoria (Eumeralla Formation).

Age—Wonthaggi Formation, predominantly Aptian upper *Cyclosporites hughesii* spore-pollen Subzone; Eumeralla Formation, Late Aptian-Early Albian *Crybelosporites striatus* spore-pollen Subzone.

Paleolatitude—Wonthaggi Formation (Strzelecki Group deposits), 77.8ºS; Eumeralla Formation (Otway Group deposits), 66.8ºS (minimum estimates; see Whitelaw 1993).

Paleoenvironment—Rift valley flood plain with predominantly meandering to braided up-stream river systems incorporating occasional high-flow regimes (Wonthaggi Formation); younger strata (Eumeralla Formation) dominated by braided river lithofacies with sporadic thick lacustrine deposits.

Recent References—Rich and Vickers-Rich (2000); Kear (2006).

Marine Reptile Taxa—Pliosauroidea indet. (represented mainly by isolated teeth).

Bulldog Shale

Major Localities—Numerous sites with most diverse faunas recorded from the opal mining areas of Coober Pedy and Andamooka, northern South Australia.

Age—Early Aptian-Early Albian *Cyclosporites hughesii*, *Crybelosporites striatus* spore-pollen zones/*Odontochitina operculata*, *Diconodinium davidii*, *Muderongia tetracantha* dinoflagellate zones. Opal-bearing strata are predominantly Aptian as indicated by macroinvertebrate assemblages (Ludbrook 1966).

Paleolatitude— ~60º-70ºS (Embleton 1984).

Paleoenvironment—Shallow, near-shore marine.

Recent Reference—Kear (2003).

Marine Reptile Taxa—Ophthalmosauridae: *Platypterygius* sp.; Rhomaleosauridae: *Leptocleidus*-like taxon; Pliosauridae: *Kronosaurus* sp.; Elasmosauridae indet.; Cryptocleidoid: *Kimmerosaurus/Aristonectes*-like intermediate taxon.

Wallumbilla Formation

Major Localities—Marine reptile remains occur throughout the Wallumbilla Formation although Cretaceous southern high-latitude occurrences are best known from the opal mining area of White Cliffs, northwestern New South Wales.

Age—Early Aptian-Early Albian *Cyclosporites hughesii*, *Crybelosporites striatus* spore-pollen zones/*Odontochitina operculata*, *Diconodinium davidii*, *Muderongia tetracantha* dinoflagellate zones. Opal-bearing strata at White Cliffs are Aptian as indicated by macroinvertebrate assemblages (Burton and Mason 1998).

Paleolatitude— ~60º-70ºS (Embleton 1984).

Paleoenvironment—Shallow, near-shore marine.

Recent Reference—Kear (2005).

Marine Reptile Taxa—Ophthalmosauridae: *Platypterygius* sp.; Pliosauridae: *Kronosaurus* sp.; Elasmosauridae indet.; Polycotylidae indet.

Griman Creek Formation

Major Localities—Lightning Ridge opal fields, northern New South Wales and Surat region, southern Queensland.

Age—Early-middle Albian, *Coptospora paradoxa* spore-pollen Zone.

Paleolatitude— ~70ºS (Embleton 1984).

Paleoenvironment—Coastal plain fluviatile/ estuarine system with ox-bow lakes and possibly coastal lagoons.

Recent References—Smith (1999); Kear (2006).

Marine Reptile Taxa—Pliosauroidea indet. (represented by isolated teeth and fragmentary postcranial elements).

DISCUSSION

The marine reptile fossils from southern Australia constitute one of a number of recognized finds from Cretaceous high-latitude deposits. Examples are known from New Zealand (Welles and Gregg 1971; Wiffen and Moisley 1986; Cruickshank and Fordyce 2002; Wilson et al. 2005), the Chatham Islands (Wilson et al. 2005), Patagonia (see Gasparini et al. 2003 for summary), Antarctica (Chatterjee and Small 1989; Martin et al. 2002), and the Canadian arctic (Nicholls and Russell 1990; Vandermark et al. 2006). Amongst the currently documented material, that from the Early Cretaceous units of southern Australia is unusual because it is found in direct association with paleoclimatic indicators (e.g. cryoturbated sediments, tillites, glacial erratics, glendonites and densely growth-banded wood) denoting seasonally very cold to near freezing conditions (see Frakes and Francis 1988, 1990; Dettman et al. 1992; Frakes et al. 1995; Constantine et al. 1998; De Lurio and Frakes 1999; Alley and Frakes 2003). Such climate regimes contrast markedly with those typically tolerated by modern aquatic reptiles, but suggest that some Mesozoic forms

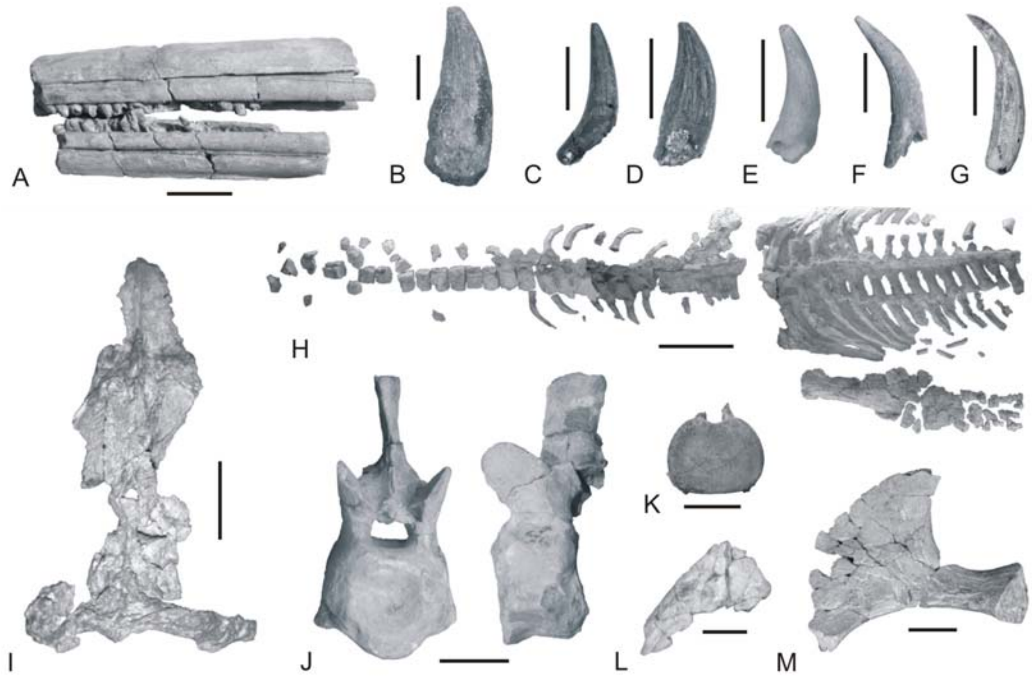

FIGURE 2. Marine reptile remains from Early Cretaceous high latitude deposits in southern Australia. A, Ichthyosaur (*Platypterygius* sp.) snout and mandible sections (SAM P14508), Marree, South Australia (Bulldog Shale); B, pliosaurid (*Kronosaurus* sp.) tooth (AM L580), White Cliffs (Wallumbilla Formation); C-F, indeterminate pliosauroid tooth crowns C (NMV P186416), Dinosaur Cove, (Eumeralla Formation), D (NMV P186376), Inverloch (Wonthaggi Formation), E (AM F121720), F (AM F121679), Lightning Ridge (Griman Creek Formation); G, cryptocleidoid tooth, and H, partial skeleton (SAM P24560), Andamooka (Bulldog Shale); I, partial skull (dorsal view) of *Leptocleidus*-like pliosauroid (AM F99374), Coober Pedy (Bulldog Shale); J, polycotylid cervical vertebrae (AM F6269) in anterior and lateral views, White Cliffs (Wallumbilla Formation); K-M, indeterminate elasmosaurid remains (Bulldog Shale), K, cervical centrum (SAM P39618), Mt Carlootana, South Australia, L clavicular arch (SAM P34156), Coober Pedy, M, scapula (SAM P14539), Andamooka. Scale bars for A, I, K-M equal 50 mm, B-G, J equal 20 mm, H equals 500 mm.

were able to cope with low average water temperatures. Exactly, what adaptations (if any) allowed these diverse taxa (ichthyosaurs and plesiosaurs) to survive is unknown. However, specialized physiological mechanisms (e.g. endothermy or inertial homeothermy) and/or behavioural strategies (e.g. seasonal migration) might have facilitated their successful exploitation of coldwater habitats in both inland river systems, and along the southern coastal margins of the Australian Cretaceous epicontinental seaway.

Of the marine reptile clades currently recorded from Australia's Cretaceous high-latitude deposits, plesiosaurs are by far the most diverse (represented by up to five families), and are the group most frequently occurring as fossils. Plesiosaurs also form a principal element in Upper Cretaceous high-latitude assemblages from both the Northern Hemisphere (Nicholls and Russell 1990) and Antarctica (Martin 2002). The reasons for this apparent faunal domination are unclear, but may be related to a greater tolerance by certain clades and/or taxa (i.e. plesiosaurs) for colder water environments. Conversely, the prevalence of cold-near freezing conditions in at least the southern reaches of the Australian Cretaceous epicontinental seaway during Late Neocomian-Early Albian (Frakes and Francis 1988) might have provided an effective barrier to the successful dispersal of other groups including chelonioid turtles, which are conspicuously absent from the Australian Cretaceous record prior to the uppermost Albian (Kear 2003, 2004; Kear and Lee 2006). Nicholls and Russell (1990) and Martin (2002) documented a similar pattern in the Upper Cretaceous deposits of North America and Antarctica respectively, where chelonioids, some mosasaurid taxa, and sharks (the latter in North American units only) showed distributions conforming to strict latitudinal boundaries (becoming rarer with increasing latitude). This was interpreted as a product of temperature restricted distribution, particularly in the case of marine turtles, in which prevailing water temperature is a critical factor in controlling the availability of nesting sites in some taxa (see Mrosovsky 1980).

The taxonomic composition of the Australian Early Cretaceous high latitude marine reptile fauna highlights its transitional nature, and comprises a mixture of cosmopolitan and locally endemic taxa. For example, the ophthalmosaurid ichthyosaur *Platypterygius* is documented from many localities around the world (McGowan, 1972), and the large pliosaurid *Kronosaurus* has been recorded from Aptian-Albian strata in both Australia and South America (Hampe 1992). Conversely, potentially endemic forms include an enigmatic cryptocleidoid (representing a possible structural intermediate between the European Jurassic *Kimmerosaurus* and Late Cretaceous austral high latitude taxon *Aristonectes*; see Kear 2003), an archaic *Leptocleidus*-like rhomaleosaurid, and possibly one of the earliest known polycotylids. This suggests that isolating barriers (perhaps including climate) were in effect, and that these may have prompted the evolution of new taxa and clades, such as the Polycotylidae, which appears to have had its origins (or at least early evolution) in the high latitude epicontinental seas of eastern Gondwana sometime in the Neocomian-Early Albian (Kear 2005).

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