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Five new injured trilobites from Cambrian and Ordovician deposits

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Injured trilobites present insight into how a completely extinct group of arthropods responded to traumatic experiences such as failed predation and moulting complications. These specimens are therefore important for more thoroughly understanding the Paleozoic predator-prey systems that involved trilobites. To expand the record of injured trilobites, we present new examples of injured *Ogygopsis klotzi* and *Olenoides serratus* from the Campsite Cliff Shale Member of the Burgess Shale Formation (Wuliuan, Miaolingian), *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* from the Jince Formation (Drumian, Miaolingian), *Ogygiocarella angustissima* from the Llanfawr Mudstones Formation (Darriwilian–Sandbian, Middle–Late Ordovician) and *Ogygiocarella debuchii* from the Meadowtown Formation, (Darriwilian–Sandbian, Middle–Late Ordovician). We explore the possible origins of these malformations and conclude that most injuries reflect failed predation. We explore possible predators and highlight that a marked shift in possible trilobite predator groups occurred during the Great Ordovician Biodiversification Event. We also collate other records of injured *Ogyg. klotzi* and *Ol. serratus,* and *Ogygi. debuchii*, highlighting that these species are targets for further understanding patterns and records of trilobite injuries.

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Abstract

Injured trilobites present insight into how a completely extinct group of arthropods responded to traumatic experiences such as failed predation and moulting complications. These specimens are therefore important for more thoroughly understanding the Paleozoic predator-prey systems that involved trilobites. To expand the record of injured trilobites, we present new examples of injured *Ogygopsis klotzi* and *Olenoides serratus* from the Campsite Cliff Shale Member of the Burgess Shale Formation (Wuliuan, Miaolingian), *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* from the Jince Formation (Drumian, Miaolingian), *Ogygiocarella angustissima* from the Llanfawr Mudstones Formation (Darriwilian–Sandbian, Middle–Late Ordovician) and *Ogygiocarella debuchii* from the Meadowtown Formation, (Darriwilian–Sandbian, Middle–Late Ordovician). We explore the possible origins of these malformations and conclude that most injuries reflect failed predation. We explore possible predators and highlight that a marked shift in possible trilobite predator groups occurred during the Great Ordovician Biodiversification Event. We also collate other records of injured *Ogyg. klotzi* and *Ol. serratus,* and *Ogygi. debuchii*, highlighting that these species are targets for further understanding patterns and records of trilobite injuries.

Keywords: Trilobites, injuries, predator-prey systems, predation, Paleozoic, Burgess Shale, Jince Formation, Llanfawr Mudstones Formation, Meadowtown Formation

Introduction

Numerous injured trilobites have been reported from Cambrian to Devonian aged deposits (Owen, 1985; Babcock, 1993; Bicknell et al., 2022d). These malformations have presented insight into the position of trilobites as prey items (Rudkin, 1979; Conway Morris & Jenkins, 1985; Owen, 1985; Zong, 2021b; Bicknell et al., 2022d), as well as how trilobites recovered from moulting complications (McNamara & Rudkin, 1984; Owen, 1985). Such specimens are therefore useful for understanding the palaeoecology and palaeobiology of the completely extinct group of arthropods (Owen, 1985; Rudkin, 1985; Babcock, 1993).

Trilobite injuries are considered exoskeletal breakage from accidental injury, attack, or moulting issues (Bicknell et al., 2022a). Injuries are generally 'L'-, 'U'-, 'V'-, or 'W'-shaped indentations (Babcock, 1993; Bicknell & Pates, 2019; Bicknell et al., 2022a) and can also be expressed as rounded and reduced exoskeletal sections, or as a 'single segment injury' (SSI; (Pates et al., 2017; Pates & Bicknell, 2019; Bicknell et al., 2022a, e). Injuries commonly show evidence for cicatrisation and/or segment repair and regeneration—records of a successful moulting after an injury. Occasionally, abnormal structures, such as fusion of exoskeletal sections or lack of segment expression, are associated with injuries (Owen, 1985; Bicknell et al., 2022a; Bicknell et al., 2023a). Such evidence reflects abnormal recovery from the injury. Importantly, these morphologies differ from teratologies that record how trilobites responded to genetic or developmental malfunctions (Owen, 1985; Babcock, 2007; Bicknell & Smith, 2021, 2022).

To expand the record of injured trilobites from lower Paleozoic deposits, five novel specimens—*Ogygiocarella angustissima* (Salter, 1865), *Ogygiocarella debuchii* (Brongniart, 1822), *Ogygopsis klotzi* (Rominger, 1887), *Olenoides serratus* (Rominger, 1887), and *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* (Boeck, 1827)—with morphologies considered injuries are reported here. We also collate other evidence of malformed specimens of these species and explore possible injury causes.

Geological context

The *Ogygopsis klotzi* (NHMUK PI I 4749) and *Olenoides serratus* (NHMUK PI IG 4437-9) figured in this study were collected from Mount Stephen in British Columbia, Canada in Walcott's (1908) "*Ogygopsis* Shale", Burgess Shale Formation on the mountain trail 850 m above the town of Field. This is horizon is now placed within the Campsite Cliff Shale Member which also outcrops at Mount Field and the Fossil Gully Fault (Fletcher & Collins, 1998, 2003). The association of articulated trilobite remains and with an underlying distal wedge facies, suggests the unit was deposition in a deeper water, potentially euoxic setting (further from the carbonate platform forming the Cathedral Formation palaeocliff edge; Allison & Brett 1995). Presence of the eponym for the *Pagetia bootes* Subzone places the member firmly within the restricted shelf *Bathyuriscus–Elrathina* Zone (Fletcher & Collins, 1998) which has been correlated with the upper portion of the open-shelf *Ptychagnostus praecurrens* Zone of North America (Robison & Babcock, 2011). This is correlated with the later portion of the Wuliuan Stage (Miaolingian) on the global scale (Peng et al., 2012).

The *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* (NHMUK PI OR 42440) figured here was collected from Jince in the Czech Republic at an unknown locality in the Jince Formation. The taxon is widely distributed over the entire Jince Basin, occurring at multiple outcrops throughout the Litavka River Valley region, hence the exact position from where the specimens derives is impossible to determine (Fatka & Szabad, 2014). However, more generally *P*. (*P*.) *paradoxissimus gracilis* occurs in the green, fine-grained greywackes and shales within the middle levels of the Jince Formation, which is thought to correspond with the peak of a transgressive event identified within the unit (Storch et al., 1993; Fatka & Szabad, 2014). The occurrence of abundant articulated agnostids, paradoxidids, and a conocoryphid species (Fatka et al., 2004), suggests a deeper water environment, within the conocoryphid biofacies of Álvaro et al. (2003). The taxon is the eponym for the *P*. (*P*.) *paradoxissimus gracilis* Zone in the Příbram-Jince Basin within the Barrandian area (Fatka & Szabad 2014 for a comprehensive discussion). Co-occurrence of the agnostid *Hypagnostus parvifrons* (Linnarsson, 1869) and the lower stratigraphic occurrence of *Onymagnostus hybridus* (Brøgger, 1878) (Fatka et al., 2004; Fatka & Szabad, 2014), suggests the zone corresponds with the middle and higher levels of the Baltic *Paradoxides* (*Paradoxides*) *paradoxissimus* Zone (Axheimer & Ahlberg, 2003; Høyberget & Bruton, 2008; Weidner & Nielsen, 2014). This region of the Chinese, one likely corresponds to the Scandinavian, South Chinese, and Australian *Ptychagnostus atavus* and *Ptychagnostus punctuosus* zones placing it in the early to mid-Drumian Stage (Miaolingian) globally (Peng et al., 2012).

The *Ogygiocarella angustissima* (NHMUK PI OR 59206) and *Ogygiocarella debuchii* (NHMUK PI In 23066) figured in this study were collected from two similarly aged deposits in Wales, United Kingdom. The *Ogygiocarella angustissima* specimen was apparently collected from Gwern-fydd, although this seems unlikely given the regional geology and lithology of the specimen. Lectotype material preserved in identical matrix has alternatively been suggested to be derived from “Harper’s quarry”, 500 m north-west of Welfield (near Builth), likely within the Llanfawr Mudstones Formation, Builth Inlier (Hughes 1979 and references therein, also see updated stratigraphy in Davies et al. 1997 and Fortey et al. 2000). The *Ogygiocarella debuchii* specimen conversely originates from Betton Quarry (near Shropshire) in the upper Meadowtown Formation, Shelve Inlier. Both units are dominated by fine mudstone and siltstone, likely being deposited on a relatively deep shelf environment nearby a volcanic arc (Fortey & Owens, 1987; Davies et al., 1997; Fortey et al., 2000; Owens, 2002). Known ranges of *Ogygiocarella angustissima* and *Ogygiocarella debuchii* suggest the taxa occur in either the *Hustedograptus teretiusculus* and/or *Nemagraptus gracilis* zones at these localities. However, without more precise details regarding the exact collection horizons (and associated graptolite or other shelly fauna) it impossible to determine which precisely (Hughes, 1979; Bettley et al., 2001). Hence, the figured material likely comes from somewhere within the regional Llandeilian (Llanvirn) or Aurelucian (Caradoc) stages. This correlates with the global Darriwilian (Middle Ordovician) to Sandbian (Late Ordovician) boundary (Bettley et al., 2001; Cooper & Sadler, 2012; Goldman et al., 2023).

Methods

Trilobite specimens within the Natural History Museum Invertebrate palaeontology collection (NHMUK PI), London were reviewed for injuries. Identified specimens were from the Campsite Cliff Shale Member of the Burgess Shale Formation, Jince Formation, and two unidentified Ordovician units around Wales, UK. These specimens were photographed under low angle LED light as stacks with a Canon EOS 600D at the NHM. Images were stacked using Helicon Focus 7 (Helicon Soft Limited) stacking software. Measurements of specimens were collated from the images using ImageJ (Schneider et al., 2012) and compiled into Table 1.

Results

Ogygopsis klotzi (Rominger, 1887), NHMUK PI I 4749, Cambrian (Miaolingian, Wuliuan), Campsite Cliff Shale Member of the Burgess Shale Formation, Canada. Figure 1B, E

NHMUK PI I 4749 is a partial, moulted exoskeleton with an injury on the right thoracic pleural lobe. The injury is an asymmetric ‘U’-shaped indentation that truncates the 5th and 6th pleural spines by a maximum of 6.6 mm. The 5th spine shows limited pleural spine recovery, and the 6th pleural spine is rounded.

Olenoides serratus (Rominger, 1887), NHMUK PI IG 4437-9, Cambrian (Miaolingian, Wuliuan) Campsite Cliff Shale Member of the Burgess Shale Formation, Canada. Figure 1A, C, D

NHMUK PI IG 4437-9 is a partial, moulted exoskeleton with two injuries on the left thoracic plural lobe. The anterior injury is a ‘V’-shaped indentation that truncates the 1st and 2nd pleural spines by 4.6 mm and 1.6 mm, respectively. The second plural spine shows development of a new spine (Figure 1C). The posterior injury is an asymmetric, cicatrised ‘U’-shaped indentation that truncates the 6th and 7th pleural spines by 7.0 mm (Figure 1D).

Paradoxides (*Paradoxides*) *paradoxissimus gracilis* (Boeck, 1827), NHMUK PI OR 42440, Cambrian (Drumian), Jince Formation, Czech Republic. Figure 2.

NHMUK PI OR 42440 is a mostly complete exoskeleton with three injuries along the thorax. One on the left thoracic pleural lobe and two on the right pleural lobe. The anterior-most injury is an SSI that truncates the 1st pleural spine on the left pleural lobe by 3.3 mm (Figure 2D). The anterior-most injury on the right pleural lobe extends across the $^{?}$8th–$^{?}$10th pleural spines ($^{?}$ denote uncertainty of the segment number as the specimen is broken anteriorly) (Figure 2B). This injury has a unique morphology. The $^{?}$8th pleural spine is rounded and truncated by 2.4 mm.

The posterior section of the ?8th segment is truncated further by 4.6 mm. The ?9th pleural spine is truncated by 6.4 mm. The ?8th and ?9th pleural spines have 'W'-shaped indentations. The ?10th pleural spine is truncated by 5.4 mm and shows rounding. The posterior-most injury on the right side is a 'W'-shaped indentation that truncates the ?13th and ?14th pleural spines by 4.3 mm and 4.7 mm, respectively (Figure 2C).

Ogygiocarella angustissima (Salter, 1865), NHMUK PI OR 59206, Ordovician (Darriwilian–Sandbian, Middle–Late), Llanfawr Mudstones Formation, Wales, UK. Figure 3.

NHMUK PI OR 59206 is a mostly complete counter-part specimen that has two injuries on the right side (=left pleural lobe in life). The anterior-most injury is a 'U'-shaped indentation that truncates the 1st–3rd pleural spines by 4.7 mm (Figure 3B, white arrows). All truncated spines show rounding, and the 3rd pleural spine shows recovery (Figure 3B, white arrows). The posterior injury is a 'V'-shaped indentation that truncates the 5th and 6th pleural spines by 2.0 mm and 4.2 mm, respectively. Both pleural spines show rounding (Figure 3B, black arrows)

Ogygiocarella debuchii (Brongniart, 1822), NHMUK PI In 23066, Ordovician (Darriwilian–Sandbian, Middle–Late), upper Meadowtown Formation, Wales, UK. Figure 4.

NHMUK PI In 23066is an isolated pygidium with two injuries. The injury on the left side has disrupted ?6th–?9th pygidial ribs (as above, ? denotes uncertainty of rib numbers as the specimen appears broken anteriorly) (Figure 4C). Ribs are disrupted at the ?6th rib showing evidence of possible fusion with the ?7th rib (Figure 4C). Additionally, more posterior ribs have irregular borders and inconsistent widths. The injury on the right side is a shallow 'U'-shaped indentation that extends 0.7 mm from the pygidial border (Figure 4B). The ?7th and ?8th pygidial ribs are also fused 0.9 mm from the axial lobe, proximal to the indentation (Figure 4B).

Discussion

Comparing the injuries documented to previously recorded examples of injured trilobites allows us to propose possible origins for the malformations. The 'U'- 'V'-, 'W'-shaped indentations observed here (Figures 1A–E; 2A, C; 3A, B; 4A, B) are comparable to examples of injured Cambrian (see Rudkin, 1979; Babcock, 1993, 2007; Pates et al., 2017; Bicknell & Pates, 2020; Zong, 2021a, b; Bicknell et al., 2022e) and Ordovician (see Ludvigsen, 1977; Babcock, 2007; Zong, 2021a; Bicknell et al., 2022d, e) trilobites. These examples are commonly attributed to failed predation. We therefore conclude that most injuries observed here reflect unsuccessful predation attempts. There are select injury morphologies that require more detailed consideration.

The abnormal indentation in *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* (NHMUK PI OR 42440, Figure 2B) could reflect two separate attacks that targeted the same exoskeletal region, or an additional moulting complication about this injury. We suggest both options as the posterior-most region of the injury (Figure 2B, blue arrow) shows more recovery than anterior sections. As trilobite recovered from injuries anterior to posterior, we would expect the more anterior region to show more evidence of recovery (McNamara & Tuura, 2011; Zong & Bicknell, 2022). As such, this injured region has experienced an additional traumatic event. The SSI observed on this specimen could also reflect failed predation (Bicknell et al., 2022a) or a moulting complication. As *P.* (*P.*) *paradoxissimus gracilis* has long pleural spines, these could have been damaged while moulting, resulting in an isolated injury (Šnajdr, 1978; Conway Morris & Jenkins, 1985; Daley & Drage, 2016; Drage, 2019). More research into the moulting patterns of *P.* (*P.*) *paradoxissimus gracilis* may help differentiate these options.

The abnormal recovery and fusion of ribs in *Ogygiocarella debuchii* (NHMUK PI In 23066; Figure 4) in two pygidial regions suggests two different traumatic events. The injury on the left side has no evidence of an indentation (Figure 4C). This indicates that a moulting complication occurred, and the ribs recovered abnormally—a condition that was propagated through subsequent moulting events. Conversely, the 'U'-shaped indentation and fused pygidial ribs on the right side illustrates a failed predation attempt that recovered abnormally.

Records of injured *Ogygopsis klotzi* represent valuable insight into possible predator-prey dynamics within the Burgess Shale biota (Table 2). These injuries were originally thought to reflect predation by *Anomalocaris canadensis* Whiteaves, 1892 (see discussion in Rudkin, 1979). However, recent three-dimensional (3D) kinematic, biomechanical, and computational fluid dynamic modelling have demonstrated that *A. canadensis* appendages were ineffective at handling biomineralised prey (De Vivo et al., 2021; Bicknell et al., 2023b). More plausible predators are the co-occurring trilobites and other artiopodans that have reinforced gnathobasic spines on walking legs (Whittington, 1980; Bruton, 1981; Bicknell et al., 2018b; Holmes et al., 2020). Trilobite fragments within the gut contents of artiopodans (Zacaï et al., 2016; Bicknell & Paterson, 2018) and 3D biomechanical analyses of gnathobase-bearing appendages (Bicknell et al., 2018a, 2021) support this mode of durophagous predation. One other option is the mantis shrimp-like arthropod *Yohoia* Walcott, 1912 that may have damaged trilobite exoskeletons using its anteriorly directed raptorial anterior appendages (Pratt, 1998; Haug et al., 2012).

The records collated in Table 2 represent the basis for developing a much larger dataset to explore *Ogygopsis klotzi* injury patterns. Documentation of more injured specimens in other collections should expand this preliminary sample and permit the left-right behavioural asymmetry hypothesis to be re-addressed (Babcock & Robison, 1989; Babcock, 1993). Recent examination of injury patterns in Cambrian trilobites have demonstrated little evidence for injury asymmetry (Pates & Bicknell, 2019; Bicknell et al., 2022a). However, with 80% of *Ogygo. klotzi* unilateral injuries being right sided, this injury distribution could be present in the population (Table 2). Illustrating this condition with a statistical dataset of one species (following Pates et al., 2017; Bicknell et al., 2019, 2022a, 2023a; Pates & Bicknell, 2019) will likely uncover interesting injury patterns and represents a clear direction for exploring this topic further.

Predators of *Olenoides serratus* are likely the same as *Ogygopsis klotzi* as both species are from the Burgess Shale. It is worth also considering the presence of male mating claspers in *Ol. serratus* that functioned similarly to claspers in male horseshoe crabs in the context of injuries (Losso & Ortega-Hernández, 2022). These claspers cause injuries to the medial region of modern female horseshoe crabs during amplexus (Shuster Jr., 1982; Brockmann, 1990; Shuster Jr., 2009; Bicknell et al., 2018c; Das et al., 2021; Bicknell et al., 2022c). Male *Ol. serratus* may therefore have caused similar injuries during mating. However, these reduced appendages would not have produced the large injuries documented here and in Table 3.

Previously documented injured specimens of "*P. gracilis*" (Boeck, 1827) permit useful comparisons (Šnajdr, 1978; Owen, 1985; De Baets et al., 2022). Injuries to Jince Formation *Paradoxides* are considered a result of moulting complications that arose from the flat morphology and elongate pleural spines common to *Paradoxides* (Šnajdr, 1978). As noted above, moulting is a viable explanation for the injuries considered in Figure 2. However, failed predation cannot be fully discounted. The most likely predators were the co-occurring paradoxidids (Babcock, 1993; Fortey & Owens, 1999; Fatka et al., 2009)—a proposal that further supports cannibalism within Cambrian trilobites (Conway Morris & Jenkins, 1985; Daley et al., 2013; Bicknell et al., 2022a). Additionally, the bivalved arthropod *Tuzoia* Walcott, 1912 could have targeted *Paradoxides* as *Tuzoia* is considered a nektobenthic to pelagic predatory or scavenger (Fatka & Herynk, 2016; Izquierdo-López & Caron, 2022).

Records of injured and malformed *Ogygiocarella debuchii* are limited (Table 4). However, the identification of five injured specimens since 2022 (Table 4) demonstrates that *Ogygi. debuchii* represents another avenue for future research into injury patterns. There is also mounting evidence to support at least three distinct arthropods groups that could have targeted *Ogygi. debuchii* as prey.

(1) The Middle Ordovician (Darriwilian) Castle Bank Biota fauna (Botting et al., 2023) includes a yohoiid-like arthropod that could have attacked *Ogygi. debuchii* using raptorial appendages (Botting et al., 2023).

(2) Ordovician eurypterids—forms known from Late Ordovician (Sandbian) aged Welsh deposits (Størmer, 1951; Tetlie, 2007)—have been highlighted as possible, albeit ineffective, predators of trilobites (Lamsdell et al., 2015; Bicknell et al., 2022b; Schmidt et al., 2022). If they were the predators, eurypterids would have targeted trilobites during a soft-shelled stage.

(3) The large asaphid trilobites themselves could have targeted each other and used gnathobasic spines on walking legs to process the biomineralised exoskeletons.

Finally, nautiloids are commonly suggested as Ordovician predators and could have damaged the exoskeletons with re-enforced beaks (Brett, 2003; Klug et al., 2018). Evidently, the Great Ordovician Biodiversification Event saw the rise of more groups that targeted trilobites as prey and likely shifted where trilobites were located within their respective palaeoecosystems.

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Author contributions

Conceptualization, R.D.C.B; Methodology, all authors; Geology, P.M.S; Investigation, all authors; Resources, R.D.C.B.; Writing – Original Draft, all authors; Writing – Review and Editing, all authors; Visualization, R.D.C.B.; Funding Acquisition, R.D.C.B.

Species	Specimen number	Stage	Cephalic length (mm)	Cephalic width (mm)	Thoracic length (mm)	Pygidial length (mm)	Pygidial width (mm)	Figure number
Ogygopsis klotzi	NHMUK PI I 4749	Cambrian (Miaolingian, Wuliuan)	22.1	46.1*	27.3	29.3	37.9*	Figure 1B, E
Olenoides serratus	NHMUK PI IG 4437-9	Cambrian (Miaolingian, Wuliuan)	21.6*	36.9*	24.2	16.4*	32.7	Figure 1A, C, D
Paradoxides (Paradoxides) paradoxissimus gracilis	NHMUK PI OR 42440	Cambrian (Drumian)	19.1	54.8	42.7*	8.0	6.7	Figure 2A–D
Ogygiocarella angustissima	NHMUK PI OR 59206	Ordovician (Middle–Late, Darriwilian–Sandbian)	22.5	65.1	22.3	28.5	53.0*	Figure 3A, B
Ogygiocarella debuchii	NHMUK PI In 23066	Ordovician (Middle–Late, Darriwilian–Sandbian)	–	–	–	11.4	19.5	Figure 4A, B

Table 1: Measurements of documented injured specimens. * indicates minimal values where the specimen is broken. – indicates exoskeletal section is not observed for the specimen.

Citation	Injury location	Injury side	Injury morphology
Rudkin (1979, fig. 1A, B)	Thorax, segments 3–6	Right	'U'-shaped
Rudkin (1979, fig. 1C, D)	Thorax, segments 6–8	Left	'W'-shaped
Rudkin (1979, fig. 1E, F)	Anterior pygidium	Right	'W'-shaped
Rudkin (1979, fig. 1G, H), refigured in Rudkin (2009, fig. 1B)	Thorax, segments 7–8	Right	'V'-shaped
Briggs & Whittington (1985, p. 37)	Thorax, segment 10, extends into anterior pygidium	Right	'U'-shaped
Pratt (1998, fig. 1A)	Anterior pygidium	Right	'W'-shaped
Nedin (1999, fig. 2C)	Thorax, segments 3–6	Bilateral	Left: 'U'-shaped (segment 5). Right: 'W'-shaped (segments 3–6)
Bicknell & Pates (2020, fig. 7A, B)	Thorax, segments 2–5	Left	'W'-shaped
Bicknell & Holland (2020, fig. 2A, C)	Thorax, segments 1–4	Right	'L'-shaped
Bicknell & Holland (2020, fig. 2B, D)	Thorax, segments 5–7	Right	'U'-shaped with pinched and warped segments
This article, Figure 1B, D	Thorax, segments 5–6	Right	'U'-shaped

Table 2: Summary of injured and malformed *Ogygopsis klotzi* documented within the literature.

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Citation	Injury location	Injury side	Injury morphology
Pratt (1998, fig. 1B), refigured in Butterfield (2001, fig. 1.2.3.1.i)	Genal spine; thorax, segments 1–3	Left	'W'-shaped
Bicknell & Paterson (2018, fig. 1F)	Thorax, segments 5–7	Left	'V'-shaped
This article, Figure 1A, C, D	Thorax, segments 1–2, 6–7	Left	'V'-shaped (segments 1–2); 'U'-shaped (segments 6–7)

265 **Table 3**: Summary of injured *Olenoides serratus* documented within the literature.

266

Citation	Species	Injury location	Injury side	Injury morphology
Bicknell et al. (2022d, fig. 4a, b)	*Ogygiocarella debuchii*	Cephalon and genal spine	Right	Truncated genal spine, ‘U’-shaped along posterior margin of spine
Bicknell et al. (2022d, fig. 4c, d)	*Ogygiocarella debuchii*	Pygidium	Left	‘U’- and ‘V’-shaped
Bicknell et al. (2022e, fig. 2.1, 2.2)	*Ogygiocarella debuchii*	Pygidium	Left	‘W’-shaped
This article, Figure 3A, B	*Ogygiocarella angustissima*	Thorax, segments 1–3, 5–6	Left (right in the counterpart)	‘U’-shaped (segments 1–3), ‘V’-shaped (segments 5–6)
This article, Figure 4A–C	*Ogygiocarella debuchii*	Pygidium	Bilateral	Left: Disrupted and fused ribs. Right: ‘U’-shaped and fused ribs

Table 4: Summary of injured *Ogygiocarella debuchii* and *Ogygiocarella angustissima* within the literature.

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Figure Captions

Figure 1: Injured *Olenoides serratus* (Rominger, 1887) and *Ogygopsis klotzi* (Rominger, 1887) from the Cambrian (Miaolingian, Wuliuan) aged Campsite Cliff Shale Member, Burgess Shale Formation, Canada. **(A, C, D)**: *Olenoides serratus*. NHMUK PI IG 4437-9. **(A)**: Complete specimen. **(C)**: Close up anterior injury showing truncated (white arrow) and recovering (black arrow) pleural spines. **(D)**: Close up of 'U'-shaped injury showing limited cicatrisation. **(B, E)**: *Ogygopsis klotzi*. NHMUK PI I 4749. **(B)**: Complete specimen. **(E)**: Close up of 'U'-shaped injury (white arrows). (A, C, D): Images converted to greyscale.

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Figure 2: Injured *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* (Boeck, 1827) from the Cambrian (Drumian) aged Jince Formation, Czech Republic. **(A–D)**: NHMUK PI OR 42440. **(A)**: Complete specimen. **(B)**: Close up of unique injury showing a truncated pleural spine (white arrow) with a notched posterior region (grey arrow), a 'W'-shaped indentation (black arrow), and a truncated, rounded pleural spine (blue arrow). **(C)**: Close up of 'W'-shaped indentation. **(D)**: Close up of SSI (black arrow).

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Figure 3: Injured *Ogygiocarella angustissima* (Salter, 1865), from the Ordovician (Middle–Late, Darriwilian–Sandbian) aged Llanfawr Mudstones Formation, Wales. **(A, B)**: NHMUK PI OR 59206. **(A)**: Complete specimen. **(B)**: Close up of 'U'-shaped (white arrows) and 'V'-shaped (black arrows) indentations.

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Figure 4: *Ogygiocarella debuchii* (Brongniart, 1822) from the Ordovician (Middle–Late, Darriwilian–Sandbian) aged upper Meadowtown Formation, Wales **(A–C)**: NHMUK PI In 23066. **(A)**: Complete specimen. **(B)**: Close up of right side showing shallow 'U'-shaped indentation (white arrow) and the fusion pygidial ribs (black arrow). **(C)**: Close up of left side showing disruption and possible fusion (white arrows) of pygidial ribs and irregular rib sizes.

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Figure 1

Injured *Olenoides serratus* (Rominger, 1887) and *Ogygopsis klotzi* (Rominger, 1887) from the Cambrian (Miaolingian, Wuliuan) aged Campsite Cliff Shale Member, Burgess Shale Formation, Canada

(A, C, D): *Olenoides serratus*. NHMUK PI IG 4437-9. **(A)**: Complete specimen. **(C)**: Close up anterior injury showing truncated (white arrow) and recovering (black arrow) pleural spines. **(D)**: Close up of 'U'-shaped injury showing limited cicatrisation. **(B, E)**: *Ogygopsis klotzi*. NHMUK PI I 4749. **(B)**: Complete specimen. **(E)**: Close up of 'U'-shaped injury (white arrows). (A, C, D): Images converted to greyscale.

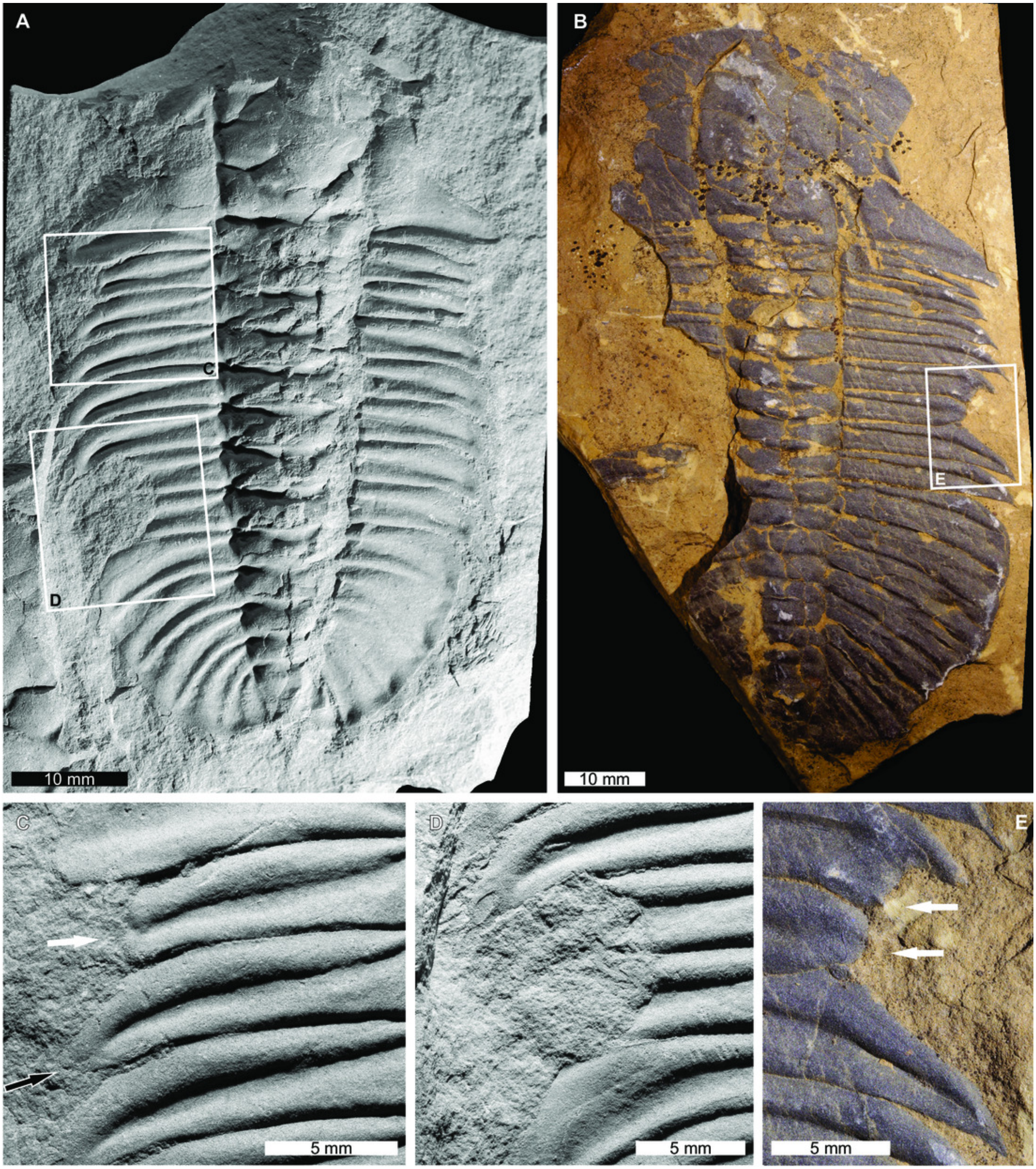
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Figure 2

Figure 2: Injured *Paradoxides* (*Paradoxides*) *paradoxissimus gracilis* (Boeck, 1827) from the Cambrian (Drumian) aged Jince Formation, Czech Republic.

(A–D): NHMUK PI OR 42440. **(A)**: Complete specimen. **(B)**: Close up of unique injury showing a truncated pleural spine (white arrow) with a notched posterior region (grey arrow), a 'W'-shaped indentation (black arrow), and a truncated, rounded pleural spine (blue arrow). **(C)**: Close up of 'W'-shaped indentation. **(D)**: Close up of SSI (black arrow).

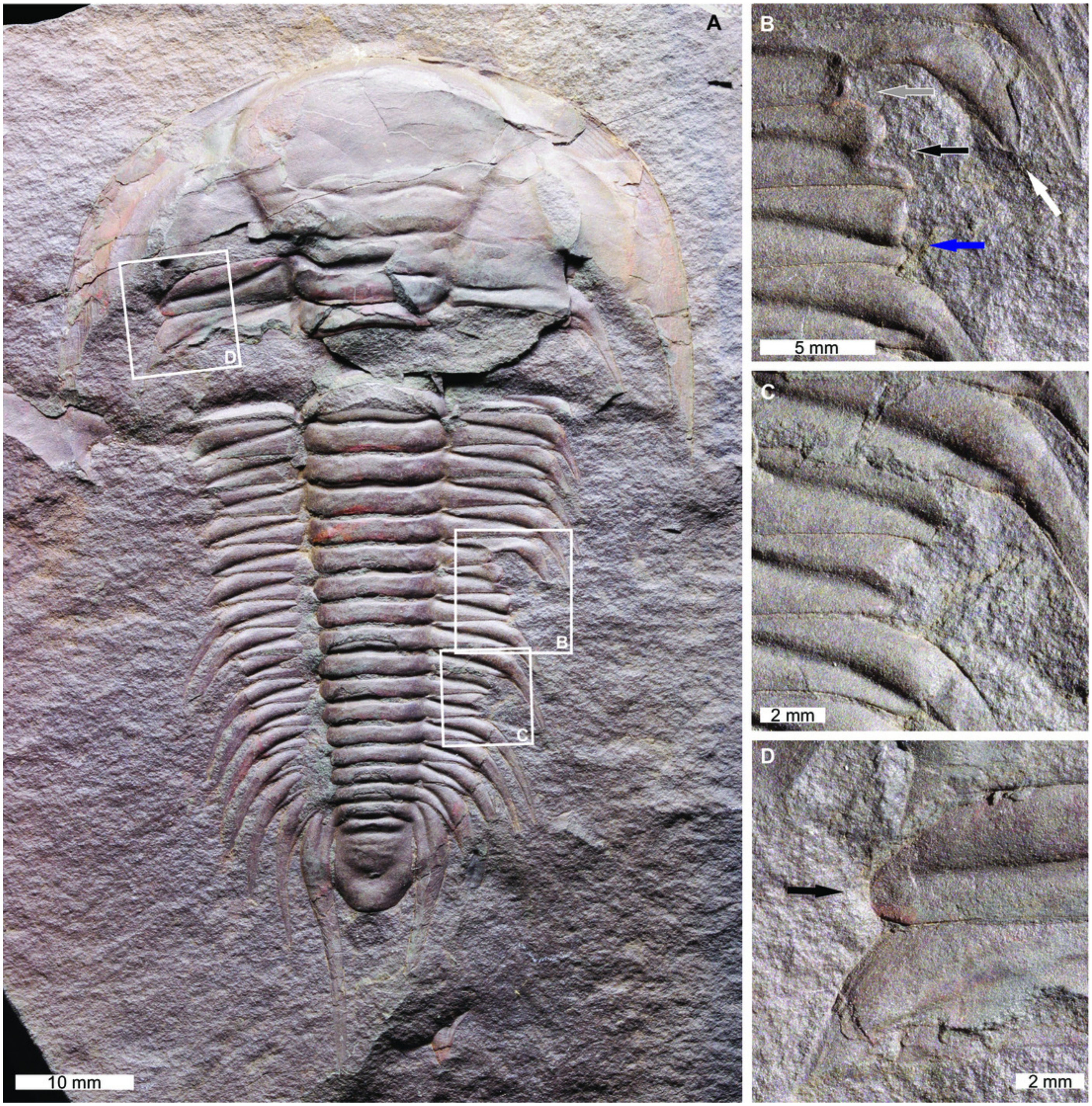
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Figure 3

Figure 3: Injured *Ogygiocarella angustissima* (Salter, 1865), from the Ordovician (Middle–Late, Darriwilian–Sandbian) aged Llanfawr Mudstones Formation, Wales.

(A, B): NHMUK PI OR 59206. **(A)**: Complete specimen. **(B)**: Close up of 'U'-shaped (white arrows) and 'V'-shaped (black arrows) indentations.

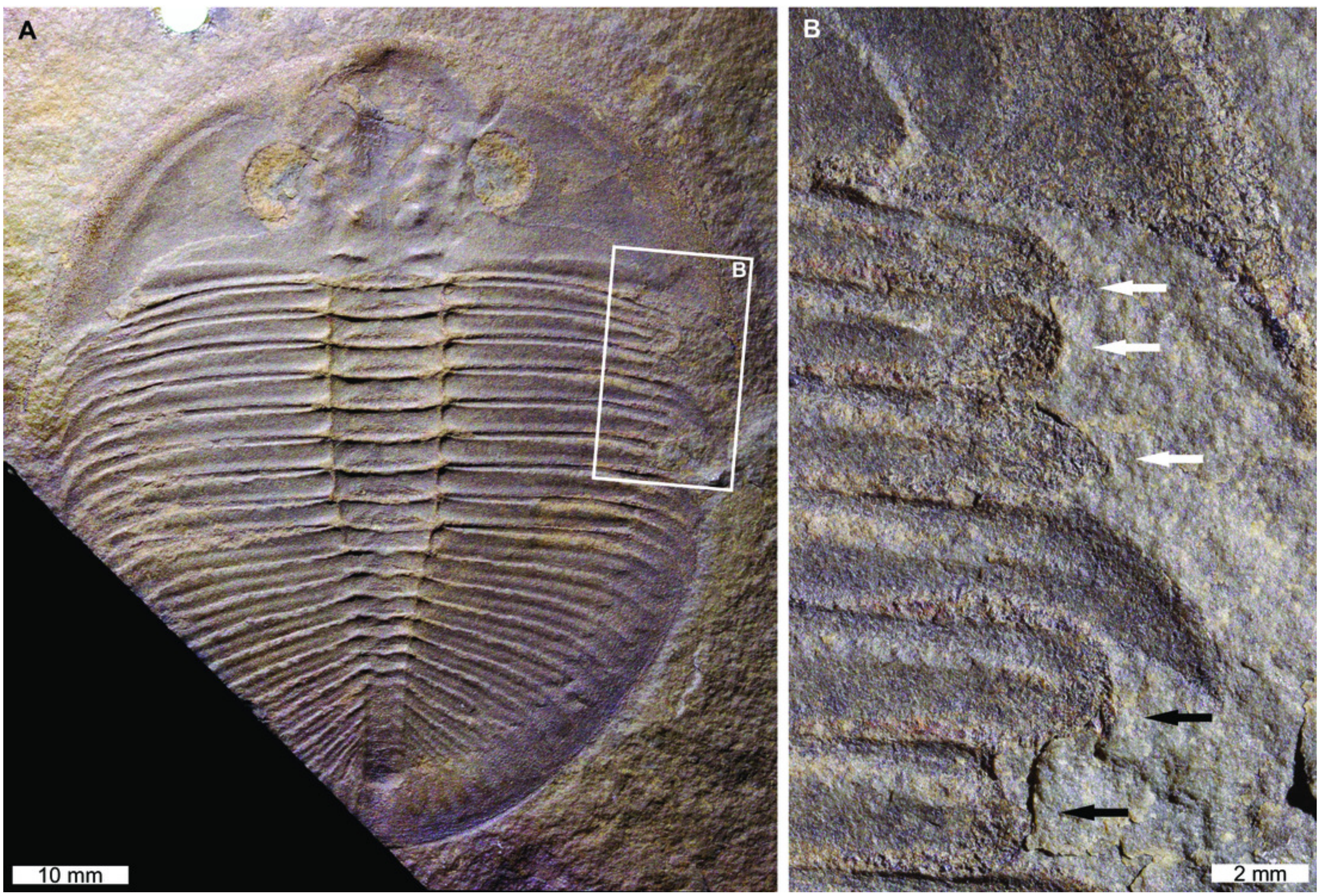
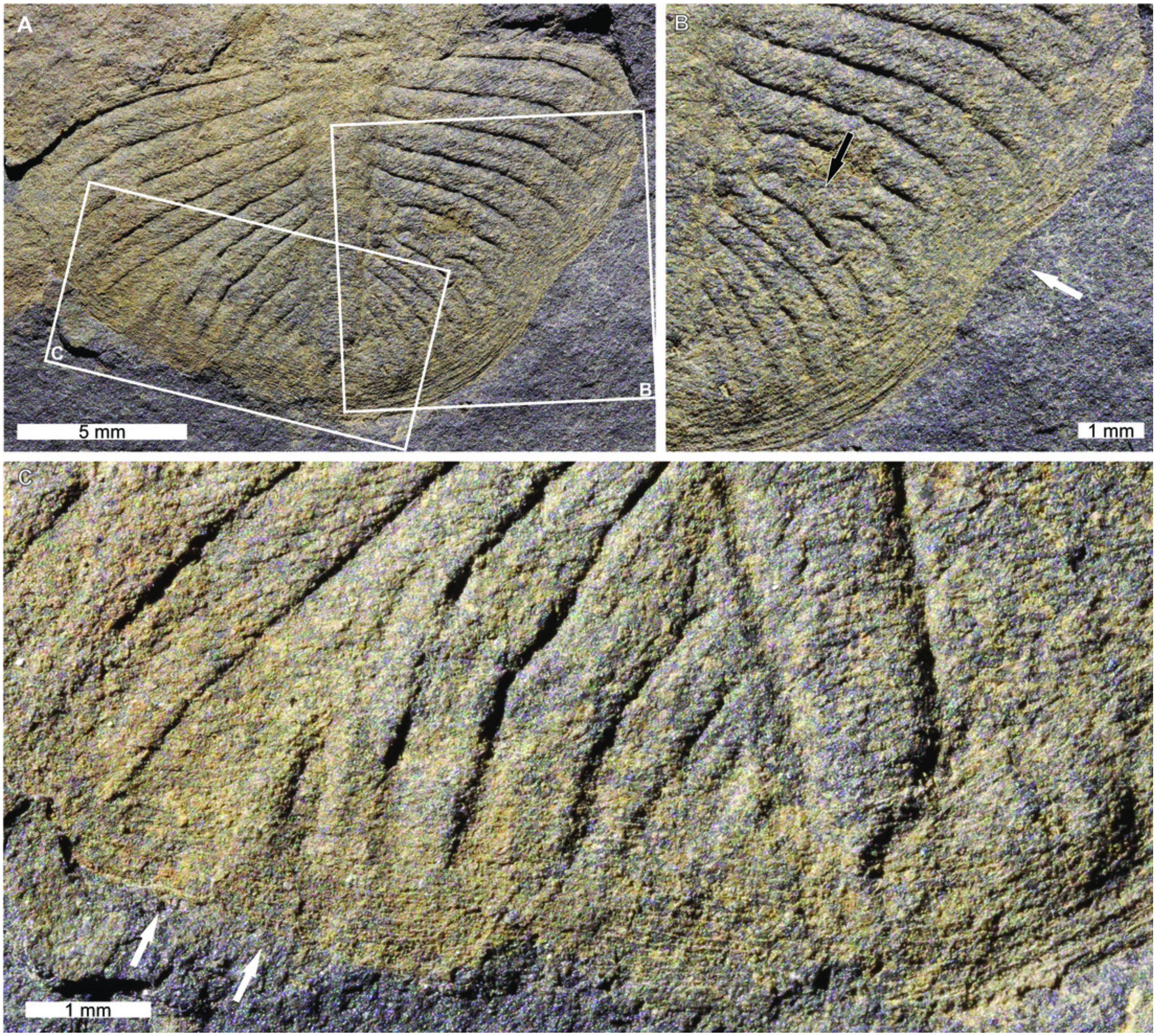


Figure 4

Figure 4: *Ogygiocarella debuchii* (Brongniart, 1822) from the Ordovician (Middle–Late, Darriwilian–Sandbian) aged upper Meadowtown Formation, Wales

(A–C): NHMUK PI In 23066. **(A)**: Complete specimen. **(B)**: Close up of right side showing shallow ‘U’-shaped indentation (white arrow) and the fusion pygidial ribs (black arrow). **(C)**: Close up of left side showing disruption and possible fusion (white arrows) of pygidial ribs and irregular rib sizes.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