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Hill River rediscovered: Early Jurassic insects of the Perth Basin, Western Australia

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ABSTRACT

Fossil insects were first recorded from the Hill River area, Western Australia, in 1968. Although the original Hill River outcrops can no longer be located, a new fossil site, named here the Mintaja insect locality, was discovered in the same general area and from the same stratigraphic unit in 1989. The Mintaja insect locality occurs within the Lower Jurassic (Sinemurian to Toarcian) Cattamarra Coal Measures of the Perth Basin; insects are preserved as impressions in a single layer of fine, brown siltstone. Although a broad range of insect elements are preserved in the assemblage, there is a distinct bias towards strongly sclerotised elements and taxa, with over half the collection consisting of disarticulated elytra, although partial bodies, heads, thoracic and abdominal sclerites are also recorded. Coleoptera is the most commonly recorded insect order, followed closely by the Blattodea; Hemiptera, Mecoptera, Neuroptera, Grylloblattodea and Diptera have also been collected but are rare. Levels of disarticulation are high in all orders and no fully articulated insects have yet been recovered. The level of element fragmentation is also high, although mostly caused by post-burial sediment fracturing. The Mintaja insect layer is thought to represent deposition in a shallow, fresh-water, possibly paludal, environment within a greater fluvial-deltaic system. The site is of interest as one of few specimen-rich insect localities from the Jurassic of Gondwana.

KEY WORDS: Early Jurassic. Western Australia. Insects. Cattamarra Coal Measures. Mintaja insect locality. Geology. Taphonomy.

INTRODUCTION

Fossil insects from the Hill River region, Western Australia, were first recorded in 1968 by E.F. Riek, an entomologist with Australia's Commonwealth Scientific and Industrial Research Organisation (C.S.I.R.O.). In his short paper, Riek identified a small number of insects, including the new beetle taxon *Mesothoris westraliensis* Riek, 1968, a poorly preserved cockroach tegmen tentatively assigned to the genus *Austroblattula* Tillyard, 1919 and other elytra considered too poorly preserved for description (Riek 1968). The material was sampled from three separate outcrops of the Cockleshell Gully Sandstone (now known as the Cattamarra Coal Measures) during the geological investigation of Hill River by the West Australian Petroleum Pty. Ltd (WAPET) in 1956 (Willmott 1960, Mory 1994). Riek, however, made no mention of the geological or stratigraphic provenance of the Hill River insect material, postulating a Late Triassic age based only on comparisons with insect assemblages from the Late Triassic of Queensland (Riek 1968). This age was proposed seemingly in spite of palynological and macrofloral studies which had previously considered the Cockleshell Gully Sandstone Early or Middle Jurassic in age (Walkom 1956, Willmott 1956, Balme 1957, Willmott 1960), and it can only be assumed that Riek was not provided with any stratigraphic information to aid his research. As further palynological studies have confirmed the Jurassic age of the Cattamarra Coal Measures (Backhouse 1992, Mory 1994), the Hill River locality follows the Late Jurassic (Kimmeridgian) Talbragar Fish Beds of New South Wales as the second of only two Jurassic insect localities recorded from the Australian continent to date (Etheridge & Olliff 1890, Jell 2004, Bean 2006).

Riek's study was the only research published on the fossil insects of Hill River, and later attempts to find the described outcrops failed (Mory, *pers. comm.* 2005). As a result, the locality was forgotten until 1989, when a new site preserving fossil insects was discovered during regional re-mapping of the Hill River area by the Geological Survey of Western Australia (Mory *pers. comm.* 2005). Although it is unlikely that this new locality corresponds geographically to any of the previous Hill River insect outcrops, comparison of the sediments and fossil insects strongly suggests derivation from the same stratigraphic unit (*pers. obs.*). In order to avoid confusion, and in deference to the uncertainty in correlating the two sites, the new outcrop is designated the Mintaja insect locality, while the name Hill River is retained specifically in regards to Riek's samples, now housed in the Palaeontology collection of the Australian Museum, Sydney. The name Mintaja is used in reference to the Mintaja Hills, which occur within the Hill River region, and in which the fossil site is located.

The diverse and material-rich insect assemblage recovered from the Lower Jurassic Mintaja insect locality is of considerable interest as few Jurassic insect sites are currently recorded from Australia or Gondwana as a whole (Schlüter 2003). The only other Jurassic Gondwanan locality previously confirmed as preserving a diverse insect assemblage is the Lower Jurassic Kotá Formation of India (Tasch 1987, Mostovski & Jarzembowski 2000, Rasnitsyn 2008), although recent collecting has indicated that the Upper Jurassic Talbragar Fish Beds of New South Wales is also insect rich (Beattie 2007). Unfortunately, little has been published on either of these two sites. This paper, intended as an introduction to the Mintaja insect locality, provides a preliminary overview of site geology, fauna, taphonomy and palaeoenvironment. As studies of the insects are ongoing, more comprehensive taxonomic results will be presented at a later date.

MATERIALS AND METHODS

Insect fossils are common at Mintaja, with over 1300 samples currently catalogued. Although a number of these insects were collected in the field, most of the material used in this study was obtained by sorting a bulk sediment sample collected from the site in 1989 and stored at the Western Australian Museum (WAM). Time constraints on this project restricted processing to only eight kilograms of this original sample, with the remainder of the material and another bulk sample collected during a June 2006 fieldtrip, as yet unstudied.

Processing involved first sieving the bulk material to remove fine sand and silt particles, with the remaining rock then washed to remove surface dust. Each fragment was inspected using a Leica MZ8 microscope under low angle light to increase the visibility of the preserved impressions. Inspection under the microscope also helped to reduce collection bias against very small insect elements. During sorting, every fragment that could be identified as insect-derived was collected, measured and catalogued in order to further reduce collection bias; however, this methodology has meant that a large proportion of the collection is unidentifiable. The resulting Mintaja collection is housed within the Invertebrate Palaeontology collection of the Western Australian Museum, Perth, Australia.

LOCATION AND GEOLOGY

The Mintaja insect locality is situated in central coastal Western Australia, roughly 200 km north-northwest of the state capital, Perth (Fig. 1). Located on the Hill River-Green Head 1:100 000 geological map sheet (Geological Survey of Western Australia map sheets prefixed SH 50-9-1937 and part SH 50-9-1837), the Hill River region consists of gently undulating topography cross-cut by numerous ephemeral creeks and gullies (Mory 1994). The insect-bearing layer crops out on a private cattle property; the exact location has been withheld due to the sensitive nature of this site and at the request of the property owners, but will be kept on record at the Western Australian Museum.

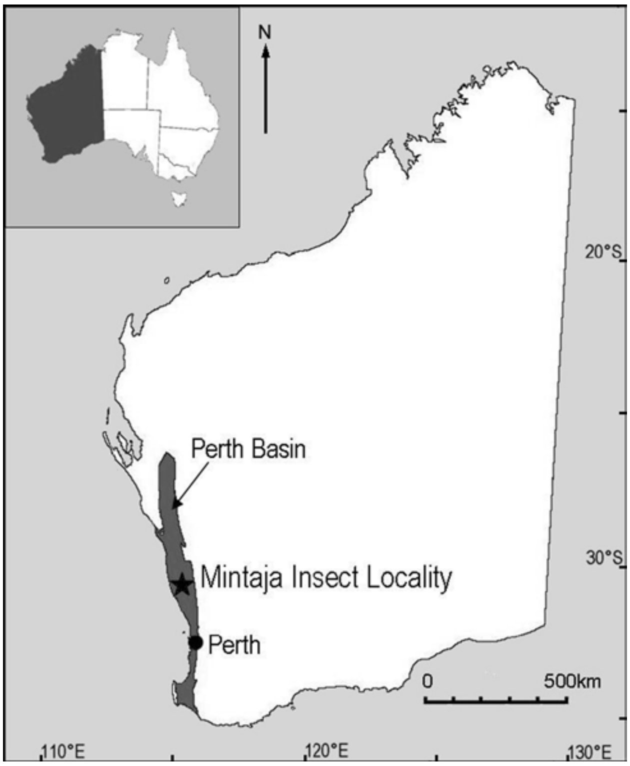

Figure 1. Map of Western Australia showing the general location of the Mintaja insect locality and the outline of the Perth Basin.

The insect-bearing sediments form part of the Cattamarra Coal Measures, a unit of variable lithology located within the onshore northern Perth Basin. This basin dominates much of the western coastline north of Perth and hosts substantial natural gas and coal reserves, resources which fuelled geological exploration in the area as early as 1849 (Mory 1994). In the Hill River area, the northern Perth Basin contains a thick sequence of Permian to Cretaceous sediments overlying Precambrian basement (Mory 1994). Much of this sequence, extending from the Early Triassic (Griesbachian) to the Early Cretaceous (Berriasian) is largely conformable, reflecting a number of marine transgressions and regressions occurring prior to the separation of Greater India from Australia in the Early Cretaceous (Mory & Iasky 1996). The Cattamarra Coal Measures themselves represent a transgressive period between the fluvial regime of the underlying Eneabba Formation and the overlying shallow marine Cadda Formation (Suwarna 1993, Mory 1994). Outcrop in the Hill River area is generally poor and restricted to actively eroding areas such as the region's numerous and mostly ephemeral waterways. Elsewhere, outcrop is obscured by Quaternary coastal limestone (Tamala Limestone) and sand dunes near the coast, and laterite and other regolith inland; as a result, the most complete sequences of the Cattamarra Coal Measures are found in coal exploration and petroleum boreholes (Mory 1994). The area is highly faulted, which, in conjunction with the poor outcrop, makes correlation of stratigraphy difficult in some areas, including the Mintaja Hills.

The Cattamarra Coal Measures consists of fine- to coarse-grained sandstones interbedded with carbonaceous siltstones, claystones and minor coal. Overall, the unit seems to represent a variety of environments within an upper delta plain, with thicker sandstone beds interpreted as fluvial sediments, and finer grained carbonaceous lithologies and coal seams deposited in interdistributary bay environments. This interpretation is supported by palaeocurrent measurements, taken from cross-bedding, which are extremely variable throughout the unit (Mory 1994, Mory & Iasky 1996).

Fossils are relatively rare within the Cattamarra Coal Measures but include diverse palynomorphs, locally abundant wood and leaves, and rare bivalves and branchiopods. Bioturbation is also seen in the unit, but only within coal exploration boreholes (Willmott 1956, Mory 1994, Mory & Iasky 1996). Unfortunately, only the palynomorphs have been formally described (Balme 1957, 1964), although fossil ferns found in association with the Hill River insects have been informally identified as cf. *Thaumatopteris* Göppert, 1841 (family Dipteridaceae) (Walkom 1956, Balme 1964) and poorly-preserved bivalves found from the same area were considered fresh-water forms but never identified (Parry & Hoelscher 1955, Willmott 1956). The palynomorphs, which have been extensively studied due to their importance to biostratigraphy, preserve a distinctive assemblage placing the Cattamarra Coal Measures within the upper *Corollina torosa* and lower *Callialasporites turbatus* zones of Helby's *et al.* (1987) Australian palynological biostratigraphic scheme; these local zones are correlated with the Sinemurian to Toarcian (192-175.6Ma) stages of the Jurassic (Balme 1957, Burdett 1962, Pudovskis 1962, Balme 1964, Helby *et al.* 1987, Mory & Iasky 1996, Partridge 2006).

The Mintaja insect locality is exposed in the channel walls of a single, shallow, ephemeral gully. Within the gully, there are three separate outcrops from which fossil insects have been obtained, numbered from north to south as Mintaja outcrop 1 (M1), Mintaja outcrop 2 (M2) and Mintaja outcrop 3 (M3). M1, which occurs at the northernmost tip of the gully, was first discovered in the late 1980s and much of the insect assemblage was collected from this outcrop. M2 and M3 were first discovered during a fieldtrip in 2006 and are located 140m and 190m respectively along the gully to the southeast. The insect layer at these minor localities appears to occur at the same stratigraphic level as at M1 and this, plus the similarity of lithology and fossils, suggests a single insect accumulation event. M2 and M3 are only newly exposed and only one fossil insect was collected from each outcrop, although it is expected that more material may be recoverable in the future. The lateral extent of the fossil layer is presently unknown due to the area's extensive regolith cover and poor outcrop, and further excavation is currently not possible due access issues.

Insects are preserved in a narrow layer (approximately 20cm thick) of fine grained carbonaceous siltstone, which is predominantly light brown with locally developed red, yellow or purplish tinges. The siltstone has a weak cleavage, and once weathered will split along these irregular planes with gentle finger pressure; the sediment is also highly fractured, breaking down naturally into small (~1cm³), roughly rectangular blocks. Layers of the insect bed dip gently throughout the Mintaja insect locality, although a minor syncline located at the southern end of the gully causes this dip to vary (Mory 1994). Apart from insects, fossils at the locality are uncommon but include fragmented and unidentifiable plant material, a single hybodont shark tooth and a small number of spinicaudatans (K. McNamara, *pers. comm.* 2005).

The fossil layer occurs within a larger sequence of fine- to medium-grained, massive or poorly bedded sandstones. The sandstones are strongly coloured and heavily iron-stained at all outcrops, suggesting that the sediments are deeply weathered. As the gully walls are extremely shallow, 0.4 to 0.5m high on average, the amount of stratigraphy exposed at the insect locality is restricted. Furthermore, the nature of outcrop in the Mintaja area means that there are no larger sedimentary sections nearby for comparison, and extensive regional faulting also makes lithological correlation of the Mintaja insect layer to nearby borehole sections difficult. As a result, the exact place of the insect layer within the stratigraphy of this unit cannot be determined using lithology alone; palynological assessment may yield the best results for correlation, but the strong oxidation of surficial sediments in the Mintaja area means that coring is needed to obtain suitable samples. Coal does not occur in the area adjacent to the fossil bed, and those nearby areas which do develop coal seams are separated from the insect locality by large-scale faults (Mory 1994).

FAUNA

Seven orders of insects – Blattodea, Grylloblattodea, Hemiptera, Coleoptera, Neuroptera, Mecoptera and Diptera – are currently recorded from the Mintaja insect locality; the provided chart shows the relative abundance of these orders (Fig. 2). The label "indeterminate" records

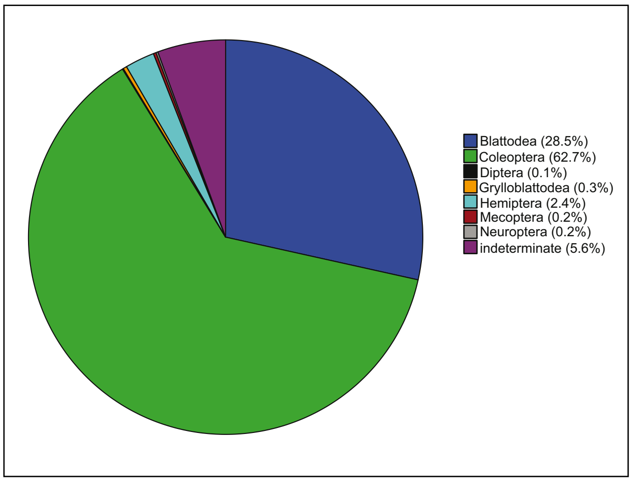

Figure 2. Pie-chart showing the relative distribution of specimens in the Mintaja insect locality, grouped by taxonomic order.

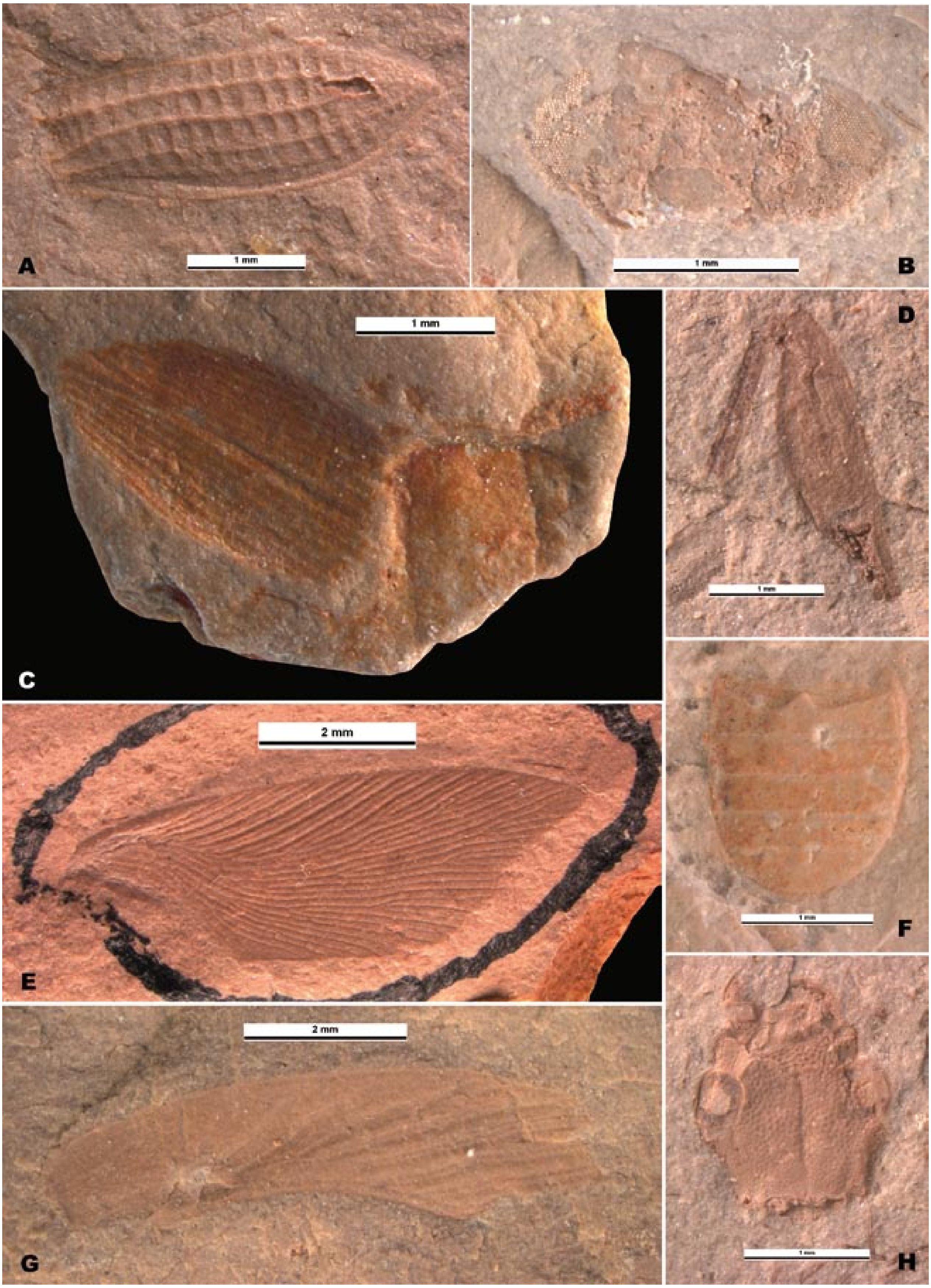

Figure 3. Examples of fossil insects collected from the Mintaja insect locality, Western Australia, illustrating the range of preservation seen in the locality. All specimens unregistered within the Invertebrate Palaeontology collection, Western Australian Museum. A. disarticulated elytron; B. partial insect head showing individual eye lenses; C. partially articulated beetle body; D. disarticulated indeterminate leg; E. cockroach tegmen lacking apex and clavus; F. partial beetle abdomen; G. partial cockroach tegmen, consisting of costal and radial regions only; H. disarticulated beetle head.

the incomplete or poorly preserved elements which were unable to be confidently assigned to any particular order; the high number of indeterminate elements can be considered a product of the collection methodology as described above. Most of the groups discovered to date appear to be represented by terrestrial adults, although further study of the beetles may possibly reveal some aquatic forms.

The assemblage is strongly biased, with the Coleoptera comprising roughly 63% of collected material. Most of these coleopterans are represented by disarticulated elytra, making taxonomy difficult; however, around 15 elytra morphotypes have been identified, indicating a relatively diverse beetle fauna. Other beetle elements include disarticulated thoracic and abdominal sclerites and partial bodies.

Blattodea is the second most common order with 28.5% of the assemblage. As in many insect assemblages, much of this cockroach material is preserved as disarticulated tegmina, although a small number of hind wings, disarticulated clavi and pronota have also been recovered. Most of the tegmina are missing the clavus and 85% (of 305 wings) are too fragmentary to identify beyond the ordinal level. Of the well preserved wings, most appear attributable to the Caloblattinidae and Liberiblattinidae, with rare Blattulidae also recovered.

Fragmented hemipteran wings belonging to the Fulgoroidea are also relatively common in the assemblage, with this order making up about 2.4% of the collection. The Grylloblattodea, Neuroptera and Mecoptera are each represented by a handful of fragmentary fore wings, making taxonomy difficult. Conversely, the single dipteran wing is complete and has been described as a new member of the Mesozoic family Protorhyphidae (Martin, this volume).

INSECT TAPHONOMY

The most common fossil elements found at the Mintaja insect locality – the insects, spinicaudatans and most plant fragments – are preserved as impressions within the fine siltstone. As impressions, the quality of insect preservation is linked strongly to the character of the preserving sediment, most obviously the prevailing grain size. Although generally fine, the grain size can change locally, partially explaining the variable preservation seen in the fossils and particularly the often poor quality of small or poorly sclerotised elements. Despite this, some fossils preserve fine detail, such as the individual eye lenses observed on some insect heads (Fig. 3B).

Insect fossils are generally small, with an average length of 3.4mm (SD=1.803, n=1324); only 1% of the material is greater than 10mm long (Fig. 4). There is a distinct bias towards heavily sclerotised elements, with over half (~55%) of the collection consisting of disarticulated elytra (*e.g.* Fig. 3A), while wings or wing fragments (*e.g.* Figs. 3E, G) contribute about one-third (~36%) of the material (Fig. 5). All other elements, including heads, pronota,

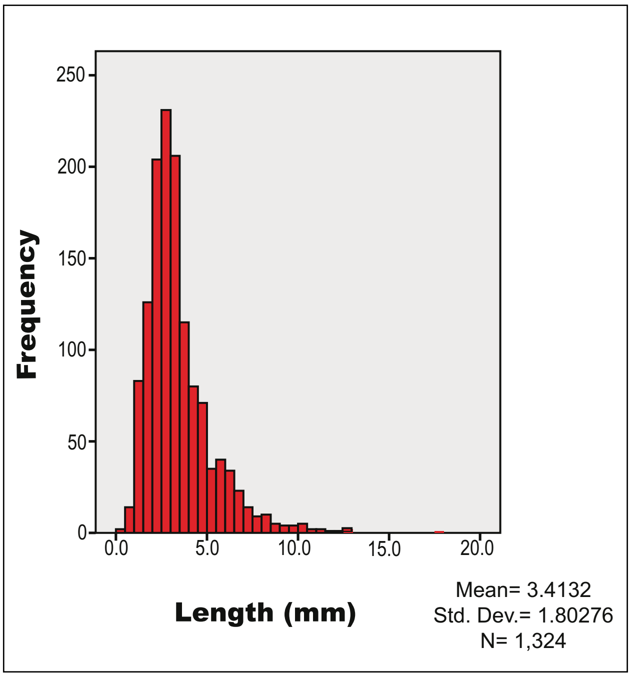

Figure 4. Length distribution of all insect elements collected to date from the Mintaja insect locality.

abdomens, legs, metasternites and partial insect bodies (*e.g.* Figs. 3B, C, F, H) together make up less than 10% of the fossils collected. Almost all of the insects are preserved dorso-ventrally, with only one indeterminate insect body seen in lateral aspect; however, a small number of the most highly rounded elytra and metasternites are preserved obliquely.

No complete insect bodies have been recovered from the Mintaja insect locality and much of the assemblage consists of fully disarticulated elements. Only 7.5% of the material is considered ‘partially articulated’, which is here applied to specimens with more than one discrete sclerite linked together. Elements considered partially articulated included abdomens consisting of more than one ventrite, associated elytra, heads when linked to pronota, cockroach tegmina with associated clavi, and partial beetles consisting of elytra, abdomen and part thorax. The eight partial beetles are the most complete insects recovered from the assemblage, although none have articulated heads and only one has legs still attached. Further evidence of disarticulation can be seen within individual elements, particularly head capsules which all lack antennae; legs lacking tarsi; and cockroach tegmen, 98% of which lack an associated clavus. Apart from the loss of clavi, cockroach tegmina often show evidence of further disarticulation, with a number of wings splitting along M to lose the cubital region and others separating along R to lose both medial and cubital regions (Fig. 3G); however, these more extreme forms of disintegration are relatively uncommon.

Roughly 72% of insects in the Mintaja collection are incompletely preserved irrespective of the level of disar-

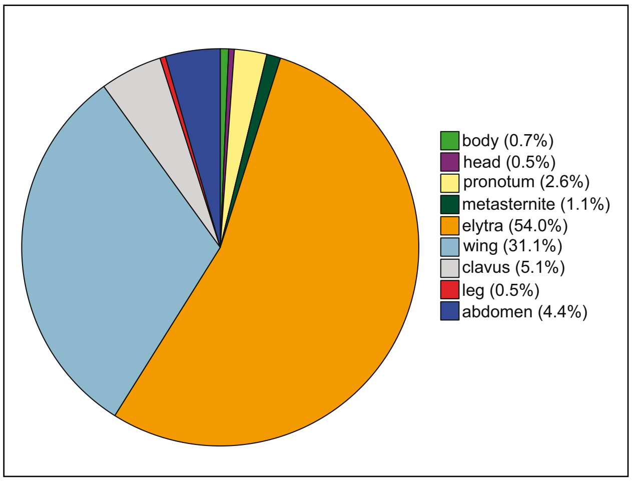

Figure 5. Pie-chart showing the relative percentage of specimens from the Mintaja insect locality collection, grouped by element type.

ticulation, including both clearly fractured material and elements partially obscured by sediments that cannot be easily removed. Of the clearly fragmented material, most breaks occur adjacent to the block edge, alongside a sharp-edged area of relief change, or due to the subtle flaking of individual cleavage planes; in these cases, fragmentation is attributed to post-burial fracturing of the sediments. Fracturing of the fossil layer is extensive, causing the sediment to break down into small blocks, and this may be the cause of the high fragmentation rate and generally small size of insect fossils in the assemblage. It is also likely that if pre-burial fragmentation had affected the preservation of insects at Mintaja, this is now masked by the pervasive nature of the later sediment fracturing.

DISCUSSION

The Mintaja fossil layer appears to have been deposited within a low-energy, continental water body. Marine influence on the depositional environment is considered negligible due to the lack of strictly marine taxa and the presence of spinicaudatans and (supposedly) fresh-water bivalves (Parry & Hoelscher 1955, Tasch 1969). The plant material found within the fossil layer indicates a well-vegetated environment adjacent to the preserving water body and, as much of this material is more fibrous than woody, the dominant vegetation appears predominantly herbaceous. Plant macrofossils of the Mintaja insect locality are mostly small and highly fragmentary, suggesting accumulation in a shallow or near-shore environment. This interpretation is supported by the silty grain-size, poorly laminated sediments and presence of spinicaudatans, which today live predominantly in shallow, or even ephemeral, water bodies (Tasch 1969).

Therefore, the Mintaja insect locality appears to have accumulated within a paludal environment, perhaps a small pool, marsh or swamp. Such interdistributary environments are common within upper delta-plain systems, corresponding well with the overall interpretation of the Cattamarra Coal Measures. Evidence for distributary channels at Mintaja can be seen in the mostly massive sandstones over- and underlying the fossil bed. Alternation between channel sands and marshlands could be caused by channel-switching, periodically inundating interdistributary areas and depositing new sand units over lenses of carbonaceous silts. This palaeoenvironmental reconstruction could explain the relatively few aquatic organisms seen in the fossil assemblage, although the single hybodont shark tooth is somewhat incongruous with this interpretation. Besides this tooth, no other vertebrate material has ever been recovered from the Mintaja insect locality, and it is possible that the fossil is reworked, or was transported to the site during a flooding event. It is hoped that further studies will help to elucidate the origins of this material.

The insects of the Mintaja site form a mostly allochthonous assemblage, based on the predominance of terrestrial forms. The high levels of disarticulation are relatively common for terrestrial insects, which must pass numerous taphonomic barriers before being buried in a suitable environment (Zherikhin 2002, Martínez-Delclòs *et al.* 2004). Actualistic decay studies have observed that elytra and wings are the toughest and most flexible of insect elements (Martínez-Delclòs & Martinell 1993, Martínez-Delclòs *et al.* 2004), increasing their preservation potential and explaining why these elements are so common in many insect localities, including Mintaja. Conversely, the rarity of articulated antennae and legs seen in the Mintaja assemblage may reflect the observation that these delicate structures are among the earliest body parts to be lost after death (Martínez-Delclòs & Martinell 1993, Smith *et al.* 2006). Actualistic studies on cockroaches have found that wings and pronota are the most resistant body parts under normal decay conditions (Duncan *et al.* 2003), explaining the presence of tegmina, pronota and hind wings as only cockroach elements seen in the Mintaja assemblage. Cockroach tegmen have also been observed to disarticulate in a defined pattern, losing first the clavus and then cubitus and media, until only isolated radial areas remain (Duncan *et al.* 2003); examples of all of these decay stages are visible within wings of the Mintaja assemblage as discussed above. Unfortunately, although biostratinomic processes appear to be most important to the prevalence of particular elements, collection bias cannot be ruled out. Being large, single sclerites, elytra and wings are more easily identifiable and so more commonly collected than body parts consisting of numerous small sclerites, such as the thorax, abdomen, or legs.

The preferred preservation of particular body parts also strongly affects the distribution of orders seen within the assemblage. As elytra are proven to be particularly resistant to transportation and decay, their high preservation potential artificially inflates the proportion of coleopterans recorded. Similarly, the high proportion of blattodeans appears due mostly to the strongly sclerotised nature of their tegmina, a fact also reflected in the moderately common, well sclerotised hemipteran wings. Beetle numbers may similarly be increased by their strongly sclerotised thoracic and abdominal sclerites, which make beetle bodies more likely to be preserved than soft bodied orders such as the Diptera. These observations fit well with actualistic studies which have found that these less robust orders are preferentially removed during specimen decay and deposition, leading to a negative bias against them in the fossil record (Martínez-Delclòs & Martinell 1993, Smith 1998, 2000).

Exposure time, amount of transportation and environmental energy have all been recognised as influences on insect preservation during biostratinomy, with increases in each leading to increased disarticulation and the loss of the least robust elements and orders (Duncan *et al.* 2003, Martínez-Delclòs *et al.* 2004). If the Mintaja locality represents a paludal environment as considered above, insects may have been introduced via two routes – by falling in directly, or indirectly by transportation from connecting streams or during flooding events. Unfortunately, as it is difficult to identify whether an individual insect decayed in still or agitated conditions (Duncan *et al.* 2003), it is possible, if not probable, that examples of both routes are represented in the assemblage. Although growths of fungal or microbial origin are thought to bind insect carcasses together and slow the rate of disarticulation in some fossil insect localities (Martínez-Delclòs *et al.* 2004), there is no evidence for such films at Mintaja, and pervasive disarticulation suggests that, if present, such an influence would be small. Predation is another process through which wings or other heavily sclerotised insect elements can be disarticulated and concentrated in an environment, as fish and reptiles often regurgitate these body parts and arthropod predators generally leave the body intact (Duncan *et al.* 2003, Martínez-Delclòs *et al.* 2004). Again, as the Mintaja assemblage shows no evidence to support or deny the possibility of predation, this remains an unknown influence on preservation.

CONCLUSION

The Mintaja insect locality has proven to be rich in fossil insect material and, as one of only a handful of specimen-rich Jurassic insect assemblages from Gondwanan continents (Schlüter 2003), will hopefully provide invaluable information on a time and place that represents a significant gap in the understanding of insect evolution. The locality is not yet fully explored and there is potential for further sampling and study, particularly at M2 and M3. These smaller outcrops are as yet insufficiently exposed for substantial collecting, but it is thought that these areas will also prove to be fossil rich, allowing the identification of new taxa and hopefully further clarifying the preserving environment.

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