

## Discussion and Reply

# Sequence stratigraphic analysis of Early and Middle Triassic alluvial and estuarine facies in the Sydney Basin, Australia

### DISCUSSION

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Sequence stratigraphy can be a powerful tool for stratigraphic correlation and palaeoenvironmental reconstruction. It is good to see the application of this technique by Herbert (1997) to Triassic sequences in the Sydney Basin. However, two problems with his particular analysis invite comment.

First is the absolute dating of stratigraphic sequences pegged to an Early–Middle Triassic (Scythian–Anisian) boundary of 240 Ma. Dating of this boundary has bounced around quite a bit in recent years (Gradstein *et al.* 1995), but high-precision dates from Triassic rocks of New Zealand and eastern Australia indicate that the Scythian–Anisian boundary was more like 245 Ma (Retallack *et al.* 1993). The new  $^{40}\text{Ar}/^{39}\text{Ar}$  single-crystal laser age for the Dalmally Basalt Member of the Clarence–Moreton Basin, and by inference the Middle Triassic (late Anisian–Ladinian) flora above and below this flow, is  $237 \pm 0.4$  Ma, a considerable difference from a problematic old K/Ar date from the same rock specimen of  $211 \pm 5$  Ma. Another new  $^{40}\text{Ar}/^{39}\text{Ar}$  age from an upper Etalian (Anisian) tuff near Dipton, New Zealand was  $242.8 \pm 0.8$  Ma (Retallack *et al.* 1993).

A second and more serious problem is Herbert's (1997) resurrection of Conolly's (1969) interpretation that redbeds of the Sydney Basin were deposits of estuaries and marine bays. This is fundamental to his analysis because redbeds are then taken as markers of maximal marine transgression in this largely fluvial sequence. As evidence for this proposition a variety of marine microfossils and trace fossils are cited, but none in my view indicates marine or even brackish conditions. Trace fossils in the Bald Hill Claystone include a variety of burrows and tracks that can be attributed to the activity of reptiles, amphibians, crayfish, insects and worms, but no definitively marine traces (Naing 1993). Because they are all within palaeosols, I regard all of these as traces of soil fauna (Retallack 1997a). Reports of coralline algae, foraminifers and holothurian sclerites from the Bald Hill Claystone and other Sydney Basin redbeds have never been illustrated or described, and I suspect that they are all variably ferruginised microspherulitic siderite (Retallack 1997a). There are reports of brackish to marine bivalves (Grant-Mackie *et al.* 1985), salt-marsh plants (Retallack 1997b) and trace fossils such as *Diplocraterion* and *Rhizocorallium* (Naing 1993) in the

Sydney Basin, but these are all in grey-green shale and sandstone of the Garie and Newport Formations (Retallack 1997a). Fossil horseshoe crabs and other plausible marine indicators in the Hawkesbury Sandstone and Wianamatta Group (Herbert 1997) are also in grey shales, not redbeds. My own field studies of redbeds have revealed abundant palaeosols in the Bald Hill Claystone near Long Reef and Garie, Patonga Claystone near Wamberal, Stanwell Park Claystone near Coalcliff, and the Wentworth Falls Claystone in Wollemi National Park and Boggy Swamp along the Putty road. Furthermore the palaeosols are deeply weathered, strongly oxidised and have deeply penetrating root traces indicating good drainage and exposure for tens to hundreds of thousands of years (Retallack 1997a). By this interpretation Sydney Basin redbeds were terraces and hills, not bays. They formed at times of marine lowstands, not highstands. Sea-level highstands were thus less numerous or profound, and at different times than indicated by Herbert (1997). Palaeosols have only recently begun to be incorporated into sequence-stratigraphic models (Wright & Marriot 1988; Retallack 1998). The profound difference they can make is well illustrated by the divergent interpretations of Herbert (1997) and Retallack (1997a).

### REPLY

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Retallack is concerned with two aspects of the sequence stratigraphic analysis of the Early to Middle Triassic in the Sydney Basin. First, the ages of the proposed sequence boundaries and secondly the environmental interpretation of redbeds in the Narrabeen Group.

I thank Retallack for bringing my attention to the discussion of the Triassic time-scale by Gradstein *et al.* (1995). However, being a year after the 1994 submission of my manuscript I unfortunately could not include a rational discussion of its significance to the Sydney Basin. Age estimates for sequence boundaries in Herbert (1997) relied on the then latest comprehensive analysis of Pangean basins by Veevers *et al.* (1994), available only just before submission of the manuscript. They suggested that the age of the Scythian–Anisian (Early–Middle Triassic) boundary was about 240 Ma, coincident with the base of the Garie Formation (base sequence D). Retallack prefers an age of 245 Ma for this boundary, presumably implying that the ages of the other proposed sequences also need modifying.

His quoted, more recent argon date of 237 Ma for the Late Anisian–Ladinian flora in the Clarence–Moreton Basin is in good agreement with the proposed age of sequence F as shown in figure 3 (Herbert 1997). However, an argon date of about 243 Ma for an Anisian tuff from New Zealand (Retallack *et al.* 1993) indicates that the older age for the Scythian–Anisian boundary is more appropriate. If the Early Triassic spans about 5 or 6 million years (i.e. from 250 or 251 to 245 Ma), then the average time for the deposition of my four Early Triassic sequences A, B, C and D would be a little more than a million years each, similar to the duration of Late Permian sequences proposed for the Sydney Basin (Herbert 1995). Thus, Retallack's accepted age dating for the Early–Middle Triassic boundary requires no substantial change in the duration of sequences, whereas, the ages in Herbert (1997), from 250–240 Ma, require a sudden doubling in the duration of 3rd-order sequences across the Permo–Triassic boundary. Therefore, I share Retallack's concern regarding the dating of sequence boundaries. Hopefully more age data will resolve these interesting points.

Retallack's second concern is the interpretation that, in his words, '... redbeds of the Sydney Basin were deposits of estuaries and marine bays'. It must be emphasised that Herbert (1997) did not state, nor imply, that redbeds in the Narrabeen Group were deposited in marine bays. In addition not *all* redbeds were considered to have been of estuarine origin. Indeed the thrust of the paper is that deposition of all sediments, including interbedded redbeds, took place dominantly on an alluvial plain which graded seawards to an estuarine coastal plain landward of marine barriers. Abundant palaeosols, which occur throughout most of the Narrabeen Group, were developed on these sediments.

Retallack interprets the palaeosols, which are equated with redbeds, as terraces and hills, not as subaqueous deposits—a fundamental point as it relates to base-level change. The most intense palaeosols which developed on the redbeds were definitely exposed as widespread and variably well-drained, low-relief terraces (but not hills) as base-level fell. However, the redbeds and other drab coloured (green and grey) sediments on which the palaeosols developed had a prior depositional history as low-level floodplain to estuarine sediments deposited during higher base-levels.

Retallack ascribes a variety of burrows and tracks in the redbed Bald Hill Claystone as traces of soil fauna '... Because they are all within palaeosols ...'. They are not *all* within palaeosols—as Naing (1990, 1993) and Herbert (1997) have observed. Many trace fossils considered indicative of fluvial to estuarine environments in the Bald Hill Claystone and throughout the Narrabeen Group occur in a variety of sediments (both red and drab coloured) that retain stratification and/or appear completely unaffected by pedogenesis. Most of the fossils and trace fossils listed in Herbert (1997) do not occur within palaeosols, although some do. It is clear that there is indeed a mix of freshwater and marine forms indicative of a transition from fluvial to estuarine environments in the Narrabeen Group. These are a mix of terrestrial and shallow subaqueous environments typically prone to repeated hiatus, exposure, and modification by pedogenesis.

All red-coloured sediments are not palaeosols. Red colouration occurs in a variety of depositional settings ranging from bathyal to shallow marine, estuarine, lacustrine, fluvial, evaporative and terrestrial environments. Retallack's assumption that redbeds in the Narrabeen Group are all palaeosols masks the real complexities. Palaeosols are not primarily depositional entities. They generally developed on, and pedogenically altered, pre-existing red, green and grey sediments that may have been deposited in a variety of environments. The pre-existing sediments can be completely unrelated to subsequent exposure and soil development. Retallack appears not to accept that the sediments in which soil profiles occur had a prior depositional history.

I agree that palaeosols are common throughout most parts of the Narrabeen Group and indeed this is emphasised throughout. However, particularly in the Patonga Claystone, thick intervals of red shale and interbedded green-grey, fine-grained sandstone retaining much of their original layering are commonly strongly bioturbated and show no overprinting pedogenesis. Rare palaeosols indicate infrequent exposure. These redbeds are considered to have been deposited subaqueously in estuarine central bay and bayhead delta environments landward of a barrier system. Redbeds in the Bald Hill Claystone are considered to have been deposited in a similar environment, but in addition have multiple, strongly developed palaeosols throughout, indicating repeated exposure. Retallack appears to suggest that these dominantly red mudstone intervals, as much as 80–100 m thick, are primarily palaeosols. These intervals cannot have been deposited as palaeosols. They are simply redbed sediments that have been overprinted by pedogenesis at different horizons during base-level changes. The transition from pedogenically altered sediment downwards to unaltered sediment with well preserved primary sedimentary structures is obvious. The problem is not that we disagree that palaeosols are abundant throughout a large part of the Narrabeen Group, but that Retallack does not recognise a prior history for the red and drab coloured sediments on which the palaeosols are superimposed.

Retallack suggests that fossil horseshoe crabs are plausible marine indicators but that they occur only in grey shales in the Hawkesbury Sandstone and Wianamatta Group. However, Pickett (1984) described *Dubbolimulus peetae* from Middle Triassic redbeds of the Ballimore Formation near Dubbo, to the northwest of the Sydney Basin (stratigraphic equivalents of the upper Narrabeen Group). Unfortunately, Pickett (1984) succumbed to the circular reasoning that since all Triassic redbeds in New South Wales were presumed to be of fluvial or lacustrine origin that, therefore, *Dubbolimulus* must be of freshwater origin. This type of reasoning concerning the environmental habitat for fossils that may have originally inhabited estuaries is a real problem for sedimentologists who would like to use fossils as environmental indicators. For example, the fossil fish *Saurichthys* is a worldwide marine genus occurring in unequivocal marine sediments with ammonites (Beltan & Tintori 1980). However, two species which occur in the upper Narrabeen Group were regarded as lacustrine forms because Beltan and Tintori (1980) deferred to the then prevailing opinion that only fluvial and lacustrine environments were present. Thus

while I share Retallack's concern about environmental interpretations, it may be necessary to review the validity of previous conclusions which appear to be incompatible with more recent sedimentological evidence. In order to arrive at a reasonable palaeoenvironmental interpretation, fossil evidence alone is often inconclusive, especially in transitional estuarine environments, and must be considered together with sedimentological and other evidence.

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