Development and trunk segmentation of early instars of a ptychopariid trilobite from Cambrian Stage 5 of China

Cen Shen¹,², Euan N. K. Clarkson³, Jie Yang¹, Tian Lan¹, Jin-bo Hou¹ & Xi-guang Zhang¹

¹Key Laboratory for Palaeobiology, Yunnan University, Kunming, Yunnan 650091, China, ²Faculty of Land Resources Engineering, Kunming University of Science and Technology, Kunming, Yunnan 650091, China, ³School of Geosciences, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, UK.

Many three-dimensionally preserved exoskeletons found from the middle Cambrian (Stage 5) Gaotai Formation in Guizhou, southern China, have been assigned to the ptychopariid trilobite Gunnia sp. They represent mainly a series of early instars, exhibiting some delicate structures and morphological variation associated with their trunk segmentation and early development. Morphometric and statistical analyses indicate that the transverse joint appears to occur with the full growth of the third axial ring of the protopygidium, which increases in size much more rapidly than its corresponding protocephalon with growth. The ‘one by one’ sequential release of thoracic segments from a transitory pygidium does not progress exactly in accordance with the development of the pygidial axis, whose axial rings increase at a relatively faster rate, and an ‘immature ring’ always appears initially at the rear end of the axis. These new data set up a testable model for revealing trilobite segmentation and provide fresh insights into the development, evolution and taphonomic surroundings associated with the Cambrian trilobites.

Trilobites are well known for their excellent fossil record and are widespread in the Palaeozoic deposits. As a stem arthropod group, abundant and highly diversified trilobites have long been a major focus of evolutionary and palaeobiological studies. In particular, researches on trilobite ontogeny, moulting process and the body segmentation have recently attracted attention.

Usually fossil trilobites are found directly on the surface of crack-out blocks of rock, and sometimes complete trilobites can be found, each of which may have all the components of the dorsal exoskeletons articulated one with another. Such exceptional material can clearly show the essential features of trunk segmentation, defined by the articulation(s). For trilobite ontogeny, the exact number of the articulations is conventionally regarded as direct evidence for the subdivision of the meraspid period (stages between the larval protaspid and the adult holaspis) into a series of degrees. However, this approach is often hindered by scarcity of material, especially where minute early instars are lacking. Trilobite fossils can also be obtained through acid dissolution of certain calcareous rocks. Without exception, the silicified or phosphatized specimens in the collection are always small and most of them are isolated skeletons of early instars; partially or fully articulated skeletons are rare. Nevertheless, acid liberated trilobites have also been used for ontogenetic studies, in which a series of growth stages, or meraspides of various degrees, have been established by taking advantage of morphometric and statistical analyses, as normally depending on a large number of specimens. Theoretically, any demonstration or conclusion resulting from such an analysis is reasonable, but not absolutely convincing unless the theoretical information can be directly compared with that measured from articulated individuals of the same taxon.

In this study the three dimensionally preserved exoskeletons assigned to the ptychopariid trilobite Gunnia sp. have enabled a detailed investigation to be undertaken on the post-embryonic development, in particular on some otherwise poorly understood aspects of the development of the early instars, including striking details of trunk segmentation with growth. Significantly, the superb material can provide convincing details for more precisely establishing how the development of the thorax, associated with segmentation took place.

Results

Geological setting and Material. All trilobites dealt with in this study were recovered from light grey or yellowish limestone nodules from the middle Cambrian (Stage 5) Gaotai Formation at an outcrop (107°36′55.73″E, 26°15′4.57″N) near Balang village in Duyun, Guizhou, China (for locality details, see fig. 1 in Ref. 11 and for
outcrop details, see fig. DR1 in Ref. 12). Apart from these trilobites there are numerous lingulate brachiopod valves, various small shelly fossils, some bradoriid carapaces, rare scalidophoran embryos, and many exoskeletons of the eodiscoid trilobite Pagetides qianensis, which as a key index fossil, confirms the geological age for this fossil assemblage. In addition, many ‘trace fossils’, in the form of small-sized coprolites of unknown affinity have also been collected from the same bed.

Of these isolated trilobite exoskeletons the majority are protaspides (Fig. 1a–i) and meraspides (Figs. 2a–i, 3a–m) of Gunnia sp., only a few holaspid cranidia (Fig. 2j) and pygidia (Fig. 3n) that have been tentatively assigned to this species have been directly identified from the crack-out specimens—the limestone nodules coming from the same horizon within the Balang outcrop.

Many other trilobite exoskeletons (including more than thirty protaspides), with notable variation in overall outline of their dorsal shields and the marginal spinosity, probably come from four separate taxa of uncertain affinity (Fig. 4a–l), of which only one group with unique glabellar and protopygidial features has been firmly identified as consisting of early instars related to some co-occurring corynexochid meraspides and holaspides (Fig. 4g–l).

94 isolated exoskeletons and 15 crack-out specimens of Gunnia sp. (including 31 protaspides, 30 cephalic and cranidia, 39 pygidia, 4 thoracic segments and 5 librigenae), and 12 protaspis or meraspis exoskeletons of affinity uncertain were used for this study. Because of incomplete preservation 27 specimens were registered (YKLP 12109–12135) but were unable to be measured for the construction of bivariate plots. All these trilobites (121 in total) are deposited in the collections of the Key Laboratory for Palaeobiology, Yunnan University in Kunming, China.

**Systematic palaeontology.** The trilobite descriptive terminology used here follows that of Chatterton and Speyer, Whittington, Hughes et al., and Zhang and Clarkson.

*Class Trilobita Walch, 1771*

*Order Ptychopariida Swinnerton, 1915*

*Family Ptychopariidae Matthew, 1887*

*Genus* Gunnia Gatehouse, 1968

**Type species.** Gunnia lutea Gatehouse, 1968 from the Middle Cambrian Tindall Limestone, Litchfield, Northern Territory, Australia.

**Diagnosis.** A genus of Ptychopariidae with a faint eye ridge. Glabella truncate-conical, with 3–4 pairs of weakly incised lateral furrows. Preocular field and preglabellar field almost equal in length (sag., exs.). Eye ridge slightly oblique and curving rearwards; mediumsized palpebral lobe relatively located in the middle or posterior of the glabella. Anterior branch of facial suture runs evenly outwards to a rounded inflection. Thorax of 14 segments.

**Remarks.** Gunnia was established by Gatehouse in 1968 but because it is a rare trilobite its taxonomic position within Ptychopariidae has been a subject of much debate for a long time. With such rare occurrence in Cambrian strata, and since it is distributed only in geographically limited areas, this ptychopariid trilobite has been regarded as an ‘endemic’ taxon. Subsequently, in a major revision some specimens previously assigned to other ptychopariid taxa from...
southern China as well as further material lately discovered from the Indian Himalaya, were all referred to this genus. Until now, many holaspid cranidia, pygidia and librigenae of *Gunnia* have been described from strata of Cambrian Series 2 (Stage 4) or Series 3 (Stage 5) in Australia, southern China, and India. Recently this genus has become even ‘popular’ with some species formerly assigned to *Ellotia* and *Yiliangaspis* being regarded as junior synonyms of *Gunnia*.

It seems apparent that *Gunnia* exhibits a good number of distinguishable characters of its own, and accordingly here we follow Kruse and Peng et al. in leaving it at generic rank. *Gunnia* sp.

Type locality and horizon. Cambrian Stage 5 Gaotai Formation at the Balang outcrop in Duyun, Guizhou, southern China.

Description. Cranidium (Fig. 2j) with anterior margin slightly arched forward. Anterior border convex; anterior furrow deep and broad. Glabella truncate-conical and strongly inflated, with three pairs of faint lateral furrows (S1–S3). Occipital ring semi-elliptical; occipital furrow nearly straight, but much more deeply incised laterally. Preglabellar field broad, with the same length (sag.) as the preocular field. Eye ridges prominent, slightly curving posteriorly, connected to palpebral lobes. Librigena (Fig. 2k, l) bearing broad genal spine, wide lateral border, and gently impressed lateral border furrow. Doublure broad underneath lateral border and genal spine, ornamented with faint ridges. Thoracic segment (Fig. 2m, n) elongated, with distinctly impressed pleural furrow. It is connected to adjacent parts of the exoskeleton via a ‘Line articulation’, with its free part bent postero-laterally. In ventral view, doublure developed beneath articulating half ring and free extremity. Pygidium (Fig. 3n) semi-circular in outline with smooth curved posterior margin. Axis prominently convex, bearing at least 7 rings, clearly defined by transverse furrows. Anterior margin slightly inflected laterally and

Figure 2 | Cephalon (or cranidia), librigenae and thoracic segments of *Gunnia* sp. from Cambrian Stage 5 Duyun fauna. (a–c) YKLP 12034, degree 0 meraspis (M0), cephalon with a pair of broad genal spines, articulated with its transitory pygidium, which displays three axial rings: (a) oblique latero-dorsal view; (b) oblique postero-dorsal view, showing the secondary coating (white arrowed) and the first transverse joint (black arrowed); (c) dorsal view. (d) YKLP 12035, cephalon of meraspis degree 0 (M0), ventral view; (e) YKLP 12036, cephalon of meraspis degree 1 (M1), dorsal view; (f) YKLP 12037, cranidium of meraspis degree 3 (M3) with fine granules on the outer surface, dorsal views. (g) YKLP 12038, fragmentary cranidium of meraspis degree 4 (M4), ventral view, showing the broad right genal spine with partially survived doublure along the posterior margin. (h) YKLP 12039, cranidium of meraspis, clearly showing deep occipital furrow and three glabellar furrows (arrowed). (i), (j) crack-out cranidia, dorsal views: (i) YKLP 12040, late maraspis showing partially preserved palpebral lobe; (j) YKLP 12041, early holaspis showing well-preserved impressions of three paired glabellar furrows. (k), (l) Librigena of *Gunnia* sp.: (k) YKLP 12042, ventral view; (l) YKLP 12043, dorsal view, showing fine granules on the surface. (m) YKLP 12044, dorsal view, right half of a meraspis thoracic segment; (n) YKLP 12045, ventral view, right half of a holaspid thoracic segment. Scale bars for (a–h) 300 μm; for (i), (j) 1 mm; for (k–n) 200 μm.
backwards. Pleural region convex with four pairs of pleural furrows faintly impressed. Border evenly arched and defined by faint border furrow.

**Ontogeny.** 109 specimens assigned to *Gunnia* sp. mainly consist of instars of various early growth stages and degrees. Most of them are disarticulated exoskeletons; only a few cranidia (Fig. 2i, j) and pygidia (Fig. 3n) were directly identified from the matrix. In the bivariate plots (Fig. 5) it is clearly shown that the size ranges provide no conclusive indications for assignment of these specimens to a certain meraspid degree or holaspid stage, although the cephalon or cranidia display a relatively wide size range with growth (Fig. 5a). Nevertheless, many isolated pygidia in our collection display a remarkable variation in their axial rings, which as careful examination has revealed, increased with growth in a traditionally recognized way. Possibly so did the protaspides, since the axis of their protopygidia bearing no axial ring or only one has been recognized. Thus based on the development of the trunk segmentation, as well as the variation in size and morphology of these exoskeletons, we can firmly refer some of them into instars belonging to a few stages and degrees, and provide a detailed, though incomplete description of the development process starting with the earliest representatives hitherto known—the protaspides, as follows.

**Protaspis period.** The 31 protaspides referred to *Gunnia* sp. show overall morphological similarities: a subrounded, moderately convex dorsal shield, poorly elevated glabella, faint axial furrows and distinct occipital ring. However, the protopygidial axis is weakly developed, displaying no axial ring (Fig. 1a–c) or only one (Fig. 1d–i). As with a transitory pygidium, more rings would be added to the protopygi-
medium with growth, thus the number of axial rings has also been applied as a criterion for the division of protaspid instars here, and the axial segment-based division of protaspid stages is fundamentally in accordance with that for the division of either meraspid degrees or holaspid stages.

There is a distinct ‘gap’ between the protopygidium with one axial ring and the meraspid degree 0 pygidium (Fig. 5b). That is, the gap may therefore just indicate an absence of some supposed protaspides (P3), of which each protopygidium bears two axial rings. As a result during the protaspid period the protopygidium would increase in size much faster than the corresponding protocephalon. Given this essential feature relevant to the axial variation of these early instars, our detailed investigation mainly focusing on protopygidia, has offered fresh data for a better understanding of the early development of this ptychopariid trilobite.

Meraspid period. Dorsal shields assigned to this developmental period, except one with an articulated cephalon and pygidium (Fig. 2a–c), are all isolated cephalia (or cranidia) (Fig. 2d–h), thoracic segments (Fig. 2m, n) and pygidia (Fig. 3a–m). It should be noted that without direct evidence from additional articulated exoskeletons the exact position these disarticulated sclerites represent within the developmental process is hard to determine, especially for cranidia. However, as based on inference from the analysis of sclerite articulation and axial segmentation on a transitory pygidium, some early meraspid pygidia may be tentatively differentiated into a series of degrees (Fig. 5b). Moreover, for isolated cephalia (or cranidia) the assignment mostly relies upon their sizes, as focusing on a comparison of the length of the posterior margin between the genal spines with that of the anterior margin of a pygidium, the approximate equality in the length of the margins indicates that corresponding exoskeletons belong to the same meraspid degree.

We identify the only articulated specimen (Fig. 2a–c) as meraspid degree 0 for three reasons: (i) this specimen has clearly displayed three fully-grown axial rings behind the occipital rings. As demonstrated in this study, with the appearance of the fourth axial ring the first thoracic segment would be released from a late meraspid degree 0 pygidium, which then becoming an early meraspid degree 1 pygi-
Figure 5 | Bivariate plot diagrams of Gunnia sp. All measured specimens represented by fine points either in (a) or (b) show an approximately isometric growth pattern, with some figured specimens labeled (e.g., 2a representing Fig. 2a; 3n representing Fig. 3n, etc.). (a) 41 cephalas and cranidia (including 19 protocephala). The boundary for Protaspid/Meraspid is defined by early instar specimens dealt with here; without enough material, the boundary in (b) for Meraspid/Holaspid is determined by matching the width of the posterior margin of a cranidium to that of a pygidium situated near the boundary. (b) 53 pygidia (including 19 protopygidia). The growth ratio (1.15) is determined by measuring all of early meraspides, and then this ratio is applied to the division of succeeding meraspid degrees and holaspid stages. The number in the slope line indicates the visible axial rings of a pygidium correspondingly. The original measurement of all specimens applied for making this figure can be found from Supplementary Tables S1 and S2 in the online version.
Ian type. Because to date no visual structure has been determined from a protaspis of this species, it seems certain that with growth the librigenae increase in size remarkably from the meraspid period onwards, and for some early meraspides the initially developed librigenae should be very small and antero-laterally situated. Thus the posterior section of the facial sutures is unlikely to reach the posterior border of the cephalon, since it bears a pair of strong genal spines. Instead, the facial suture may only cut through the lateral border, and in this case the facial suture of these early instars should represent the opisthoparian condition. In other words, the facial suture would shift from the lateral border to the posterior border with subsequent growth. Nonetheless, this is not conclusive because the inference is based on observation of limited number of holaspid cranidia and librigenae, and how the transfer happened remains obscure. An alternative explanation is that the doublure attached to either lateral margin of some protaspides (Fig. 1d–f) might actually be the undeveloped librigena, which, however, bears only the ventral half of the genal spine, and may be completely lost along the facial suture (Fig. 1g). Additional material is required to verify the hypothesis, in particular, how such a “half” genal spine become fully developed with growth.

**Segmentation.** The superb trilobite exoskeletons from the Duyun fauna clearly show how segmentation occurred with growth.

**Release of thoracic segments.** Traditionally it seems apparent that with the appearance of a visible axial ring terminally added to the axis, a new transverse joint started to develop in the transitory pygidium. This finally would lead to the formation of a new thoracic segment. Such a mode of meraspid development (anamorphosis) has long been recognized and conventionally applied to ontogenetic studies on many trilobite lineages, including the psycho-pariid *Gunnia* sp. herein.

As demonstrated here the protopygidium of the latest protaspides (P2) so far known bears only one axial ring behind the occipital ring (Fig. 1d–i), whereas the earliest meraspid (M0) in our collection displays three axial rings (Fig. 2a–c). Most likely, this indicates that instars belonging to protaspis stage (P3) have not been obtained; these should bear two pygidal axial rings. During subsequent development with the appearance of the third ring, the protopygidium would start to separate from the protocephalon through the first transverse joint in the exoskeleton, in the process of becoming meraspid degree 0 (M0a). Accordingly, some of the smallest transitory pygidia representing this degree do show three axial rings (Figs. 2a–c, 3a), and with the appearance of the fourth ring the first thoracic segment would start to release from the meraspis pygidium, which then became an early meraspid degree 1 instar displaying also three axial rings (Fig. 3d). In this way these isolated transitory pygidia with three axial rings are representatives of two meraspis degrees (M0, M1), of which the larger one exhibits well elevated axial rings (Fig. 3d). Likewise, pygidia of subsequent instars with four, five, or six axial rings display also three axial rings (Fig. 3a). As demonstrated here, at least some early instars (protaspides) of *Gunnia* sp., have had minute terrace lines well-developed on their lateral doublures during ontogeny. By considering the alternative hypothesis of mechanical function previously proposed, we have no additional evidence to verify whether the fine terrace lines may have played a role as a current monitor or just simply increased friction for some sort of movement, especially since the terrace lines are so fine and only appear on the narrow surface of the doublure. Curiously such fine lines appear to vanish with subsequent growth, since none has been found on the doublure of either the cephalon or pygidium of a meraspid or holaspid (e.g. Figs. 2d, 3m). Nevertheless, as the first record of this kind of fine structure found in trilobite protaspides, it is potentially significant for understanding the function of the terrace lines associated with the mode of life for this ptychopariid trilobite.

At the first glimpse, the terrace lines on both lateral doublures appear to be bilaterally symmetrical. However a close view reveals that the pattern of fine ridges on the right surface of the doublure is not exactly the same as that on the left (Fig. 1d). That is, it is an example of bilateral, or pseudo-bilateral asymmetry.

**Facial sutures.** It is generally accepted that the facial sutures played an important role during ecdysis in many trilobites, but in phacopids the facial suture was nonfunctional in the adult stages while it was useful in earlier stages of its development. There is no sign of a facial suture or librigenae in any of the protaspides of *Gunnia* sp., nor even for some early meraspides (Fig. 2a–c). During the subsequent meraspis development onwards, the facial suture, which outlines the inner edge of the missing librigenae along both lateral margins has been determined from some meraspid cranidia (Fig. 2f–h). It seems certain that the junction line between cephalon and thorax (or pygidium) became functional earlier in moulting during the early development phase than the facial suture became obvious. This indicates that with or without the facial suture, there may be two different ways of moulting for some meraspis instars of *Gunnia* sp. This phenomenon has also been observed in the ontogeny of Protopygidae.
Based on all measured early meraspides the growth rate for these instars is about 1.15. Accordingly, this ratio is applied to define the subsequent meraspid degrees and holaspid stages. The expressing mode of development and abbreviations mainly following Hughes et al.\textsuperscript{14}. 

**Figure 6 | Trunk segmentation schedules of *Gunnia* sp.** Based on all measured early meraspides the growth rate for these instars is about 1.15. Accordingly, this ratio is applied to define the subsequent meraspid degrees and holaspid stages. The expressing mode of development and abbreviations mainly following Hughes et al.\textsuperscript{14}. 

---

*R: Scientific Reports*
axial rings are also of the same development pattern. That is, pygidia with four axial rings correspond to meraspid degree 2 (M2) and degree 3 (M3); pygidia with five axial rings correspond to meraspid degree 4 (M4) and degree 5 (M5). The regular pattern is well confirmed by the bivariate plots (Fig. 5b). However, the distribution is not exactly defined by size, sometimes pygidia with a different number of axial rings overlap or are irregularly scattered (e.g., Fig. 3l, 3m). One interpretation is that a newly added axial ring at the beginning is always so tiny that is too difficult to firmly determine whether, to count it or not to count immediately leads two separate results. Perhaps the releasing process may have changed its pattern to some extent in later meraspid growth. To date we have no exact idea how the segment-releasing model would transfer from up to a maximum of three axial rings to four, five and six. Such a transference must happen because a typical holaspide pygidium bears seven axial rings (Fig. 3n).

In summary some meraspides instars may have no thoracic segments released with growth, but the number of axial rings of the meraspide pygidium would increase constantly. In other words, meraspid degrees did not necessarily correspond to meraspid instars27. Here, as with the protopygidium of a protaspis, the transitory pygidium of Gunnia sp. also exhibits a marked increase of axial segments stages before the thorax is completed. In a previous study a similar growth schedule determined from Shumardia (Conophrys) salopiensis has been illustrated28.

Discussion

Most protaspides reported here, including those of Gunnia sp., are in general comparable to some adult-like protaspide larvae described by Speyer and Chatterton29, and most likely to have adopted a benthic mode of life. This is in accordance with the co-occurrence of these trilobite larvae together with some of their subsequent instars, including some holaspides (Fig. 4). In addition, the taphonomic features may infer an intricate surrounding environment, where numerous skeletal animal remains coexisting with rare scalidophoran embryos in Orsten-type preservation were assumed to have been buried in situ, or at least had not suffered long-distance transportation31.

Like other known trilobites, the head of Gunnia sp. displays a constant number of five segments throughout ontogenetic process. In contrast, its meraspide pygidia vary greatly in size, morphology and the axial rings as reported here. Some basic features associated with their development are recognized: (i) With growth the axis of early meraspide pygidia would increase stably from three to seven rings, and instars with the same number of rings are roughly scattered into clusters (Fig. 5b). However, the size plots alone cannot exactly divide all instars into a series of growth degrees, since instars belonging to two adjacent degrees may overlap with each other. As our measurements indicate pygidia with three axial rings display a size range from 0.47 to 0.53 mm in width, which represents a size increasing ratio of 1.13. It should be pointed out that the ratio may increase but will not reduce with new discoveries of additional material, since the newly obtained specimens, either smaller or larger, can only increase the size range. Likewise, pygidia with four, five and six axial rings the measured size increasing ratios are 1.35, 1.42 and 1.50 respectively. Even if the average ratio would be 1.35, some of the specimens that measured size increasing ratios are 1.35, 1.42 and 1.50 respectively.

Figure 7 | Development and trunk segmentation of Gunnia sp. The increase of pygidial rings is faster than that of thoracic segments, so that a later meraspide may bear more axial rings than the preceding one(s). Thoracic segment appears to occur in a punctuated manner, but the growth of an axial ring is a continuing process, first emerging as a tiny or even nearly invisible ‘immature ring’ to link two adjacent meraspid degrees.

Phosphatization, as a unique process, has provided the highest fidelity of detail for various fossilized organisms, and has opened...
up a special window for us to look into an unexpected microworld. As examples some micron scale setae or setulae and spine pores and lenses of compound eyes have been well illustrated. Moreover, as clearly shown here the continuing development of an axial ring terminally added to the axis could be traced through a series of forms from a tiny one (which might be too minute to see) to a fully developed ring. However, the ontogenetic stages and degrees of a trilobite taxon are conventionally divided into a series of punctuated groups based on its axial segments. It should be noted, however, that stages or degrees are really artifacts, which are hardly able to measure precisely the developmental process of a trilobite taxon; possible minute variations, such as an "immature ring"—an axial ring in its halfway growth, linking two adjacent meraspid degrees are definitely recorded by the phosphatized material here (Figs. 3d, f, i, 7), but inevitably could be missed, especially when based on some crack-out material with only submillimetre or even millimetre scale resolution. Accordingly doubts about the reliability of impressions in the exoskeleton to be the only crucial criterion for evaluation of trunk segmentation have been raised, along with a new hypothesis about the epimorphic development adopted by Cambrian eodiscoid trilobites, but so far have attracted little attention. Nonetheless, the artificial subdivision of stages and degrees do no more than construct a frame, based on which we can demonstrate the continuing variation exhibited by a trilobite during its development.

It is worth noting that the Cambrian Stage 5 Duyun fauna has yielded variously diversified trilobite protaspides (Fig. 4) as demonstrated here, but to date for many of them little has been learned about the likely corresponding post-protaspis instars. On this ground the phylogenetic affinity for these early trilobite instars remain uncertain, although in previous study such acid-liberated ground the phylogenetic affinity for these early trilobite instars exhibited by a trilobite during its development.

frame, based on which we can demonstrate the continuing variation exhibited by a trilobite during its development.

Methods
By following the acid liberating procedure introduced by Shen et al., limestone nodules were digested in acetic acid of low concentration (5 per cent), and the insoluble residue was taken out of the acid solution every day (in summer) or every other day (in winter) depending on the seasonal fluctuation of temperature. Then all of the acid-liberated fossils were picked from the residue using a stereomicroscope.

The images of these fossils were taken (secondary electron: 10–20 kV) by using a scanning electron microscopy (model FEI Quanta 200), and digital images for fossils on the surface of crack-out specimens were captured by using a Leica M205C photomicroscope. All images were processed in Adobe Photoshop CS 4.

Acknowledgments
This study was supported by the National Natural Science Foundation of China (41272027, 41302012) and Ministry of Education of China (20110311100001). We thank M. Tian and H.-Q. Zhang for specimen preparation.

Author contributions
C.S. and X.G.Z. conceived the project; X.G.Z. arranged fieldwork; X.G.Z., C.S., E.N.K.C., J.Y., J.B.H. and T.L. conducted research; C.S. wrote the manuscript; X.G.Z. and E.N.K.C. revised and edited the manuscript.

Additional information
Supplementary information accompanies this paper at http://www.nature.com/scientificreports
Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Shen, C. et al. Development and trunk segmentation of early instars of a psycoparid trilobite from Cambrian Stage 5 of China. Sci. Rep. 4, 6970; DOI:10.1038/srep06970 (2014).

This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in the credit line; if the material is not included under the Creative Commons license, users will need to obtain permission from the license holder in order to reproduce the material. To view a copy of this license, visit http://creativecommons.org/licenses/by-nc-sa/4.0/