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Upper Cambrian (Mindyallan) trilobites and stratigraphy of the Kayrunnera Group, western New South Wales

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Nine species of trilobites are recorded from three localities within a restricted stratigraphic interval near the base of the newly defined Kayrunnera Group (previously Kayrunnera Beds) on Kayrunnera station, western New South Wales. These occurrences come from the Boshy Formation of the Kayrunnera Group. The trilobites described include species of *Ammagnostus, Meteoraspis, Biaverta, Blackwelderia, Bergeronites,* and *Placosema.* This assemblage is early Late Cambrian (Mindyallan), and most closely referable to the late Mindyallan zone of *Glyptagnostus stolidotus.* The steeply dipping, weakly cleaved Upper Cambrian–basal Ordovician Kayrunnera Group overlies, with a well-defined angular unconformity, a more deformed tightly folded and strongly cleaved, graded, turbidite sandstone sequence. The turbidite succession is considered to be Early to Middle Cambrian, by lithological correlation with similar rocks containing sponge spicules and trace fossils elsewhere in the Wonominta Block. The upright isoclinal folds of this sequence and the angular unconformity were produced during a major orogenic phase, probably an early expression of the Delamerian Orogeny, in late Middle Cambrian time. After uplift and erosion there followed a period of early–middle Late Cambrian marine transgression, during which the lower part of the Kayrunnera Group was deposited. The beds include the trilobite-bearing Boshy Formation, of shallow marine origin.

Introduction

In 1963, officers of the Geological Survey of New South Wales discovered and mapped a trilobite-bearing sequence near Kayrunnera homestead, and this sequence was observed to overlie an older basement (Rose & others, 1964; Rose, 1974). Trilobites collected from near the base of the sequence south of the homestead were identified by A.A. Öpik (1975) and found to be of Mindyallan (early Late Cambrian) age. The sequence was referred to informally as the Kayrunnera Beds (Brunker & others, 1971).

One of the authors (KJM) mapped the extent of the trilobite-bearing sequence in detail from a fault south of Kayrunnera homestead northwest to the southeastern flanks of Koonenberry Mountain, a distance of 28 km (Fig. 1). The unconformity at the base of the sequence can be traced from south of Kayrunnera homestead northwest to Morden Creek, a distance of 16 km. Throughout its length the unconformity surface appears remarkably smooth and eroded across an older tightly folded and cleaved, immature, graded, lithic sandstone sequence, which has undergone low grade regional metamorphism. The fossiliferous sequence is less-cleaved, but dips steeply, and the extent of its exposure is controlled by near-vertical faults, which curve southeast and east from the Koonenberry Fault System near Koonenberry Mountain. On Kayrunnera station only the lower part of the sequence is preserved, but southeast of Koonenberry Mountain, on Wonnaminta station, over 2000 m of section has been measured. The sequence has been formally renamed the Kayrunnera Group and divided into three formations — the basal Morden Formation, the Boshy Formation and the Watties Bore Formation (Webby & others, 1988).

The purpose of this paper is to record new observations on the Mindyallan (early Late Cambrian) trilobite fauna collected from three localities near the base of the Kayrunnera Group. The localities are defined by reference to the Australian Map Grid on 1:100 000 topographic sheets of the Central Mapping Authority, New South Wales, as follows:

Locality No. I (including BMR locality K333): Kayrunnera 7436; grid ref.476-041
Locality No. II: Wonnaminta 7336; grid ref. 409-089
Locality No. III: Wonnaminta 7336; grid ref. 409-088

All localities belong to a fairly restricted stratigraphic interval within the Boshy Formation (Fig. 2). The trilobites are preserved as moulds in a fine-grained silty calcareous sandstone.

The three localities have produced the following assemblages. From locality No.I, the association includes *Ammagnostus* sp. indet., *Meteoraspis* sp. cf. *M. bidens* Öpik, 1967, *Biaverta* sp. cf. *B. reineri* Öpik, 1967, *Blackwelderia* sp. cf. *B. repanda* Öpik, 1967, *Bergeronites italops* (Öpik, 1967) and *Bergeronites* sp. indet. At locality No.II the assemblage comprises *M.* cf. *bidens, Biaverta* cf. *reineri, Blackwelderia* cf. *repanda* and *Placosema* cf. *adnatum* Öpik, 1967. A third assemblage has been recorded from locality No. III, and it includes *Biaverta* cf. *reineri, Biaverta* sp. indet. and *Blackwelderia* cf. *repanda.*

Compared with the distribution of trilobites in the Mindyallan successions of western Queensland (Öpik, 1963; 1967), these New South Wales assemblages seem most closely comparable with those of the Zones of *Acmarhachis quasivespa* and *Glyptagnostus stolidotus.* The agnostid genus *Ammagnostus* ranges through these Mindyallan Zones in Queensland. Of the polymeroid species, *Blackwelderia repanda* and the genus *Meteoraspis* are restricted to the Zone of *Glyptagnostus stolidotus,* while *Bergeronites italops* and *Placosema adnatum* are known from both the *A. quasivespa* and *G. stolidotus* Zones. *Biaverta reineri* is recorded only from the early Mindyallan *Erediaspis eretes* and *Acmarhachis quasivespa* Zones (Öpik, 1967). Over all, it seems that the ranges of the New South Wales assemblages are best regarded as belonging to the Zone of *Glyptagnostus stolidotus*, or, less likely, to a position near the boundary between the Zones of *Acmarhachis quasivespa* and *G. stolidotus.*

Structural and stratigraphical relationships

The steeply dipping Koonenberry Fault is a major tectonic feature developed parallel to the structural grain of the older basement rocks. This fault may be traced throughout the length of the Wonominta Block, either by surface expression (brecciated and sheared rocks) or by means of aeromagnetic maps, which reveal a marked contrast in magnetic signature across the fault trace (Leitch & others, 1987). Rocks as young as Late Palaeozoic age are cut by the fault, and Upper

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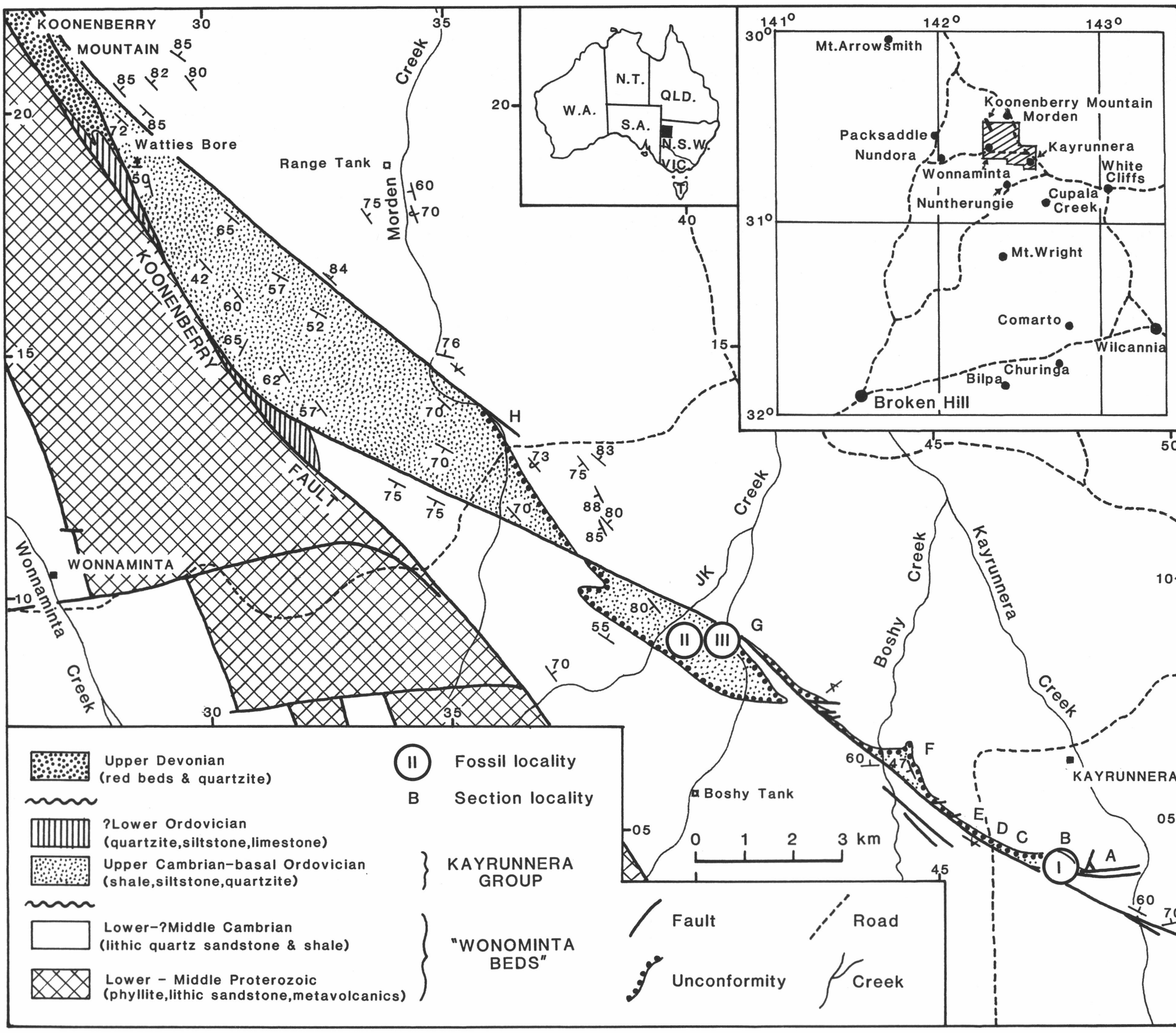

Figure 1. Geological map of the Kayrunnera-Wonnaminta area and inset locality maps of far western New South Wales to show location of the trilobite collecting localities Nos.I, II and III, and the positions of the sections shown in Fig.2.

Devonian quartzite is commonly preserved as upended or downfaulted slivers caught within the fault zone. Whereas in some places the fault is a simple planar structure, in others it branches into a number of sub-parallel surfaces, such as those which define the flanks of Koonenberry Mountain, an elongate upended blade of Upper Devonian quartzite and other Palaeozoic rocks several hundred metres wide and up to 10 km long (Fig. 1). Several near-vertical faults branch off from the Koonenberry Fault on the eastern side and trend towards the southeast and east. In the region between Koonenberry Mountain and Kayrunnera these branch faults control the distribution of the Kayrunnera Group, so that it is bounded either by these faults or by the basal unconformity. Movement on the Koonenberry Fault System is undoubtedly large, but evidence of the sense of movement is equivocal. From the curvature of some of the branch faults it may be suggested that they had a large component of dip-slip movement (northeast side down) through the Palaeozoic.

The Kayrunnera Group occurs as a series of steeply dipping fault-bounded wedges and is known only east of the Koonenberry Fault in the Koonenberry–Kayrunnera region, where it overlies a monotonous sequence of tight to isoclinally folded and well-cleaved, immature, feldspathic lithic sandstone of turbidite aspect. However, correlatives of the Kayrunnera Group may occur at Cupala Creek, Comarto and Churinga (east of the Koonenberry Fault), and at Mt Arrowsmith, Mt Wright and near Bilpa (west of the Koonenberry Fault).

Both the Kayrunnera Group and the underlying sequence tend to weather very readily, leading to subdued topography and poor exposure east of the Koonenberry Fault. Higher ground to the west of the Koonenberry Fault shows better exposures of Precambrian Wonominta Beds, a more thoroughly deformed sequence dominated by wide belts of phyllite and fine-grained lithic sandstone metamorphosed to the biotite zone of regional metamorphism. Within this older sequence are a number of magnetitic phyllite horizons and basic rock units, which define an interesting pattern on aeromagnetic maps (Stevens, 1985). To the west of the older rocks is a further belt of lithic sandstone, like that exposed east of the Koonenberry Fault. This belt passes through Wonnaminta and Nuntherungie homesteads. Slaty units within this belt near Wonnaminta homestead contain sponge spicules. Sponge spicules, along with trace fossils, are also found in the Copper Mine Range Beds (Webby, 1984), which unconformably underlie the Upper Cambrian Cupala Creek Formation (Powell & others, 1982) near Cupala Creek (30 km SSE of Kayrunnera homestead). No fossils have so far been found in the lithic sandstone or rarer slate beds that

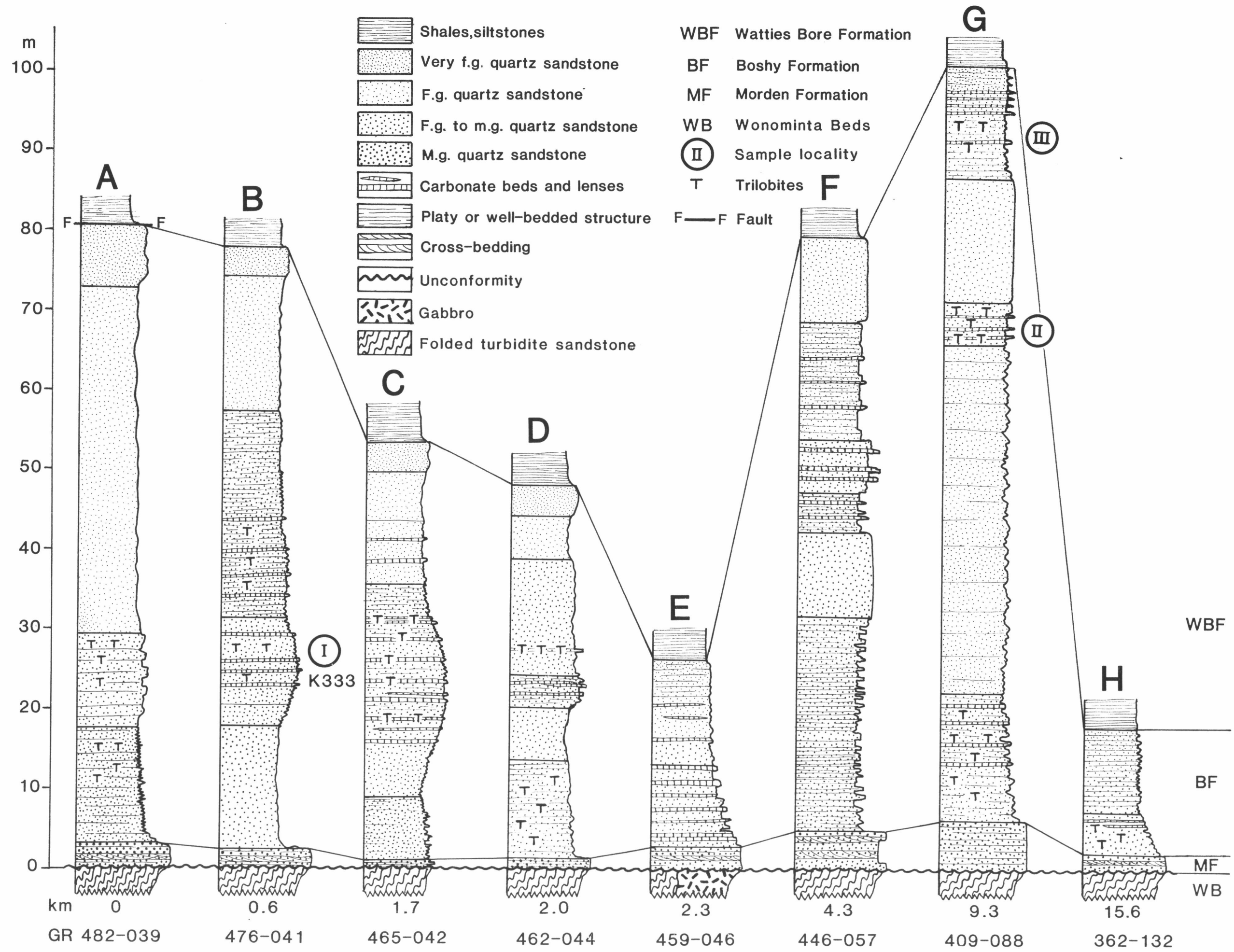

Figure 2. Stratigraphic columns of sections through the lower part of the Kayrunnera Group in the Kayrunnera-Wonnaminta area. For location of these columns see Fig. 1.

Note the stratigraphic positions of the trilobite collecting localities Nos. I (including BMR locality K333), II and III in the lower Upper Cambrian Boshy Formation of the Kayrunnera Group. The other horizons shown as exhibiting trilobites in the columns are either too fragmentary or too poorly preserved to be worthy of further detailed study. WB Wonominta Beds; MF Morden Formation; BF Boshy Formation; WBF Watties Bore Formation.

underlie the Kayrunnera Group, but, by lithological correlation with some sections of the Copper Mine Range Beds and the lithic sandstone and slate beds around Wonnaminta homestead, an Early to Middle Cambrian age is considered likely.

The greatest thickness of the Kayrunnera Group (over 2000 m) is preserved in the Koonenberry-Wonnaminta region, where most of the section is composed of weakly cleaved shaly slate and siltstone of the Watties Bore Formation. The best exposures of the lower part of the sequence (Morden and Boshy Formations) and the basal unconformity occur to the southeast on Kayrunnera Station. Eight stratigraphic sections, A to H (Fig. 2), have been measured from the unconformity through the Morden and Boshy Formations.

The sections illustrate wide variation in thickness and lithological character of the lower part of the succession, and also show the stratigraphic position of the sampled localities.

Where the Kayrunnera Group shows well-preserved lamination or bedding, it characteristically dips very steeply to the west and is, for the most part, west facing. Silty and shaly rocks within the sequence may show a weak to moderate sub-vertical cleavage trending 120°, which initiates pencil slate weathering in finely laminated shales. The degree of metamorphism is slight (chlorite zone), and narrow quartz veins are only rarely encountered. White quartz veins and pods are a prominent feature of the older basement rocks, especially in the multiply deformed phyllites west of the Koonenberry Fault. The unconformity at the base of section E (Fig. 2) appears to overlie a weathered gabbro intrusion into the older basement. No basic intrusions penetrate the Kayrunnera Group.

The basal unit of the Kayrunnera Group is the Morden Formation, consisting of a distinctive hard white medium-grained quartzite, 1–6 m thick, forming prominent exposed outcrops over much of its strike length. Within the unit, bedding is often defined by fine silty laminations or partings. Small to medium scale cross-bedded units are not uncommon (Fig. 2, Sections A,B,E,F) and, based on 6 measurements, suggest a southeasterly current source. Thin limestone lenses and a calcareous cement may be found in places (e.g. section E, Fig. 2).

The overlying Boshy Formation consists of interbedded fine-grained quartz sandstone, feldspathic quartz sandstone, siltstone, and some calcarenite and impure limestone beds and lenses. The measured sections A to H show considerable variation in thickness of this formation (from 15.7 m in section H to 94.3 m in section G, 6.3 km south). The base of the formation is defined by a sharp contact with the hard medium-grained quartzite of the Morden Formation, and the top is sharply defined by the incoming of soft recessive yellow-weathering shale of the Watties Bore Formation. The lithological variation within the sections makes it difficult to correlate units from one section to another. Some tentative correlations can be made where the sections are closer together (e.g. sections A to D, Fig. 2). A very fine-grained angular weathering pale-pink to buff-cream coloured sandstone at the top of the section can be correlated from A to D. Some sections are more richly fossiliferous than others, and trilobites, usually associated with carbonate-rich beds and lenses, may be found in one or more horizons in a column (e.g. section G). No particular age distinctions were made between specimens recovered at localities 4 and 5 within section G. Further sampling may eventually reveal subtle age differences.

The Morden and Boshy Formations together represent a progression of nearshore to shallow marine facies, accumulated during a Late Cambrian marine transgression across eroded rocks of the earlier, pre-Middle Cambrian fold belt succession. Exposed in the creek channel at grid ref. 410-076 (Wonnaminta sheet 7336) is a local lens of lithic conglomerate, reminiscent of that at the base of the Cupala Creek Formation, but preserved here at the base of the Morden Formation. This conglomerate contains rounded pebbles and cobbles of lithic arenite, up to 50 mm across, and may represent a localised fluvial deposit that formed immediately before the main marine transgression. Elsewhere, the unconformity surface at the base of the Kayrunnera Group appears remarkably smooth, with the eroded debris being composed of a blanket of medium-grained quartz sand. Above the Boshy Formation is a thick sequence (>2000 m) of finely laminated siltstone and shale of the Watties Bore Formation. These rocks represent a deeper marine facies and contain species of trilobites more representative of an 'outer detrital facies' (Webby & others, 1988). This shaly sequence continues upward into the lowermost Ordovician with the appearance of *Hysterolenus* sp.

Correlation of Upper Cambrian sequences in the Wonominta Block

Figure 3 presents a tentative correlation of the Kayrunnera Group with some other Upper Cambrian and Lower Ordovician units within the Wonominta Block. The figure shows an almost two-dimensional section from Mt Wright to Koonenberry Mountain by way of Cupala Creek and Kayrunnera. Middle Upper Cambrian (Idamean) trilobites have been described from shale and shaly limestone near the top of the Cupala Creek Formation (Jell, in Powell & others, 1982), and trilobites of latest Cambrian–early Ordovician ages have been recorded from a number of levels through the Mootwingee Group (Shergold, 1971).

A gap of at least 10 Ma is inferred in the upper part of the Middle Cambrian succession, representing the major

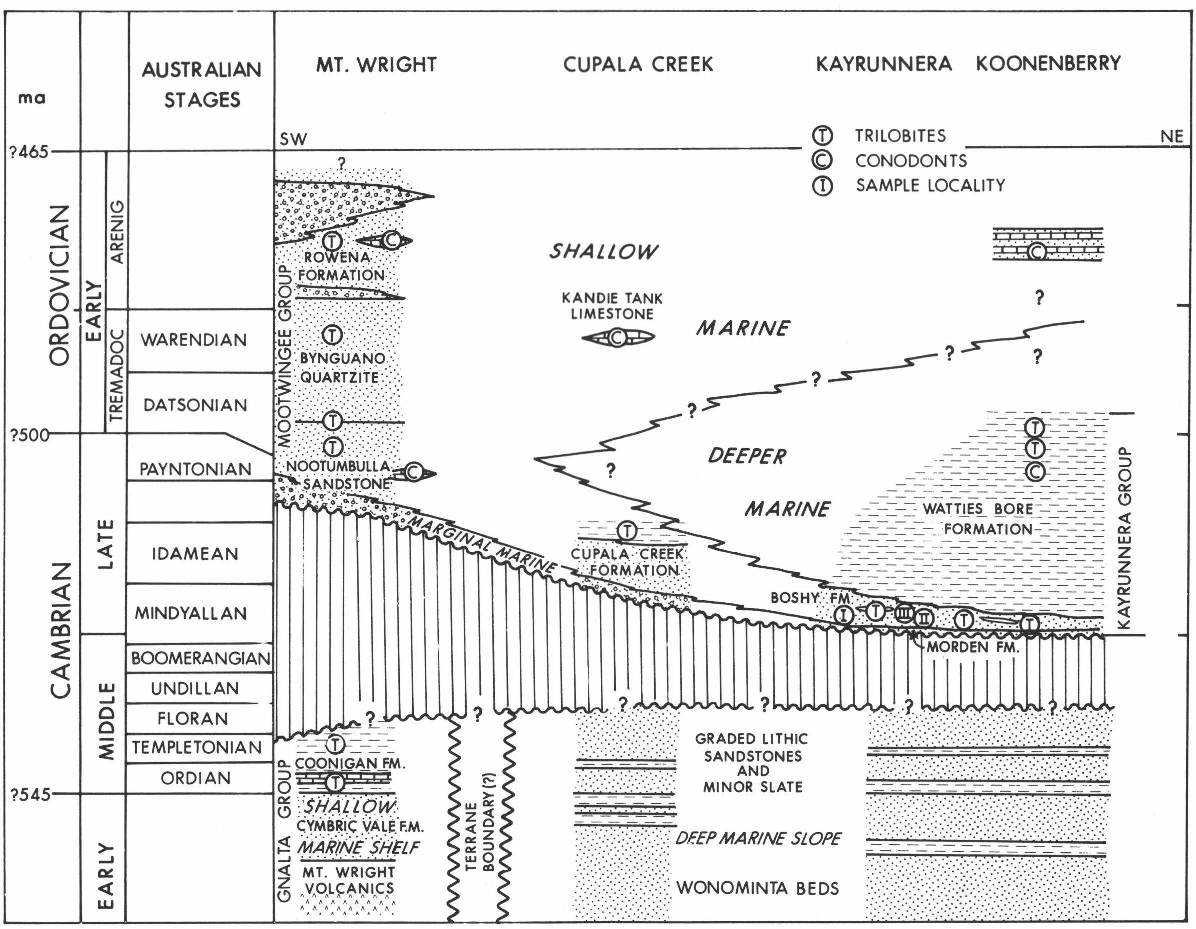

Figure 3. Diagram showing the inferred stratigraphical age and environmental relationships of the Cambrian–Early Ordovician deposits in Western New South Wales.

Note the major late Middle–Late Cambrian break (Mootwingee Movement of the Delamerian Orogeny) shown by the vertical lines.

orogenic phase, probably the main expression of the Delamerian Orogeny, in western New South Wales. This was a time of intense, upright, tight to isoclinal folding of the previously deposited, deeper marine turbidite facies, lithic sandstone of Early to early Middle Cambrian age in the central and eastern parts of the Wonominta Block. These intensely deformed rocks are separated from the less intensely folded and metamorphosed western shallow shelf facies at Mt Arrowsmith and Mt Wright (Gnalta Group) by one and two terrane boundaries, respectively (Leitch & others, 1987).

The stratigraphic break that developed above these Early–early Middle Cambrian deposits existed through the late Middle Cambrian of the Kayrunnera and Wonnaminta areas, a little longer, to early Late Cambrian, at Cupala Creek, and until the mid–late Late Cambrian in the Mt Wright area. This break was previously identified near Mt Wright as representing an important orogenic pulse (Mootwingee Movement) of the Delamerian Orogeny (Webby, 1978). The major break in the Amadeus Basin is, by comparison, also identified as reflecting the Delamerian Orogeny, but only extends through the Late Cambrian (post-Mindyallan to pre-Payntonian) interval (Shergold, 1986). In the Flinders Ranges of South Australia, Jago & Daily (in Cooper & Grindley, 1982, p.11) noted that at least part of the Lake Frome Group is late Middle Cambrian age, but then sedimentation was 'halted by the Late Cambrian–Ordovician Delamerian Orogeny'. Most of the evidence of age of the Delamerian Orogeny as near the Cambrian–Ordovician boundary in the Adelaide Fold Belt seems to come from radiometric dates of granites (Preiss, 1987), but these probably reflect the cooling history rather than the timing of major folding and uplift events in the fold belt. In western New South Wales, the break seems to have been established a little earlier than elsewhere, and it may be interpreted as suggesting a slightly earlier start to the major orogeny in this most easterly part of the Precambrian–Early Palaeozoic fold belt.

The markedly diachronous overlying Late Cambrian–Early Ordovician sequences formed part of a depositional system with common provenance, facies and faunal relationships, and a consistent palaeogeography. They have linkages across a region formerly divided into three terranes (Leitch & others, 1987). In terms of generalised palaeogeography, most of the area of the Wonominta Block had a shelf-like configuration, and has been referred to the Gnalta Shelf (Webby, 1978; 1983). It represented a part of the Gondwana continental shelf, and was dominated by a large delta complex with successive influxes of siliciclastic material being transported across the shelf from the south and west. Gross facies variations and cross-bedding directions support this interpretation. A major Late Cambrian–Early Ordovician transgressive–regressive cycle is depicted in Fig. 3, with sandy, trilobite-bearing, on-shelf facies moving slowly southwards through Mindyallan (Boshy Formation) to Payntonian (Nootumbulla Sandstone) time, during the initial transgression. By latest Cambrian–earliest Ordovician (Payntonian–Datsonian) time, near the maximum of the transgression, a deeper, silty, trilobite-bearing, off-shelf (slope or basinal) facies (Watties Bore Formation) developed in the Koonenberry–Kayrunnera area (Webby & others, 1988), while contemporaneous deposits to the south at Mt Wright were marginal to shallow marine, and still farther south at Bilpa, fluvial to marginal marine (Webby, 1983). In the succeeding Warendian to younger regressive phase, there are records of isolated occurrences of shallow-water carbonate (Kandie Tank Limestone of Pogson & Scheibner, 1971) near Cupala Creek, and thin-bedded shelf-type carbonate, shale and quartzite at Koonenberry Gap, these latter closely analogous to Early Ordovician (Arenig) sequences (Yandaminta Quartzite and Tabita Formation) at Mt Arrowsmith (Webby & others, 1981).

Systematic descriptions

Specimens bearing the prefix SUP are deposited in the collection of the Department of Geology and Geophysics, University of Sydney; those bearing the prefix CPC are housed in the Commonwealth Palaeontological Collection of the Bureau of Mineral Resources, Canberra. References to suprageneric taxa erected before 1959 may be found in the *Treatise on Invertebrate Paleontology,* part O (Moore, 1959).

All the material described here is rather poorly preserved as moulds in siltstone or sandstone, and all has been deformed to some degree. It is clearly referable taxonomically to elements of the lower Upper Cambrian (Mindyallan) fauna of western Queensland (Öpik, 1967), but the preservation generally does not allow us to be categoric in our determinations. Accordingly, we have made full use of the confer (cf.). Since this Mindyallan fauna has been described at length by Öpik (1967), minimal description is given here unless significant new information is available as in the case of *Blackwelderia* cf. *repanda,* a practice again dictated by preservation. We do, however, comment at some length on the distribution of the main faunal components, to give some idea of the age limits and geographic spread of this characteristic Asian/Australian biofacies.

Order **Agnostida** Salter, 1864
Suborder **Agnostina** Salter, 1864
Family **Diplagnostidae** Whitehouse, 1936
Subfamily **Ammagnostinae** Öpik, 1967
Genus ***Ammagnostus*** Öpik, 1967

Type species. *Ammagnostus psammius* Öpik, 1967

Ammagnostus sp. indet.
Fig. 4A–D

Material. Two cephalic internal moulds (CPC 26515 & 26516), one of which is incomplete, and two pygidial internal mounds (CPC 26517 & 26518), all from locality No. I.

Remarks. Originally, it was thought that the agnostoid material described here represented two distinct genera. Both cephala are laterally compressed to some extent, and thus the distinctiveness of the second glabellar lobe and the configuration of the furrow separating it from the posterior lobe is emphasised to resemble the situation found commonly in *Idolagnostus* Öpik, 1967. In the pygidium, the effaced elongate axis, deliquiate border furrows, wide borders and acrolobe constriction all resemble conditions seen in early Mindyallan species of *Agnostoglossa* Öpik, 1967, already reported from Kayrunnera by Öpik (1975, p.7).

Allowing for preservation and deformation, however, the combination of cephalon and pygidium found at Kayrunnera seems more likely to represent a single species of *Ammagnostus.* Öpik (1967) described four species of this genus from the Mindyallan *Acmarhachis quasivespa* and *Glyptagnostus stolidotus* Zones in western Queensland, and other material has been described from Lesser Karatau, southern Kazakhstan (Ergaliev, 1980) that is of similar age. The genus possibly also occurs in Liaoning Province,

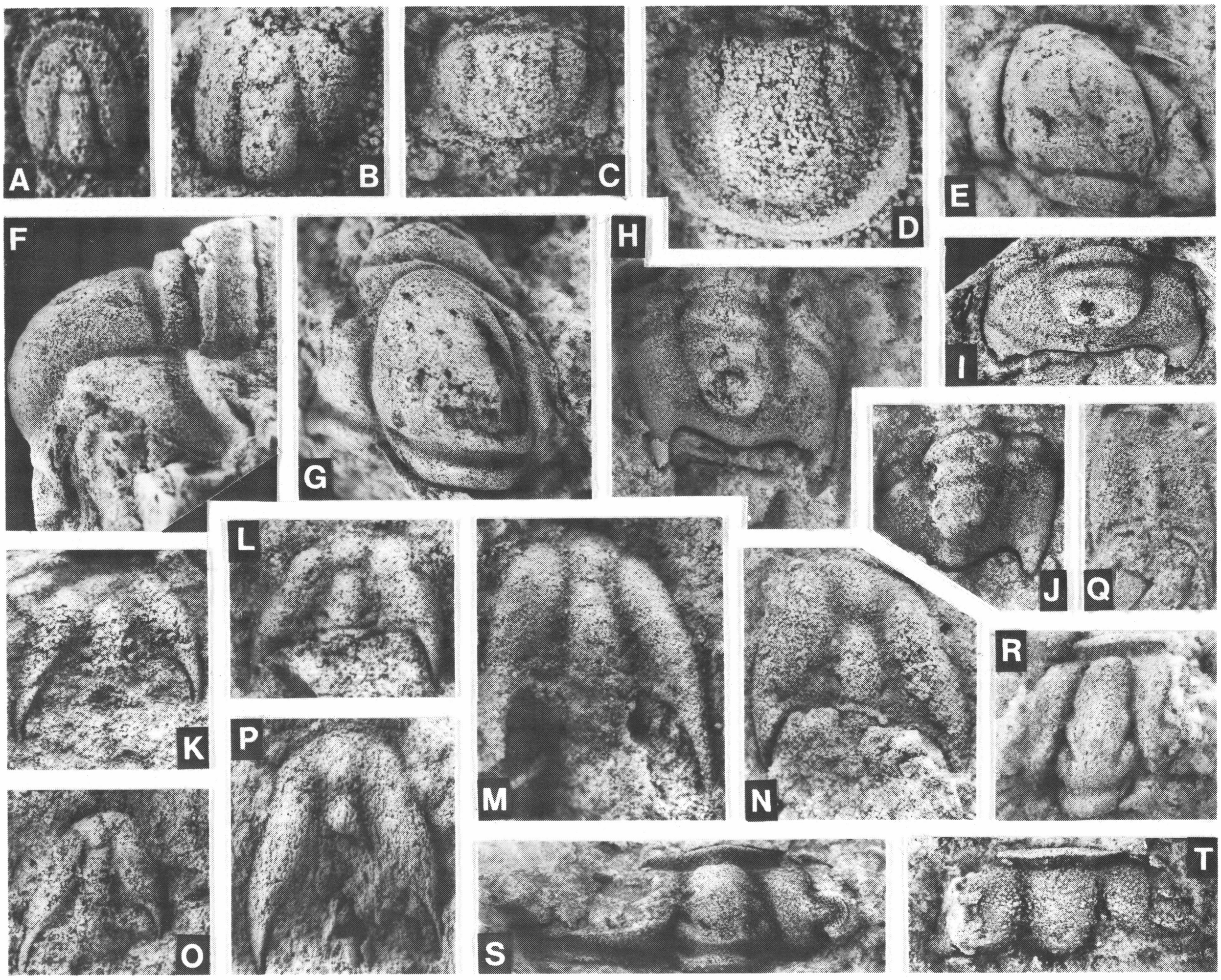

Figure 4. Late Cambrian (Mindyallan) trilobites from the Boshy Formation (Kayrunnera Group) at Kayrunnera.
A–D *Ammagnostus* sp. indet., x10; locality No. I. A, internal mould of cephalon, CPC 26515. B, internal mould of incomplete cephalon, CPC 26516. C, internal mould of incomplete pygidium, CPC 26517. D, internal mould of pygidium, CPC 26518. **E–J *Meteoraspis* sp. cf. *M. bidens*, Öpik, 1967,** x3; E–G from locality No. II, H–J from locality No. I. E, external mould of cranidium of paratype, SUP 54901. F–G, lateral and dorsal views of internal mould of holotype cranidium, SUP 54900. G, internal mould of holotype cranidium, SUP 54900. H, internal mould of paratype pygidium CPC 26519. I, internal mould of paratype pygidium CPC 26520. J, internal mould of paratype pygidium SUP 54902. **K–P *Biaverta* sp. cf. *B. reineri* Öpik, 1967,** x5; locality No. I. K, internal mould of cranidium, CPC 26521. L, internal mould of cranidium, SUP 54903. M, external mould of cranidium, CPC 26522. N, internal mould of cranidium, SUP 54904. O, internal mould of cranidium, SUP 54905. P, internal mould of incomplete cranidium CPC 26523. Q ***Biaverta* sp. indet.**, x5, internal mould of cranidium SUP 54906 from locality No. III. **R–T *Blackwelderia* sp. cf. *B repanda* Öpik, 1967,** x2; locality No. I. R, external mould of cranidium, CPC 26524. S, internal mould of cranidium, CPC 26525. T, internal mould of incomplete cranidium, CPC 26526.

northeastern China (Schrank, 1975) and in the southeast of the Altai Mountains, Siberia (Romanenko *in* Zhuravleva & Rozova, 1977).

The material from Kayrunnera seems most closely to resemble the type species, *A. psammius* Öpik, 1967, from the O'Hara Shale of western Queensland, particularly in glabellar and pygidial axis characteristics, even though the third anterior ring of the latter is not visible. Nevertheless, the general construction of the pygidium, with its constricted acrolobes, broad borders and deliquiate border furrow, and possession of a long (sag.) laterally expanded saccate posterior axial lobe, which extends to the posterior border furrow, seems quite typical. Since the original cephalic shape cannot be determined, and because sufficient comparative material is unavailable, the species from western New South Wales is left under open nomenclature.

Order **Ptychopariida** Swinnerton, 1915
Suborder **Ptychopariina** Richter, 1933
Family **Tricrepicephalidae** Palmer, 1954
Genus ***Meteoraspis*** Resser, 1935

Type species. *Ptychoparia? metra* Walcott, 1890

Meteoraspis sp. cf. *M. bidens* Öpik, 1967
Fig. 4E–J

cf. 1967 *Meteoraspis bidens* sp. nov.; Öpik, 1967, pp. 195-198, pl. 5, figs 4–9.

Material. Two cranidia, SUP 54900, an internal mould, and SUP 54901, an external mould; and three pygidial internal moulds, CPC 26519 & 26520 and SUP 54902. Material is from both localities I and II.

Remarks. The genus *Meteoraspis* is widely distributed in North America, Asia and Australia. Up to now, twenty species (apart from uncertain and questionable forms) have been assigned to the genus, among which are the Australian species *M. bidens* Öpik, 1967 and *M.* aff. *bidens* Öpik, 1967 from the early Late Cambrian (Mindyallan) Georgina Limestone, Mungerebar Limestone and O'Hara Shale of western Queensland. A Chinese species of *Meteoraspis* occurs in the Upper Cambrian Lindagogou Group, Nidaogou, Hualong, Qinghai Province (see Xiang & others, 1981, p.62).

Most species of *Meteoraspis,* however, have been described from North America: *M. laticephalus* Kobayashi, 1938, *M. banffensis* Resser, 1942, *M. borealis* Lochman, 1938, *M. spinosa* Lochman, *in* Lochman & Duncan, 1944, *M. robusta* Lochman, *in* Lochman & Duncan, 1944, *M. elongata* Lochman, *in* Lochman & Duncan, 1944, *M. keeganensis* Duncan, *in* Lochman & Duncan, 1944, *M. boulderensis* DeLand, *in* DeLand & Shaw, 1956, *M. globosa* (Miller, 1936), *M. intermedia* Lochman & Hu, 1961, *M. metra* (Walcott, 1890), *M. bipunctata* Lochman, 1938, *M. delia* Lochman, 1940, *M. mutica* Rasetti, 1961, *M. brevispinosa* Rasetti, 1965, and *M. minuta* (Raymond, 1937). One additional species, *M. tinguirensis* Rusconi, 1954 has been reported from Argentina.

The above-listed species are restricted to sequences of the Late Cambrian Mindyallan Zone of *Glyptagnostus stolidotus* in Australia and the *Cedaria* to *Crepicephalus* Zones of North and South America. It is too difficult to analyse all the relationships between these described species because the recorded material is so incomplete: in some, for example, the pygidium is unknown. Nevertheless, the species as a whole may be divided into groups depending on the presence or absence of pygidial spines. The first is typified by *M. brevispinosa* Resetti which has short pygidial spines. The second, characterised by *M. mutica* Rasetti, from the Dresbachian Conococheague Formation of Virginia, has a broad median notch on the posterior margin and lacks pygidial spines. Most species, including all those from Australia, belong to the first group. They are differentiated by cranidial convexity, geometry and organisation of the preglabellar area, size and position of the palpebral lobes, segmentation of the pygidium, and size, shape and orientation of the spines and posterior margin.

Kayrunnera material is quite similar to *Meteoraspis bidens* Öpik, from the Late Cambrian Mindyallan Zone of *Glyptagnostus stolidotus* in western Queensland, but even allowing for indifferent preservation, there are discrete differences. In particular, the cranidium seems more convex (sag., tr.), the glabella proportionately longer (sag.), the preglabellar area slopes adventrally, and the palpebral areas may be narrower (tr.). The pygidium appears to have only two well-defined axial rings, whereas in *M. bidens* there are three, with a fourth indicated, but less distinct. The posterolateral spines are distally incurved (adaxially), whereas in *M. bidens* they are directed straight backwards. There is also cranidial similarity with *Meteoraspis brevispinosa* described by Rasetti (1965) from the late Cambrian *Crepicephalus* Zone of the Lower Limestone Member of the Nolichucky Formation of Tennessee, but again the pygidium assigned to this species has three, rather than two, distinctive axial rings. The American species additionally possesses a straight posterior pygidial margin between the spine bases, whereas on the Australian ones it is always curved.

Family **Menomoniidae** Walcott, 1916
Genus ***Biaverta*** Öpik, 1967

Type species. *Biaverta biaverta* Öpik, 1967

Biaverta sp. cf. ***B. reineri*** Öpik, 1967
Fig. 4K–P

cf. 1967 *Biaverta reineri* Öpik, 1967, pp. 371–372, pl. 39, Figs. 1–5

?1967 *Ascionepea anitys* Öpik, 1967, p. 366, pl. 40, figs. 4–6; pl. 46, fig. 4.

Material. Öpik's original type specimens of *Biaverta reineri* from the Mindyallan Mungerebar Limestone of western Queensland are deposited in the collections of the Bureau of Mineral Resources, Canberra, CPC 5660–5664. The New South Wales material described herein includes a large number of cranidial internal moulds and a few cranidial external moulds CPC 26521–26523 and SUP 54903–54905. These specimens come from all the localities described herein. All the New South Wales material has to a certain degree been compressed or tectonically distorted, and affected by preservation in the sandstone lithology.

Age. In western Queensland the species ranges from the Mindyallan Zone of *Erediaspis eretes* to low in the Zone of *Glyptagnostus stolidotus.*

Remarks. Specimens from New South Wales are essentially similar to *Biaverta reineri* as described by Öpik (1967) from western Queensland. They are, however, larger, have a more strongly convex preglabellar field, and better defined lateral glabellar lobes and furrows. They also have posterolateral limbs which are larger and more strongly retrally directed. Their observed lack of prosopon is probably a function of their preservation in sandstone. *Biaverta* cf. *reineri* is also very similar to *Ascionepea anitys* Öpik, 1967, which is also from the *Erediaspis eretes* Zone in western Queensland. Both, for example, have ill-developed ocular ridges which are in line with the front of the glabella, and bear no anterior border or border furrow. According to Öpik's descriptions, *A. anitys* differs from *Biaverta reineri* Öpik, mainly in being smaller and having minute palpebral lobes (0.2 of the glabellar length), although the latter cannot be seen on Öpik's figures 4–6. *A. anitys* is better considered an early representative of the genus *Biaverta* Öpik, perhaps even a synonym of *Biaverta reineri.* The type species of *Ascionepea* Öpik, *A. janitrix* Öpik, is distinctly different from *Biaverta* in having prominent eyes and a glabella projecting forward beyond the ocular ridges.

Biaverta sp. indet.
Fig. 4Q

Material. One reasonably well-preserved internal cranidial mould (SUP 54906), from locality No. III.

Remarks. This single specimen of *Biaverta* Öpik is related to the type species, *B. biaverta,* but has a shorter glabella, a shorter (sag.) anterior border, and a longer (sag.) depressed preglabellar field. There is insufficient material to diagnose this species accurately and consequently it is left in open nomenclature.

Family **Damesellidae** Kobayashi, 1935
Subfamily **Damesellinae** Kobayashi, 1935
Genus ***Blackwelderia*** Walcott, 1905

Type species. *Calymene? sinensis* Bergeron, 1899

Age and distribution. Although *Blackwelderia* is known from the late Middle to early Late Cambrian in parts of Asia, in Australia it is confined to the Late Cambrian, Mindyallan Zones of *Erediaspis eretes* through *Glyptagnostus stolidotus* (Öpik, 1967) where its representatives are *B. sabulosa* Öpik, 1967, *B. gibberina* Öpik, 1967 and *B. repanda* Öpik, 1967.

In the Soviet Union, the genus occurs in the late Middle to early Late Cambrian. It is represented by *B.? florens* Lazarenko, 1966 from the Late Cambrian of northern Siberia, and *B. sinensis* (Bergeron, 1899), *B.* cf. *repanda* Öpik, 1967 and *Blackwelderia* sp. from the late Mayan and Ayusokkanian Stages (*Lejopyge laevigata* to *Glyptagnostus* *stolidotus* Zones) of Maly Karatau, southern Kazakhstan (Ergaliev, 1980, 1981).

In the Himalaya, a probable species of *Blackwelderia* has been reported from the Trahagam Formation, Hundwara Tehsil, Kashmir (Jell, 1986).

In China, *Blackwelderia* occurs mainly in the early Late Cambrian Gushan Stage, and has been found in such regions as the North China Platform, the Kunlun-Qiling subprovince, the Yangzi Platform and the Jiangnan geological subprovince. On the North China Platform the Gushan Stage is divided into two zones, the *Blackwelderia* Zone (below) and the *Drepanura* Zone (above). However, *Blackwelderia* is usually found in both zones, even in the type section and locality of the stage, at Gushan County, Shandong Province. Many species of *Blackwelderia* have been described from the North China Platform, including: *B. sinensis* (Bergeron, 1899), *B. sinensis lingchengensis* Sun, 1924, *B. chiawangensis* Chu, 1959, *B. gigas* Sun, 1924, *B. granosa* Endo, *in* Endo & Resser, 1937, *B. liaoningensis* Chu, 1959, *B. longispina* Endo & Resser, 1937, *B. mui* Chu, 1959, *B. octaspina* (Kobayashi, 1935), *B. paronai* (Airaghi, 1902), *B. paronai* var. *penchiensis* Chu, 1959, *B. paronai tieni* Sun, 1924, *B. pingluensis* Zhang & Wang, 1986, *B. shenhi* Chu, 1959, *B. similis* Endo, *in* Endo & Resser, 1937, *B. spectabilis* (Resser & Endo, *in* Endo & Resser, 1937) *B. triangularis* Chu, 1959, *B. disticha* Zhang *in* Qiu & others, 1983, *B. tenuicarina* Zhang *in* Qiu & others, 1983, *B. fengshanensis* Kuo, 1965, and *B. minuta* Zhang & Wang, 1985. Older species have been recently revised by Zhang & Jell (1987).

In the Oulongbuluke area of the Kulun-Qiling geological subprovince, stable platform-type lithological sequences of Cambrian age contain North China-type trilobites, although the Kulun-Qiling subprovince was strictly part of a transitional (intermediate depth) region at that time (Chang, 1988). *Blackwelderia* sp. is often found in the upper portion of the Middle-Upper Cambrian Oulongbuluke Formation, at Oulongbuluke in Qinghai Province, and it has also been reported from the Late Cambrian Wugongy Formation of Xinzigou and Caigou, Xichuan, Henan Province, in the eastern part of the Qiling Mountains (Xiang & others, 1981, pp. 63, 68). On the Yangzi Platform, which was mainly a hypersaline shallow sea during the Middle–Late Cambrian, *Blackwelderia* is rather rare, and only found in some local intercalations of normal shallow marine beds. Species include *B. quangxiensis* Zhou *in* Zhou & others, 1977 from the Upper Cambrian at Shechang, Longlin Ge Autonomous County of Guangxi Province, *B. sinensis* Bergeron, 1899 and *B. paronai* (Airaghi, 1902) from the early Late Cambrian sequences near the border between Yunnan Province and Vietnam; *Blackwelderia* sp. from the lower portion of the Upper Cambrian of Dingyan, Xianfeng (Zhou & others, 1977), and *B. nodosaria* Zhu, 1987 from Xijiadian, Junxian, both in Hubei Province.

The transitional Jiangnan geological subprovince contains a probable species of *Blackwelderia* in the *Paradamesopsis jimaensis–Cyclolorenzella tuma* Zone of Guizhou Province. This zone predates the Gushan Stage and contains *Lejopyge laevigata,* regarded as indicating the uppermost Middle Cambrian in Europe (Yin & Li, 1978). *Blackwelderia* therefore mainly has a normal shallow marine occurrence in the early Late Cambrian of China. However it probably appeared earlier during late Middle Cambrian times, in the transitional regions.

Blackwelderia sp. cf. ***B. repanda*** Öpik, 1967
Fig. 4R–T; Fig. 5A–I

cf. 1967 *Blackwelderia repanda* Öpik, pp. 315–316; pl. 32, fig. 2, pl. 47, fig. 10.

Material. Öpik's previously described type specimens of *Blackwelderia repanda* from the O'Hara Shale of western Queensland are deposited in the collections of the Bureau of Mineral Resources, Canberra, CPC 5736 & 5605. The presently described New South Wales material includes a large number of specimens (cranidia, pygidia and free cheeks) from all localities at Kayrunnera. The best-preserved specimens, though still to a certain degree affected by tectonic distortion, are described herein because they contribute new information on this species. They are referred to specimen numbers CPC 26524–25631 and SUP 54907–54910.

Age. In western Queensland this species is restricted to the early Late Cambrian Mindyallan Zone of *Glyptagnostus stolidotus.*

Description. Cranidium trapezoidal, moderately to strongly convex. Glabella long, forwards tapering, anteriorly truncated, strongly elevated, with three pairs of lateral glabellar furrows and deep well-defined axial furrows; first and second pairs of glabellar furrows (counting from the rear) long, deep, extending inwards and rearwards; third anteriormost pair shorter, sometimes imperceptible, nearly transverse. Occipital ring longer (sag.) at middle, gently narrowing and backwardly curved laterally; occipital furrow broad (sag.) and deep. Preglabellar area consists of broad (sag.), deep and extended anterior border furrow and straight, ridge-like, upturned border; no preglabellar field; pair of indistinct pits (fossulae) located at anterolateral corners of glabella, at intersection of axial and anterior border furrows. Fixed cheeks strongly convex, about two-thirds of glabellar width at level of anterior margins of palpebral lobes; palpebral lobe about 50–60% the glabellar length, crescentic, highly elevated and with deep palpebral furrow on adaxial side; ocular ridge weakly developed extending from anterior end of the palpebral lobe towards anterolateral corner of glabella. Posterolateral limbs narrow (exsag.) and long (tr.), steeply downturned posteriorly; posterior border furrow deep, broad, widening gently laterally; posterior border narrow (exsag.), ridge-like. Anterior branches of facial suture gently convex and forwards converging; posterior branches run nearly transversely and slightly posteriorly, cutting posterior border at a considerable distance (about maximum width of glabella) out from the axial furrow. Dorsal surface of cranidium covered with coarse granules set in a matrix of closely spaced fine granules.

Lateral border of free cheek broad, slightly convex, well-defined by shallow and broad furrow that is continuous with posterior border furrow, but somewhat deeper at genal angle; genal spines long, narrowing from a thickened base, but not in continuity with curvature of outer margin of free cheeks; base of spine situated well in front of posterolateral corner of cephalon; free cheeks also show on their broad, moderately convex external surface a covering of fine and coarse granules.

Pygidium (except for spines) is reversed trapezoidal in dorsal outline, and moderately convex. Axis as wide as the pleural field anteriorly, strongly convex, tapering backwards, consisting of four to five axial rings with semicircular terminal piece; four moderately to strongly convex pleurae divided by deep and broad interpleural grooves. Seven pairs of backwardly and outwardly directed marginal spines developed; fifth pair (from front) more prolonged and robust, but first to fourth (especially the first) also relatively long; sixth and seventh presented as short, dentate extensions of posterior border; base of each spine bears a more or less

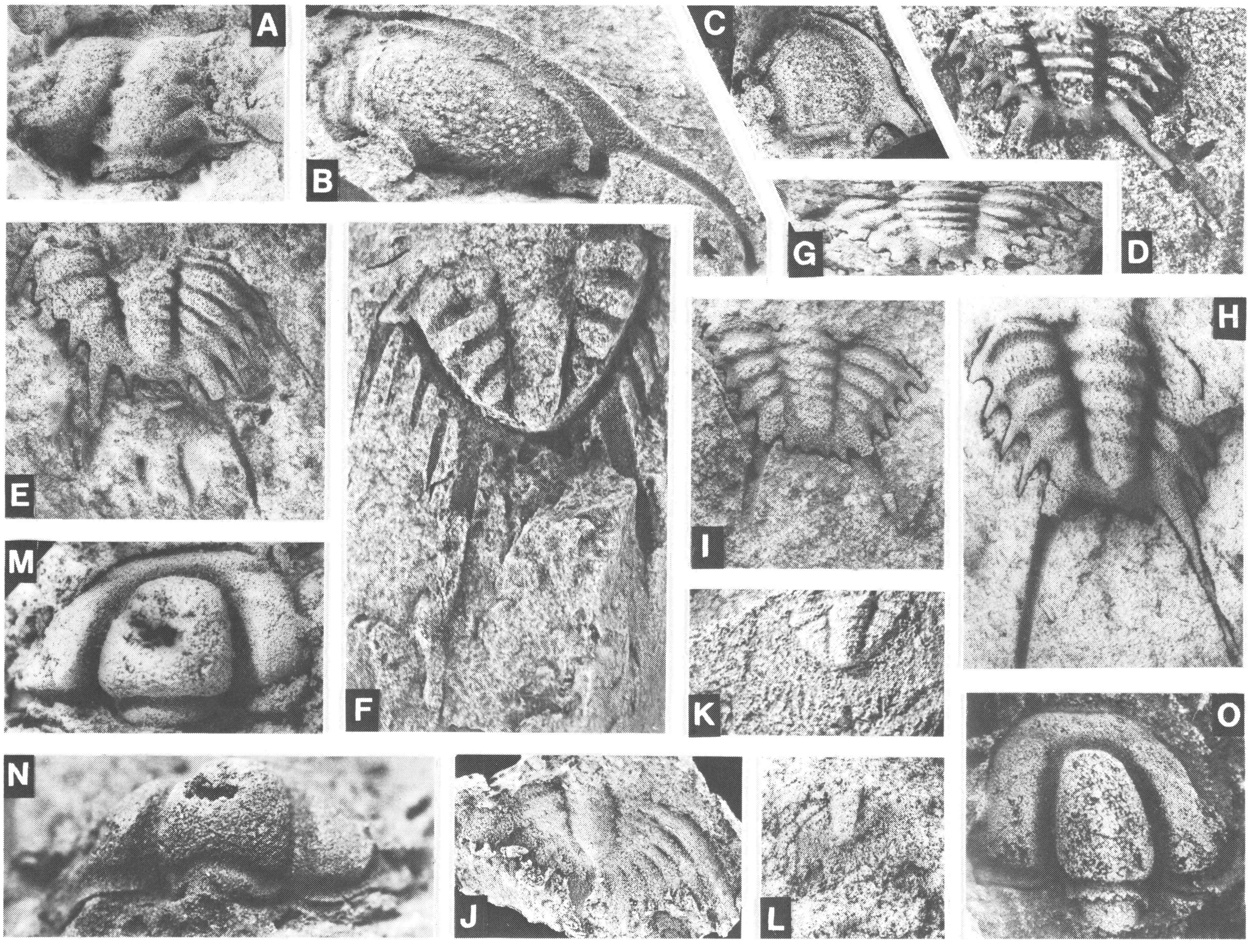

Figure 5. Late Cambrian (Mindyallan) trilobites from the Boshy Formation(Kayrunnera Group) at Kayrunnera.
A–I *Blackwelderia* sp. cf. *B. repanda* Öpik, 1967, x2. A–E & I, locality No. I, F & H, locality No. II. G, locality No. III. A, internal mould of cranidium, CPC 26527. B, internal mould of free cheek, CPC 26528. C, internal mould of free cheek, CPC 26529. D, internal mould of pygidium, CPC 26530. E, internal mould of pygidium, CPC 26531. F, internal mould of pygidium, SUP 54907. G, internal mould of pygidium, SUP 54908. H, internal mould of pygidium, SUP 54909. I, internal mould of pygidium, SUP 54910. J ***Bergeronites italops*** (Öpik, 1967), x2, external mould of pygidium, CPC 26532, locality No. I. **K–L *Bergeronites* sp. indet.,** x2; locality No. I. K, internal mould of pygidium, SUP 54911. L, internal mould of pygidium, CPC 26533. **M–O *Placosema adnatum* Öpik, 1967,** x5; locality No. II. M–N, dorsal and posterodorsal views of internal mould of cranidium, SUP 54912. O, internal mould of cranidium, SUP 54913.

clearly defined granule, only seen on well-preserved specimens (see Fig. 5 D). Surface of pygidium bigranulate.

Remarks. The illustrated cranidia and pygidia have the basic characteristics of *Blackwelderia repanda* Öpik. They have, for example, a straight, upturned and ridge-like anterior border, an extended cephalic marginal furrow, crescentic palpebral lobe, faint ocular ridges, strongly developed pygidial spines, especially the fifth pair, and a granule on the base of each pygidial spine. The only difference between the New South Wales material and that from western Queensland is that the former are a little larger. They also seem to have more closely spaced granulation and a better developed, longer, fifth pair of pygidial spines, but these are comparatively minor distinctions, probably in part reflecting differences in preservation.

Subfamily **Drepanurinae** Hupé, 1953
Genus ***Bergeronites*** Sun *in* Kuo, 1965
[= ***Palaeodotes*** Öpik, 1967, = ***Drepanura*** (***Spinopanura***) Kushan, 1973, = ***Bergeronites*** (***Palaeodotes***) Öpik, 1967 ***sensu*** Peng, 1987]

Type species. *Bergeronites ketteleri* (Monke, 1903)

Remarks: Daily & Jago (1976) first indicated the synonymy of *Palaeodotes* Öpik, 1967 (containing *P. dissidens* Öpik, *P.* aff. *dissidens* Öpik and *P. italops* Öpik) with *Bergeronites* Kuo, 1965. This synonymy was confirmed by Zhou & others (1977) who also suggested the synonymy of *Drepanura (Spinapanura)* Kushan, 1973 (containing *D. (S.) erbeni* Kushan and D. *(Spinapanura)* sp.). Peng (1987) has recently regarded *Palaeodotes* as a subgenus of *Bergeronites* but his justification is not convincing. The type species, *B. ketteleri* (Monke), has recently been reviewed by Zhang & Jell (1987).

Age and distribution. *Bergeronites* is widely distributed in Europe, Asia, Australia and Antarctica and, until now, 33 species have been assigned to the genus. Australian species are *B. dissidens* (Öpik, 1967), *B.* aff. *dissidens* (Öpik, 1967) and *B. italops* (Öpik, 1967) from the Mindyallan *Acmarhachis quasivespa* to *Glyptagnostus stolidotus* Zones of western Queensland. *B.* cf. *italops* (Öpik, 1967) has been identified from the Bowers Group, Mariner Glacier sequence, North Victoria Land (Cooper & others, 1976). *B. eremita* (Westergård, 1947) has been recorded from the *Agnostus pisiformis* Zone of Sweden, and *B. erbeni* (Kushan, 1973) and *Bergeronites* sp. from the early Late Cambrian of northern Iran.

In the Soviet Union *B. ingens* (Poletaeva, 1960) occurs in the Upper Cambrian of West Siberia; *B. acutisulcatus* (Ergaliev, 1980), *B.* cf. *italops* (Öpik, 1967), *B. angustus* (Ergaliev, 1980) and *Bergeronites* sp. occur in the late Middle to early Late Cambrian Mayan to Ayusokkanian Stages (*Lejopyge laevigata* to *Kormagnostus simplex* Zones) of Maly Karatau, southern Kazakhstan; and *B. latus* (Romanenko, 1977) has been found in the Upper Cambrian of the North-East Altai.

In China, *Bergeronites* has been reported from the North China Platform, the Jiangnan transitional region, the Yangzi Platform, and the Talimu, North Tibet–West Yunnan and Qilian geological subprovinces. *B. ketteleri* (Monke, 1903), *B. minus* (Resser & Endo, *in* Endo & Resser, 1937), *B. transversus* (Chu, 1959; = *B. yanshanensis,* Guo & Duan, 1978), *B. huoshanensis* Zhang & Wang, 1985, and *B. wuanensis* Zhang & Wang, 1985 have been described from the early Late Cambrian Gushan Stage of the North China Platform. Other species have been recorded from the upper Middle to lower Upper Cambrian sequences of southern Anhui, western Hunan and eastern Guizhou Provinces in the Jiangnan transitional region, including *B. hunanensis* Yang, 1978, *B. hunanensis minocollus* Qiu, *in* Qiu & others, 1983, *B. austricus* Yang, 1978, *B. major* Zhou, *in* Zhou & others, 1977, *B. augustus* Zhang *in* Qiu & others, 1983, *B bellus* Qiu, *in* Qiu & others, 1983, *B. changdeensis* Peng, 1987, *B. guichiensis* Qiu, *in* Qiu & others, 1983, *B. taoyuanensis* Peng, 1987, *B. transversus* Qiu, *in* Qiu & others, 1983, *B. wannanensis* Qiu, *in* Qiu & others, 1983, *B. wulingensis* Peng, 1987, *B. dissidens* (Öpik, 1967) and *Bergeronites* sp. Additionally, in the eastern part of the Yangzi Platform, specifically in the Langyashan area, Jiangnan-type transitional sediments have yielded *B. langyashanensis* Lu & Zhu, 1980, and *Bergeronites* sp. has been reported from the Upper Cambrian Longpen Formation of the Chuxian-Quangjiao region, Anhui Province. Near the border between Yunnan Province and Vietnam, *B. ketteleri* (Monke) has been recorded, and *Bergeronites* sp. has been reported from the lower Upper Cambrian Hetaoping Formation of Baoshan County, Yunnan Province, as well as in the North Tibet–West Yunnan geological subprovince (Xiang & others, 1981, p.70) and from the Upper Cambrian Lindaogou Group, Liangzui, Yuedu, Qinghai Province from a basinal sequence in the Qilian geological subprovince (Xiang & others, 1981, pp. 60–61). Jiangnan-type deposits and fauna also accumulated during the Middle–Late Cambrian boundary interval of the Kuruktag (formerly called Kulukoshan, in Geelan and Twitchett, 1974) area of the Talimu geological subprovince, where the Mokeershan Formation contains *B.* cf. *hunanensis* Yang, 1978.

In summary, *Bergeronites,* like *Blackwelderia,* has a late Middle Cambrian to early Late Cambrian age, and is found both in platform and basinal deposits, apparently occurring earlier in the latter.

Bergeronites italops (Öpik, 1967)
Fig. 5J

1967 *Palaeodotus italops* Öpik, pp. 345–347, text-figs 132, 133; pl. 16, fig. 2; pl. 50, figs. 9–12; pl. 51, figs. 1–4.

Material. The type specimens of *Bergeronites italops* (Öpik, 1967) from the O'Hara Shale of western Queensland are deposited in the collections of the Bureau of Mineral Resources, Canberra, CPC 5757–5764 and CPC 5486. The presently described New South Wales material comprises only one incomplete external mould of a pygidium (CPC 26532), and comes from locality No.I at Kayrunnera.

Age. In western Queensland this species is recorded from the Mindyallan Zones of *Acmarhachis quasivespa* and *Glyptagnostus stolidotus.*

Remarks. Although the material is poorly preserved, it is larger, and shows the essential features of *Bergeronites italops* (Öpik). In common with that species, the axis consists of four rings, a terminal piece and a short postaxial ridge; the seventh pair of spines is short and close together; and a broad and slightly concave border is present.

Bergeronites sp. indet.
Fig. 5K–L

Material. Two poorly preserved pygidia are recorded from locality No.I. One is an internal mould and the other exhibits both internal and external moulds (CPC 26533 and SUP 54911).

Remarks. Although these pygidia have a more convex axis and pleural fields, they also show the basic features of *Bergeronites italops* (Öpik, 1967). For example, they have an axis consisting of four rings and a terminal piece, a relatively broad and flattened border, and seven pairs of marginal spines, of which the anterior ones are the longer and stronger, and the seventh pair the strongest. The specimens are, however, too poorly preserved to establish whether the material is conspecific with *Bergeronites italops* (Öpik, 1967).

Family **Placosematidae** Öpik, 1967
Genus ***Placosema*** Öpik, 1967

Type species. *Placosema caelatum* Öpik, 1967

Placosema sp. cf. ***P. adnatum*** Öpik, 1967
Fig. 5M–O

cf. 1967 *Placosema adnatum* Öpik, p. 382, pl. 19, fig. 6, pl. 20, fig. 1
cf. 1971 *Placosema adnatum* Hill, Playford & Woods, p. 14, pl. VII, fig. 5.

Material. Öpik's types of *Placosema adnatum* from the Georgina Limestone of western Queensland are deposited in the collections of the Bureau of Mineral Resources, Canberra, CPC 5516 & 5517. The New South Wales material recorded here includes two cranidial internal moulds (SUP 54912 & 54913) and comes from locality No. II.

Age. In western Queensland the species is recognised in the Mindyallan Zones of *Acmarhachis quasivespa* and *Glyptagnostus stolidotus.*

Remarks. The genus Placosema Öpik contains only two species, *P. caelatum* Öpik, 1967 and *P. adnatum* Öpik, 1967. The former is reported by Öpik from the Mungerebar Limestone of western Queensland, and the latter from the Georgina Limestone as well. In addition, the genus is reported by Xiang & others (1981, p.62) from the Upper Cambrian Lindaogou Group, Nidangou, Hualong, Qinghai province.

The two cranidia from the Kayrunnera area of western New South Wales are very similar to *P. adnatum* Öpik, showing the same type of preglabellar border furrow and anteriorly slightly constricted though well-rounded glabella. The only difference between the New South Wales material and Öpik's types of *Placosema adnatum* is the presence of somewhat narrower (tr.) fixed cheeks (about 50 per cent of the glabellar width) but this may be merely an artefact of the tectonic distortion of the former specimens, hence the confer (cf.) used in the determination.

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