

Supplementary materials

Origin of ecdysis: fossil evidence from 535-million-year-old scalidophoran worms

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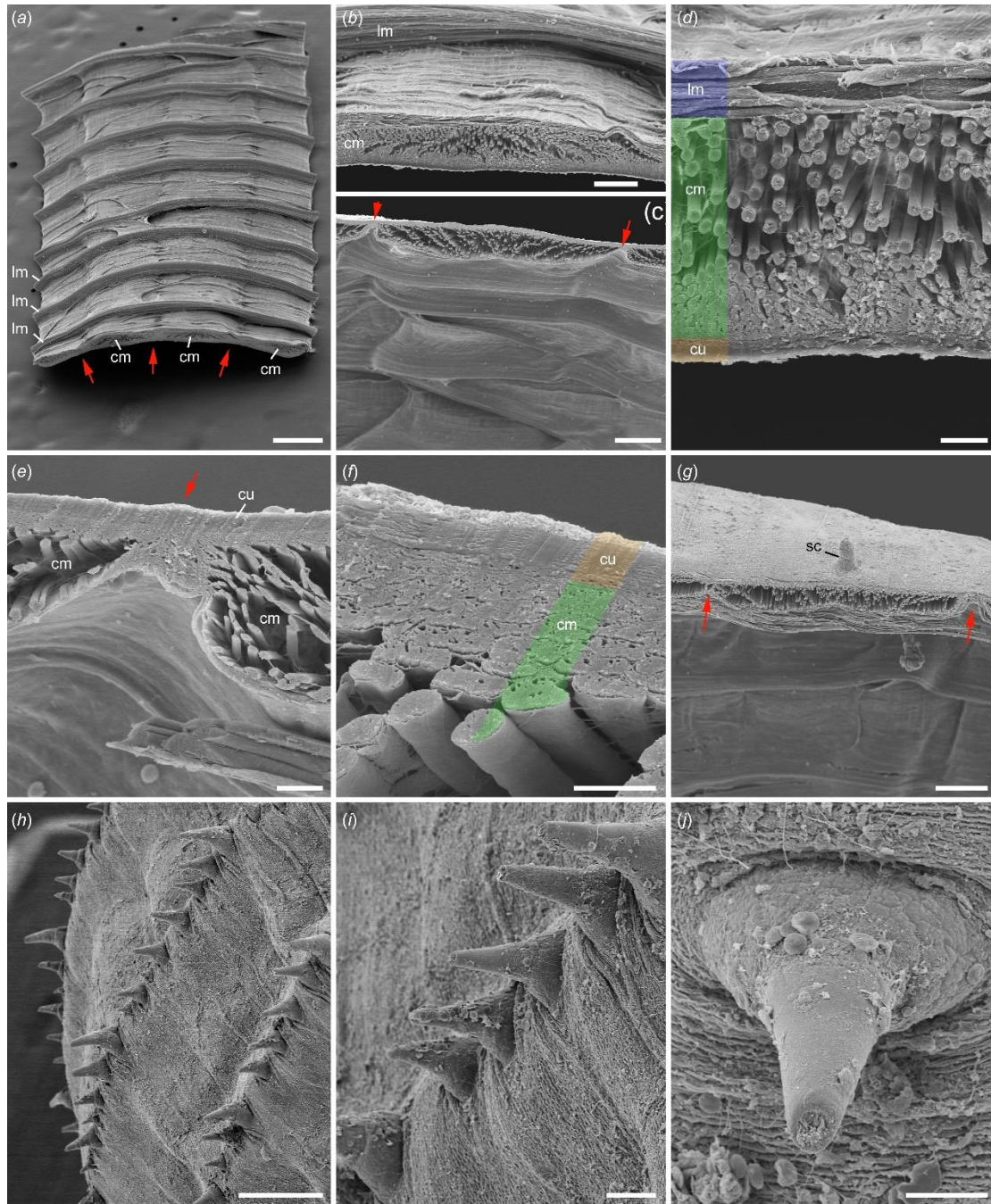


Figure S1. Cuticle and associated muscles in *Priapulus caudatus* (Priapulida) from Sweden [S1]. (a), fragment of body wall showing circular and longitudinal muscles. (b, c), transverse sections through circular muscles. (d), transverse section showing the cuticle (orange), circular (green) and longitudinal (blue) muscles. (e, f), transverse section showing details of chitinous cuticle and underlying muscle fibers. (g), transverse section near scalids. (h-j), scalids distributed in longitudinal rows along the proboscis and details of conical scalids. Red arrows represent boundaries between adjacent annuli. All SEM images. Abbreviations: cm, circular muscles; cu, cuticle; lm, longitudinal muscles; sc, scalids. Scale bars: 500 μm (a, h); 200 μm (c, g), 100 μm (b, i); 50 μm (j); 20 μm (d, e); 10 μm (f).

Species	References	Syst. position	Stratigraphy	Age	Preservation	Description
<i>Schistoscolex umbilictus</i>	[S2], fig.12b	Palaeoscolecida	Monastery Creek Fm.	Cambrian (Ser.3, St.5)	3D, phosphatized	Double layered cuticular structure
<i>Tabelliscolex hexagonus</i>	[S3], pl.1, fig.2a,b [S9], fig.1	Palaeoscolecida	Heilinpu Fm.	Cambrian (Ser.2, St.3)	BST (compression)	Strongly distorted cuticle
<i>Wronascolex antiquus</i>	[S10], fig.3d,e	Palaeoscolecida	Murero Fm.	Cambrian (Ser.3, St.5)	BST (compression)	Weakly expressed annulations; wrinkles
<i>Eximiprialulus globocaudatus</i>	[S5], figs 1-5	Priapulida	Heilinpu Fm.	Cambrian (Ser.2, St.3)	BST (compression)	Contracted/distorted shape; no internal organs
<i>Otoia prolifica</i>	[S11], fig.4	Priapulida	Burgess Shale Fm.	Cambrian (Ser.3, St.5)	BST (compression)	Body wall detached from cuticle; no internal organs
						proboscis incomplete
<i>Sirilorica pustulosa</i>	[S7], figs 6, 7	Loricifera	Buen Fm.	Cambrian (Ser.2, St.3)	BST (compression)	Molted individual emerging from lorica
Form D	[S8], fig.7.3	Scalidophora	Kuanchuanpu Fm.	Cambrian (Fortunian St.)	3D, phosphatized	Strongly distorted cuticle

Table S2. Cambrian scalidophoran worms with assumed exuviae. Abbreviations are as follows: BST, Burgess-Shale-type preservation; Fm, Formation; Ser., Series; St., Stage; 3D, three-dimensions.

S3. Morphological descriptions of the two indeterminate scalidophoran worms described in the present paper (see Figures 1, 3), both from the lowermost Cambrian Kuanchuanpu Formation, Shaanxi Province, China.

Scalidophora Lemburg, 1995

Indeterminate Form 1

2015 *Eokinorhynchus rarus*, Zhang et al., fig. 3h–i.

2015 Form I, Zhang et al., fig. 4a.

2018 Form B, Zhang et al., fig. 5.1–3.

2018 Indeterminate Form 1, Liu et al., fig. 9A–B.

Material. Twelve specimens: ELIXX86-112, ELIXX63-29, ELIXX94-84, ELIXX99-492, ELIXX40-125, ELIXX85-284, ELIXX90-221, ELIXX85-429, ELIXX57-467, ELIXX98-179, ELIXX78-205 and ELIXX85-16; all from Bed 2 [16] of the Lower Cambrian Kuanchuanpu Formation (Fortunian Stage, Terreneuvian Series) in the Zhangjiagou Section in Xixiang County, Shaanxi Province South China. ELIXX86-112, ELIXX63-29, ELIXX94-84, ELIXX99-492, ELIXX40-125, ELIXX85-284, ELIXX90-221, ELIXX85-429 and ELIXX85-16 display positive relief (PER; see explanation in text). ELIXX98-179, ELIXX78-205 and ELIXX57-467 display negative relief (NER see explanation in text).

Measurements. See Table S5.

Description. Annulated trunk fragments lined with small and large spinose sclerites. Small sclerites tightly juxtaposed around annuli, each with an expanded elliptical base and a spinose projection, not aligned in longitudinal columns but showing a staggered pattern. Large sclerites with the base extending over 3 or 4 annuli and bearing a stout spinose projection. Base of small and large sclerites and other cuticular areas with well-defined reticular ornament.

Comparisons. These specimens show overall similarities to the trunk of three scalidophoran species and one indeterminate form found in the same biota. They resemble *Eokinorhynchus rarus* in having closely packed small sclerites around annuli. However, the small sclerites of *E. rarus* have a sub-quadrangular basis and do not bear a spine. The trunk of *Qinscolex spinosus* has five large spinose sclerites whereas the present indeterminate form has only two such features. In Indeterminate Form 1 (this paper), the small spinose sclerites are in close contact with each other and have about the same length as the annulus, whereas they do not reach the annulus margin and are more widely spaced in *Shanscolex decorus*. Our specimens resemble “Form Ia” described by Zhang et al. 2015 in many respects (e.g. shape and distribution of sclerites). Both forms have large spinose sclerites that are three times wider than the small ones within a single annulus (Figure 1(g) and [S12] text-fig. 9A–B).

Orientation. Comparisons with complete specimens of scalidophoran worms from the Kuanchuanpu Formation [8, 12–14] allow us to determine the anterior-posterior polarity of the trunk

fragments of Indeterminate Form 1 (this paper). Sclerites project radially with their main axis pointing posteriorly.

Indeterminate Form 2

2018 Indeterminate Form 1 Liu et al., fig. 9C.

Materials. From the same bed as Indeterminate Form 1 (see above). ELIXX85-120 with negative external relief (NER; see explanation in text) from the same bed as Indeterminate Form 1 (see above).

Measurements. See Table S5.

Description. Single cylindrical trunk fragment with six annuli. Small, discrete spinose sclerites border each annulus, exhibiting a spoon-shaped base and a central conical spine; base about two-thirds as long as the annulus. Base of sclerites and other cuticular areas with well-defined reticular ornament. Fragment exhibits only one type of sclerite (small).

Comparison. This specimen resembles the trunk of *Qinscolex spinosus* and *Shanscolex decorus* in having well-separated sclerites along the annuli. However, its unusual spoon-shaped sclerites have no equivalent in *Q. spinosus* (rounded shape), *S. decorus* (narrow elliptical shape) or other scalidophorans from the Kuanchuanpu Formation, including Indeterminate Form 1 (this paper; see above), which exhibits large spinose sclerites. Although preserved in negative relief, this specimen closely resembles Indeterminate Form 1 described by Liu et al. 2018 ([12] text-fig. 9C).

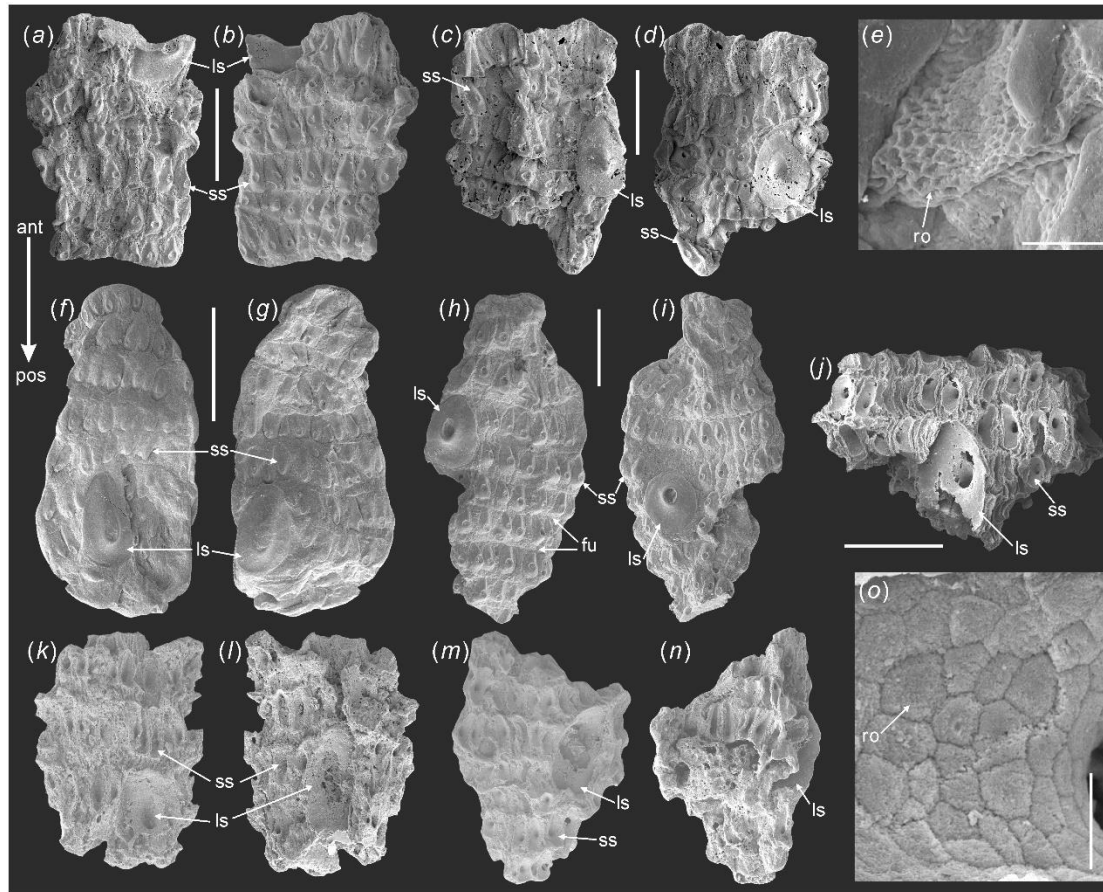


Figure S4. Indeterminate Form 1 (see description in S3) from the lowermost Cambrian Kuanchuanpu Formation, Shaanxi Province, China. (a-i) specimens showing positive external relief (PER; see explanation in text). (j-o) specimens showing negative external relief (NER; see explanation in text). (a, b), ELIXX85-284, general views from two opposite sides showing small and large sclerites. (c-e), ELIXX40-125, general views from two opposite sides showing small sclerites on annuli and a large sclerite and details of reticulated ornament along basal part of sclerite. (f, g), ELIXX94-84, general views from two opposite sides showing small and large sclerites. (h, i), ELIXX99-492, general views from two opposite sides showing small and large sclerites. (j, o), ELIXX78-205, wrinkled trunk fragments showing small and large sclerites and details of reticulated ornament along the basal part of the inner surface of a sclerite. (k, l), ELIXX57-467 general views from two opposite sides showing small and large sclerites. (m, n), ELIXX98-179, general views from two opposite sides showing small and large sclerites. All SEM images. Abbreviations: ant, anterior part; fu, furrow between annuli; ls, large spinose sclerite; pos, posterior part; ro, reticulated ornament; ss, small spinose sclerite. Scale bars: 500 µm (a-d), (f-n), 50 µm (e, o).

Species/Form	Coll. number	TRUNK			ANNULUS			SMALL SCLERITES				LARGE SCLERITES					ORNAMENT
		L (μm)	W (μm)	shape	L (μm)	nss/a	N	N (μm)	W (μm)	basis	arrangement	L (μm)	W (μm)	N	nas	basis	D (μm)
Indeterminate Form 1 (this paper)	ELIXX86-112	1636	680-750	flat	160-204	16-24	11	100-165	44-88	elliptical	closely packed	533-605	242-264	2	4	elliptical	4-11
	ELIXX63-291	1269	631-718	flat	185-222	16-20	10	130-218	74-111	elliptical	closely packed	255-377	188-236	2	3	elliptical	6-9
	ELIXX94-84	1441	603-695	flat	152-202	16-22	11	131-175	54-86	elliptical	separated	415-428	224-246	2	3	elliptical	8-12
	ELIXX99-492	2166	894-1061	flat	196-347	14-18	10	166-241	76-136	elliptical	separated	422-483	332	2	2-3	elliptical	9-12
	ELIXX40-125	1486	992-1039	flat	243-364	20-24	6	189-271	68-85	elliptical	closely packed	337-432	283-324	2	3	elliptical	12-16
	ELIXX85-284	1375	883-937	flat	175-287	14-22	7	100-287	62-100	elliptical	closely packed	nm	275	1	2	elliptical	nm
	ELIXX90-221	3015	953-987	cylindrical	178-321	16-20	14	107-285	71-108	elliptical	closely packed	250-464	nm	2	1-3	elliptical	5-10
	ELIXX85-429	1212	529-604	flat	227-302	8-10	6	182-242	76-91	elliptical	closely packed	530	302	1	3	elliptical	nm
	ELIXX57-467	1275	904-937	flat	287-352	16-18	4	212-275	63-100	elliptical	closely packed	462-562	337-375	2	2	elliptical	nm
	ELIXX78-205	833	1084-1169	crumpled	193-210	20-24	4	104-174	52-87	elliptical	closely packed	482	272	1	3	elliptical	6-13
	ELIXX98-179	1214	712-836	flat	143-210	12-18	7	110-164	52-67	elliptical	closely packed	442	222	2	3	elliptical	7-8
	ELIXX85-16	2018	367-702	flat	161-362	16-18	8	101-209	33-57	elliptical	closely packed	215	nm	2	2	elliptical	nm
	Indeterminate Form 2 (this paper)	ELIXX85-120	2742	1072-1494	cylindrical	426-491	20-24	6	168-354	58-137	spoon-shaped	separated	na	na	na	na	7-13
Form B sensu [S8]	NIGP 160438-41	607-1163	986-1527	flat	130-250	20-40	3-8	130-250	30-100	elliptical	close	500	340	1	4	elliptical	10-13
Form Ia sensu [S13]	XXDW 001	1421	1125-1314	flat	180-300	20-40	10	180	110	rectangular	close	330-410	390	3	2-3	elliptical	nm
<i>Eokinorhynchus rarus</i> sensu [S13]	NIGP 160400	756-1260	159-308	cylindrical	20-60	20-40	~20	32-100	23	rectangular	separated	180	90-190	15	2-3	elliptical	nm
<i>Qinscolex spinosus</i> sensu [S12]	UMCU14CHD 0618-006	1800	1130	crumpled	34-160	40-50	10	35-150	29-60	elliptical	separated	340	300	1	2	rounded	nm
<i>Shanscolex decorus</i> sensu [S12]	UMCU15CHD 0819-009	3250	1310	flat	143-428	22-24	12	70-300	56-100	rectangular	separated	434-480	360-480	5	2	elliptical/	nm
Indeterminate Form 1 sensu [S12]	UMCU16CHD 0102-001,002	1140-1340	1180-1300	flat	45-110	24-28	7-9	119-210	45-189	elliptical	close	380	314	2	2	rounded	nm
Indeterminate Form 2 sensu [S12]	UMCU16CHD 0306-003	1440	1440	flat	340	18-22	5	238	120	spoon-shaped	separated	na	na	na	na	na	nm

Table S5. Measurements of scalidophoran specimens described in the present paper and previous studies, all from the lowermost Kuanchuanpu Formation of China. D, diameter of ornamented pentagonal cell; L, length; n, number; Coll., Collections; na, not applicable; nas, number of annuli straddled by a large sclerite; nm, not measured due to poor preservation; nss/a, number of small sclerites per annulus; W, width.

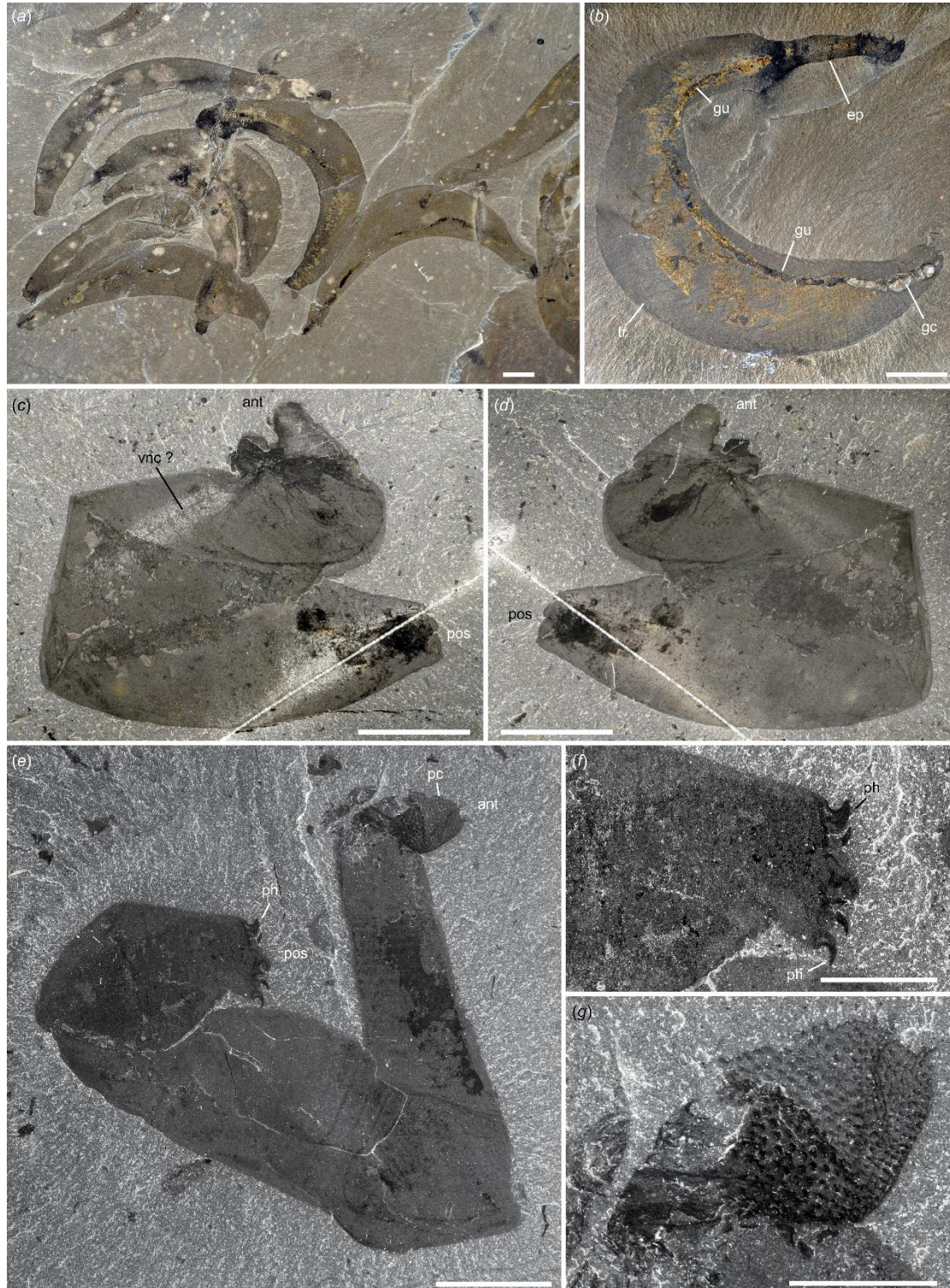


Figure S6. *Ottoia prolifica* from the middle Cambrian Burgess Shale, Canada. (a) ROMIP 61780, clustered specimens (body fossils). (b) ROMIP 61779 showing gut tract and gut contents (small brachiopods). (c) and (d) WQ94-0014, presumed exuvia, part and counterpart. (e) USNM 188637, presumed exuvia. (f) and (g) show close-ups of the anterior and posterior parts of the specimen shown in (e). All photographs in polarized light. Abbreviations: ant, anterior part of exuvia; ep, everted pharynx; gc, gut content (small brachiopods); gu, gut; pc, pharyngeal cuticle; ph, posterior hook; pos, posterior part of exuvia; tr, trunk; vnc?, ventral nerve chord?. Scale bars: 1cm (a-e), 5 mm (f, g).

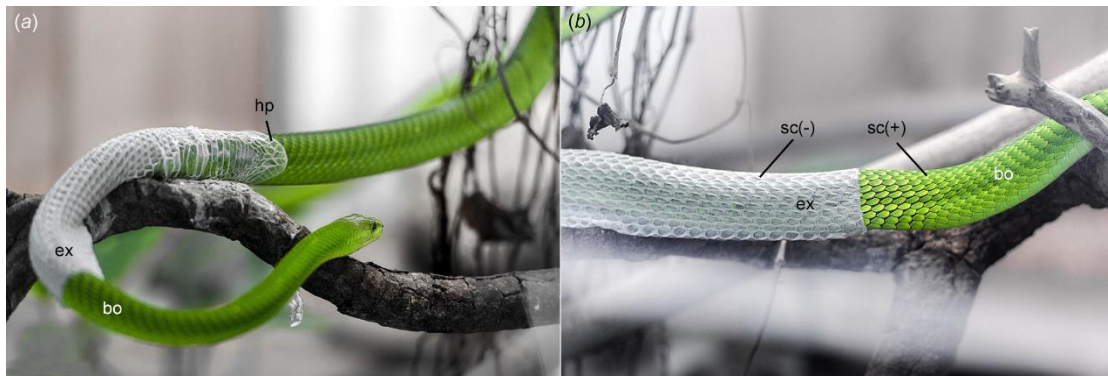


Figure S7. Moulting in a mamba snake. (a) Snake crawling out of its exuvia and turning it inside out. (b) The external surface of the exuvia shows a negative relief. Abbreviations: bo, body; ex, exuvia; hp, head part of exuvia; sc(+) and sc(-), scales with a positive (body) and negative relief (exuvia). Courtesy Julia Sundukova.

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