A POTENTIAL GONDWANAN POLAR JEHOL BIOTA LOOKALIKE IN VICTORIA, AUSTRALIA

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The Early Cretaceous Jehol Biota from northeastern China has produced an abundance of well preserved birds, mammals and feathered dinosaurs, amongst other fossils. The similarities in the nature of the deposits producing these fossils to the lacustrine facies of the Strzelecki Group of southwest Gippsland, Victoria, Australia suggests that a prolonged, systematic search of those rocks in Australia could yield fossils of similar quality.

Key words: Early Cretaceous, Jehol Biota, China, Australia, Gondwana.

THE EARLY CRETACEOUS JEHOL BIOTA from western Liaoning Province, People's Republic of China, in the past two decades has become the richest known source of feathered dinosaurs, birds, pterosaurs and mammal skeletons of the Mesozoic Era (Chang 2003). Prior to the discovery of these tetrapods, the same rocks that yielded them were long known to primarily produce the remains of fish, arthropods, and plants. The fossil-bearing rocks from which these fossils were recovered were, for the most part, clays laid down in the quiet waters of lakes [= lacustrine deposits] preserved today as fine-grained shales characterised by thin, alternating light and dark layers or varves, in some places in the order of 10 to 100 per centimetre. The laminar nature of the fossiliferous rock suggests that there were few, if any, organisms living in or on the bottom of the lake, disturbing the sediments in which the fossils occur; that is, there was no bioturbation, and presumably the water column was stratified for at least part of the year, rather than mixed, the bottom water being anoxic, having little or no oxygen (Fürsich et al. 2007; Liu et al. 2002).

At present, there is no known fossil locality in Australia, much less anywhere in Gondwana or from any site within either the Palaeoarctic or Palaeoantarctic circles (Rich et al. 2002), comparable to the Jehol Biota locales in the quality of its preservation of Mesozoic tetrapods. If even a few such fossils could be found in Australia, it would be a major advance in the understanding of tetrapod evolution here.

In the Strzelecki Ranges of southeastern Victoria, Australia, near the hamlet of Koonwarra, a fossil site that yields Early Cretaceous fish, arthropods, and plants has long been known. The fossils there occur in shales of lacustrine origin. Based on the scientific literature describing both the Jehol and Koonwarra occurrences, it is clear they are similar in the kinds of fossils found and the laminated nature of the rocks in which they occur. Like Jehol, at Koonwarra there are few, if any, signs of bioturbation in the fossil-bearing shales, a feature indicative of anoxic conditions (Waldman 1971). To date, the only tetrapod fossils that have been found at Koonwarra are half a dozen small feathers. Scanty though this evidence is, it is significant in two important ways. First, it demonstrates that birds or feathered dinosaurs were in proximity to this site. Second, it is indicative of a depositional environment at Koonwarra which has the potential to not only preserve fossil bones of tetrapods but also traces of their soft parts as well in a manner similar to that characteristic of the Jehol Biota locales.

Such commonalities between the Chinese and Australian sediments suggest that tetrapod skeletons might be found at Koonwarra or elsewhere in the Strzelecki Ranges where similar lacustrine deposits occur. Because of this, T. H. Rich made a brief visit to two sites in the Jehol area to determine if the apparent similarities might, in fact, be useful in framing an efficient search strategy for Early Cretaceous tetrapod fossil bearing sites in the Strzelecki Ranges.

INVESTIGATION OF THE JEHOL BIOTA

Dr. Wang Yuanqing of the Institute of Vertebrate Paleontology and Paleoanthropology, Beijing [IVPP] organised for a vehicle from the Institute plus a driver, Mr. Shou Huaquan, and student guide, Mr Liu

Fig. 1. Visitor facility of the *Sihetun Landscape Fossil Bird National Geopark of Chaoyang City*, Liaoning Province, People's Republic of China. The area of 400 metres^2 where the thirty-one fossil tetrapods are exposed is under the part of the building with the arched roof to the left of the main entrance. The area to the right has two floors of exhibits.

Qingguo, to take Rich to two sites where the Jehol Biota occurs on 13 and 14 June 2009. In that brief time, they were able to visit two localities, the *Fossil Bird National Geopark,* which is located in a suburb of Chaoyang, Liaoning Province and the *Sihetun Landscape Fossil Bird National Geopark of Chaoyang City,* 30 km east of that city.

In the two decades that have passed since the initial discoveries of tetrapods in the Jehol Group, more than 4,000 such fossils are said to have been recovered from it. IVPP in Beijing possesses a significant collection of these fossils.

During the course of Rich's visit in June 2009, conversations about those fossils were held with staff of the IVPP and Mr. Li He Ming, who participated in the excavations at the *Sihetun Landscape Fossil Bird National Geopark of Chaoyang City.* Based on that information, courses of action were identified that could well lead to the recovery of tetrapod fossils from the Koonwarra locality itself or from similar rocks elsewhere in the Strzelecki Ranges where sediments comparable to those in the Jehol Group occur.

The most informative of the two sites was the *Sihetun Landscape Fossil Bird National Geopark of Chaoyang City* (Figs 1-4). There, under cover in a quite substantial building, are exposed thirty-one fossil tetrapods found over an area of 400 metres^2. The fossils were seemingly distributed at random. There were twenty-six plastic boxes enclosing the fossils. Most often there was one fossil fish, bird or dinosaur in each box, but three of these boxes each had two specimens and there was another box containing three specimens. It is fortunate that the purpose of this exhibit was to show the tetrapod fossils in place so none have been removed, and thus the distribution of the fossils and their abundance is accurately known.

All thirty-one of the tetrapod fossils on display in situ at the Sihetun visitor facility are complete or virtually complete skeletons. There are no isolated bones. Numerous fish, plants and arthropod fossils were found as well as the tetrapods which together with the fossiliferous rock being a fine-grained fissile shale are all aspects reminiscent of the Koonwarra locality.

The thirty-one *in situ* tetrapods on display at the Sihetun visitor facility occur within a dark shale rather than in one of the numerous tuffs so common in the area.

Fig. 2. Looking east at the gallery at the Sihetun visitor facility showing the twenty-six illuminated plastic boxes each containing one or more fossil tetrapod skeletons. Each skeleton is still in place where it was uncovered. No fossil tetrapods have been removed from this area. The width of this space is 10 metres and the depth from the point where the image was made, about 35 metres.

In 1998 and 1999, IVPP carried out excavations about 100 metres south of the Sihetun visitor facility. Wang *et al.* (2000) indicated that the vertebrates collected during the course of these excavations occurred primarily through a thickness of 2 metres of grey or greyish black shale.

Jiang and Sha (2007, Figs 5-6) carried out a study of the depositional environments in the Sihetun area. One rock unit in their section where, "…abundant non-marine…vertebrates…," occur, is, "*3.2.8. Laminated mudstones (M2),*" (see Fig. 6). Their only other mention of non-marine vertebrates is in the unit "*3.2.11 Channel-fill, cross-stratified pebbly sandstones (S3)"* where turtle fragments occur locally. No fossil vertebrates were indicated in any of the other ten lithologies identified in their three sections close to the Sihetun visitor facility or mentioned in their descriptions of them including the tuffs.

Jiang and Sha (2007) stated, "During volcanic eruptions, animals and plants living in or around the lake were killed, transported into the lake, and were rapidly buried by abundant volcaniclastic sediments." Rapid burial related to volcanic events, however, seems to be contrary to their characterisation of their unit M2 in which the majority of the fossil tetrapods occur in, "…greyish-green and dark grey, planar-laminated volcanic siltstones, silty claystones

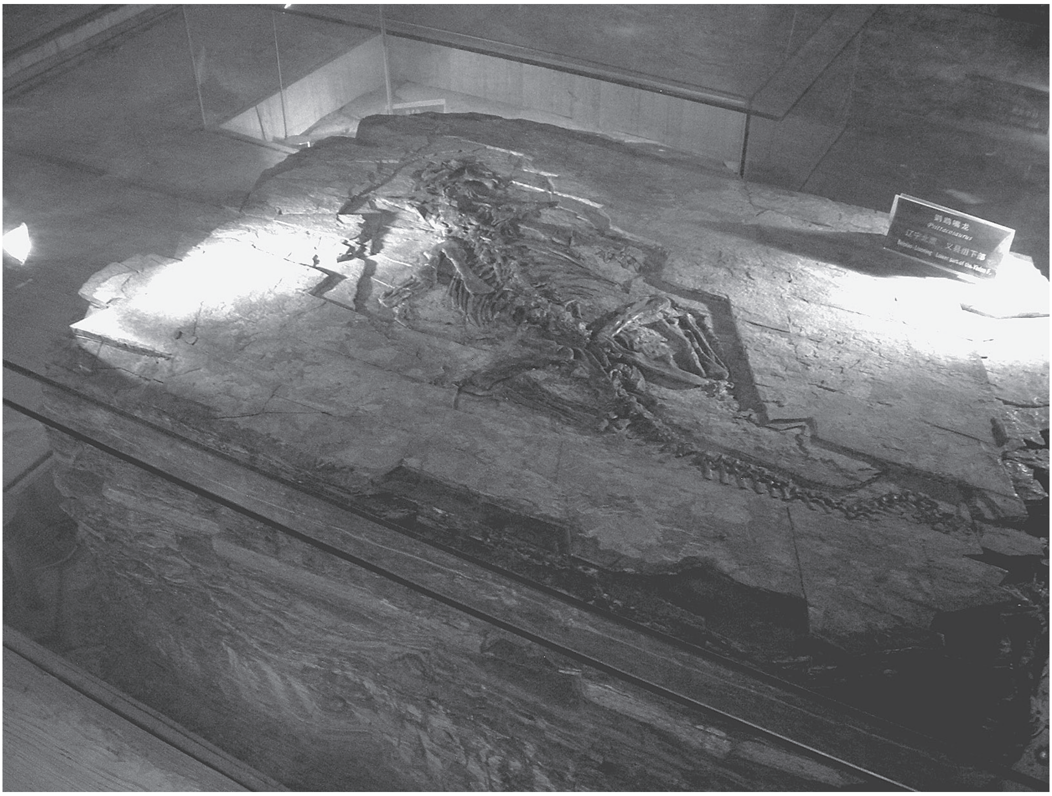

Fig. 3. Skeleton of the small dinosaur *Psittacosaurus* Osborn, 1923 to show how each specimen at the Sihetun visitor facility is encased.

and claystones (shales), intercalated with gypsum and calcareous claystones, sometimes with convoluted bedding…. The laminae are 0.1-1 mm thick and normally graded."

Fürsich et al. (2007) carried out a detailed taphonomic analysis of a section in a test pit located less than 2 km east of the Sihetun visitor facility. The test pit was 3.5 metres deep, about 9 metres^2 at the top and 5.5 metres^2 at the bottom. The focus of the study was a faunal assemblage dominated by two species, an insect nymph and a conchostrean. They occurred most abundantly in the mudstone component of the S/M facies of Jiang and Sha (2007). The conclusion of Fürsich et al. (2007) was that the mass mortality events was owing to anoxia that took place in a lake at the end of summer rather than invoking any aspect of volcanism. Anoxia was hypothesized by Waldman (1971) to explain the mass death of fish at Koonwarra. The only difference being that he envisioned these mass mortality events having taken place there owing to a winter-kill mechanism where a sheet of ice prevented the passage of oxygen from the atmosphere into the water of the lake.

In light of the evidence that anoxia may have played the same role to explain the accumulation of the arthropods and fish, it seems reasonable to use the rock unit at the Sihetun visitor facility, where the thirty-one tetrapods are preserved, as a guide to developing a strategy for attempting to recover fossil tetrapods from the lacustrine deposits of the Strzelecki Group. This is because the two are so similar both in the nature of the rocks in which the fossils occur and in the types of fossils represented.

If the frequency of tetrapod fossils preserved within the lacustrine facies of the Strzelecki Group is similar to that of the Chinese rock unit where the thirty-one tetrapods occur (on display at the Sihetun visitor facility), the question arises, "what is the probability of finding one or more tetrapod fossils if a given area is excavated of the lacustrine rock in the Strzelecki Group?" Table 1 suggests an answer to that question.

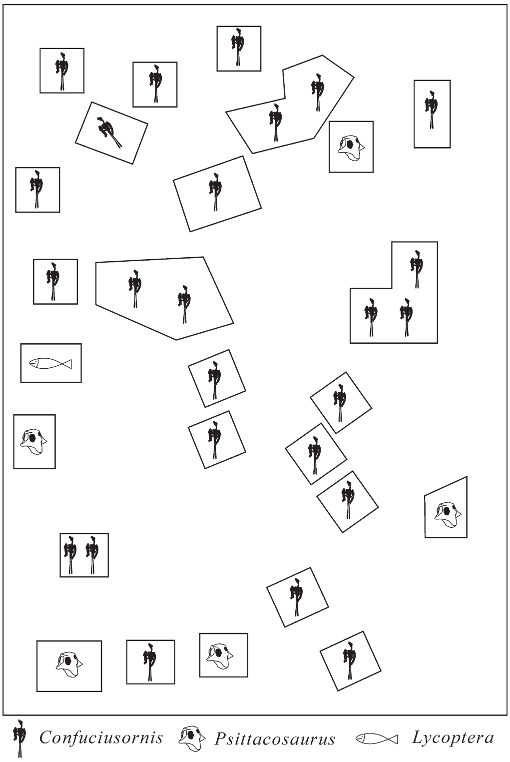

Fig. 4. Map of the Sihetun fossil site. West is at the top, north is to the right. Each polygon represents one case containing one to three *in situ* fossils on the floor of the Sihetun visitor facility. In addition to the large specimens in cases, the fossil remains of many small fish, arthropods and plants are visible on the exposed rock surface. Not to scale as the vertical dimension represents 40 metres and the horizontal dimension, 10 metres.

The figures in Table 1 are generated by the simple equation $\mathbf{P} = 1 - e^{-\mathbf{np}}$. Where **P** is the probability of one or more successes after **n** trials each with a probability of success of **p** for each independent trial. In this instance, **P** is the likelihood of finding one or more specimens, **n** is the number of square metres excavated at the Sihetun visitor facility [400 $metres^2$], and **p** in this instance is the number of specimens found at the Sihetun visitor facility divided by the area of the Sihetun visitor facility [31 specimens/400 $metres^2$].

Table 1. The probability of finding one or more tetrapod specimens per square metre excavated at the Sihetun visitor facility.

Square metres excavated in the Sihetun visitor facility	Likelihood of finding one or more tetrapod specimens
10	54%
20	79%
30	90%
40	98%
50	99%

The question that comes to mind is how much area of fossiliferous rock has been previously excavated at Koonwarra? T. H. Rich participated in the second major excavation at Koonwarra in 1982. Based on that excavation and the description of the work carried out there in 1965-6 in Waldman (1971), much less than 10 $metres^2$ have been excavated at Koonwarra. Assuming the circumstances of deposition at the Sihetun visitor facility and Koonwarra are comparable, the chances of having discovered a tetrapod skeleton to date in the small area excavated at the latter would seem to be not even 50%. Rather, what is remarkable is that any trace at all of tetrapods was found in the small area uncovered to date at Koonwarra, namely the half dozen feathers. Their discovery bodes well for recovering more complete tetrapod specimens if a much larger area is excavated in the lacustrine facies of the Strzelecki Group, using the Sihetun visitor facility as a guide.

THE WAY AHEAD IN THE STRZELECKI GROUP

Based on the information available concerning the occurrence of thirty-one tetrapods on display at the Sihetun visitor facility, it would seem that the lacustrine deposits of the Strzelecki Group may have been deposited in a similar manner. This is indicated both by the similarity of the most common fossils in the two (fish, arthropods, and plants) coupled with the similarity of the lithologies in which these fossils occur. In light of those considerations, the reason why no tetrapods have yet to be recovered from the lacustrine deposits of the Strzelecki Group would seem to be disarmingly straight forward: not enough rock has been excavated.

Generally when fossil tetrapods are excavated, there is an expectation that numerous isolated bones and teeth are found for every partial or complete skeleton. In sharp contrast, the tetrapod fossils uncovered at the Sihetun visitor facility are all complete or nearly so. Thus, while in the process of excavating in the lacustrine facies of the Strzelecki Group, a lack of isolated tetrapod bones and teeth during an exploratory excavation should not be interpreted as indicative that rarer partial or complete skeletons are unlikely to be found.

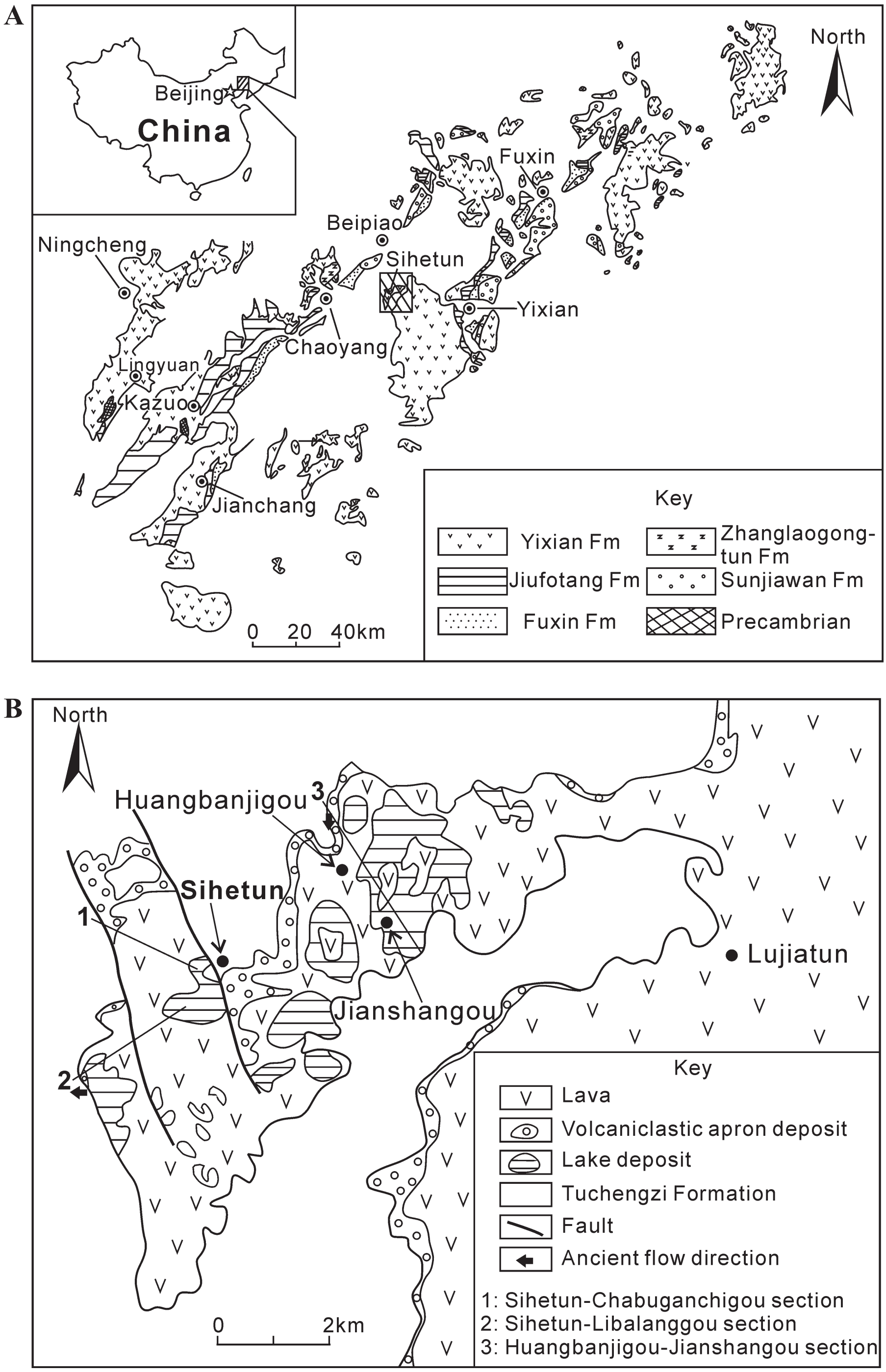

Fig. 5. Figure 1 of Jiang and Sha (2007) (with permission). "Distribution of the upper Mesozoic formations in western Liaoning (A) and the location of the study area (B)."

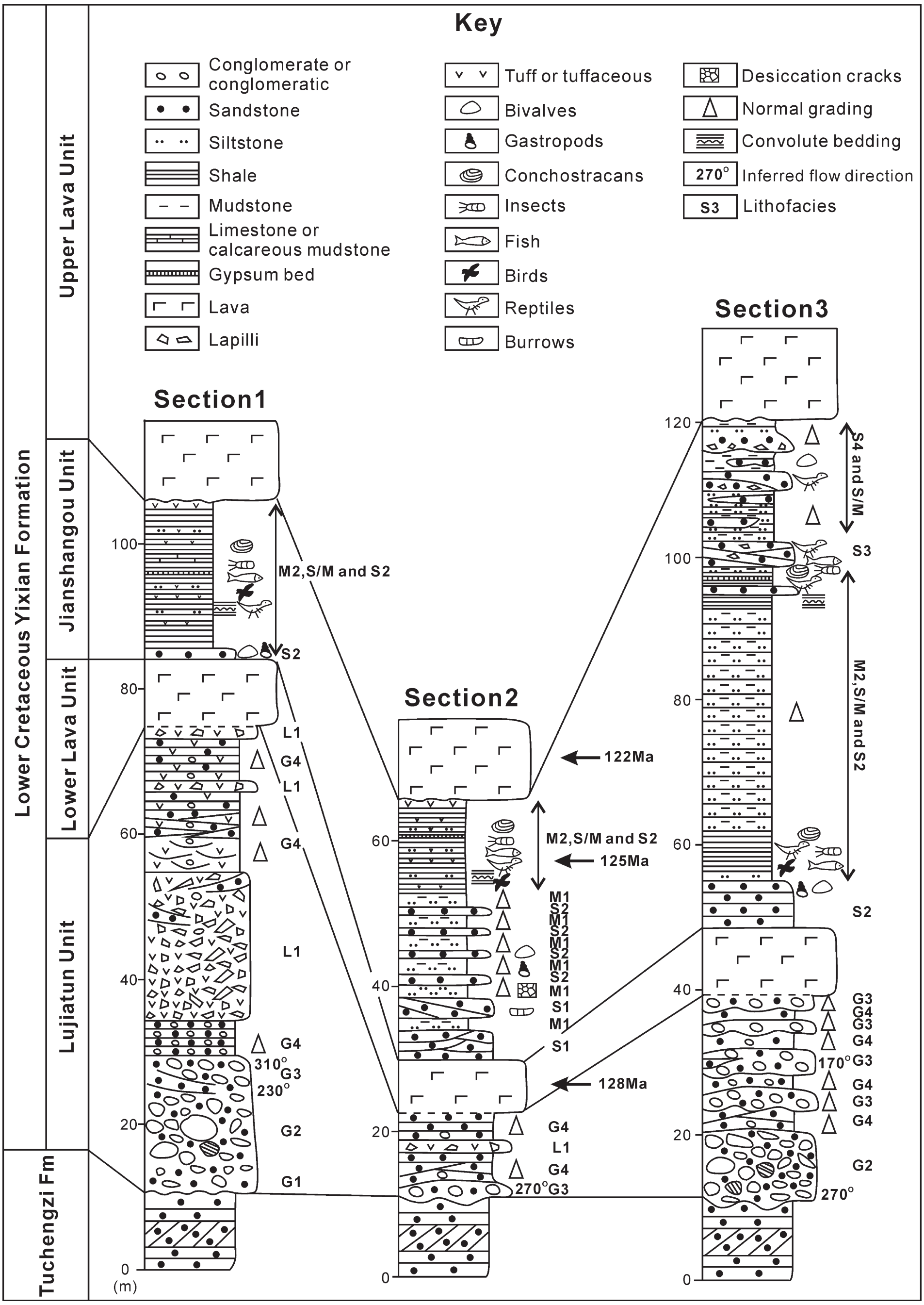

Fig. 6. Figure 2 of Jiang and Sha (2007) (with permission). "Stratigraphic correlation and distribution of lithofacies of the Yixian Formation." Facies abbreviations: G1 Matrix-supported conglomerates; G2 Unstratified, clast-supported conglomerates; G3 Stratified, clast-supported conglomerates; G4 Stratified sandy conglomerates and pebbly sandstones; L1 Lapillistones and lapilli-tuffs; S1 Cross-stratified sandstones; M1 Horizontally stratified homogeneous mudstones; M2 Laminated mudstones; S2 Horizontally stratified, homogeneous sandstones and tuffs; S/M Normally graded sandstones and mudstones; S3 Channel-fill, cross-stratified pebbly sandstones; and S4 Normally graded pebbly sandstones.

To excavate sufficient lacustrine rock in the Strzelecki Group in order to test whether or not tetrapods do occur there in the frequency that they do at the Sihetun visitor facility requires that 50 metres^2 be exposed to have a 99% chance of finding one or more tetrapods. This can be done in one of two ways. First, such an excavation can be done at Koonwarra itself. Second, such an excavation can be carried out elsewhere.

To uncover 50 metres^2 at Koonwarra would entail excavating an area underground comparable to the Slippery Rock site at Dinosaur Cove (Rich & Vickers-Rich 2000). Logistically, this would be in some ways easier and in some ways more difficult than cutting the tunnels at the latter site. The great difficulty in excavating underground extensively at Koonwarra is that the fossiliferous unit dips downward at about 37° while the hill above it is about as steep in the other direction. Because the surface of that hill is unstable, having been logged late in the 19th century, an adit is thought to be the safest way to excavate at Koonwarra. An open-cut there would mean that the footwall would be more than 1 metre higher for every 1 metre further inward that such an excavation was extended. Unexpected collapse of the soil surface on the hill above could result in serious injury to those working the site. This, in addition to making an unsightly scar in the landscape that an adit would not, are reasons favouring working this site underground.

Finding another Koonwarra-like lacustrine occurrence elsewhere in the Strzelecki Ranges in more favourable circumstances from the point of view of excavation logistics is a second approach. Lacustrine deposits similar to those at Koonwarra do occur elsewhere in the Strzelecki Ranges. Fragments of fossil fish have been found in a road cut a few kilometres from Koonwarra. Because the Strzelecki Ranges are heavily vegetated, locating of other lacustrine deposits will not be easy, but artifical excavations may help overcome this difficulty.

CONCLUSIONS

The most difficult fossil to find is the first one. The discovery in lacustrine deposits of the Strzelecki Group of a single tetrapod specimen similar in preservation to those on display at the Sihetun visitor facility would fundamentally transform the study of Mesozoic terrestrial vertebrates in Australia. The outcome could well be analogous to the flow on effect of the discovery of a single jaw of a Cretaceous mammal at a site not 20 km away from Koonwarra in 1997, which subsequently led to the collection of more than 85% of all Mesozoic mammal specimens now known from this continent. From that modest beginning, a number of quite unexpected insights as to the history of that group in Australia during that era have been forthcoming.

Operationally, when carrying out exploratory excavations in the lacustrine facies of the Strzelecki Group, there are two particularly important aspects of the occurrence of tetrapods at the Chinese site to be borne in mind. First, an area of 50 metres^2 must be uncovered in order to have a good chance of finding one or more fossil tetrapod skeletons if they occur at the frequency they do at the Sihetun locality. Second, in the process of carrying out such an excavation, just because no isolated tetrapod bones and teeth are found midway through an excavation, is no reason to abandon the effort before at least 50 metres^2 are uncovered. This is because it is most likely that complete or nearly complete skeletons will be uncovered if any tetrapod fossil material is found at all.

ACKNOWLEDGEMENTS

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