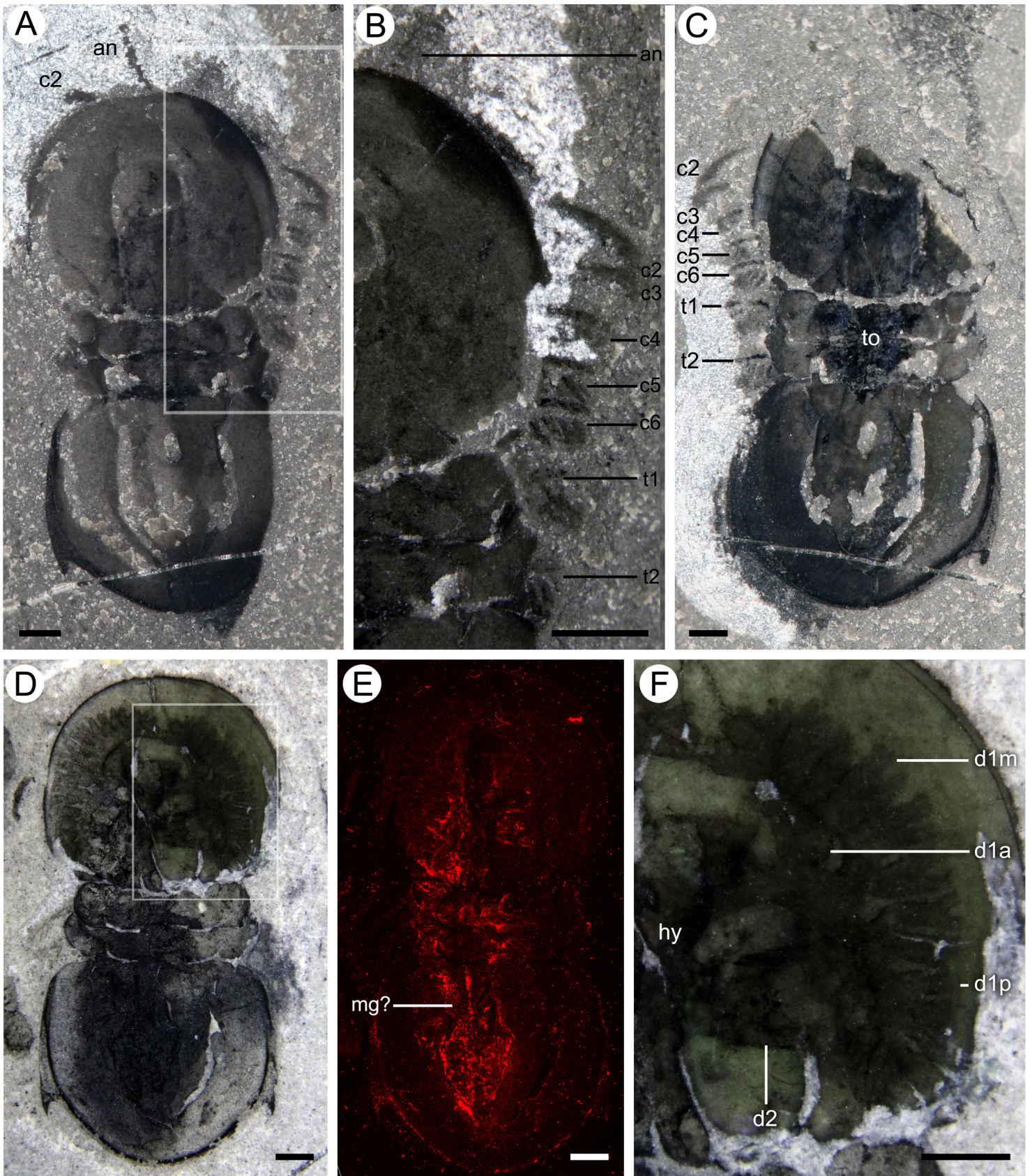


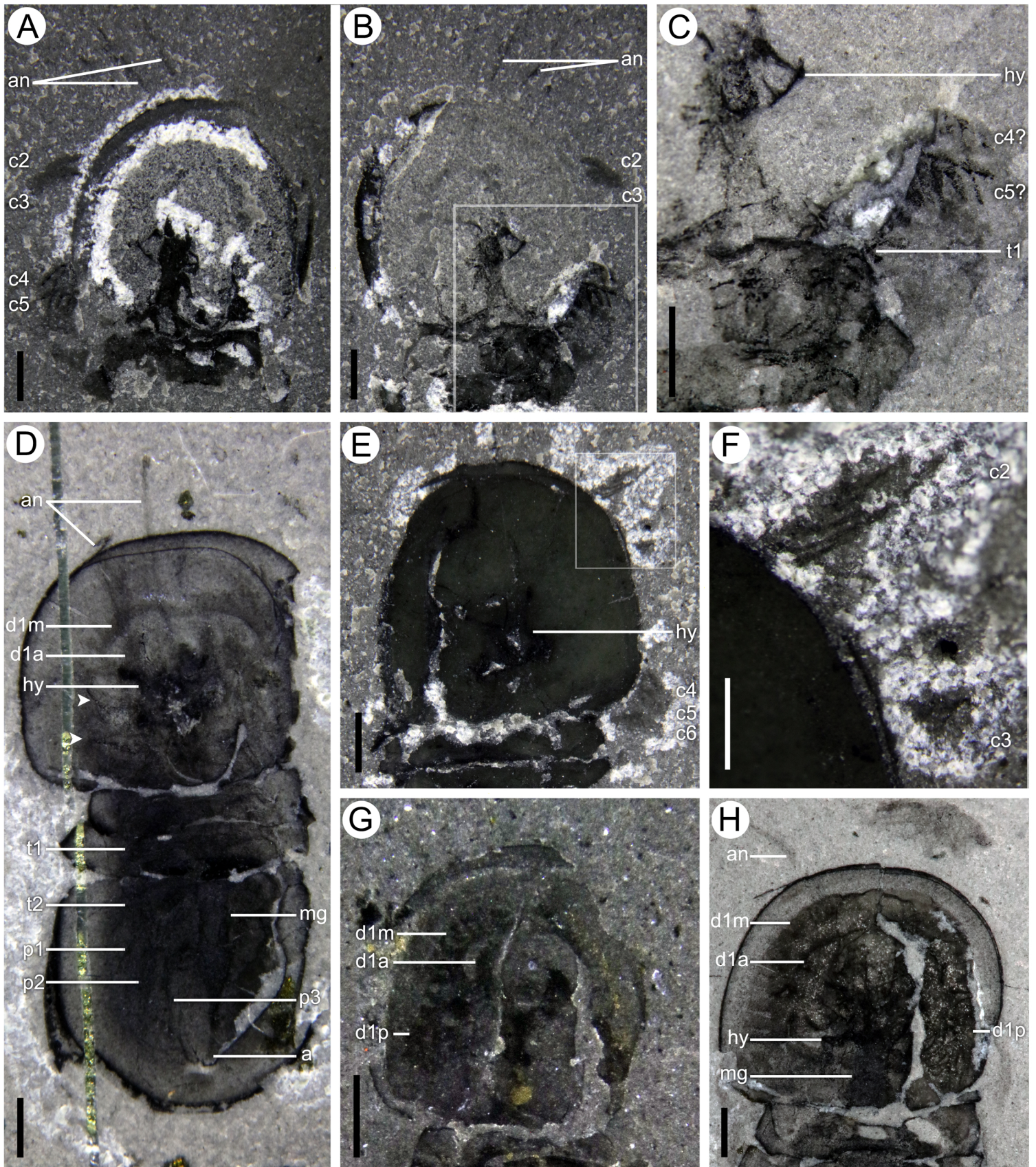
Supplementary Information

Contents

Supplementary Figures	2-3
Table 1: Summary Table of Important Characters	4-17
Complete Phylogenetic Results	18-19
Modifications to Phylogenetic Character Matrix	20-23
Table 2: List of Specimens with Soft Tissues	24-28
Supplementary References	29-30



Supplementary Figure 1 | Additional photos of *Peronopsis* specimens figured in main figures. **A,B,C**, *Pe. cf. columbiensis*, ROMIP 64990 from MC, dry; **A**, counterpart, boxed area corresponds to **B**; **B**, closeup showing cephalic and trunk appendages; **C**, part, showing whole specimen; **D,E,F**, *Pe. cf. columbiensis* ROMIP 64982 from MC; **D**, whole specimen, underwater, boxed area corresponds to **F**; **E**, whole specimen carbon map, showing probable midgut/hindgut and faintly carbonaceous cephalic diverticulae; **F**, Closeup of cephalic diverticulae, underwater. Bars = 1mm. See Figs. 1 and 2 for abbreviations.



Supplementary Figure 2 | Additional specimens of *Ptychagnostus* and *Peronopsis*. **A-C**, *Pe. cf. columbiensis*, ROMIP 64986; **A**, part, dry; **B**, counterpart, dry, boxed area corresponds to **C**; **C**, closeup showing appendages, underwater; **D**, *Pe. cf. columbiensis*, ROMIP 62941 from MC, underwater, arrows indicating cephalic appendages (unknown number); **E,F**, *Pt. cf. praecurrens*, ROMIP 65010 from MC, dry; **E**, cephalon, boxed area corresponds to **F**; **F**, closeup of cephalic appendages 2 and 3 showing setae; **G**, *Pt. praecurrens*, ROMIP 65027 from WQ, underwater, showing d1; **H**, *Pe. cf. columbiensis*, ROMIP 64996 from MC, underwater, with well preserved d1p. Bars: A-E,G,H = 1mm; F = 0.5mm. See Figs. 1 and 2 for abbreviations.

Supplementary Table 1: Summary table of characters important to the agnostid problem. Proposed homologies are listed with their references, as well as any counterarguments that have been raised. The far right column lists the treatment of these homologies in this study.

<u>Section</u>	<u>Character</u>	<u>Potential homologues found in</u>	<u>Reference</u>	<u>Counterargument</u>	<u>Reference</u>	<u>In this study</u>
Appendages	short "feeding" antennule, rather than antenniform	Crustacean larvae + Orsten "stem-crustaceans" (<i>Oelandocaris</i> ; <i>Martinssonina</i> , <i>Cambropachycope</i> , <i>Goticaris</i> , <i>Henningsmoenicaris</i>)	Müller & Walossek, 1987; Walossek & Müller, 1990; Stein et al. 2005; Bergström & Hou, 2005; Stein et al. 2013 (excluded <i>Agnostus</i> from lamellipedia because of few antennule podomeres)			<i>Peronopsis</i> and <i>Ptychagnostus</i> have long, antenniform antennules in contrast to those reconstructed for <i>Agnostus</i> . This variation may be taphonomic, as the antennules of <i>Agnostus</i> are broken in known specimens, or it may represent a real biological difference. We have recoded <i>Agnostus</i> as ? for ch. 79.
Appendages	antennule podomeres armed with mediodistal setae/spines	"stem-crustacea" (e.g. <i>Henningsmoenicaris</i> , <i>Oelandocaris</i>)	Stein et al. 2005; Stein et al. 2013	small spines also present on antennules of <i>Marrella</i> , some artiopodans like <i>Kuamaia</i>	Bergström & Hou, 2005; Babcock et al. 2017	Considered in ch. 225.

Appendages	pendant limbs	crustacea, megacheirans, but not artiopodans	Müller & Walossek, 1987; Bergström, 1992; Bergström & Hou, 2005	1) the limbs of some artiopodans were also situated in 'pendant' position; 2) some trilobitomorph limbs may have rotated during ontogeny; 3) limb stance is partly a product of taphonomy and is not a reliable character	1) Haug & Haug, 2016; 2) Stein et al. 2013; 3) Edgecombe & Ramsköld, 1999	Given counterargument 3, we refrain from using this character.
Appendages	fusion of the proximal podomeres on the endopod and exopod (behind post-antennular limb pair 3)	<i>Henningsmoenicaris</i> , <i>Oelandocaris</i>	Müller & Walossek, 1987; Walossek & Müller, 1990; Stein et al. 2005	also likely found in <i>Emeraldella</i> and possibly other artiopodans	Stein & Selden, 2012	The proximal limbs of many fossil taxa are poorly known, and the true phylogenetic distribution of this character remains to be established. We do not include it in our analysis.
Appendages	reduction of cephalic endopods	mandibulates, marrellomorphs	Müller & Walossek, 1987; Boxshall, 2004; Stein et al. 2013, Aria & Caron, 2017T ¹	6-segmented endopod also present on first post-antennular limb of <i>Emeraldella</i>	Stein & Selden, 2012	Considered in ch. 85-6.

¹ T = *Tokummia*, ref. 46 in main manuscript

Appendages	slender spines at tip of endopod, as opposed to 'claws' of trilobites	"stem-crustacea" (e.g. <i>Henningsmoenicaris</i> , <i>Oelandocaris</i> , <i>Martinssonina</i>)	Walossek & Müller, 1990; Bergström & Hou, 2005			Considered in ch. 205.
Appendages	proximal endopod podomeres 1-4 (or 5) bearing paired, mediodistal spines/endites	"stem-crustacea" (<i>Henningsmoenicaris</i> , <i>Oelandocaris</i>); some artiopodans	Müller & Walossek, 1987 (5); Stein et al. 2013 (4); Bergström & Hou, 2005	also found in <i>Tokummia</i> , <i>Canadaspis</i> , <i>Sidneyia</i> , leanchoiliids, walking legs of some eurypterids	Aria & Caron, 2017T	Considered in ch. 198, 200-204.
Appendages	first two post-antennular limbs differentiated; multisegmented exopods bearing mediodistal or a pair of lateral setae; few-segmented on more posterior limbs	<i>Oelandocaris</i> , many crustaceans	Müller & Walossek, 1987; Boxshall, 2004; Stein et al. 2005; Bergström & Hou, 2005; Stein, 2008; Haug et al. 2010; Stein & Selden, 2012; Stein et al. 2013; Babcock et al. 2017	multisegmented cephalic exopods also present outside of crustacea, e.g. marrellomorphs, habeliids (though lacking setae), <i>Offacolus</i> , <i>Dibasterium</i>	Sutton et al. 2002; Briggs et al. 2012; Haug et al. 2012; Aria & Caron, 2017H ²	Considered in ch. 104, 106.

² H = *Habelia*, ref. 44 in main manuscript

Appendages	exopods subdivided into proximal and distal lobes	many artiopodans; modified to different states in e.g. <i>Triarthrus</i>	Edgecombe & Ramsköld, 1999 (though not mentioned for <i>Agnostus</i>); Stein et al. 2013			Considered in ch. 188. It is not possible to assess whether the highly reduced exopods of <i>Agnostus</i> are subdivided in the same way as those of many artiopodans, so we remain ambiguous in our coding.
Appendages	exopod paddle shaped	<i>Henningsmoenicaris</i> , <i>Oelandocaris</i>	Haug et al. 2010			The trunk exopods of <i>Agnostus</i> are highly reduced and are rather unlike the bona fide lobate exopods found in taxa like <i>Oelandocaris</i> , leancholiids, habeliids and some artiopodans. We do not consider this a valid homology.
Appendages	exopod setae directed laterally (rather than medially)	non-crustaceans	Bergström & Hou, 2005			The orientation of exopod setae is highly variable, with a number of taxa (e.g. <i>Oelandocaris</i> , Stein et al. 2008; <i>Skara</i> , Haug et al. 2010b; <i>Emeraldella</i> , Stein & Selden, 2012) bearing both laterally and medially directed setae on different appendages. As such

						we have chosen not to treat this character here.
Appendages	"soft" pennaceous setae on exopods	<i>Henningsmoenicaris</i>	Müller & Walossek, 1987; Walossek & Müller, 1990; Bergström & Hou, 2005			The similarity of the 'soft' setae of <i>Henningsmoenicaris</i> (figured in Haug et al. 2010) with the much longer pennaceous setae seen in <i>Agnostus</i> has been overstated. <i>Agnostus</i> ' setae do resemble those of some crustaceans (branchiopods, ostracods, etc.; Martin et al. 2014). However, the setae of <i>Agnostus</i> could alternatively represent early developmental stage lamellae. Lamellae of some artiopodans (e.g. <i>Emeraldella</i> ; Stein & Selden, 2012) are likewise adorned with marginal setules. We do not include this character in our matrix.

Appendages	setae with rounded cross section, as opposed to lamellae	non-'lamellipedian' arthropods	Müller & Walossek, 1987; Walossek & Müller, 1990; Bergström, 1992; Bergström & Hou, 2005			Considered in ch. 184. Both lamellae and rounded setae seem to have a wide yet discontinuous phylogenetic distribution, being found among panchelicerates, artiopodans, megacheirans, mandibulates, etc. In addition, some taxa seem to possess both types of setal ornamentation (e.g. <i>Emeraldella</i> ; Stein & Selden, 2012).
Digestive Tract	genal caecae (ramifying gut diverticulae)	some trilobites?, <i>Burgessia</i> , <i>Naraoia</i> , <i>Notchia</i> , xiphosurans, several crustacean clades	Öpik, 1959; Jell, 1978; Vannier & Chen, 2002; Cotton & Fortey, 2005; Lerosey-Aubril, 2015	trilobite genal caecae anastomose, have much smaller diameter than those of agnostinids, and may emerge from several attachment sites in the cephalon; they are probably non-homologous with the digestive structures of other taxa	Bergström, 1973; Jell, 1978; Bergström & Hou, 2005	Considered in ch. 142, 143, 220, and discussion. Agnostinids and naraoiids share diverticulae originating from the hypostome complex.

Hypostome	natant hypostome	eodiscinids, many polymeroid trilobites	Robison 1972; Fortey & Theron, 1994; Shergold, 2008	1) also found in <i>Henningsmoenicaris</i> ; 2) eodiscinid ontogeny begins with conterminant hypostome	1) Walossek & Müller, 1990; 2) Cederstrom et al. 2009	Considered in ch. 62.
Hypostome	hypostome fenestrules covered by membranous fields	<i>Henningsmoenicaris</i>	Walossek & Müller, 1990	1) could be homologous with 'sensory pits' (maculae) on trilobite hypostome and with similar structures in some artiopodans (e.g. xandarellids; Hou & Bergström, 1997), and potentially with the ventral eyes of <i>Limulus</i> ; 2) could be related to the development of the labrum from paired appendages, homologous with similar structures in artiopodans, habelliids and some mandibulates	1) Jell, 1975; Müller & Walossek, 1987; Zhang et al. 2007; Ortega-Hernández, 2016; 2) Aria & Caron, 2017T+H	While their functional identity (sensory or otherwise) remains unclear, we consider the homology of bilobed labral protrusions across a range of euarthropods to be possible and follow the coding of Vannier et al., 2018 (ch. 72), with the exception of recoding hymenocarines as ? until more definitive evidence for the bilobed nature of the anteroventral protrusion can be provided. The equivalence of trilobite maculae to bilobed labral protrusions in other taxa is less clear, and we do not assume their homology here.

Hypostome	membrane lateral to mouth putatively a labrum	"labrophoran" crustaceans	Walossek et al. 2007	1) hypostome-labrum complex is a symplesiomorphic for Euarthropods, as it is also found in putative upper stem group lineages; 2) 'hypostome' of Orsten taxa, including <i>Agnostus</i> is non-homologous with the lamellipedian hypostome	1) Ortega-Hernández, 2016; 2) Bergström & Hou, 2005	Considered in ch. 57.
Ontogeny	lack of a (trilobite-like) protaspid stage	non-trilobites	Fortey & Theron, 1994; Hughes, 2006; Shergold, 2008	1) This character is also not present in olenelline trilobites, and therefore may not be ancestral for Trilobita; Qian (1982) described putative agnostinid protaspids, but this has been questioned - see 2)	1) Walossek & Müller, 1990; 2) Naimark, 2007	The absence of ontogenetic data for many taxa in our matrix, precludes the inclusion of this character.
Sensory	simple ventral eyes (?)	<i>Oelandocaris</i> ; <i>Henningsmoenicaris</i> , <i>Skara</i> , other Orsten taxa?	Stein et al. 2005; Stein et al. 2008	'lateral frontal organs' are also widespread among euarthropods; their identity as median eyes is controversial	Edgecombe & Ramsköld, 1999; Cotton & Braddy 2004; Ortega-Hernández, 2015; Aria & Caron, 2017T	Considered in ch. 19.

Sensory	lack of dorsal eyes embedded in tergal shield	most crustaceans, megacheirans, some arthropods, habeliids, etc.	Bergström, 1992	1) 'blindness' is an autapomorphy of agnostinids; 2) <i>Oculagnostus</i> has palpebral lobes; but, 3) the palpebral lobes of <i>Oculagnostus</i> have been argued to be muscle insertion scars	1) Fortey & Theron, 1994; Cotton & Fortey, 2005; 2) Ahlberg, 1988; 3) Shergold, 2008	Considered in ch. 26.
Tergites	cuticle mineralization	trilobites, aglaspids, <i>Phyotphilaspis?</i> , but also widespread amongst other euarthropod groups	Fortey & Theron, 1994; Edgecombe & Ramsköld, 1999; Cotton & Fortey, 2005; Stein et al. 2013			Considered in ch. 4. Given a lack of clarity over whether many extinct taxa mineralized their cuticles primarily with calcium carbonate or phosphate, we eliminated ch. 5 from the Vannier et al. (2018) matrix in our analysis.
Tergites	trilobite-like articulation of tergites (as opposed to simple tergite overlap)	trilobites	Fortey & Theron, 1994; Cotton & Fortey, 2005	"edge to edge" articulation with articulating half rings and flanges also present in <i>Kwanyinaspis</i> , <i>Siriocaris</i> , trilobitomorphs, basally branching euchelicerates	Edgecombe & Ramsköld, 1999; Stein et al. 2013; Lamsdell, 2013	Considered in ch. 40, 162, 163.

Tergites	trilobation	trilobites, some other artiopodans (e.g. <i>Phytophilaspis</i> , emucarids)	Fortey & Theron, 1994; Cotton & Fortey, 2005; Stein et al. 2013	also found in a range of other arthropods (e.g. some chelicerates, fuxianhuiids, malacostracan crustaceans)	Stein et al. 2005; Scholtz & Edgecombe, 2005; Aria & Caron, 2017T	Considered in ch. 159.
Tergites	pleural furrows	trilobites	Müller & Walossek, 1987			Considered in ch. 163.
Tergites	tips of anterior pleurae angled backwards; anteriormost thoracic tergite narrower but longer than more posterior tergites	eodiscinids	Cotton & Fortey, 2005; Dai & Zhang, 2013	narrowing of anterior of trunk relative to head shield also present in naraoiids, some panchelicerates	Edgecombe & Ramsköld, 1999; Lamsdell, 2013; Mayers et al. 2018	Considered in ch. 218.
Tergites	glabella defined dorsally	trilobites	Fortey & Theron, 1994; Cotton & Fortey, 2005			Also shared with <i>Phytophilaspis</i> and some aglaspidids. Considered in ch. 41, 159.
Tergites	cephalic border	trilobites	Fortey & Theron, 1994			We do not consider this character in our analysis. We expect it might further support a trilobite + agnostinid clade, though a cephalic border is also variably expressed among other arachnomorphs (e.g.

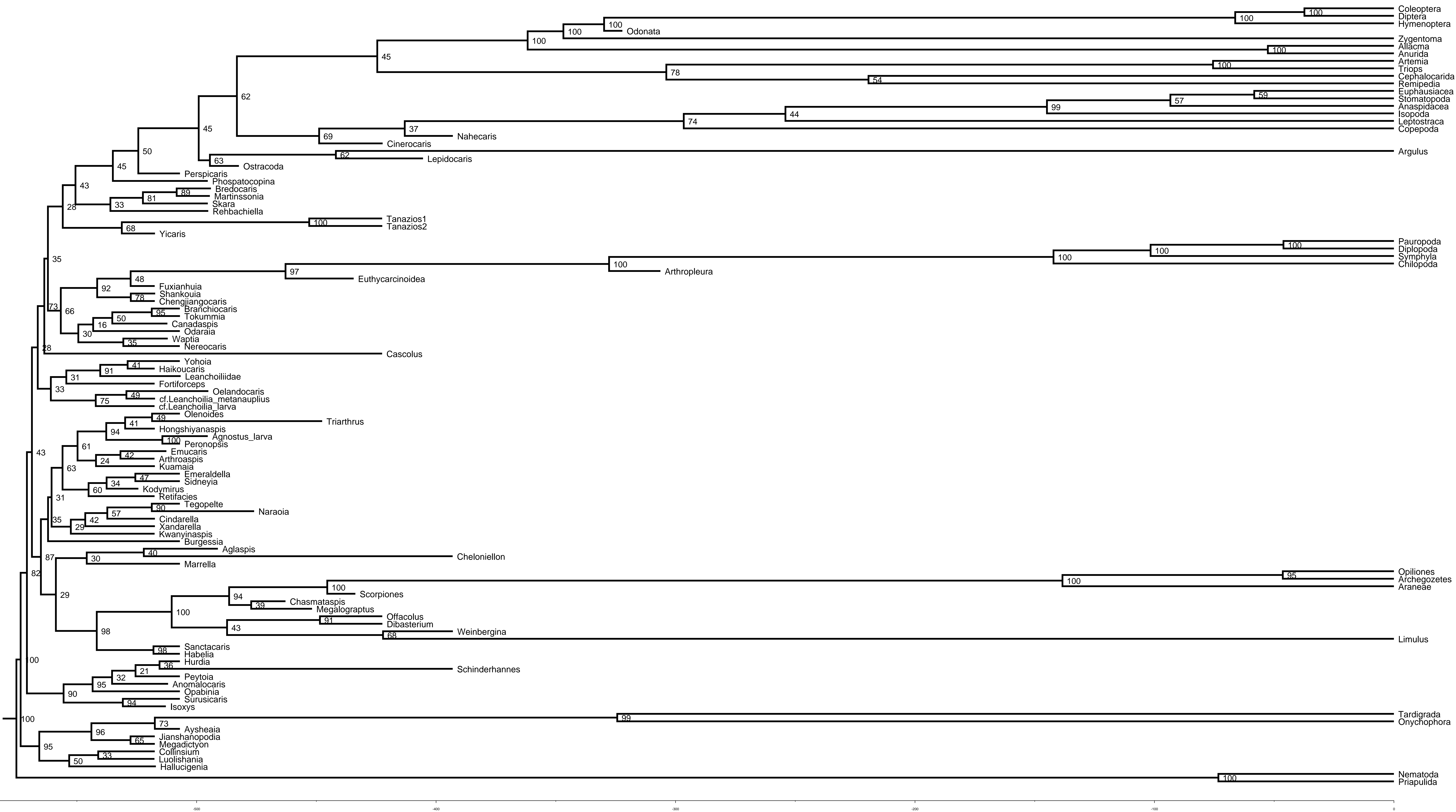
						xiphosurans, chasmataspids).
Tergites	dorsal expression of last (occipital) segment of cephalic shield	trilobites, <i>Phytophilaspis</i> , <i>Sinoburius</i> , <i>Arthroaspis</i> , xiphosurans	Cotton & Fortey, 2005; Stein et al. 2013; Lamsdell, 2013			Considered in ch. 42.
Tergites	genal spines	trilobites, <i>Phytophilaspis</i> , <i>Sinoburius</i> , some aglaspidids	Fortey & Theron, 1994; Cotton & Fortey, 2005; Stein et al. 2013	has been argued that the 'fulcral spines' of agnostinids are non-homologous with trilobite genal spines	Shergold, 2008	The genal spines of agnostinids may well be homologous with those of many trilobites and other arachnomorphs. Considered in ch. 223.
Tergites	lack of (trilobite-like) facial sutures, submarginal sutures	non-trilobites	Walossek & Müller, 1990; Bergström, 1992; Bergström & Hou, 2005; Cotton & Fortey, 2005; Hughes, 2006; Shergold, 2008			Considered in ch. 219.
Tergites	no palpebro-ocular ridges	non-trilobites	Fortey & Theron, 1994			Considered in ch. 27.

Tergites	pygidium (newly formed segments fused to next anterior segment, may separate later in ontogeny)	trilobitomorphs, but also <i>Henningsmoenicaris</i> , <i>Retifacies</i>	Fortey & Theron, 1994; Edgecombe & Ramsköld, 1999; Haug et al. 2010; Stein et al. 2013			Considered in ch. 215. We here consider the tergites covering multiple appendages in xandarellids to be a separate condition, although it may share a developmental basis with the pygidia of other artiopodans.
Tergites	posterolateral pygidial spines	many pygidium-bearing artiopodans	Shergold, 2008	pygidium lacking lateral spines was a putative synapomorphy of a clade including trilobites (with internal reversals) and <i>Phytophilaspis</i> ; but is also found in a number of other artiopodans	Edgecombe & Ramsköld, 1999; Stein et al. 2013	The effacement of dorsal segmentation in the pygidial shield of agnostinids and many other pygidium-bearing taxa makes it a challenge to assess this proposed homology. We removed ch. 219 from the 2018 Vannier et al. matrix because its vague definition was drawing together taxa whose pygidial ornamentation was unlikely to be homologous.

Other	loss/fusion of the tritocerebral sternite (could this be the first step towards the evolution of the sternum of more derived crustacea or the intercalary segment of hexapods and myriapods?)	"labrophoran" crustaceans	Walossek et al. 2007; Stein & Selden, 2012	the degree of cephalic sternite fusion is variable among different crustacean groups, questioning the validity of this character as a defining synapomorphy for "labrophorans"	Aria & Caron, 2017T (Ch. 61)	Considered in ch. 65, 66.
Other	mouth situated in atrium oris (depression behind labrum, which bulges from posterior of hypostome)	"labrophoran" crustacea (<i>Oelandocaris</i> , <i>Martinssonina</i> , <i>Henningsmoenicaris</i> , Phosphatocopina, eucrustacea)	Stein et al. 2005			Given that the mouth is situated behind the hypostome-labrum complex in all euarthropods (e.g. Ortega-Hernández, 2016) and considering the lack of mandibles and paragnaths to complete the enclosure of the pre-oral cavity, we consider an atrium oris to be absent in agnostinids.

<p>Other</p>	<p>offset between tergal and somitic segmentation, 4.5 cephalic appendage pairs</p>	<p>artiopodans</p>	<p>Edgecombe & Ramsköld, 1999; Stein et al. 2005; Stein et al. 2013</p>	<p>tergal offset not present in <i>Agnostus</i></p>	<p>Müller & Walossek, 1987; Ortega-Hernández & Brena, 2012</p>	<p>Whether trilobites and other artiopodans possessed 4 or 4.5 head appendage pairs has long been controversial. The best case for such a tergal offset has been made using specimens of <i>Triarthrus</i> (Ortega-Hernández & Brena, 2012), but its distribution among other artiopodans is less clear. We therefore opt not to include it in our analysis.</p>
---------------------	---	--------------------	---	---	--	--

Supplementary Figure 3 (next page) | Complete results of Bayesian time calibrated phylogenetic analysis. Based on a matrix incorporating 225 characters and 124 taxa (see Vannier et al. 2018 and associated nexus file for further methodological details). Numbers next to nodes denote posterior probabilities. Time scale is in millions of years.



Modifications to Phylogenetic Character Matrix

The various modifications made to the matrix published in Vannier et al. 2018 are listed below.

Characters Deleted

* Note: numbering given in this section corresponds to that in Vannier et al. (2018). Numbering in our matrix was adjusted given the deletions (i.e. ch. 6 in Vannier et al. 2018 became ch. 5, etc.). Numbering in sections below (Characters Added, Coding Modifications) corresponds to that in our matrix, following these deletions.

Ch. 5 – Given the contention over the original cuticle mineralogy of several extinct groups, we chose to omit this character.

Ch. 219 – The definition of this character was too vague and was drawing together taxa that were unlikely to share homologous pygidial ornamentation.

Characters Added

[218] Trunk tergites taper anteriorly relative to cephalic shield

- 0. Absent
- 1. Present

Remarks: See Edgecombe & Ramsköld, 1999 ch.19; Cotton & Braddy, 2004 ch. 39; Paterson et al. 2010 ch. 15; Ortega-Hernández et al. 2013 ch. 49; Mayers et al. 2018 ch. 22. This character is present in agnostids (Cotton & Fortey, 2005), among other taxa. Applicable only for taxa with a cephalic shield and horizontal pleurae.

[219] Visual surface with calcified lenses, bounded by circumocular suture

- 0. Absent
- 1. Present

Remarks: See Edgecombe & Ramsköld, 1999 ch. 5; Cotton & Braddy, 2004 ch. 21; Paterson et al. 2010 ch. 4; Ortega-Hernández et al. 2013 ch. 21; Mayers et al. 2018 ch. 9. Applicable for taxa with eyes embedded in the tergal shield.

[220] Main ramified cephalic diverticulae connect to the alimentary canal through the hypostome-labrum complex

- a. Absent
- b. Present

Remarks: (new character) While cephalic diverticulae occur among disparate arthropod groups, attachment to the anteriormost section of the alimentary canal through the hypostome-labrum complex seems to be unique to agnostinids and naraoiids.

[221] Segmental impressions in pygidial shield

- 0. Absent/highly effaced
- 1. Strongly developed

Remarks: Modified from Paterson et al. 2010 ch. 16; Mayers et al. 2018 ch. 5.

[222] Shape of posteriormost margin of pygidium

- 0. Convex
- 1. Sub-straight to concave

Remarks: Ch. 28 Mayers et al. 2018.

[223] Axial spine on preterminal trunk segment

- 0. Absent
- 1. Present

Remarks: Modified from Mayers et al. 2018 ch. 31. This character unites xandarellids in our analysis. We did not assume the homology of medially positioned spines fused into effaced pygidia (e.g. in *Naraoia*, *Kuamaia*), though some of these may be homologous.

[224] Genal spines

- 0. Absent
- 1. Present

Remarks: There has been some debate as to whether agnostinids have true genal spines (Fortey & Theron, 1994) or ‘fulcral’ spines (Shergold, 2008); however, Cotton & Fortey (2005) provided a compelling argument for the homology of agnostinid spines with other genal spines based on the morphogenesis of these structures. We therefore opt for coding them as potentially homologous to the genal spines of other arthropods. See also e.g. Ortega-Hernández et al. 2013 ch. 21; Mayers et al. ch. 17.

[225] Medial spines or enlarged setae on antennules

- 0. Absent
- 1. Present

Remarks: This character is widespread and variously developed among euarthropods.

Taxa Added

Peronopsis, *Triarthrus*, *Hongshiyanaspis*, *Retifacies*, *Cindarella*, *Kodymirus*, *Arthroaspis*, *Tegopelte*, *Kwanyinaspis*, *Emucaris*, *Cheloniellon*

Taxa Removed

pycnogonida, *pycnogonum larva*, *Cambropycnogon*, *Aquilonifer*

Pycnogonids have been highly problematic in previous analyses and in Vannier et al. (2018) formed an unexpected clade with marrellomorphs and *Aquilonifer*. Given that these taxa likely have little relevance to the agnostid problem, we have removed them from our analysis for now.

Coding Modifications

Ch. 31 (somites in head) – changed to ? for *Agnostus* (coded state 2 for *Peronopsis*), state 3 for *Xandarella* (this assumes that the seventh appendage pair is part of the head tagma, as opposed to lying at the head-trunk boundary), state 1 for *Naraoia*, ? for *Kuamaia*

Ch. 40 (tergal articulation) – changed to state 1 for *Agnostus* and *Peronopsis*, to acknowledge the distinct state from trilobites

Ch. 72 (bipartite ventral protrusion) – recoded as state 1 for *Xandarella*¹, and as ? for *Tokummia*, *Branchiocaris*, and *Waptia*²

Ch. 79 (type of multisegmented frontalmost appendage) – recoded as ? for *Agnostus*

Ch. 90 (endopod of 5th appendage pair) – recoded as ? for *Agnostus*

Ch. 92 (repeated appendage morphology) – recoded as ? for *Agnostus*

Ch. 99 (ramification of postantennular appendage) – recoded as state 0 for *Agnostus*, ? for *Aglaspis*³

Ch. 104 (postantennular exopod type) – recoded as ? for *Aglaspis*³

Ch. 105 (other cephalic exopods) – recoded as ? for *Aglaspis*³

Ch. 106 (other cephalic exopod type) – recoded as ? for *Aglaspis*³

Ch. 107 (multisetose exopod tip) – recoded as ? for *Aglaspis*³

Ch. 108 (detachment of exopods) – recoded as ? for *Aglaspis*³

Ch. 124 (5th appendage vestigial) – recoded as ? for *Agnostus*

Ch. 125 (palp on 5th appendage) – recoded as ? for *Agnostus*

Ch. 156 (tergo-sternal decoupling) – recoded as ? for *Naraoia*⁴

Ch. 165 (proximo-distal differentiation of endopod podomeres) – recoded as 0 for *Marrella*⁵

Ch. 180 (gnathobase) – recoded as state 1 for *Agnostus*

Ch. 194 (exopod subdivision) – recoded as ? for *Agnostus*

Ch. 205 (limb tip) – recoded as state 5 for *Agnostus*⁶

Ch. 207 (telson) – recoded as state 0 for *Xandarella*⁷

Ch. 208 (telson type) – recoded as - for *Xandarella*⁷

Ch. 209 (anus location) – recoded as state 0 for *Xandarella*⁷

¹Hou & Bergström (1997) illustrated specimens of *Xandarella* that show bulbous protrusions associated with the hypostome complex, similar to that of e.g. naraoiids.

²We have coded these taxa as ? until definitive evidence for the bilobed nature of the frontal protrusion can be provided.

³We prefer to code the cephalic appendages of *Aglaspis* as questionably biramous/uniramous rather than uniramous given their poor visibility in the single published specimen (Briggs et al. 1979).

⁴The entirely fused and effaced trunk tergal shield makes it impossible to tell if this character is present in naraoiids.

⁵We argue that the stenopodous endopod podomeres of *Marrella* (Whittington, 1971) show no evidence of significant proximo-distal differentiation.

⁶We have recoded this character to better reflect the differentiation between the limb tip of polymeroid trilobites and *Agnostus* (Müller & Walossek, 1987).

⁷The axial spine of xandarellids occurs on a pre-terminal segment and is therefore not a telson (Hou & Bergström, 1997; Ramsköld et al. 1997). It is not clear whether the terminal tergal plate can strictly be considered homologous to the pygidia of other arachnomorphs given the offset between tergal segmentation and appendages in these taxa.

Supplementary Table 2: Summary of ROM specimens with soft tissue preservation observed in this study.

Locality	Field No.	ROMIP No.	Part/Counter-Part	Strat. Level	Taxon	Soft Tissues	Quality	Figured in	Max. Cephalon Width (mm)	Total Sagittal Length (mm)
Walcott Quarry BW	94-415	60750	nc	-120	<i>Ptychagnostus praecurrens</i>	cephalic and trunk limbs	**		4.3	9
Marble Canyon MCC1	12-194	62930	ab	-378	<i>Peronopsis cf. columbiensis</i>	antennules	**		2.5	5
Marble Canyon MCC1	12-720	62941	c	-377	<i>Peronopsis cf. columbiensis</i>	antennule, trunk limb traces	*	Fig. 2 I,J; SI		9.9
Marble Canyon MCC1	14-1010	64390	ab	-405	<i>Peronopsis cf. columbiensis</i>	faint cephalic diverticulae; cephalic limbs protruding	**		6.6	12.6
Marble Canyon MCC1	12-168	64976	a	talus	<i>Peronopsis cf. columbiensis</i>	pygidial limbs; gut, including diverticulae	***		6.5	12.5
Marble Canyon MCC1	12-183	64977	ab	-378	<i>Peronopsis cf. columbiensis</i>	gut, including diverticulae	**	SI	6.2	12.5
Marble Canyon MCC1	12-530	64978	nc	-366	<i>Peronopsis cf. columbiensis</i>	cephalic limbs	**		5.6	11.1
Marble Canyon MCC1	12-600	64979	a	-406	<i>Peronopsis cf. columbiensis</i>	cephalic limb with clubs; complete gut with diverticulae	***	Fig. 1 C	5.3	10.4
Marble Canyon MCC1	12-604	64980	b	-406	<i>Peronopsis cf. columbiensis</i>	?				

Marble Canyon MCC1	12-668	64981	nc	-403	<i>Peronopsis cf. columbiensis</i>	gut			5.5	9.5
Marble Canyon MCC1	12-684	64982	b	-393	<i>Peronopsis cf. columbiensis</i>	cephalic diverticulae; trunk limbs with clubs	***	Fig. 1 A; SI	5.6	12
Marble Canyon MCC1	12-762	64983	ab	talus	<i>Peronopsis cf. columbiensis</i>	gut	*			
Marble Canyon MCC1	14-1026	64984	ab	-384	peronopsid	gut	*			
Marble Canyon MCC1	14-1390	64985	ab	-351	<i>Peronopsis cf. columbiensis</i>	pygidial limbs?; gut?	**			
Marble Canyon MCC1	14-1414	64986	ab	-360	<i>Peronopsis cf. columbiensis</i>	antennule, cephalic limbs, trunk limbs	***	Fig. 2 H; SI	5.5	12.7
Marble Canyon MCC1	14-587	64987	nc	-245	<i>Peronopsis cf. columbiensis</i>	?; poorly preserved			6.7	12.4
Marble Canyon MCC1	14-724	64988	bc	-383	<i>Peronopsis cf. columbiensis</i>	gut; cephalic limbs				
Marble Canyon MCC1	14-727	64989	nc	-385	<i>Peronopsis cf. columbiensis</i>	antennules; bases of cephalic limbs	**	Fig. 1 B	6.3	12.7
Marble Canyon MCC1	14-735	64990	ab	-383	<i>Peronopsis cf. columbiensis</i>	limbs; diverticulae; triangular organ?	***	Fig. 1 E,F; 2 F,G; SI	6.4	13.2
Marble Canyon MCC1	14-736	64991	ab	-385	<i>Peronopsis cf. columbiensis</i>	bases of cephalic limbs	**			12.1

Marble Canyon MCC1	14-757	64992	ab	-388	<i>Peronopsis cf. columbiensis</i>	posterior gut	**	SI		
Marble Canyon MCC1	14-764	64993	bc	-386	<i>Peronopsis cf. columbiensis</i>	cephalic limbs	***	Fig. 2 B-E	6.8	
Marble Canyon MCC1	14-842	64994	nc	-403	<i>Peronopsis cf. columbiensis</i>	diverticulae	**	Fig. 1 D	5.6	11.5
Marble Canyon MCC1	14-847	64995	nc	-408	<i>Peronopsis cf. columbiensis</i>	limbs?; partial gut	*		3.9	6.6
Marble Canyon MCC1	14-865	64996	b	-374	<i>Peronopsis cf. columbiensis</i>	cephalic limbs, diverticulae and gut	***	SI	6.6	13.3
Marble Canyon MCC1	14-882	64997	ab	-363	peronopsid	dark tissue under pygidial axis	*		0.9	1.9
Marble Canyon MCC1	14-930	64998	b	-376	<i>Peronopsis cf. columbiensis</i>	cephalic tissue?				
Marble Canyon MCC1	14-972	64999	ab	-388	<i>Peronopsis cf. columbiensis</i>	limb	**		5.6	12.3
Marble Canyon MCC1	14-996	65000	ab	-388	<i>Peronopsis cf. columbiensis</i>	pygidial limb?; dark tissue under pygidium	*			
Marble Canyon MCC1	16-1030	65001	ab	-381	<i>Peronopsis cf. columbiensis</i>	thoracic, cephalic limbs; gut; extruded gut stain	***		6.6	12.7
Marble Canyon MCC1	16-777	65002	ab	-242	<i>Peronopsis cf. columbiensis</i>	gut; cephalic limbs?; cephalic diverticulae	**		7.1	13.4

Marble Canyon MCC1	16-789	65003	ab	-386	<i>Peronopsis cf. columbiensis</i>	gut	*		5.3	10
Marble Canyon MCC1	16-790	65004	ab	-380	<i>Peronopsis cf. columbiensis</i>	gut?				
Marble Canyon MCC1	16-832	65005	nc	-417	<i>Peronopsis cf. columbiensis</i>	cephalic diverticulae?	*		5.7	
Marble Canyon MCC1	16-841	65006	a	-395	<i>Peronopsis cf. columbiensis</i>	gut	*			
Marble Canyon MCC1	16-845	65007	ab	-416	<i>Peronopsis cf. columbiensis</i>	cephalic tissue?				
Marble Canyon MCC1	16-873	65008	ab	-496	<i>Ptychagnostus cf. praecurrens</i>	limb traces	*		4.3	9.3
Marble Canyon MCC1	16-905	65009	nc	-496	<i>Peronopsis cf. columbiensis</i>	?			4.7	9.7
Marble Canyon MCC1	16-926	65010	nc	-515	<i>Ptychagnostus cf. praecurrens</i>	cephalic and trunk limbs	***	SI		9.6
Marble Canyon MCC1	16-935	65011	nc	-382	<i>Itagnostus?</i>	cephalic limbs? (poorly preserved)				
Marble Canyon MCC1	16-938	65012	nc	-485	<i>Peronopsis cf. columbiensis</i>	cephalic limbs? (poorly preserved)			5.7	12.9
Marble Canyon MCC1	16-947	65013	ab	-500	<i>Ptychagnostus cf. praecurrens</i>	limb with clubs sticking out on enrolled specimen	*			

Marble Canyon MCC1	16-951	65014	ab	-448	<i>Itagnostus?</i>	cephalic limbs				9.3
Marble Canyon MCC1	16-951	65014	b	-448	peronopsid	cephalic limbs	**			
Marble Canyon MCC1	16-959	65015	ab	-480	peronopsid	dark cephalic tissue?				
Walcott Quarry BW	94-1852	65016	ab	-110	<i>Ptychagnostus praecurrens</i>	cephalic limbs	*		3.8	8.1
Walcott Quarry BW	94-2256	65017	ab	-130	<i>Ptychagnostus praecurrens</i>	cephalic limbs	***	Fig. 2A	3.7	8.1
Walcott Quarry BW	98-1910	65018	ab	-235	<i>Ptychagnostus praecurrens</i>	antennule				
Walcott Quarry BW	98-2374	65019	ab	-235	<i>Ptychagnostus praecurrens</i>	limbs, poorly preserved				
Walcott Quarry BW	98-438	65020	ab	-170	<i>Ptychagnostus praecurrens</i>	?			3.8	7.1
Walcott Quarry BW	98-477	65021	ab	-170	<i>Ptychagnostus praecurrens</i>	limbs?				8.1
Walcott Quarry BW	98-706	65022	ab	-210	<i>Ptychagnostus praecurrens</i>	limbs	*			7.2
Walcott Quarry BW	98-821	65023	ab	-210	<i>Ptychagnostus praecurrens</i>	limbs?			5.1	10.9
Walcott Quarry BW	98-881	65024	ab	-150	<i>Ptychagnostus praecurrens</i>	?			4.5	9.6
Walcott Quarry BW	98-895	65025	ab	-210	<i>Ptychagnostus praecurrens</i>	internal tissue?				
Walcott Quarry BW	98-904	65026	ab	-150	<i>Ptychagnostus praecurrens</i>	?				
Walcott Quarry WQ	94-1564	65027	ab	10	<i>Ptychagnostus praecurrens</i>	cephalic and trunk limbs; diverticulae	**	SI		7.7

References (in addition to those in main text)

- Ahlberg, P. (1988). Ocular structures in an Ordovician agnostid trilobite. *Lethaia*, 21(2), 115-120.
- Babcock, L. E., Peng, S., & Ahlberg, P. (2017). Cambrian trilobite biostratigraphy and its role in developing an integrated history of the Earth system. *Lethaia*, 50(3), 381-399.
- Boxshall, G. A. (2004). The evolution of arthropod limbs. *Biological Reviews*, 79(2), 253-300.
- Briggs, D. E., Siveter, D. J., Siveter, D. J., Sutton, M. D., Garwood, R. J., & Legg, D. (2012). Silurian horseshoe crab illuminates the evolution of arthropod limbs. *Proceedings of the National Academy of Sciences*, 109(39), 15702-15705.
- Cederström, P., Ahlberg, P., Clarkson, E. N., Nilsson, C. H., & Axheimer, N. (2009). The lower Cambrian eodiscoid trilobite *Calodiscus lobatus* from Sweden: morphology, ontogeny and distribution. *Palaeontology*, 52(3), 491-539.
- Dai, T., & Zhang, X. (2013). Morphology and ontogeny of the eodiscoid trilobite *Sinodiscus changyangensis* from the lower Cambrian of South China. *Palaeontology*, 56(2), 411-420.
- Edgecombe, G. D., & Ramsköld, L. (1999). Relationships of Cambrian Arachnata and the systematic position of Trilobita. *Journal of Paleontology*, 73(2), 263-287.
- Haug, J. T., Waloszek, D., Haug, C., & Maas, A. (2010). High-level phylogenetic analysis using developmental sequences: The Cambrian† *Martinsonia elongata*, † *Musacaris gerdgeyeri* gen. et sp. nov. and their position in early crustacean evolution. *Arthropod Structure & Development*, 39(2-3), 154-173.
- Hughes, N. C., Minelli, A., & Fusco, G. (2006). The ontogeny of trilobite segmentation: a comparative approach. *Paleobiology*, 32(4), 602-627.
- Jell, P.A. (1975). Australian Middle Cambrian Eodiscoids with a review of the superfamily. *Palaeontographica Abteilung A*. 150, 1-97.
- Lamsdell, J. C. (2013). Revised systematics of Palaeozoic 'horseshoe crabs' and the myth of monophyletic Xiphosura. *Zoological Journal of the Linnean Society*, 167(1), 1-27.
- Lamsdell, J. C., Stein, M., & Selden, P. A. (2013). *Kodymirus* and the case for convergence of raptorial appendages in Cambrian arthropods. *Naturwissenschaften*, 100(9), 811-825.
- Minter, N. J., Mángano, M. G., & Caron, J. B. (2012). Skimming the surface with Burgess Shale arthropod locomotion. *Proc. R. Soc. B*, 279(1733), 1613-1620.
- Moore, R. A., Briggs, D. E., & Bartels, C. (2008). The arthropod *Bundenbachiellus giganteus* from the Lower Devonian Hunsrück Slate, Germany. *Paläontologische Zeitschrift*, 82(1), 31-39.
- Naimark, E. B. (2007). Comparative ontogeny of different species of agnostina. *Paleontological Journal*, 41(1), 69-78.
- Ortega-Hernández, J. (2015). Homology of head sclerites in Burgess Shale euarthropods. *Current Biology*, 25(12), 1625-1631.

- Ortega-Hernández, J. (2016). Making sense of 'lower' and 'upper' stem-group Euarthropoda, with comments on the strict use of the name Arthropoda von Siebold, 1848. *Biological Reviews*, 91(1), 255-273.
- Ortega-Hernández, J., & Brena, C. (2012). Ancestral patterning of tergite formation in a centipede suggests derived mode of trunk segmentation in trilobites. *PLoS One*, 7(12), e52623.
- Ortega-Hernández, J., Janssen, R., & Budd, G. E. (2017). Origin and evolution of the panarthropod head—A palaeobiological and developmental perspective. *Arthropod structure & development*, 46(3), 354-379.
- Stürmer, W., & Bergström, J. (1978). The arthropod *Cheloniellon* from the Devonian Hunsrück Shale. *Paläontologische Zeitschrift*, 52(1-2), 57-81.
- Sutton, M. D., Briggs, D. E., Siveter, D. J., Siveter, D. J., & Orr, P. J. (2002). The arthropod *Offacolus kingi* (Chelicerata) from the Silurian of Herefordshire, England: computer based morphological reconstructions and phylogenetic affinities. *Proceedings of the Royal Society of London B: Biological Sciences*, 269(1497), 1195-1203.
- Waloszek, D., Maas, A., Chen, J., & Stein, M. (2007). Evolution of cephalic feeding structures and the phylogeny of Arthropoda. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 254(1-2), 273-287.
- Whittington, H. B. (1971). Redescription of *Marrella splendens* (Trilobitoidea) from the Burgess Shale, Middle Cambrian, British Columbia. *Geological Survey of Canada, Bulletin*, 209, 1-24.