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Significance of a Late Ordovician *Triarthrus* (Trilobita, Olenidae) from New South Wales, Australia

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Natural History in all its Branches

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ABSTRACT

Triarthrus novoaustralis, a new species of olenid trilobite, is described from the Malachis Hill Formation (mid-Katian, Late Ordovician) near Keenans Bridge and Canobolas State Forest, west of Orange, New South Wales, Australia. This is the second named (and youngest) olenid occurrence from the entire Ordovician of eastern Gondwana. Additionally, its recognition enables revised stratigraphic correlation and enhanced biostratigraphic constraint of the upper Keenans Bridge section to the pre-*Paraorthograptus pacificus* graptolite Zone of early Bolindian age, based on the co-occurrence of *Triarthrus* with age-diagnostic graptolites from Canobolas State Forest.

INTRODUCTION

Olenid trilobites have a near global distribution and were a temporally long ranging family persisting from the 'middle' Cambrian, Guzhangian Stage into the Late Ordovician, Katian Stage (Fortey 1980). Only a single olenid species has been formally named from the entire Ordovician of east Gondwana, *Porterfieldia goldwyerensis* (Legg, 1976) from the Early Ordovician Goldwyer Formation of the Canning Basin in Western Australia. *Hypermecaspis mimitis* (Henderson, 1983) from the Early Ordovician Rollston Range Formation of the Georgina Basin in Queensland was previously assigned to the family, but has since been reassigned to the closely related Hypermecaspididae (Monti et al. 2022). The dearth of published Ordovician olenids contrasts with their moderate diversity (at least 12 species) in east Gondwana during the late Cambrian, Furongian Stage (Whitehouse 1939; Öpik 1963; Shergold 1980; Jell et al. 1991; Bao and Jago 2000; Shergold et al. 2007).

Three published reports of indeterminate species, all assigned to the late surviving genus *Triarthrus*, are known from east Gondwana. The oldest record comes from the Peel Formation in the Cobb River Valley of the South Island, New Zealand (Skwarko 1962). The report was based on only a single cranidium which was questionably assigned to the genus and was never figured. Instead, it was listed as an accessory taxon to a more diverse Gisbornian (Sandbian) graptolite fauna. Unfortunately, efforts to relocate this specimen have failed, and it is presumed lost. The sole morphological feature mentioned was an uncharacteristically inflated glabella, strongly suggesting it belonged in another genus. Next reported were two specimens from the Malachis Hill Formation (previously considered part of the Cheesemans Creek Formation) at a quarry near Keenans Bridge, New South Wales (Webby 1974). These were briefly described, with one being figured (Webby 1974, pl. 32, fig. 13; SUP.37999, now AM F.127540) and the other only mentioned (MMF 18638). Finally, the most recently reported material was found also in the Malachis Hill Formation (previous mapped as the Weemalla Formation) at Canobolas State Forest, New South Wales. Like the New Zealand material, it was mentioned as part of a diverse Bolindian graptolite fauna (see Zhen and Percival 2004, p. 157; Percival et al. 2015, p. 49). Unfortunately, no cranidia were figured, a criterion which Ludvigsen and Tuffnell (1983), Monti and Confalonieri (2019), and Ghobadi Pour (2022) all agreed was necessary for species level discrimination.

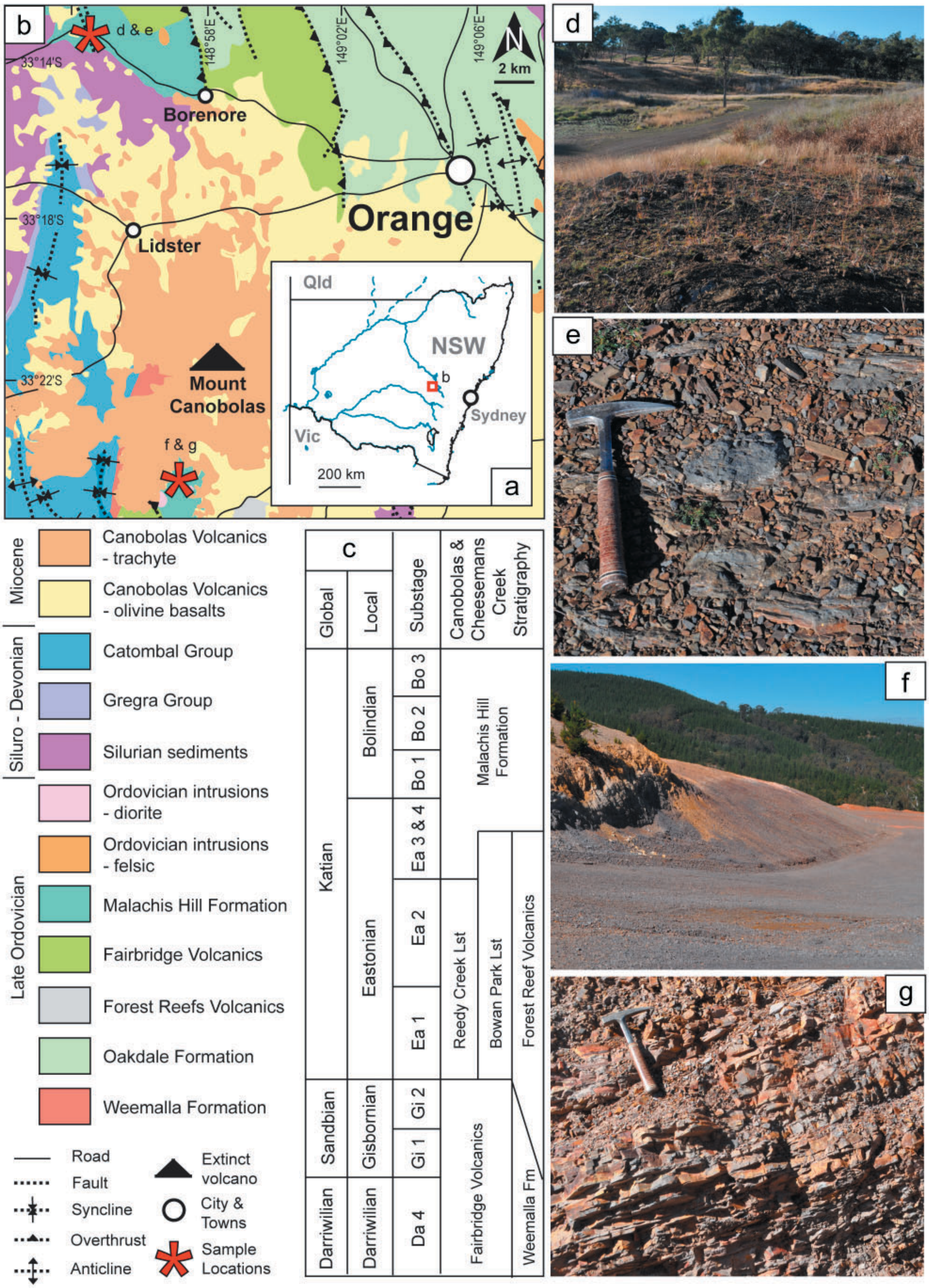
Recently the discovery of new material from both the Keenans Bridge and Canobolas State Forest localities, including a semi-complete specimen as well as five additional cephala has allowed for the description of this species as a new taxon. Hence, herein we document in detail *Triarthrus novoaustralis* sp. nov., the second named and youngest olenid species known from the Ordovician of eastern Gondwana. This new species additionally better constrains the age of the upper Keenans Bridge section to the early Bolindian (Bo2, pre-*Paraorthograptus pacificus* graptolite Zone).

LOCALITY AND STRATIGRAPHY

The fossil material described herein comes from two separate localities. The first is a disused quarry located near old Keenans Bridge (GPS: 33°13'21.8"S, 148°54'21.9"E), close to the abandoned township of Cheesemans Creek, ~25 km west-northwest of Orange, New South Wales (Fig. 1a, b). The name Keenans Bridge only appears on historic maps, having been replaced by an unnamed bridge that crosses Boree Creek along the Escort Way, west of Borenore. This quarry forms part of the type section for the now obsolete Cheesemans Creek Formation, originally erected by Sherwin (1971). Scott et al. (in Pogson and Watkins 1998, p. 68) initially synonymised the Malachis Hill Formation (of the Bowan Park area further to the west) with the Cheesemans Creek Formation owing to strong similarities in their lithology, stratigraphic relationships, and age. However, this synonymy was not followed subsequently by other authors, who continued to consider the two units as separate even in recent stratigraphic summaries and geological maps (e.g. see Percival and Glen 2007; Percival et al. 2011; Colquhoun et al. 2022; Percival et al. 2023). We agree with the synonymy of Scott et al. (in Pogson and Watkins 1998) based on the similarity in both graptolite and trilobite faunas, as well as their near-identical lithology. However, under the International Commission on Stratigraphy guidelines, priority dictates that the Malachis Hill Formation (erected by Stevens 1957) must replace the subsequently-named Cheesemans Creek Formation, thus reversing the change made by Scott et al. (in Pogson and Watkins 1998). This view is adopted herein.

The Malachis Hill Formation at Keenans Bridge quarry crops out as a series of interbedded andesites, tuffs, greywackes, and siltstones. It overlies the Reedy Creek Limestone of early Eastonian (Ea 1-2) age (though the contact is not obvious) and is disconformably overlain locally by the Miocene-aged Canobolas Volcanics. Approximately 900 m true stratigraphic thickness is exposed, which can be roughly divided into upper and lower portions. The lower consists of coarser grained greywackes and finer grained siltstones with interbedded thin tuff laminations and andesites. The upper part is largely dominated by very fine-grained siltstones that are slightly calcareous and dark grey in colour (Fig. 1d,

Figure 1 (below). Geography, geology, and stratigraphy of the Malachis Hill Formation. a, map of New South Wales showing location of Orange district (red square highlighting area shown in b). b, simplified geological map of the Orange district (modified from Colquhoun et al. 2022) with trilobite sample locality near Keenans Bridge and Canobolas State Forest indicated by red stars (with photograph localities shown in d, e, f, g listed against each site). c, simplified stratigraphy of the Middle to Late Ordovician rock units near Keenans Bridge and Canobolas State Forest with global and local stages shown on the left-hand side of the column. d, photograph of Keenans Bridge quarry, facing east towards shale outcrop exposed along the access road. e, photograph of field exposure of fossiliferous siltstone facies within the Malachis Hill Formation at the Keenans Bridge quarry. f, photograph of Canobolas State Forest quarry (just northeast of fossil site), facing south towards extensive shale outcrop exposed. g, photograph of field exposure of fossiliferous siltstone facies within the Malachis Hill Formation at Canobolas State Forest.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- trachyte
Canobolas Volcanics
- olivine basalts
Siluro - Devonian
Catombal Group
Gregra Group
Silurian sediments
Late Ordovician
Ordovician intrusions
- diorite
Ordovician intrusions
- felsic
Malachis Hill Formation
Fairbridge Volcanics
Forest Reefs Volcanics
Oakdale Formation
Weemalla Formation
Road
Fault
Syncline
Overthrust
Anticline
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Cheesemans
Creek
Stratigraphy
Katian
Bolindian
Bo 3
Bo 2
Bo 1
Eastonian
Ea 3 & 4
Ea 2
Ea 1
Malachis Hill
Formation
Reedy Creek Lst
Bowan Park Lst
Forest Reef Volcanics
Sandbian
Gisbornian
Gi 2
Gi 1
Darriwilian
Darriwilian
Da 4
Fairbridge Volcanics
Weemalla Fm
d
e
f
g

e) and yield the trilobites described herein, which were collected high up in the upper portion (i.e. MO/I/5, Rickards et al. 2001).

The second locality is approximately 22 km south-southeast of the first site, part of a cutting on Charleville Road in Canobolas State Forest (GPS: 33°25'19.6"S, 148°57'10.6"E), close to Four Mile Creek, ~28 km southwest of Orange (Fig. 1a, b). Originally the rocks in this area were mapped as Weemalla Formation (Pogson and Watkins 1998), but subsequently were assigned to the Malongulli Formation (Zhen and Percival 2004), and later the Malachis Hill Formation (Percival et al. 2015). Here it disconformably overlies the Fairbridge Volcanics and interfingers laterally (particularly at the base) with the Forest Reefs Volcanics. The Malachis Hill Formation here consists mostly of dark grey calcareous siltstones (weathering white and tan coloured) which are extremely well-bedded, thinly laminated, silicified and often tuffaceous (Fig. 1f, g). Interbedded are fine grained sandstones, mudstones, and occasional limestone conglomerates associated with large scale slumping and scouring. The true stratigraphic thickness is obscured by dense vegetation and deep cover (due to weathering of the overlying Canobolas Volcanics). However, based on exposures seen in nearby road cuts and quarries (GPS: 33°24'52.9"S 148°57'32.5"E and 33°24'52.9"S 148°57'32.5"E), the thickness is estimated at about 900 m. The trilobite material appears to come from the middle portion of the sequence.

The siltstones of the Malachis Hill Formation at both localities are mostly composed of angular albite crystals, although occasional spiculites can be observed, potentially representing dense clusters of radiolarians. Bedding within the siltstones shows evidence of grading, cross bedding and channelling, suggestive of mild turbidity currents. Taken together with the presence of abundant graptolites (Sherwin and Rickards 2000; Rickards et al. 2001; VandenBerg 2003), and a very low amount of shelly fossil remains (see Pogson and Watkins 1998, table Al.9), a deeper water depositional setting is suggested, likely below storm wave base. Such an environment is consistent with olenid occurrences globally, which are generally found in black siltstone facies (Fortey 1975; Fortey and Owens 1978; Wei et al. 2023). Additionally, the presence of interbedded lava flows, volcaniclastic sediments, and allochthonous limestone reef detritus suggests the depositional setting was proximal to reefs, fringing volcanic islands, or sea mounts (Webby 1992). These would have formed part of the inter-oceanic Macquarie Volcanic Arc, along the easterly Molong Volcanic Belt (Percival et al. 2023 and references therein).

Sherwin and Rickards (2000) and Rickards et al. (2001) reported a small graptolite fauna from the lower portion of Keenans Bridge quarry section (their locality MO/I/1), below the *Triarthrus* occurrence reported herein. They assigned a late Gisbornian to early or mid-Eastonian age to this fauna. However, VandenBerg (2003) reinterpreted these graptolites, reassigning them to the early Bolindian, within either the Bo1 (*Alulagraptus uncinatus* graptolite Zone) or possibly Bo2 (pre-*Paraorthograptus pacificus* graptolite Zone) subzones. This lower graptolite assemblage is comparable to that reported from the *Triarthrus* horizon in Canobolas State Forest by Percival et al. (2015), sharing *Anticostia thorsteinssoni* and *Dicellograptus ornatus*. These and other graptolites recorded by Percival et al. (2015) from the Canobolas State Forest section firmly place the trilobite occurrence at both sites within the Bo2 substage of the Bolindian (i.e. the pre-*P. pacificus* graptolite Zone). Such an age is consistent with a Bolindian (Bo2) graptolite fauna collected (Ian Percival pers. comm.) from the middle portion of the Malachis Hill Formation type section (locality g3 of Semeniuk 1970, see Percival and Glen 2007), as well as in-situ mid-Bolindian (Bo3) stromatoporoid and coral assemblage (Webby 1969; McLean and Webby 1976; Wang et al. 2020) from near the top of the section. Thus, the *Triarthrus* occurrence herein corresponds to the mid-Katian on the global Ordovician timescale (Goldman et al. 2020 and references therein) which would make this species the youngest Ordovician trilobite documented in New South Wales (Campbell and Durham 1970; Webby et al. 1970; Webby 1971, 1973, 1974; Edgecombe and Webby 2006, 2007; Holloway et al. 2020).

SYSTEMATIC PALAEONTOLOGY (Smith)

Morphological terminology follows Whittington and Kelly (1997). Photographed specimens were stained with black Indian ink and then coated with magnesium oxide. All described specimens are either from the Palaeontology Collection, Australian Museum, Sydney (prefixed with AM F) or the Geological Survey of New South Wales Fossil Collection housed at the WB Clarke Geoscience Centre, Londonderry (prefixed with MMF). Specimens were photographed with a Nikon Z7 using a Nikon 105 mm S macro lens. Images were stacked using Helicon Focus 7 (Helicon Soft Limited) stacking software.

CLASS TRILOBITA Walch, 1771
ORDER OLENIDA Adrain, 2011

Family OLENIDAE Burmeister, 1843
Subfamily TRIARTHRINAE Ulrich, 1930

Genus *Triarthrus* Green, 1832

Triarthrus Green 1832, p. 87; Ludvigsen and Tuffnell 1983, p. 571–572; Ludvigsen and Tuffnell 1994, p. 193–194; Månsson 1998, p. 50; Edgecombe *et al*. 2005, p. 105–107.

Type species

By monotypy *Triarthrus beckii* Green, 1832, from the Snake Hill Formation, Cohoes Falls, New York, United States; *Dicranograptus caudatus* to *Diplacanthograptus spiniferus* graptolite zones (Ludvigsen and Tuffnell 1994), lower Katian.

Remarks

Currently there are 15 named species assigned to *Triarthrus*. These are restricted to the Sandbian and Katian of the Late Ordovician. Stratigraphically older species previously considered members of the genus are now reassigned to the closely related *Bienvillia* Clark, 1924, and *Porterfieldia* Cooper, 1953 (see Ludvigsen and Tuffnell 1994). The three genera are extremely similar morphologically, differing largely in the positioning of the anterior facial suture. A detailed phylogenetic study could assess the importance of this character state, compared with other potential synapomorphies (e.g. palpebral lobe position, glabella outline, effacement of the glabella furrows, and pygidial outline). However, such a revision of the entire Triarthrinae is beyond the scope of this present study. Hence, we have taken a conservative approach and followed the traditional diagnoses for these genera.

Species currently attributed to the genus include: *Triarthrus akkermensis* Ghobadi Pour, 2022; *Triarthrus beckii* Green, 1832; *Triarthrus billingsi* Barrande, 1872; *Triarthrus canadensis* Smith, 1861; *Triarthrus eatoni* (Hall, 1838) (= *Triarthrus becki macastyensis* Twenhofel, 1914); *Triarthrus freji* Thorslund, 1940; *Triarthrus glaber* Billings, 1859; *Triarthrus huguesensis* Foerste, 1924; *Triarthrus jachalensis* (Harrington and Leanza, 1957); *Triarthrus jemtlandicus* Linnarsson, 1875; *Triarthrus latissimus* Månsson, 1998; *Triarthrus linnarssoni* Thorslund, 1940 (= *Triarthrus skutensis* Thorslund, 1940; also see Owen, 1981); *Triarthrus rougensis* Parks, 1921; *Triarthrus sichuansis* Lu in Lu and Zhang, 1974; *Triarthrus spinosus* Billings, 1857; and *Triarthrus novoaustralis* sp. nov. (described herein). Material reported as *Triarthrus butuonsis* Li, 1978, *Triarthrus pygmaeus* Törnquist, 1884, and *Triarthrus similis* Li, 1978 is too limited and poorly preserved to be confident of the generic assignment.

The new taxon from New South Wales possesses characteristics of both *Triarthrus* (*Triarthrus*) Green, 1832 and *Triarthrus* (*Danarcus*) Ludvigsen and Tuffnell, 1994. Such characters include the semicircular cephalon (excluding genal spines), narrow (tr.) free cheeks, and small pygidium ascribed to the former; as well as the transverse to backwardly bowed anterior glabellar margin of the latter. Hence, we follow Månsson (1998) and Edgecombe et al. (2005) in abandoning the subgenera erected by Ludvigsen and Tuffnell (1994).

Triarthrus novoaustralis sp. nov.
Figures 2–4

1974 *Triarthrus* sp. Webby, p. 214, 215, pl. 32, fig. 13.

Etymology

Latin, *novo* = new, *australis* = south; in reference to the species being from the state of New South Wales.

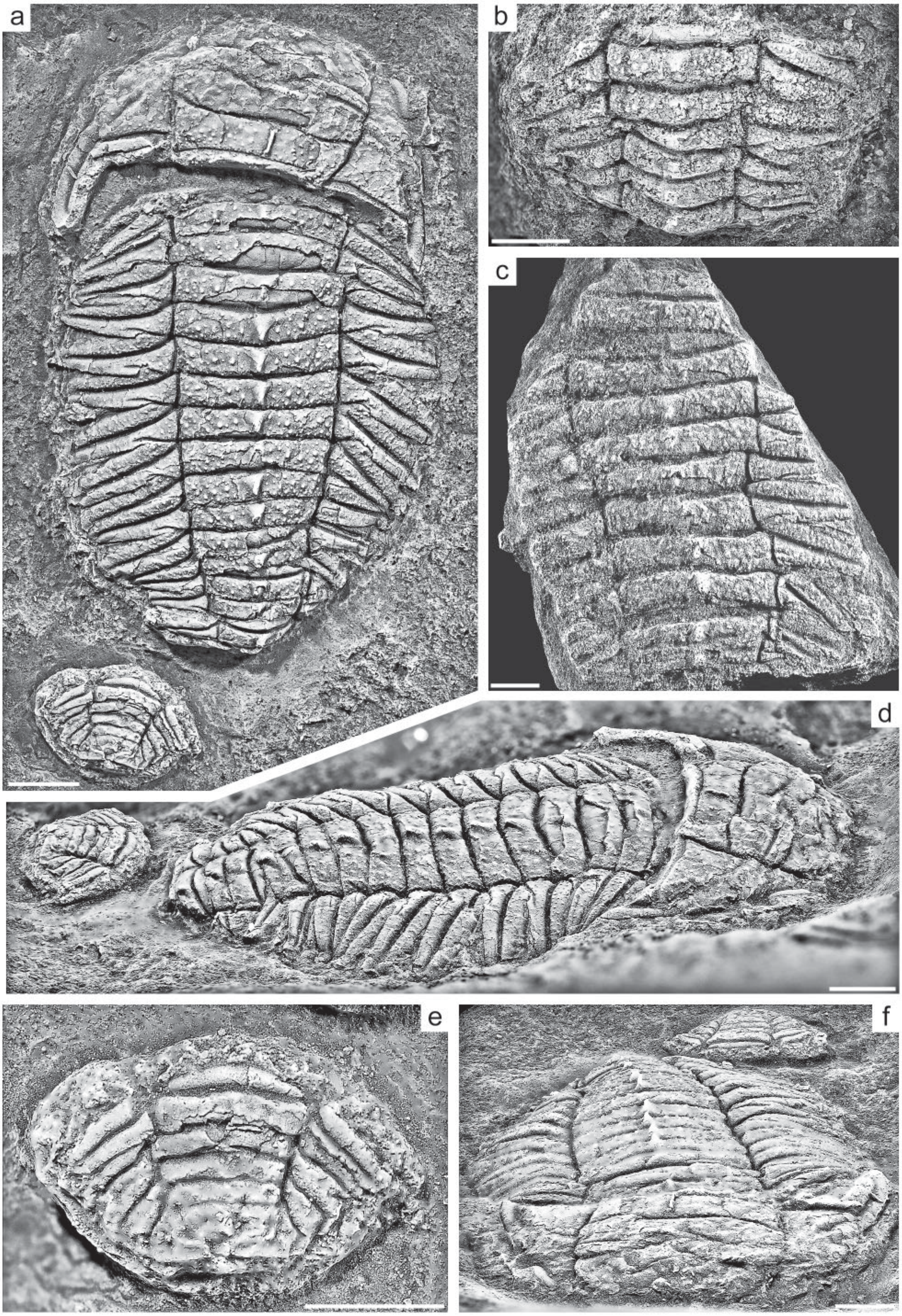
Holotype

MMF 47648B, semi-disarticulated specimen (Fig. 2a, d, e, f) from the Malachis Hill Formation in a cutting on Charleville Road in Canobolas State Forest (GPS: 33°25'19.6"S, 148°57'10.6"E), close to Four Mile Creek, New South Wales.

Paratypes

Two partial articulated thoraxes, MMF 47646 (Fig. 2b), and MMF 47647 (Fig. 2c) from the same locality as the holotype. One cephalon, MMF 27475A (part, Fig. 3b, h) and MMF 27475B (counterpart, Fig. 3a); four cranidia, AM F.164557 (Fig. 3c), AM F.163113 (Fig. 3d), AM F.145111 (Fig. 3e), MMF 47649A (Fig. 3g); three partial articulated

Figure 2 (below). *Triarthrus novoaustralis* sp. nov. from the mid-Katian (Bolindian) Malachis Hill Formation. All specimens from Canobolas State Forest, New South Wales, approximately within the middle portion of the unit. a, d, e, f, holotype MMF 47648B, semi-disarticulated specimen, internal mould; a, dorsal view; d, oblique lateral view; e, close up of pygidium; f, oblique anterior view. b, paratype MMF 47646, dorsal view of partially articulated thorax, internal mould. c, paratype MMF 47647, dorsal view of partially articulated thorax, internal mould. All scale bars are 2 mm.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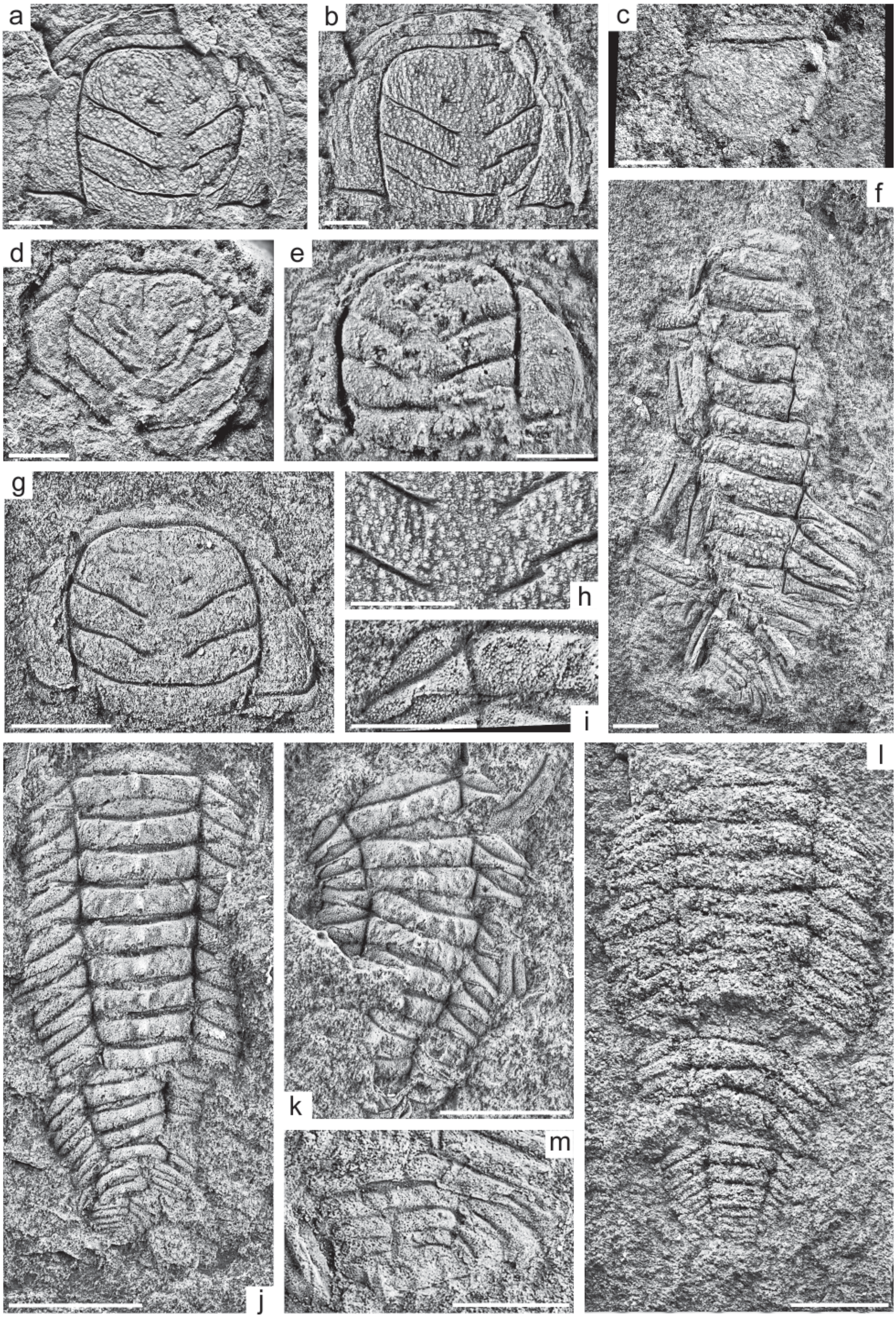
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Figure 3 (above). *Triarthrus novoaustralis* sp. nov. from the mid-Katian (Bolindian) Malachis Hill Formation. All specimens from the quarry near old Keenans Bridge, New South Wales, within horizon MO/I/5 of Rickards et al. (2001, fig. 2). a, paratype MMF 27475B, dorsal view of partial cephalon, latex cast. b, h, paratype MMF 27475A, partial cephalon, counterpart of MMF 27475B, internal mould; b, dorsal view; h, close up of glabella sculpture. c, paratype AM F.164557, dorsal view of cranidium, latex cast. d, paratype AM F.163113, dorsal view of cranidium, latex cast. e, paratype AM F.145111, dorsal view of juvenile cranidium, internal mould. f, m, paratype AM F.145110, partially articulated thoracopyga, latex cast; f, dorsal view; m, close up of pygidium. g, paratype MMF 47649A, dorsal view of cranidium, latex cast. i, k, paratype AM F.164558, partially articulated thoracopyga, latex cast; i, close up of thoracic pleura and axis ornamentation; k, dorsal view. j, paratype AM F.127540, dorsal view of partially articulated thorax, latex cast (originally figured in Webby 1974, pl. 32, fig. 13 under Sydney University Palaeontology collection number, SUP.37999). l, paratype AM F.148112, dorsal view of partially articulated thoracopyga, internal mould. All scale bars are 2 mm, except e and i = 1 mm.

thoracopyga, AM F.145110 (Fig. 3f, m), AM F.127540 (Fig. 3j) (originally figured in Webby 1974, pl. 32, fig. 13 under Sydney University Palaeontology collection number SUP.37999), AM F.148112 (Fig. 3l); and one partial articulated thorax, AM F.164558 (Fig. 3i, k); from the Malachis Hill Formation at horizon MO/I/5 of Rickards et al. (2001, fig. 2) within a disused quarry near old Keenans Bridge, New South Wales (GPS: 33°13’21.8”S, 148°54’21.9”E).

Diagnosis

Glabellar anterior margin straight to bowed slightly backwards in larger specimens. Glabellar frontal lobe bearing short, shallow, very narrow (tr.) sagittal furrow. Palpebral lobes positioned within anterior half of cranidium, anterior tip situated slightly behind S4, posterior tip approximately positioned in line with abaxial end of S2. Short (exsag.) genal spines reaching third or fourth thoracic segment. Thorax with 15 segments. Sculpture of closely spaced pustules over most of dorsal exoskeleton and granules on pygidium.

Description

Cephalon semicircular in outline excluding genal spines, up to 10 mm long (sag.). Cranidium 84% as long as wide; maximum width (tr.) at distal tips of posterolateral projections; very slightly convex (sag., exsag. and tr.). Anterior margin almost straight (tr.). Posterior margin bowed backwards. Glabella subrectangular, 100 to 105% as wide as long, occupying 80 to 93% of the cephalon length (sag.), lateral margins bowed outwards, anterior margin straight to bowed slightly backwards in larger specimen; bordered by deep and narrow (sag. and tr.) axial furrows. S1 well defined, deep and narrow (exsag.), intersecting axial furrow approximately in line with cranidium mid-length (sag.), directed posteromedially for 48% of the glabellar width (tr.), slight flexure forward. S2 identical in depth and orientation to S1, intersecting axial furrow approximately level with ε. S3 shallow, slit-like; adaxial end in line (exsag.) with S1 and S2, subparallel to them; approximately 45% of glabellar width (tr.) from lateral glabella margin; not intersecting the axial furrows; directed posteromedially. S4 similar to S3; positioned more distally at 40% of glabellar width (tr.) from lateral glabella margins; not intersecting the axial furrows; directed slightly less posteriorly. Frontal lobe of the glabella bearing shallow, very narrow (tr.) sagittal furrow, ending approximately in line with S4. Occipital ring of consistent width (sag. and exsag.), 16% of glabella length (sag.), surmounted by a narrow (tr.) and elongate (sag.) median tubercle. SO narrow, strongly bowed backwards medially. Preglabellar field very short (sag, exsag.), sloping slightly downwards towards anterior margin. Eye ridges poorly preserved or absent. Palpebral lobes small (exsag.), reniform in outline; defined by narrow (tr.), deep palpebral furrow; positioned within anterior half of cranidium, anterior tip situated slightly behind anterior glabella furrow, posterior tip approximately in line with S2. Palpebral area slightly convex, sloping downward towards lateral margins; maximum width (tr.) in line with ε, approximately 18% adjacent glabellar width. Pre-ocular branches of the facial suture (α–γ) very short, strongly deflecting inwards anteriorly to divide the preglabellar field. Post-ocular branches of the facial suture (ε–ω) poorly preserved. Postocular fixigenal field of moderate length (exsag.), sloping downwards slightly toward the posterior border furrow. Posterolateral projections long (tr.) and narrowing (sag.), slightly sloping downwards towards the posterolateral corners. Posterior border narrow (exsag.), separated from the rest of the cephalon by moderately deep, narrow (exsag.) border furrow.

Librigenae yoked. Librigenal field poorly preserved. Lateral border well defined by a deep,

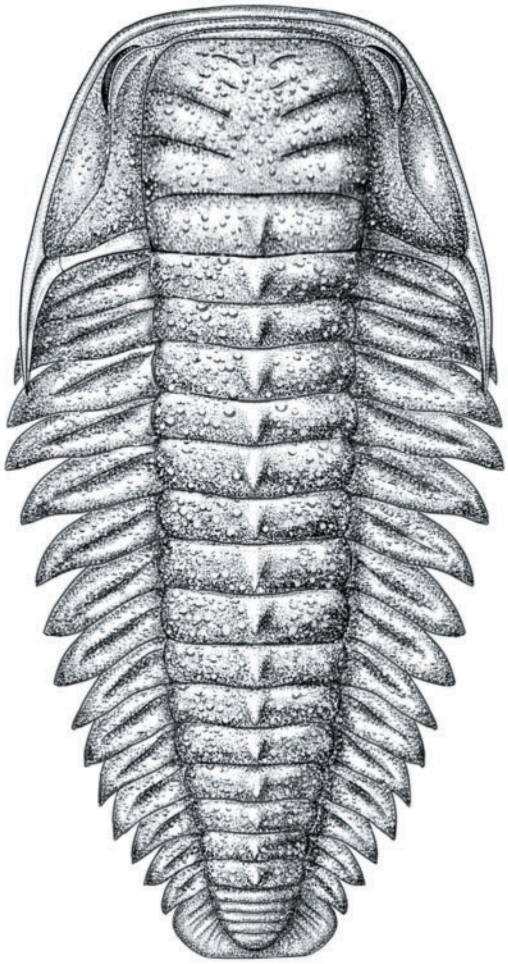

Figure 4. ***Triarthrus novoaustralis*** **sp. nov., schematic reconstruction in dorsal view. Figure credit: © Katrina Kenny 2024.**

narrow (tr.) border furrow which continues onto the genal spine to the distal tip. Genal spines blade-like, short (exsag.), reaching third or fourth thoracic segment; flattened ovoid in cross section; slightly curved inwards posteriorly. Posterior border well defined by a deep, narrow (tr.) border furrow, merging with the lateral border furrow and genal spine furrow at the genal angle. Doublure poorly preserved.

Thorax with 15 segments, slightly convex. Narrowing very slightly behind eighth segment, last segment approximately 47% as wide (tr.) as first. Axial furrows deep, well developed. Axial rings 23–29% (mean = 27%, n = 3) as long (sag.) as wide (tr.), bowed slightly backwards. All axial rings surmounted by a prominent median tubercle positioned approximately at the midpoint (sag.). Articulating half ring approximately 50% the length (sag.) of axial ring, articulating furrow very deep, bowed slightly backwards. Pleurae approximately 75% the width (tr.) of the axis. Pleural furrow connected to axial furrow, straight, extending from the anteromedial corner of the pleura to the distal tip of the thoracic pleural spine. Articulating flange furrow present (Fig. 2a), connected to axial furrow, slightly sinuous, extending from the posteromedial corner of the pleura for approximately 40% of the width (tr.) of the pleura. Thoracic pleural spine short, thorn-like, lacking articulating facets.

Largest pygidium approximately 2.8 mm in length (sag.); 35% as long (sag.) as wide (tr.), subpentagonal outline in dorsal view, slightly convex. Axis strongly tapered; slightly convex; taking up entire pygidial length (sag.); about 38% of maximum pygidial width (tr.) at anterior; 87% as wide (tr.) as long (sag.); defined by narrow (tr.), deep axial furrows which shallow around the terminal piece. Terminal piece poorly defined, transversely ovoid in outline. Articulating half-ring of moderate length (sag., exsag.), narrowing considerably abaxially; separated from anterior axial ring by deep, narrow (sag.), articulating furrow. Five axial rings, the last very faint, all weakly bowed forward. First axial ring narrowing (sag.) medially; pseudo-articulating half ring between it and second axial ring. Pleural field very slightly sloped posteriorly. Four pleural furrows, narrow, approximately straight, extending to posterior margin; all deep and clearly defined. Three interpleural furrows, straight, narrow (exsag.), first and second pleural furrow most clearly defined, third furrow faint to effaced. Border absent. Posterior margin mostly bowed backwards.

Sculpture of closely spaced pustules over most of dorsal exoskeleton, although these are variably developed on different specimens. Glabella and thoracic axis with largest pustules, which appear only slightly larger than on rest of exoskeleton. Smaller pustules occur on palpebral lobes, fixigenal and librigenal genal fields, as well as the thoracic pleurae. Pygidium with sculpture of fine, dense granulation, evenly developed on axial rings and pleural ribs.

Deformation

All specimens illustrated (Fig. 2a, 3a–e, g, h) have undergone a slight degree of deformation. For example, the apparent difference in the width (tr.) of the fixigenae between the two smallest (Fig. 3e, g) and single largest specimen (Fig. 3a, b) is undoubtedly due to lateral compression. In particular this can be seen in the larger specimen with the displacement of the right librigena over the fixigena. Likewise, the apparent forward narrowing of the glabella in front of S2, and rounded anterolateral extremities, in some specimens (Fig. 2a, 3g, d) is likely the result of deformation anteriorly. Both the smallest (Fig. 3e) and largest (Fig. 3a, b) specimens have an anteriorly subquadrate glabella (only visible on the right side in the former case). The anterior deformation may additionally account for the subtle variation in the anterior outline of the glabella between specimens (i.e. weakly bowed forward, backward or more or less transverse).

Remarks

A single specimen of this species was initially figured from Keenans Bridge by Webby (1974, pl. 32, fig. 13) who briefly described it as *Triarthrus* sp. based on a fragment of the left librigena and near complete thoracopyga (refigured here, Fig. 3j).

A backwards bow in the anterior glabellar margin, glabellar frontal lobe with sagittal furrow, far anteriorly-placed palpebral lobes, short (exsag.) genal spines, 15 thoracic segments and a distinctly pustulose sculpture all clearly distinguish *T. novoaustralis* sp. nov. from other *Triarthrus* species. Greatest similarity is to *T. beckii* which possesses a subrectangular glabella, anteriorly placed palpebral lobes, and a near identical pygidium. However, *T. novoaustralis* can be easily distinguished by its short genal spines, prominent axial nodes, 15 (rather than 16) thoracic segments and its pustulose sculpture. *Triarthrus novoaustralis* also shares the forward placement of the palpebral lobes with *T. sichuanensis* (compare Fig. 3a, b with refigured material in Wei et al. 2023), but *T. novoaustralis* differs by its narrower (tr.) glabella, more distinctive occipital node, and 15 (rather than 14) thoracic segments. Likewise, *T.*? *butuonsis*, and *T.*? *similis* from South China possess many of the same similarities and differences as those listed for *T. sichuanensis* (with which they are likely synonymous). Both these Chinese species are based on limited material, and poorly preserved, making further comparisons difficult.

Two other species, *T. akkermensis* and *T. jachalensis*, possess a similar pustulose sculpture to *T. novoaustralis*, albeit with smaller individual pustules (i.e. the microgranular sculpture of Ghobadi Pour 2022; see also Edgecombe et al. 2005). However, both lack the backwards bow in the anterior glabellar margin, glabellar frontal lobe with shallow sagittal furrow and four or five axial rings in the adult pygidia when compared to *T. novoaustralis*. The backwards bow in the anterior glabellar margin, sagittal furrow on the frontal lobe, anterior placement of the palpebral lobe, and prominent pustules suggest an affinity for *T. novoaustralis* with the monospecific genus *Anaximander* Fortey, 1974 from the Early Ordovician of Norway. However, *Anaximander* differs considerably in possessing facial sutures that cross the anterior border, no S3 or S4, 12 thoracic segments (instead of 15), as well as a pygidium with more axial rings and no pygidial pleural furrows. It is unlikely the two are closely related, as many of the shared features with *T. novoaustralis* also occur, to a lesser degree, in several different genera of olenids (e.g. *Acerocare* Angelin, 1854, *Balnibarbi* Fortey, 1974 and *Bienvillia*). Hence, such traits are highly convergent and likely only of intraspecific importance.

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