The Late Cambrian (Steptoean) trilobite genus *Bynumina* Resser, 1942, in North America

STEPHEN R. WESTROP, RAINA A. WASKIEWICZ &
JONATHAN M. ADRAIN

WESTROP, S.R., WASKIEWICZ, R.A. & ADRAIN, J.M., 2007:12:21. The Late Cambrian (Steptoean) trilobite genus *Bynumina* Resser, 1942, in North America. *Memoirs of the Association of Australasian Palaeontologists 34*, 357-376. ISSN 0810-8889.

Bynumina Resser, 1942, is the youngest representative of the family Kingstoniidae Kobayashi, 1933. The genus is defined by synapomorphies that include an unequally convex pygidial axis in which at least the first axial ring stands well above the level of the weakly arched posterior rings. It comprises six species, two of which are new; *B. kimbellorum* sp. nov., from the Honey Creek Formation of Oklahoma, is formally named. All species occur in a relatively narrow stratigraphic interval in the lower half of the upper Steptoean *Elvinia* Zone and have potential for biostratigraphic correlation.

Stephen R. Westrop (swestrop@ou.edu), Oklahoma Museum of Natural History and School of Geology and Geophysics, University of Oklahoma, Norman, Oklahoma 73072, USA; Raina A. Waskiewicz , School of Geology and Geophysics, University of Oklahoma, Norman, Oklahoma 73019, USA; Jonathan M. Adrain (jonathan.adrain@uiowa.edu), Department of Geoscience, University of Iowa, Iowa City, Iowa 52242, USA. Received 12 September 2007.

Keywords: Cambrian, Steptoean, Laurentia, Trilobita, Kingstoniidae, *Bynumina.*

THE GENUS *Bynumina* was established by Resser (1942) for small, effaced trilobites from south-eastern Missouri (see also Kurtz 1975), and has been reported subsequently from Pennsylvania (Wilson 1951), Nevada (Palmer 1960, 1965), Montana and Wyoming (Grant 1965), Indiana (Palmer 1982) and Arkansas (Hohensee & Stitt 1989). All occurrences are from the late Steptoean *Elvinia* Zone, where it may be locally abundant (Fig. 1). The genus is the youngest unequivocal representative of the Kingstoniidae Kobayashi, 1933, and is one of only two genera of the family known from Steptoean strata.

Discovery of abundant sclerites of *B. globosa* (Walcott, 1884) at two sites in Nevada, as well as a new species from Oklahoma, prompted this revision of *Bynumina* that includes restudy of type material from Missouri and Pennsylvania. The genus appears to have a relatively short stratigraphic range in the lower *Elvinia* Zone and has previously unrecognised biostratigraphic utility.

STRATIGRAPHIC SETTING OF NEW COLLECTIONS

Complete documentation of the stratigraphy and sedimentary facies of our study sites in the Great Basin and Oklahoma will be presented elsewhere, and only a brief summary is presented below. Among other occurrences, Kurtz (1975) published the most recent discussion of *Bynumina* in the Davis Formation of Missouri and included detailed lithologic logs of measured sections. Material described from drill core in southern Indiana (Palmer 1982) is also from strata that are assigned to the Davis Formation. The classic sources of information on the faunas and stratigraphy of the Ore Hill Member of the Gatesburg Formation in Pennsylvania are papers by Wilson (1951, 1952). Loch & Taylor (2004; see also Loch & Taylor 1995; Taylor *et al*. 1999) have presented some of the results of their work on the Ore Hill, including lithologic logs and trilobite range charts that show occurrences of *Bynumina*. The record of the genus from Arkansas is restricted to a single specimen in a shelf margin-derived debris flow in continental slope or basinal facies of the Collier Shale (Hohensee & Stitt 1989). Finally, *Bynumina* is known from only two cranidia from the Dry Creek Member of the Snowy Range Formation in Montana and Wyoming (Grant 1965).

Nevada

In Nevada, *Bynumina* occurs in strata that were assigned to the Corset Spring Shale by Palmer (1965). Hintze & Palmer (1975) treated the Corset Spring as one of five members of the Orr

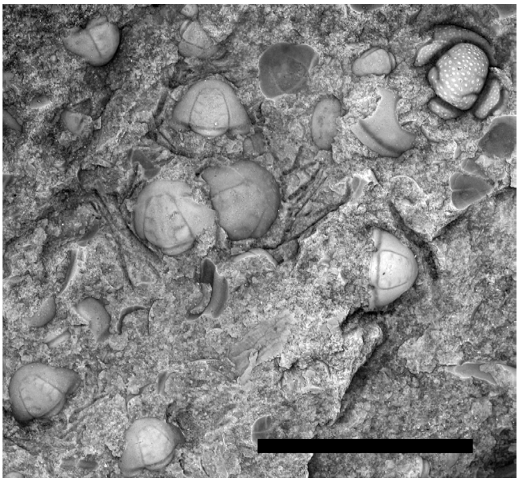


Fig. 1. Slab (USNM 108741) with numerous cranidia of *Bynumina caelata* Resser, 1942, part of which is figured by Resser (1942, pl. 10, fig. 26). Davis Formation, Flat River, Missouri. Scale bar = 1 cm.

Formation, a thick unit that encompassed the upper Marjuman-lower Sunwaptan succession of the northern House Range of west-central Utah. Here, the lower Steptoean shales and carbonates of the Candland Shale Member are succeeded by carbonates of the Johns Wash Limestone Member that are, in turn, overlain by the Corset Spring Shale Member. At the type section of the Orr Formation at Orr Ridge (Hintze & Palmer 1975; Westrop & Adrain unpublished data), limestone is a minor component of the shale-rich lower Corset Spring, but it becomes more abundant in the upper part of the member, which grades upward into the overlying carbonate-dominated Sneakover Member.

At our study sites in Nevada (Fig. 2), Patterson Pass and Shingle Pass (Palmer 1965, p. 95) in the Schell Creek and south Egan Ranges, respectively, the Orr Formation cannot be recognised, and the Corset Spring is a 33-50 m thick, recessive interval that punctuates a resistant, cliff-forming, upper Marjuman-Sunwaptan carbonate succession. Kellogg (1963) assigned the Marjuman-Steptoean carbonate interval to the Emigrant Springs Formation, although Palmer (1965, p. 95, pl. 22) identified the thick carbonates that underlie the Corset Spring as the Johns Wash Limestone. The cherty carbonates that overlie the Corset Spring have been referred to the Whipple Cave Formation (Taylor & Cook 1976). At both Patterson Pass and Shingle Pass, the intervals in the middle of the Corset Spring that yield *Bynumina* consist of stacked cycles that begin with thinly bedded bioclastic grainstone and rudstone with shaly partings that grade up into amalgamated units (up to 2.3 m thick) of cross-bedded bioclastic and oolitic pack-, grain- and rudstone. At Patterson Pass, the genus occurs at a single horizon (PP 292.5), 27 m above the base of the Corset Spring, and it was recovered from two collections that were 18.25 m and 18.6 m above the base of the unit at Shingle Pass.

Oklahoma

Bynumina was discovered in collections from exposures of the Honey Creek Formation on the Kimbell Ranch in the Slick Hills, which lie along the northern flanks of the Wichita Mountains (Fig. 2). The Kimbell Ranch locality is in the Blue Creek Canyon area that yielded some of the Steptoean trilobites that were collected by C.D. Walcott and described subsequently by Resser (1942). We measured, logged and sampled two overlapping sections on the northern (KR1) and western (KR2) sides of Ring Top Mountain (Fig. 2). *Bynumina* is common in a narrow stratigraphic interval located 42.25-42.75 m above the base of section KR2, and also occurs in the correlative interval in section KR1 (9.5 m above the base). At both sections, this part of the succession consists of interbedded glauconitic sandstone and glauconitic, bioclastic carbonates. Stitt (1977, p. 58; unit 4, 220-411 feet above the base of the section) assigned a correlative interval of this sandy facies at his Chandler Creek section (5.7 km south-east of KR2) to the Reagan Sandstone, which underlies the Honey Creek Formation. However, previous (e.g., Frederickson 1948a) and subsequent (e.g., Donovan 1986; McElmoyl & Donovan 2000) workers have placed the facies in the Honey Creek Formation, and their interpretation is followed here.

BIOSTRATIGRAPHIC SIGNIFICANCE

All previous studies (Wilson 1951; Palmer 1965, 1982; Grant 1965; Kurtz 1975; Hohensee & Stitt 1989) have described species of *Bynumina* from strata that have been assigned to the upper Steptoean *Elvinia* Zone. New records in Oklahoma and Nevada are also from this zone. Although it is a widely recognised biostratigraphic unit, the *Elvinia* Zone encompasses a thick stratigraphic interval, and previous work hints at the potential for a more finely divided zonal nomenclature. Using data from Texas and Oklahoma, respectively, both Wilson (1949) and Stitt (1977) suggested that a three-fold division of the zone might be possible (see also Loch & Taylor 2004 for a comparable approach to the succession in Pennsylvania). The oldest fauna of the *Elvinia* Zone in both regions includes such species as *Plataspella anatina* (Resser, 1942) and *Kindbladia wichitaensis* Resser, 1942, and is succeeded by assemblages that are characterised

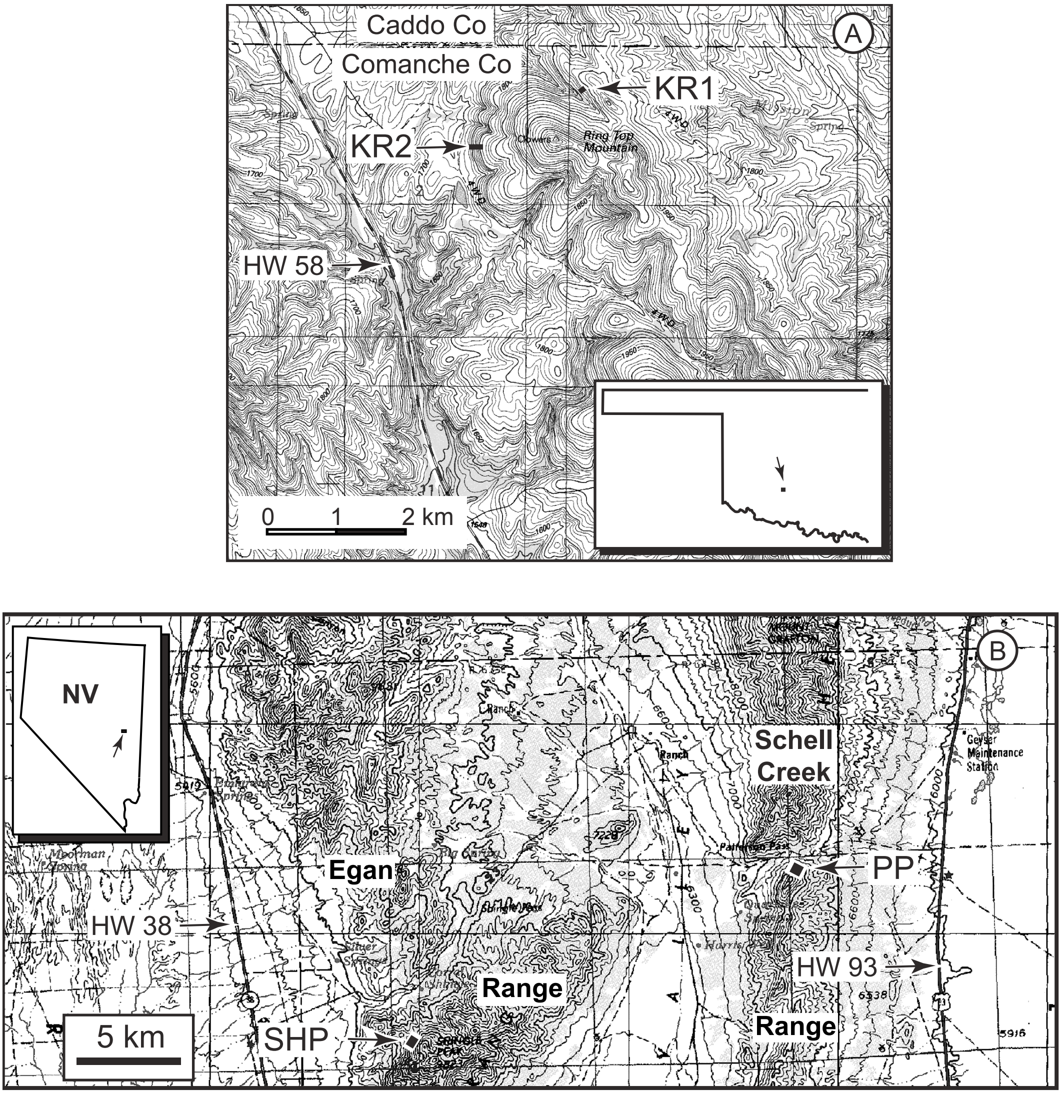


Fig. 2. Maps showing locations of measured sections that yielded collections of *Bynumina*. A, Ring Top Mountain, Kimbell Ranch, northern Comanche County, Oklahoma, sections KR1 and KR2. B, Shingle Pass, south Egan Range (SHP) and Patterson Pass, south Schell Creek Range (PP), Lincoln County, Nevada.

by species of *Camaraspis*, *Cliffia* and *Dellea*, among others. The youngest of the faunas, the *Irvingella major* Subzone of Palmer (1979), has already been formalised as a separate zone by Chatterton & Ludvigsen (1998). Further revision of the *Elvinia* Zone is beyond the scope of this paper; here we evaluate the potential contribution of *Bynumina* to such a revision. Much of the data are from new collections that are still under study, but preliminary assessments of the associated faunas are included below.

At Patterson Pass, Nevada, the stratigraphic occurrence of *Bynumina globosa* (Walcott, 1884) at a single horizon (PP 292.5) is constrained by under- and overlying collections. Associated species in PP 292.5 include *Pterocephalia* cf. *P. sanctisabae* Roemer, 1849, *Housia* cf. *H. ovata* Palmer, 1965, undescribed species of *Dellea* Wilson, 1949 and *Pulchricapitus* Kurtz, 1975, and the agnostoid arthropod, *Pseudagnostus* Jaekel, 1909. *Housia*, *Pseudagnostus* and *Pterocephalia* occur in underlying collections (PP 280.4, 280.5, 287), along with *Cheilocephalus* Berkey, 1898, and *Pseudosaratogia* Wilson, 1951. The closest overlying collection (PP 302) is separated from PP 292.5 by a stratigraphic gap of 9.5 m, and is characterised by *Sigmacheilus flabellifer* (Hall & Whitfield, 1877) and *Elvinia* cf. *E. roemeri* (Shumard, 1861). The data from Shingle Pass are restricted to two closely spaced collections from a stratigraphic interval of 35 cm (SHP 18.25, 18.6). These yield a diverse fauna that, in addition to *B. globosa*, includes *S. flabellifer*, *E.* cf. *E. roemeri*, *H.* cf. *H. ovata*, *Elvinia granulata* Resser, 1942, *Oligometopus breviceps* (Walcott, 1884), *Irvingella* cf. *I. angustilimbata* Kobayashi, 1938, *Kindbladia* cf. *K. affinis* (Walcott, 1884), as well as species of *Cheilocephalus*, *Dellea*, *Pseudagnostus*, *Pseudosaratogia* and *Pulchricapitus*. Taken together, species occurrence data from Nevada suggest that *Bynumina* has a short stratigraphic range in the lower *Elvinia* Zone that probably encompasses no more than about 10 m of section.

The occurrence of *Kindbladia* in the upper part of the local range of *Bynumina* in Nevada is of interest because these genera are also associated in the Honey Creek Formation of Oklahoma, in the Davis Formation of Missouri (Kurtz 1975), and in the Gatesburg Formation of Pennsylvania (Loch & Taylor 2004). In Oklahoma, the stratigraphic range of *B. kimbellorum* sp. nov. is constrained by under- and overlying collections only in section KR2. The sampled range of this species is less than a metre (KR2 42.25, 42.75), but subjacent (KR2 37) and superjacent (KR2 48.2) collections are each separated by stratigraphic gaps of nearly 6 m. Species that occur with *B. kimbellorum* include *Camaraspis parabola* Frederickson, 1948b, *Elvinia roemeri*, *Cliffia* cf. *C. latagenae* (Wilson, 1949), *Dellea* cf. *D. wilbernensis* Wilson, 1949, as well as *Plataspella*, *Pseudosaratogia* and *Kindbladia*. It is worth noting that our collections from the lower Honey Creek Formation include cranidia of *Kindbladia* that both possess and lack occipital spines, so that previous identifications of only a single species in the Honey Creek (Stitt 1971, 1977) may be incorrect; cranidia associated with *B. kimbellorum* are non-spinose and resemble *K. angustana* Resser, 1942.

New data from Pennsylvania (Loch & Taylor 2004, fig. 2) show that *B. terrenda* Wilson, 1951, is associated with *Kindbladia* and *Plataspella* in the lower part of the local range of *Cliffia*. This is identical to the situation in Oklahoma, indicating that *B. terrenda* and *B. kimbellorum* are similar in age. Moreover, a similar pattern is evident in the Davis Formation (Kurtz 1975, fig. 6), where *Bynumina* occurs through the same stratigraphic interval as *Kindbladia*, and both genera overlap with the lower part of the range of *Cliffia*. Finally, in the subsurface of Indiana, *B. caelata* Resser, 1942, co-occurs with *Elvinia granulata* in the Davis Formation (at 4,520 feet in the FMC No WD-1 core; Palmer 1982), so that the former is coeval with *B. globosa* (Walcott) over at least part of its stratigraphic range.

In summary, the stratigraphic ranges of species of *Bynumina* treated herein fall within a relatively narrow interval (Fig. 3) that corresponds to part of the lower informal subzone of the *Elvinia* Zone that was proposed by Stitt (1977). Various species have potential for high resolution biostratigraphic correlation within basins, and they will certainly contribute to future revisions of upper Steptoean zonal nomenclature.

SYSTEMATIC PALAEONTOLOGY

Repositories are indicated by the following abbreviations: OU, Oklahoma Museum of Natural History, University of Oklahoma; YPM, Peabody Museum of Natural History, Yale University; USNM, National Museum of Natural History, Washington. Collection numbers used throughout the text indicate metres above the bases of measured sections; localities are: PP, Patterson Pass, Nevada; SHP, Shingle Pass, Nevada; KR1 and KR2, Ring Top Mountain, Kimbell Ranch, Oklahoma. Proportions expressed in percentages in descriptions and diagnoses are means, with numbers in parentheses indicating the range of values. All measurements were made on digital images to the nearest tenth of a millimeter using the Measure Tool of Adobe Photoshop ™.

Family KINGSTONIIDAE Kobayashi, 1933

Discussion. Following Westrop (1992), occipital ring morphology (often expressed only on internal moulds) is interpreted as a synapomorphy uniting *Kingstonia* Walcott, 1924, *Blountia* Walcott, 1916, *Maryvillia* Walcott, 1916, *Bynumia* Walcott, 1924, *Komaspidella* Kobayashi, 1938, and *Bynumina* Resser, 1942, in the family Kingstoniidae. In detail, the occipital ring is transected near the posterior margin by a finely etched transverse furrow that isolates a very narrow (sag.), rim-like band (e.g., Fig. 4D). Several effaced genera assigned previously to the family, including *Acheilus* Clark, 1924, and *Pugionicauda* Westrop, 1986, are now excluded (see also Adrain & Westrop 2004, p. 25-26). As revised, kingstoniid trilobites occur predominantly in Marjuman strata; *Blountia* ranges into basal Steptoean strata (e.g., Palmer 1965; Rasetti 1965), and *Bynumina*, the youngest representative of the family, occurs in the upper Steptoean succession across the United States.

Jell (in Jell & Adrain 2003) included several genera in the Kingstoniidae that should now be excluded from the family. *Kingstonioides* Rasetti, 1963 (pl. 68, figs 26-30), from allochthonous boulders in debris flows of the Gaspé Peninsula, Quebec, is relatively effaced, and has an upturned anterior border similar to, but more convex than, the border of *Bynumina kimbellorum* sp. nov.

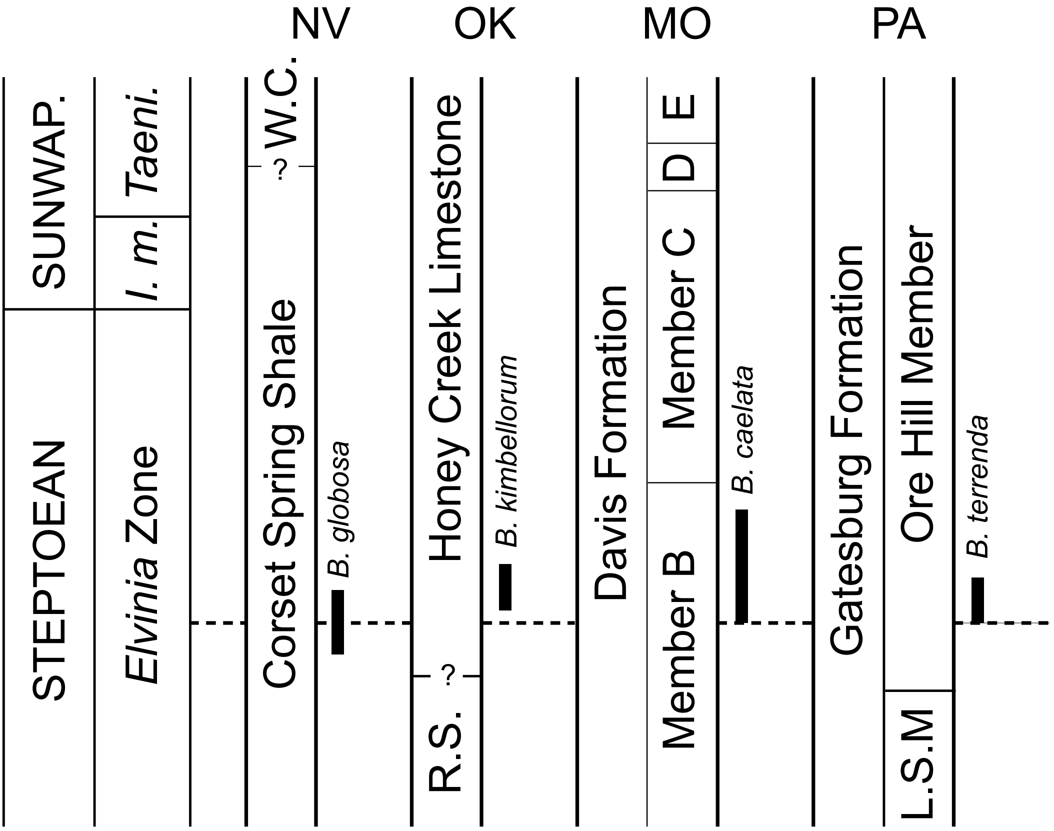


Fig. 3. Correlation of late Steptoean-lower Sunwaptan strata in Nevada (Palmer 1965; Westrop & Adrain, unpublished), Oklahoma (Stitt 1977; Waskiewicz & Westrop unpublished), Missouri (Kurtz 1975) and Pennsylvania (Loch & Taylor 2004), showing ranges of species of *Bynumina* (datum indicated by dashed line is the lowest occurrence of *Kindbladia* Frederickson, 1949). Sunwap., Sunwaptan; I.m., *Irvingella major* Zone; *Taeni*, *Taenicephalus* Zone; W.C., Whipple Cave Formation; R.S., Reagan Sandstone; L.S.M., Lower Sandy Member. Question marks indicate uncertainty about age of formation boundaries.

However, the well defined, backwardly bowed occipital ring of *Kingstonioides* clearly differs from the condition in kingstoniid genera, and this genus is better assigned to the Asaphiscidae Raymond, 1924, as suggested by Fritz *et al.* (1970). The poorly known *Saonella* Rozova, 1968 (pl. 3, figs 13-15), from the Upper Cambrian Madui horizon of north-west Siberia, is effaced with a trapezoidal glabella and weakly convex anterior border that resembles some species of *Bynumina*, but it too has a conventional occipital ring that appears to be inflated abaxially.

Brachyaspidion Miller, 1936, has long been assigned to the Kingstoniidae (e.g., Lochman 1953; Robison 1964) on the basis of such characters as the subtrapezoidal glabella and general cranidial effacement. However, the prominent, triangular glabella that is extended into a spine in some species, long genal spines, and strongly furrowed pygidium (Robison 1971, pl. 90, figs 1-10) all indicate that the affinities of this genus lie elsewhere. We are uncertain about the relationships of *Brachyaspidion*, although cranidial comparisons can certainly be made with some species currently assigned to *Aphelotoxon* Palmer, 1965 (pl. 19, figs 1, 3-6).

As suggested by Shergold (1991), the poorly known *Wanwanaspis* Kobayashi, 1966, and *Wanwanoglobus* Kobayashi, 1966, are excluded from the Kingstoniidae (but see Jell in Jell & Adrain 2003, for an alternative view). '*Kingstonia*' *euryaxis* Peng *et al.*, 2004, from north-west China has been assigned recently to the Kingstoniidae. It is known only from testate sclerites, and the structure of the occipital ring is obscured by effacement (Peng *et al.* 2004, pl. 33, fig. 7); exfoliated material will be needed to evaluate the relationships of this species. However, as noted by Peng *et al.*, the broad, roughly triangular pygidial axis of this species (Peng *et al.* 2004, pl. 33, figs 9, 11, 13-14) contrasts with the narrow, gently tapered axes of Laurentian species of *Kingstonia* (e.g., see Pratt 1992, pl. 25, figs 8-10, 18). Indeed, all other kingstoniid genera possess narrow, gently tapered axes (e.g., Lochman & Hu 1962, pl. 3, figs 22, 28, 29, pl. 4, figs 4, 20, 29, 40, 43), which casts some doubt on both the generic assignment of '*K.*' *euryaxis* as well its relationship with the Kingstoniidae.

Bynumina Resser, 1942

Type species. *Bynumina caelata* Resser, 1942, from the Davis Formation, Missouri (by original designation).

Diagnosis. Kingstoniidae with gently to strongly impressed glabellar furrows on internal mould. Pygidium with at least one strongly convex axial ring at anterior end of axis that stands well above level of other rings on internal mould.

Other species. *Bynumina globosa* (Walcott, 1884); *B. terrenda* Wilson, 1951; *B. lirae* Kurtz, 1975; *B. kimbellorum* sp. nov.; *B*. sp. nov. 1.

Discussion. As in other effaced taxa, diagnoses of kingstoniid genera have been based primarily on the degree to which furrows and other features have been lost, and unequivocal character support for monophyly is limited. In terms of grade of effacement, cranidia of *Bynumina* are most similar to those of *Bynumia* Walcott, 1924 (e.g., Resser 1942, pl. 9, figs 8, 10, 14, 17, 28; Robison 1988, fig. 17.1-17.2, 17.4, 17.9-17.10) in that the glabella is typically defined by faint axial and preglabellar furrows. In establishing the genus, Resser (1942, p. 58), drew attention to the development of lateral glabellar furrows in *Bynumina*. However, as noted by Palmer (1960, p. 94), Resser did not recognise that almost all of his specimens are internal moulds. Faint (Figs 4A, 9E, H, L) to well impressed (Figs 4D, 10P, W, Z) furrows in the S1 position occur on all moulds, with S2 and S3 furrows evident on some specimens; weak glabellar furrows may also be present on the external surface of the exoskeleton (Figs 6I, 7H, 10J). Among kingstoniid genera, expression of glabellar furrows on the internal mould appears to be unique to *Bynumina*.

Resser (1942, p. 59, pl. 10, fig. 22) assigned a pygidium to *B. caelata* but his photograph is very poor and provides little information about the morphology of this sclerite. It is reillustrated here (Fig. 4M-N), along with two similar, previously unfigured pygidia (Fig. 4O-R) that are associated with paratype cranidia of *B. missouriensis* Resser, 1942 (= *B. caelata*; see Kurtz 1975). These pygidia, all of which are internal moulds, are subelliptical in outline and have convex pleural fields that are faintly furrowed. The long axes are composed of six segments; as recognised by Palmer (1960, p. 94), the first two pairs of axial rings are strongly convex and stand well above the level of the remainder of the axis. Closely comparable internal moulds of pygidia are associated with *B. globosa* (Walcott) in Nevada (Figs 6K-M, 7Q-R), differing from those of *B. caelata* in having only one strongly convex ring at the anterior end of the axis. Although other kingstoniid genera may show well defined axial rings on internal moulds (e.g., Resser 1942, pl. 8, fig. 7, pl. 9, figs 24, 34, 44; Lochman & Hu 1962, pl. 3, figs 22, 28-29, 35, 45, pl. 4, figs 4, 20, 29, 32-34, 40, 43; Westrop 1992, figs 15.23, 16.2, 18.1), none display the differential convexity evident in *Bynumina*, which is interpreted as a synapomorphy for the genus. In other respects, exfoliated pygidia of *Bynumina* are similar to those of *Bynumia* Walcott, 1924.

Two species of *Bynumina* are associated with pygidia that preserve the external surface. *Bynumina kimbellorum* sp. nov., from the Honey Creek Formation of Oklahoma is most similar in outline to *B. globosa* and carries a sculpture of well developed terrace ridges. In contrast, the pygidium attributed to *B. terrenda* Wilson, 1951, from Pennsylvania (Fig. 8B, E-F), is smooth. This sclerite also differs from other pygidia illustrated here in its large size. It is similar in dimensions to the largest cephalon of *B. terrenda* illustrated to date (Fig. 8A, C-D) and is at least twice the size of pygidia associated with other species. *Bynumina* is common in new collections from Nevada and Oklahoma, and cranidia in the former region (Figs 6-7) encompass a similar size range to the type cephala and cranidium of *B. terrenda*. However, pygidia comparable to the paratype of *B. terrenda* have not been recovered from our collections. We conclude that the paratype is misassigned and may in fact belong to *Pseudokingstonia* Palmer, 1965, which is characterised by comparable effaced pygidia (e.g., Palmer 1965, pl. 1, fig. 19; Westrop 1986, pl. 29, fig. 1; Hohensee & Stitt 1989, fig. 5.6).

Several Sunwaptan occurrences of *Bynumina* have been reported in the literature, but all represent other taxa. *Bynumina vescula* Stitt, 1971 (pl. 7, figs 16-18), from the Signal Mountain Formation of Oklahoma (see Taylor 1976 and Westrop 1986 for other occurrences), was assigned to a new plethopeltid genus, *Glaberaspis*, by Adrain & Westrop (2004). Loch *et al*. (1993, fig. 7.4) identified an incomplete cranidium from the Survey Peak Formation, Alberta, as *Bynumina* sp. undet., and compared it to *G. vescula*. However, the granulose sculpture and firmly impressed, backwardly curved S1

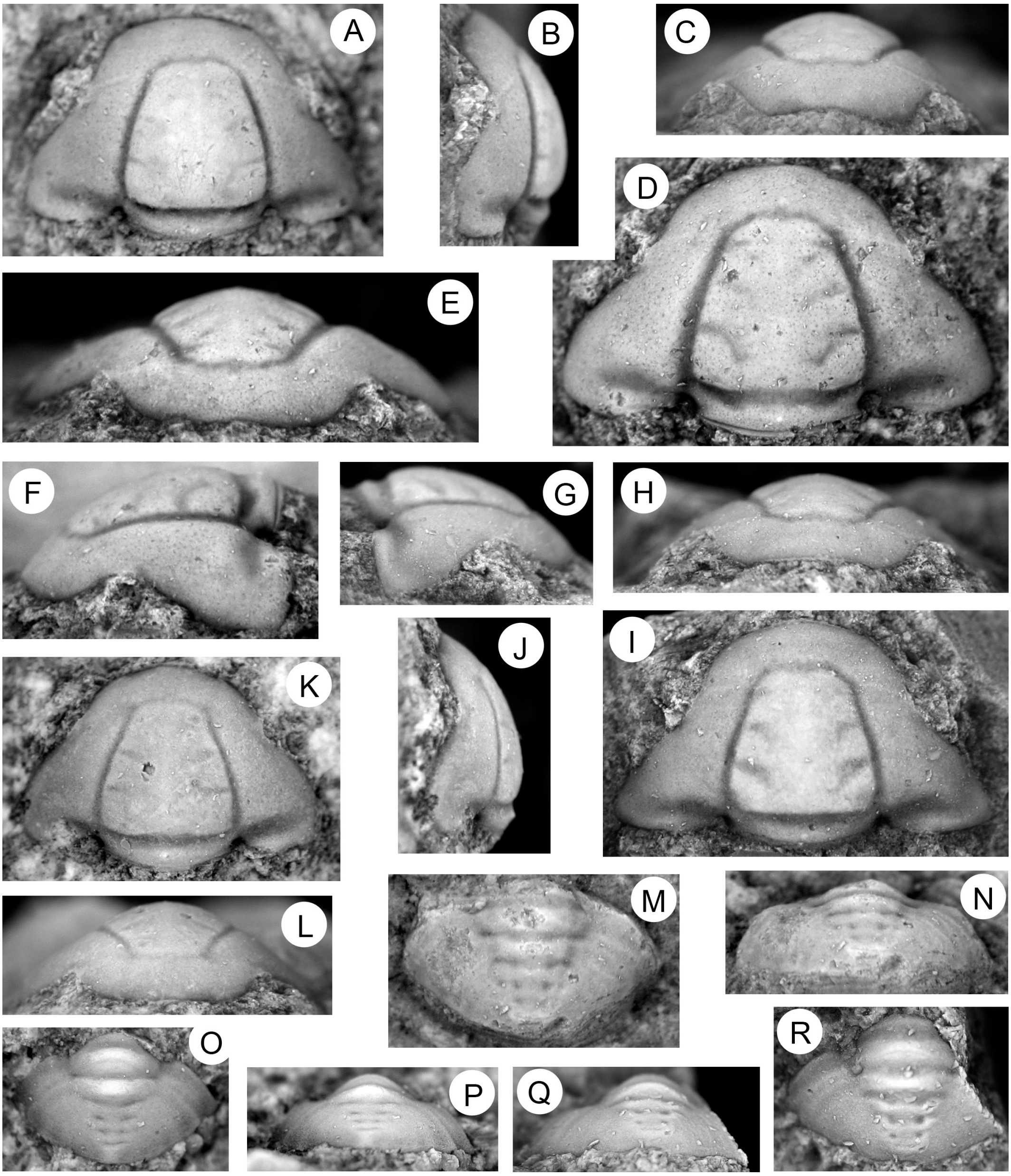


Fig. 4. *Bynumina caelata* Resser, 1942. Davis Formation, Missouri. All x12. All specimens exfoliated. A-C, cranidium, dorsal, lateral and anterior views, USNM 108740a (holotype); D-F, cranidium, dorsal, anterior and lateral views, OU 3509b; G-I, cranidium, lateral, anterior and dorsal views, OU 3509a; J-L, cranidium, lateral, dorsal and anterior views, OU 3508; M-N, pygidium, dorsal and posterior views, USNM 108740b (paratype); O-P, pygidium, dorsal and posterior views, USNM 108741b; Q-R, pygidium, posterior and dorsal views, USNM 108741c.

furrows of the former make an assignment to *Glaberaspis* unlikely, and it probably represents a poorly preserved specimen of *Theodenisia* Clark, 1948 (e.g., see Ludvigsen 1986, fig. 2.3-2.4). The status of the incomplete cranidium attributed to *Bynumina* by Grant (1965, pl. 15, fig. 17) is uncertain. Judging from the tapered, anteriorly rounded glabella that is outlined by well incised axial and preglabellar furrows, it could well belong to a species of *Clelandia* Cössman, 1902 (e.g., see Westrop 1986, pl. 41, figs 1-4, 6-7). Finally, Fortey (1983) assigned *Plethopeltis laevis*

Raymond, 1924 to *Bynumina*, but this species was subsequently transferred to *Acheilus* Clark by Ludvigsen (1986).

Bynumina caelata Resser, 1942 (Figs. 1, 4-5)

1942 *Bynumina caelata*; Resser, p. 58, pl. 10, fig. 22 [only; figs 18-21 = *Bynumina* sp. nov. 1].
1942 *Bynumina missouriensis*; Resser, p. 59, pl. 10, figs 23-26.
1975 *Bynumina caelata* Resser; Kurtz, p. 1032, pl. 2, figs 1-4.
1982 *Bynumina caelata* Resser; Palmer, p. 4, pl. 1, fig. 22 [only; fig. 21 = *Bynumina* sp. indet.].

Diagnosis. *Bynumina* with weakly convex, anteriorly tapered glabella expressed on internal mould. Mould also shows faint to firmly impressed, geniculate S1 furrow; oblique S2 and S3 furrows and narrow (tr.), transverse S4 furrows may also be expressed. Anterior border furrow not expressed on dorsal or ventral surfaces of exoskeleton; frontal area of internal mould slopes evenly forward and is relatively short, occupying 18% (16-21) of cranidial length. Palpebral lobes centered opposite L3 lobe, so that posterior fixigena (directly behind palpebral lobes) is relatively long (exsag.) and equal to 50% (47-52) of cranidial length (sag.). Pygidium with two strongly convex rings at anterior end of axis that stand well above level of posterior rings.

Holotype. A cranidium (USNM 108740a) from the Davis Formation, Federal Lead Mine number 4, Flat River, Missouri (Fig. 4A-C).

Description. Description based on internal mould. Cranidium subtrapezoidal in outline, width between palpebral lobes equal to 66% (63-70) of width at posterior margin; strongly arched in anterior (e.g., Figs 4C, 5E) and lateral (e.g., Figs 4B, 5F) views. Weakly convex glabella tapered anteriorly and subtrapezoidal in outline, with width at anterior corners equal to 59% (53-64) of width at SO furrow; anterior taper uneven, with shallow axial furrow bowed gently outward between SO and S1 furrows, but with weak (e.g., Fig. 5D) to conspicuous (e.g., Figs 4K, 5A) constriction of glabella opposite S3 on many specimens. SO transverse medially, broad (sag.), but curves forward and becomes shorter (exsag.) near axial furrows. LO nearly transverse, occupies 17% (15-20) of glabellar length; transected near posterior margin by finely etched groove that isolates very short, rim-like band. S1 expressed as firmly (e.g., Fig. 4D) to weakly (e.g., Fig. 4A) impressed, geniculate furrow; L1 accounts for 23% (21-25) of glabella length. S2 shallow, curved obliquely backward; L2 slighly shorter than L1. On some specimens (e.g., Figs 4D, 5N), S3 expressed as faint, pit-like furrow far from axial furrow and in line with distal tips of S2. S4 may be expressed as shallow, nearly transverse groove, intersecting lateral glabellar margin slightly behind level of inner edge of palpebral ridge. Anterior border furrow not expressed on dorsal or ventral surfaces of exoskeleton; frontal area on internal mould slopes evenly forward and relatively short, occupying 18% (16-21) of cranidial length. Palpebral lobes centered opposite L3 lobe, so that posterior fixigenae (directly behind palpebral lobe) are relatively long (exsag) and equal to 50% (47-52) of cranidial length (sag.). Anterior branches of facial sutures converge gradually forward from palpebral lobe; posterior branches initially divergent, but become subparallel near posterior corner of cranidium. Fixigenae flexed sharply downward. Palpebral area width equals 22% (20-24) of cranidial width. Posterior border furrow expressed as broad groove that shallows abruptly near mid-point of posterior fixigena. Posterior border well defined on adaxial half of fixigena but only weakly differentiated near posterior corner of cranidium. Internal mould of most cranidia faintly (e.g., Fig. 4A, I) to strongly (e.g., Figs 4D, 5G) punctate; LO with small median node (e.g., Fig. 5A, D, O).

Pygidium moderately arched in posterior view and subelliptical in outline, with maximum width opposite second axial ring furrow; pygidial length equals 62% (61-63) of maximum pygidial width. Axis long, occupies 93% (91-95) of pygidial length, and with width at anteriormost ring equal to 43% (41-44) maximum pygidial length; tapers backward, so that width at terminal piece is 43% (40-44) of width at anteriormost ring. Axial furrows very shallow and axis defined largely by change in slope where it reaches pleural field. Axis composed of six segments; first and second rings strongly convex, raised well above posterior rings and separated by firmly impressed, transverse ring furrows; articulating half-ring prominent, curved strongly forward. Third and fourth axial ring furrows in form of paired pits or slits that do not connect across axis (e.g., Fig. 4O, R); posteriormost ring furrow is finely-etched groove that defines anterior limit of very short terminal piece. Pleural field weakly arched near axial furrow but flexed sharply downward distally; broad (exsag.), shallow pleural furrow and weak interpleural furrow present anteriorly. Remainder of pleural field with faint pleural furrows expressed near pygidial margin. External surface of internal moulds is smooth.

Discussion. Kurtz (1975, p. 1032) synonymised

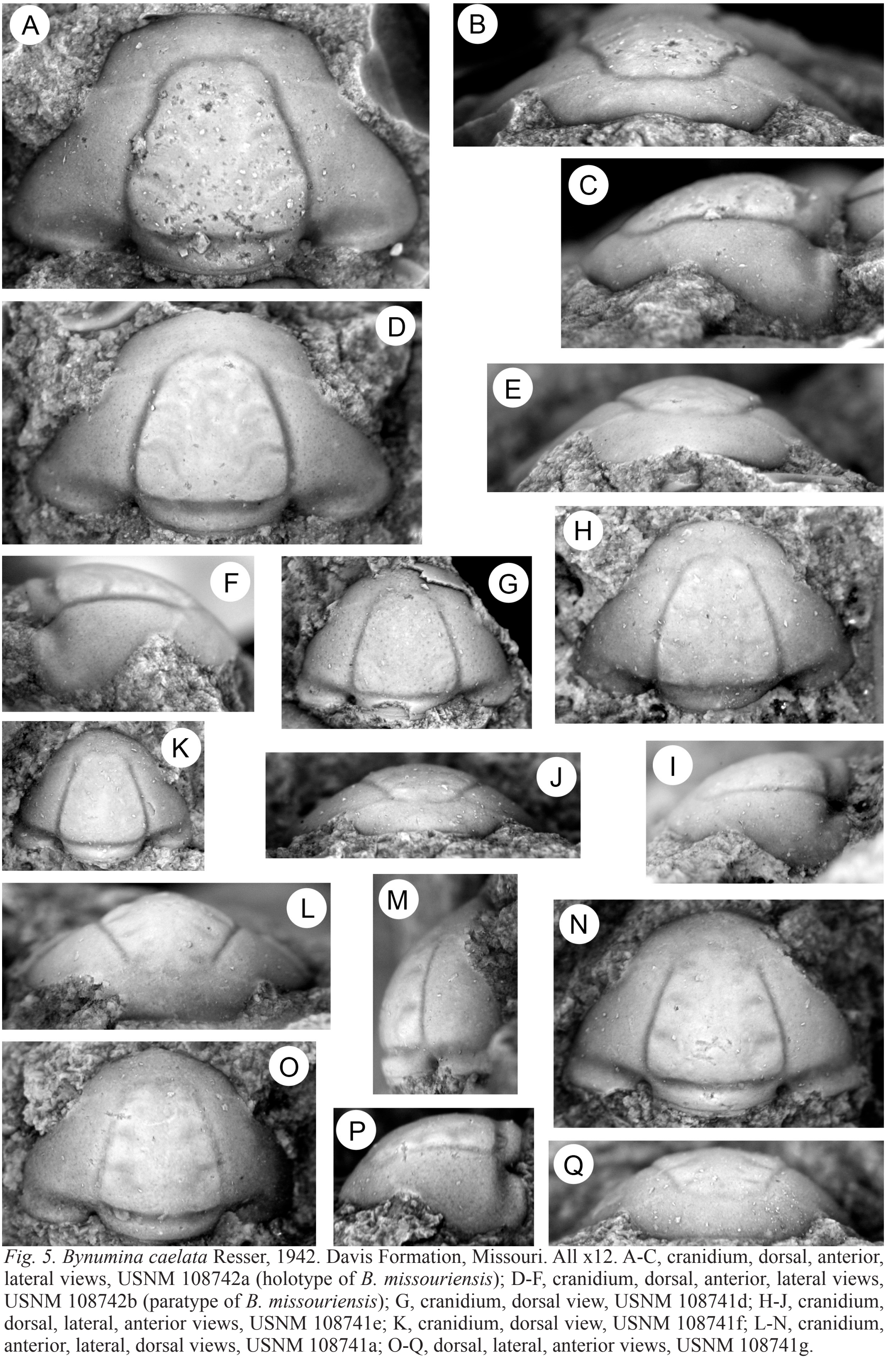
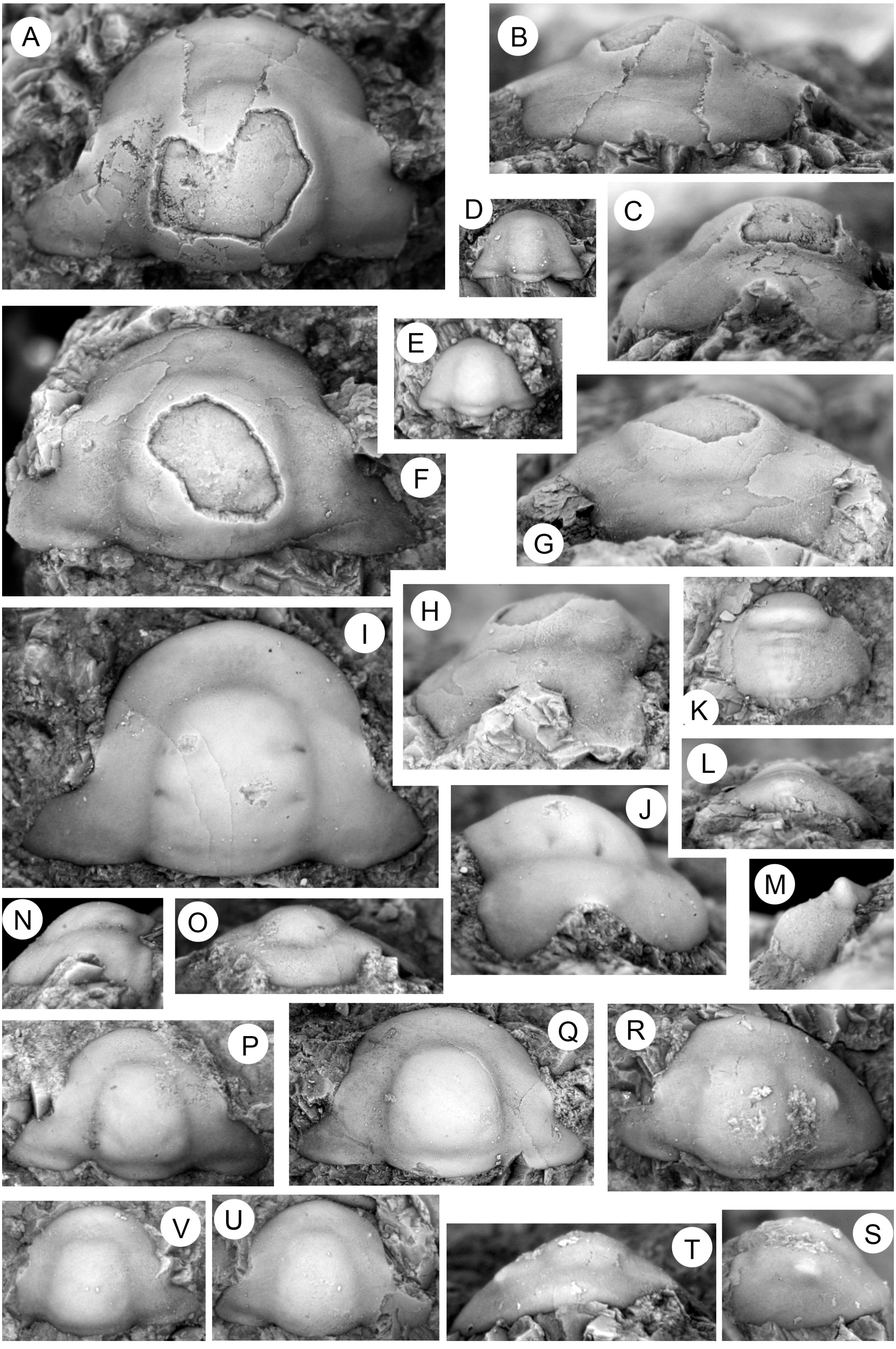


Fig. 5. Bynumina caelata Resser, 1942. Davis Formation, Missouri. All x12. A-C, cranidium, dorsal, anterior, lateral views, USNM 108742a (holotype of *B. missouriensis*); D-F, cranidium, dorsal, anterior, lateral views, USNM 108742b (paratype of *B. missouriensis*); G, cranidium, dorsal view, USNM 108741d; H-J, cranidium, dorsal, lateral, anterior views, USNM 108741e; K, cranidium, dorsal view, USNM 108741f; L-N, cranidium, anterior, lateral, dorsal views, USNM 108741a; O-Q, dorsal, lateral, anterior views, USNM 108741g.


A
B
D
C
E
F
G
H
K
I
L
J
M
N
O
P
Q
R
V
U
T
S

Bynumina caelata and *B. missouriensis* Resser, 1942 without comment. The type cranidia of both species (Figs 4A-C, 5A-C) share a small, anteriorly positioned palpebral lobe that clearly differentiates them from other members of the genus. The holotype cranidium of *B. caelata* (Fig. 4A-C) is very similar to a somewhat larger paratype (Fig. 5D-F) of *B. missouriensis*, differing in having shallower impressions of S1 on the internal mould. Accordingly, Kurtz's interpretation is followed here. As revised, *B. caelata* shows variation in several cranidial characters. Some individuals have an anteriorly constricted glabella (e.g., Figs 4K, 5A), and the anterior cranidial margin varies from rounded (e.g., Fig. 5N) to more transverse (e.g., Fig. 5A). Among the cranidia assigned to *B. caelata* by Kurtz (1975), two individuals (Fig. 4D, I) have relatively deep glabellar furrows on the internal mould, and the larger has a more rounded anterior cranidial margin.

Palmer (1982, fig. 21) illustrated a testate cranidium from the subsurface of west-central Indiana that he identified as *B. caelata*. It occurs 5.18 m (seventeen feet) lower in the core than an unequivocal exfoliated cranidium (Palmer 1982, fig. 22) of *B. caelata*, from which it differs in having a posterior glabellar margin that is bowed sharply backwards rather than nearly transverse. In this respect, the testate cranidium is comparable to *B. terrenda* Wilson, 1951 (e.g., Fig. 8H), with the latter differing in having larger, more posteriorly positioned palpebral lobes. The identity of Palmer's testate cranidium is uncertain and it may represent an undescribed species.

In lacking any trace of an anterior border on the internal mould, *B. caelata* most closely resembles *B*. sp. nov. 1 (Fig. 9C, E-I); comparisons between these species are made below, in the discussion section of the latter.

Both *B. terrenda* Wilson, 1951 (Fig. 8A, C-D, G-L) and *B. kimbellorum* sp. nov. (Fig. 10A-Z, AA) have distinct anterior borders on the external surface of the cranidium, and a border is expressed on the internal mould of the holotype of *B. lirae* Kurtz, 1975 (Fig. 9A-B, D). These three species and *B. globosa* (Walcott, 1884; Figs 6-7) are also differentiated from *B. caelata* in possessing more posteriorly positioned palpebral lobes (and, consequently, shorter posterior fixigenae) and more convex, weakly tapered to barrel-shaped glabellae.

Bynumina globosa (Walcott, 1884) (Figs 6-7)

1884 *Agraulos*? *globosa*; Walcott, p. 61, pl. 9, fig. 23.
1936 *Kingstonia globosa* (Walcott); Resser, p. 24.
1960 *Bynumina globosa* (Walcott); Palmer, p. 94, pl. 10, fig. 8.
1965 *Bynumina globosa* (Walcott); Palmer, p. 82, pl. 18, figs 22- 23.

Diagnosis. *Bynumina* that lacks anterior border and border furrow on external surface of exoskeleton. Strongly convex glabella stands well above fixigenae and outlined by shallow but clearly defined axial and preglabellar furrows. Occipital furrow evident on external surface, and most specimens have faint S1. Palpebral lobe centered opposite anterior end of L2; posterior fixigenae (directly behind palpebral lobes) are relatively short (exsag.) and equal to 34% (30-42) of cranidial length (sag). Pygidium with one strongly convex axial ring at anterior standing well above level of remaining rings; well defined articulating facet at anterior corner.

Occurrence. Corset Spring Shale, Patterson Pass (collections PP 292.5) and Shingle Pass (collections SHP 18.25 and 18.6), Nevada; Walcott's (1884) original material is from the Dunderberg Formation, Eureka Mining District, Nevada (Palmer 1960). See Palmer (1965) for other occurrences of this species in the Great Basin.

Description. Strongly convex cephalon roughly semielliptical in outline, with posterior margin curved gently forward towards genal angle; length 57% (56-59) of maximum width. Cranidium subtrapezoidal in outline, length equal to 34% (31-42) of cranidial width at posterior margin; width across the palpebral lobes equal to 71% (66-76) of width at posterior. Strongly convex glabella barrel-shaped in outline, stands well above fixigenae, and outlined by shallow but clearly defined axial and preglabellar furrows; occupies 79% (75-87; higher values in small

Fig. 6. Bynumina globosa (Walcott, 1884). Corset Spring Shale, Nevada. All x12. All from collection SHP 18.25, except Q (collection PP 292.5). A-C, cranidium, dorsal, anterior and lateral views, OU 12331; D, cranidium, dorsal view, OU 12332; E, cranidium, dorsal view, OU 12333; F-H, cranidium, dorsal, anterior and lateral views, OU 12334; K-M, pygidium, dorsal, posterior and lateral views, OU 12335; N-P, cranidium, lateral, anterior and dorsal views, OU 12336; Q, cranidium, dorsal view, OU 12337; R-T, incomplete cephalon, dorsal, lateral and anterior views, OU 12338; U, cranidium, dorsal view, OU 12339; V, cranidium, dorsal view, OU 12340.

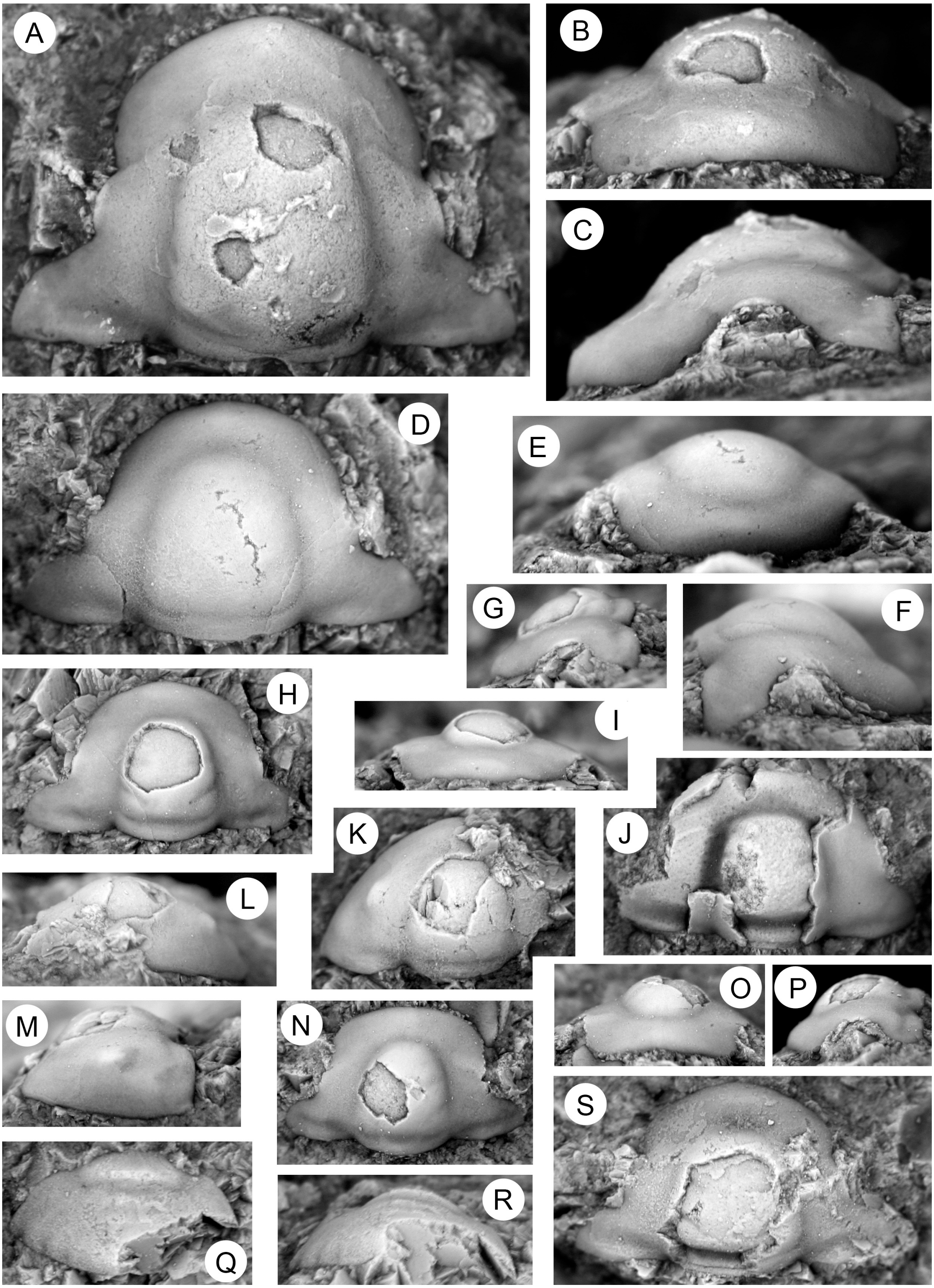


Fig. 7. Bynumina globosa (Walcott, 1884). Corset Spring Shale, Nevada. All x12. All from collection SHP 18.25, except G-J, N-P (collection PP 292.5). A-C, cranidium, dorsal, anterior and lateral views, OU 12341; D-F, cranidium, dorsal, anterior and lateral views, OU 12342; G-I, cranidium, lateral, dorsal and anterior views. OU 12343; J, cranidium, dorsal view, OU 12344; K-M, incomplete cranidium, dorsal, anterior and lateral views, OU 12345; N-P, cranidium, dorsal, anterior and lateral views, OU 12346; Q-R, incomplete pygidium, dorsal and posterior views, OU 12347; S, cranidium, dorsal view, OU 12348.

cranidia, e.g., Fig. 6D-E) of cranidial length. SO furrow shallow on external surface but expressed as firmly impressed groove on internal mould (e.g., Fig. 7J, S). LO accounts for 12% (6-17) of glabellar length; transected near posterior margin by finely etched, transverse groove that isolates very short, rim-like band; minute median node present immediately in front of transverse groove. Faint, oblique S1 furrows on external surface of most specimens; expressed as deeper furrow on internal mould (e.g., Fig. 7S). L1 equal to 22% (19-25) of glabellar length (exsag.). Faint S2 furrows may be present on external surface (e.g., Figs 6I, 7N); deeper, narrow (tr.), oblique furrow evident on internal mould (Fig. 7J). Anterior border furrow not expressed on external surface or internal mould of long, forwardly inclined frontal area; slope of frontal area steepens sharply near anterior cranidial margin. Palpebral lobe centered opposite anterior end of S2 lobe; posterior fixigenae (directly behind palpebral lobes) are relatively short (exsag.) and equal to 34% (30-42) of cranidial length (sag). Oblique palpebral ridge evident on external surface of most cranidia, reaches axial furrow near anterior corner of glabella; ridge better defined on internal mould (Fig. 7J). Palpebral area accounts for 21% (17-23) of cranidial width across palpebral lobes. Anterior branches of facial sutures converge gradually forward before swinging sharply inward along anterior cranidial margin; posterior branches initially strongly divergent, becoming less so near posterior corners of cranidium. Posterior border furrow well defined on smaller individuals (e.g., Fig. 6D-E, P), curved gently forward and extends from axial furrow to posterior corner of cranidium; shallower and effaced distally on larger specimens (e.g., Figs 6I, 7A, D); posterior border weakly convex. External surface smooth but internal mould is finely punctate (Fig. 7J).

Librigena small (tr.), flexed steeply downward in anterior view. Lateral and posterior border furrows not expressed on external surface. Genal angle bluntly pointed (Fig. 7M). External surface smooth.

Pygidium subelliptical in outline, with length slightly more than 60% of maximum width; strongly arched in posterior view (e.g., Fig. 6L); well defined articulating facet at anterior corner. Axial furrows barely perceptible, and axis defined largely by change in slope at pleural field. Axis long, accounting for more than 90% of pygidial length and tapers backward, with axis width at posterior about 35% of width at first axial ring; apart from strongly convex ring at anterior, weakly arched and raised only slightly above pleural field. Axial ring furrows largely effaced; up to four indistinct axial rings evident behind convex first ring. Articulating half-ring prominent, semi-elliptical in outline. Pleural field flexed steeply downward and mostly effaced. Shallow pleural furrow present at anterior; two additional shallow furrows expressed only near pygidial margin. Surface of internal mould smooth.

Discussion. Palmer (1960, 1965) noted that the well defined glabella separated *Bynumina globosa* (Walcott) from all other members of the genus known at that time. *Bynumina kimbellorum* sp. nov. (Fig. 10) is similar to *B. globosa* in the expression of the glabella and the occipital ring, but clearly differs in the presence of a well defined anterior border on the cranidium.

Bynumina globosa displays variation in the relative length of the cranidium and in the degree of curvature of the anterior cranidial margin in dorsal view (e.g., compare Fig. 6F and I). Although larger cranidia tend to be relatively longer (e.g., Fig. 7A), there is no consistent relationship with size.

Two incomplete cephala (Figs 6R-T, 7K-M) occur in collection SHP 18.25 from the Corset Spring Shale and are closely comparable in outline and convexity to cephala of *B. terrenda* (Fig. 8A, C-D, G-I). The glabella of *B. globosa* is more convex, with better defined axial furrows; the genal angle is bluntly pointed, whereas *B. terrenda* has a very small spine.

Bynumina terrenda Wilson, 1951 (Fig. 8A, C-D, G-L)

1951 *Bynumina terrenda*; Wilson, p. 628, pl. 89, figs 7-10 [only; ?fig. 11 = *Pseudokingstonia* sp.].
?1965 *Bynumina terrenda* Wilson; Grant, p. 126, pl. 8, fig. 11
?1989 *Bynumina terrenda* Wilson; Hohensee & Stitt, p. 871, fig. 5.25.

Diagnosis. *Bynumina* with weakly convex anterior border on external surface of exoskeleton that is barely differentiated from preglabellar field. Axial and preglabellar furrows shallow and indistinct; margins of glabella defined largely by inflexion in slope on sagittal and anterior profiles. Occipital furrow not expressed on external surface; posterior margin of glabella bowed backward. Posterior branches of the facial suture sharply divergent near palpebral lobe before curving sharply backward.

Holotype. A cranidium (YPM 18556) from the Ore Hill Member, Gatesburg Formation, Pennsylvania (Fig. 8A, C-D).

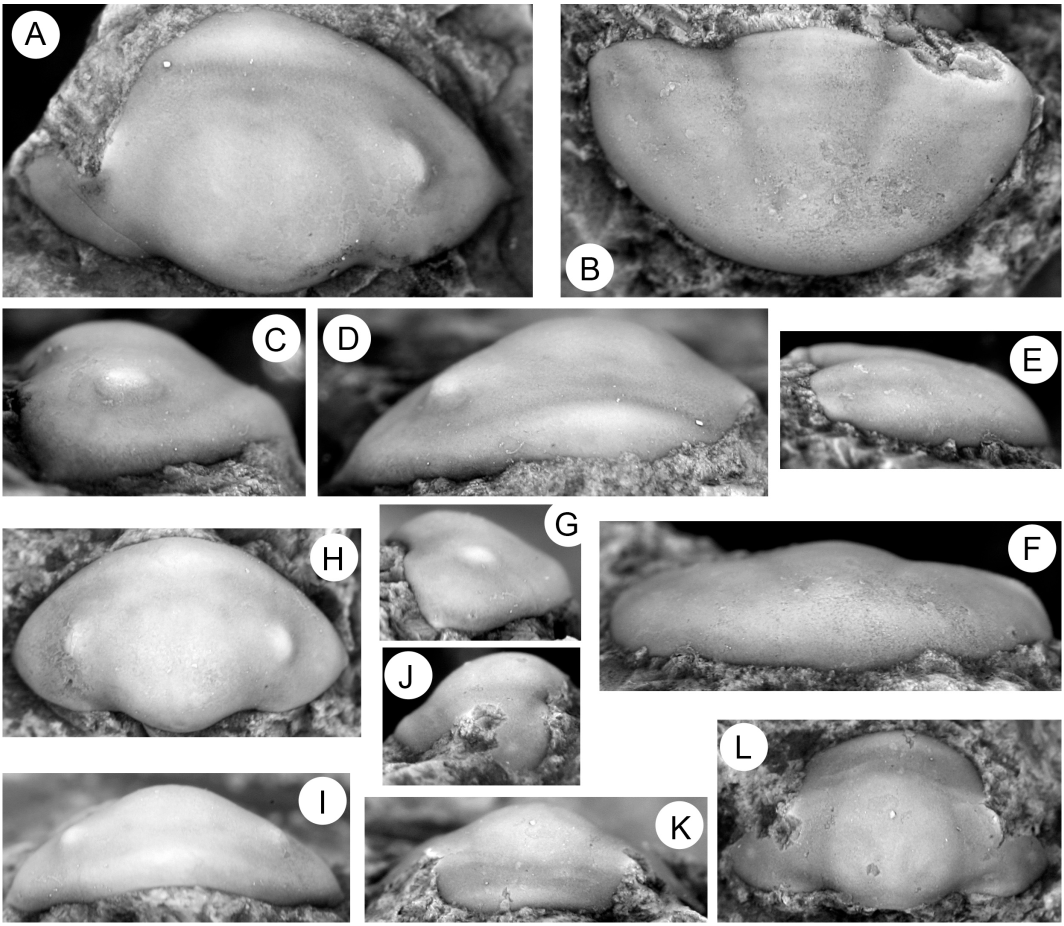


Fig. 8. A, C-D, G-L, *Bynumina terrenda* Wilson, 1951. Ore Hill Member, Gatesburg Formation, Pennsylvania. All x12. A, C-D, incomplete cephalon, dorsal, lateral and anterior views, YPM 18556 (holotype); G-I, cephalon, lateral, dorsal and anterior views, YPM 18555; J-L, cranidium, lateral, anterior and dorsal views, YPM 18557. B, E-F, *Pseudokingstonia*? sp., Ore Hill Member, Gatesburg Formation, Pennsylvania, pygidium, dorsal, lateral and anterior views, YPM 18554, x12 (assigned to *B. terrenda* by Wilson 1951).

Discussion. Wilson (1951, p. 628-629) provided a full description of *Bynumina terrenda*. The expression of an anterior border on the external surface of the cranidium separates this species from all others except *B. kimbellorum* sp. nov. Comparisons between these two species are presented below.

Hohensee & Stitt (1989, p. 871, fig. 5.25) illustrated a very small cranidium from the Collier Shale in Arkansas that they identified without comment as *B. terrenda*. It is strongly effaced with no evidence of an anterior border, which raises doubt about its identity. Similarly, an incomplete cranidium from the Snowy Range Formation of Montana that was assigned to *B. terrenda* by Grant (1965, pl. 8, fig. 11) is also of uncertain status. The tiny stereopair images provided by Grant do not permit a confident evaluation of this specimen, but it appears to have a more convex glabella and a better defined anterior border than the types of *B. terrenda*. In these respects, it is closer to *B. kimbellorum* sp. nov. from Oklahoma (Fig. 10).

Bynumina lirae Kurtz, 1975 (Fig. 9A-B, D)

1975 *Bynumina lirae*; Kurtz, p. 1032, pl. 2, fig. 6 [only; fig. 5 = *Bynumina* sp. nov. 1].
non 1983 *Bynumina lirae* Kurtz; Stitt, p. 101, fig. 3A-H.

Diagnosis. *Bynumina* with short frontal area subequally divided into preglabellar field and anterior border on internal mould. Glabella convex, quadrate in outline, with firmly impressed axial, preglabellar and occipital furrows on internal mould. Posterior branches of facial sutures diverge gradually backward, so that posterior fixigena tapers uniformly abaxially, and

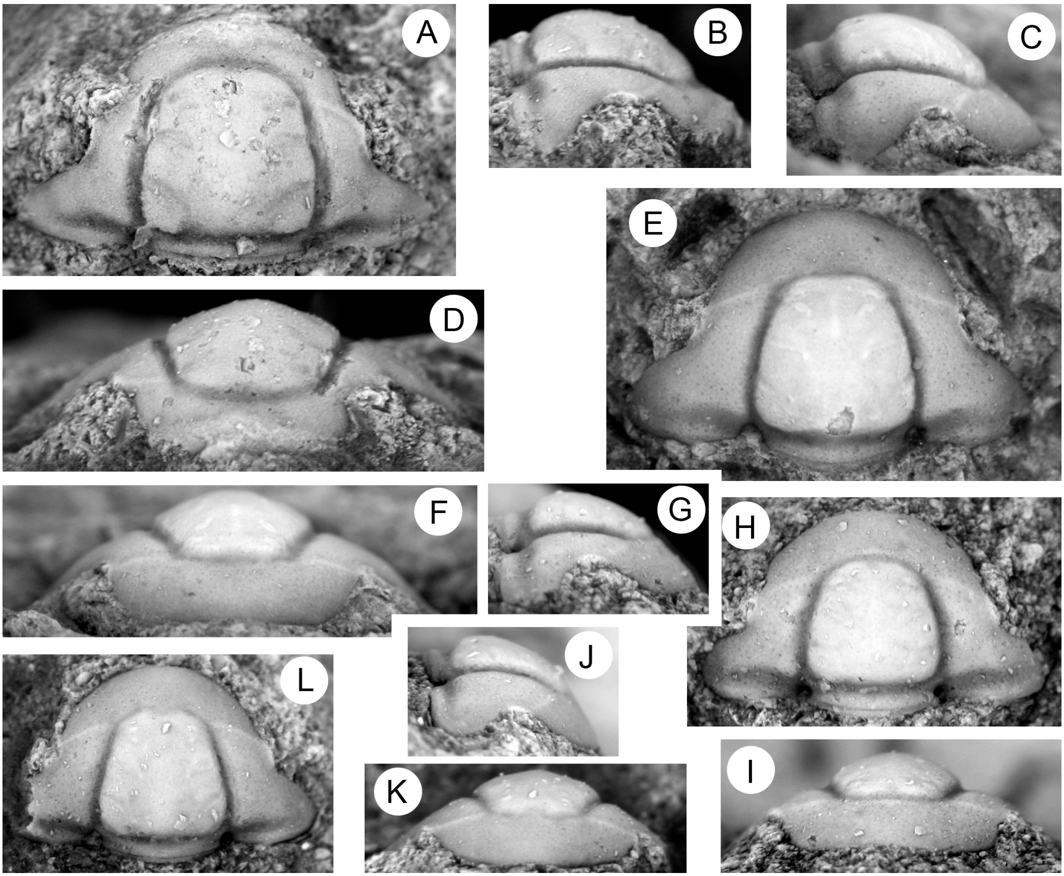


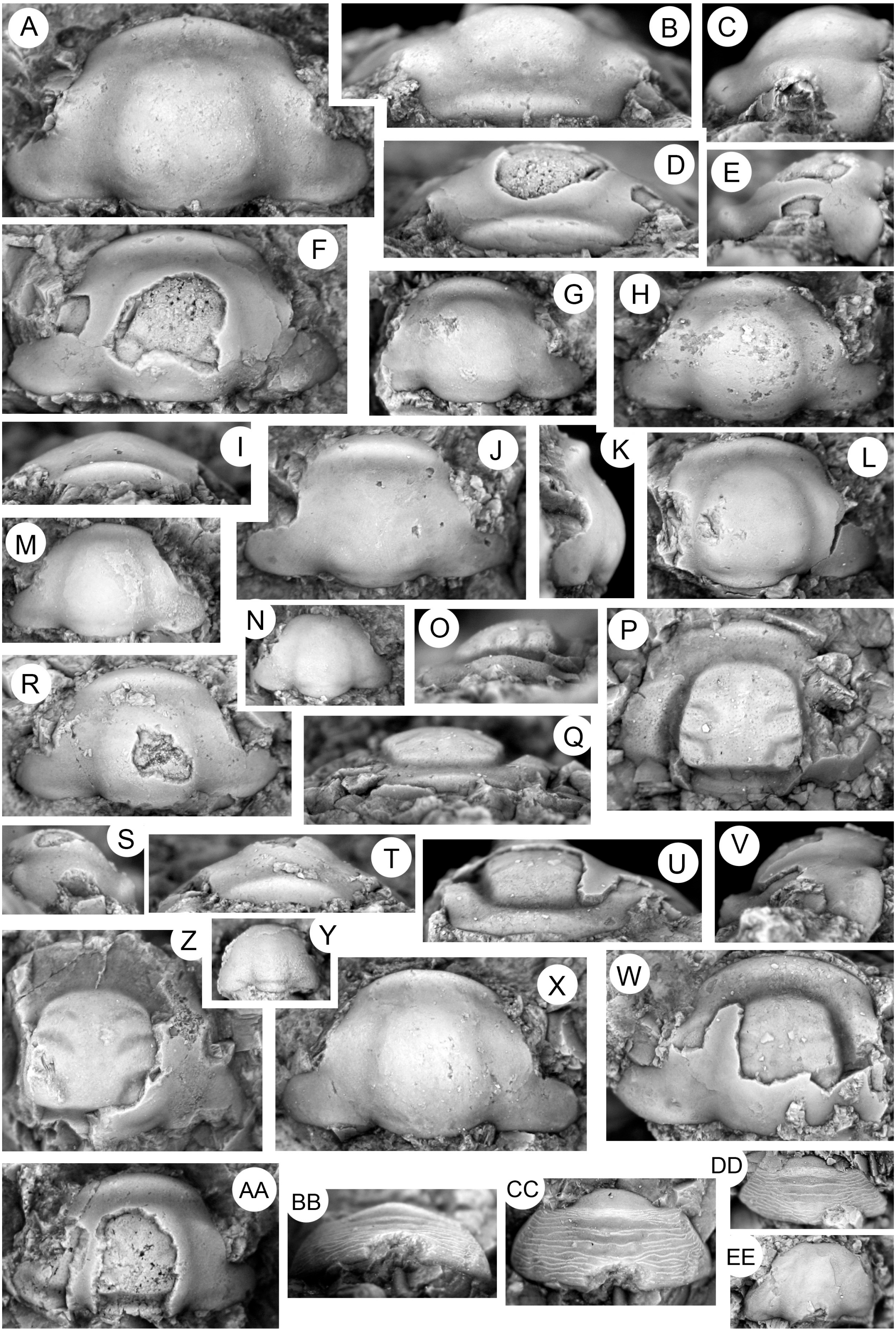
Fig. 9. A-B, D, *Bynumina lirae* Kurtz, 1975. Davis Formation, Missouri, cranidium, dorsal, lateral and anterior views, OU 3510 (holotype) , x12. C, E-L, *Bynumina* sp. nov. 1. Davis Formation. Missouri. All x12. C, E-F, cranidium, dorsal, anterior and lateral views. USNM 108740c (paratype of *B. caelata* Resser that was assigned to *B. lirae* by Kurtz 1975); G-I, cranidium, lateral, dorsal and anterior views, OU 3511a (designated paratype of *B. lirae* by Kurtz 1975); J-L, cranidium, lateral, anterior and dorsal views, OU 3511b (previously unillustrated specimen on same piece of limestone as Fig. 9G-I).

is roughly triangular in outline.

Holotype. A cranidium (OU 3510) from Unit B, Davis Formation, Missouri (Fig. 9A-B, D).

Discussion. The holotype cranidium of *Bynumina lirae* Kurtz (Fig. 9A-B, D) is exfoliated, and displays the quadrate glabella, firmly impressed, axial, preglabellar and occipital furrows, and shallow anterior border furrow (“marginal furrow”) described by Kurtz (1975, p. 1032). However, the paratype (Fig. 9G-I) has a relatively longer, more steeply sloping frontal area that lacks an anterior border and border furrow. In these respects, it is closely comparable to, and in our opinion conspecific with, a paratype of *B. caelata* (Fig. 9C, E-F) that was transferred to *B. lirae* by Kurtz (1975). Both of these specimens are assigned to a new species (*B*. n. sp. 1; see below), leaving *B. lirae* restricted to the holotype.

In his study of enrolled trilobites from the Davis Formation, Stitt (1983, fig. 3A-H) assigned some specimens to *B. lirae*. However, these are identified incorrectly, and do not represent *Bynumina*, let alone *B. lirae*. Their small size makes them difficult to evaluate fully, but they clearly possess conspicuous, convex, backwardly curved occipital rings that differ not only from *Bynumina* but also from all other kingstoniid genera. The deeply incised posterior border furrows and conspicuous lateral border and border furrow on the librigenae (Stitt 1983, fig. 3A, E) are also features that are not expressed in *Bynumina* (e.g., Figs 6R, 7K, 8A, H). Finally, the best preserved enrolled individual (Stitt 1983, fig. 3E) appears to have inflated L1 and L2 glabellar lobes that contrast with the more effaced condition in all species currently assigned to *Bynumina*. Although clearly not a species of *Bynumina*, we are not certain about the correct identity of


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
R
Q
S
T
U
V
Z
Y
X
W
AA
BB
CC
DD
EE

Stitt's material. There are some similarities with "*Morosa*" *simplex* Stitt, 1971 (pl. 1, fig. 20) from the Honey Creek Formation of Oklahoma, but more, better preserved material is needed for a confident identification.

Bynumina kimbellorum sp. nov. (Fig. 10)

Etymology. For the Kimbell family, who provided us with access to the exposures of the Honey Creek Formation on their property in the Blue Creek Canyon area, Comanche County, Oklahoma.

Diagnosis. *Bynumina* with convex anterior border on external surface of cranidium that stands well above level of preglabellar field; anterior margin slopes almost vertically downward. Glabella convex and outlined by shallow but well defined axial and preglabellar furrows; occipital furrow expressed on external surface. Axial and preglabellar furrows expressed as firmly impressed grooves on internal mould, as are geniculate S1 and backwardly curved S2 and, in some cases, S3 furrows. Near palpebral lobe, the posterior branches of facial suture abruptly diverge, running subparallel to the posterior cranidial margin before curving sharply backward. Consequently, the abaxial portion of posterior fixigena is long (exsag.). Pygidium (excluding articulating half-ring) subtrapezoidal in outline with prominent articulating facet runs along lateral margin. External surface carries sculpture of coarse, roughly transverse terrace ridges; axial ring furrows and lateral margins of axis defined largely by breaks in sculpture. Apart from convex anterior axial ring, axis is barely raised above level of pleural field; remaining rings defined largely by one or two coarse terrace ridges that extend onto pleural field.

Holotype. A partly exfoliated cranidium (OU 12350) from the Honey Creek Formation, collection KR2 42.25 (Fig. 10E-G).

Occurrence. Honey Creek Formation, Kimbell Ranch, Comanche County, Oklahoma, collections KR1 9.25, KR2 42.25, KR2 42.5, KR2 42.75.

Description. The cranidia of *Bynumina kimbellorum* and *B. globosa* (Walcott) are sufficiently similar in expression of the glabella and cranidial furrows that a comparison will be made between them in lieu of a full description. The former species has a convex anterior border on both the internal mould and external surface that is absent in the latter. Occupying about half of the length of the frontal area, the border is raised well above the level of the preglabellar field, and the anterior margin descends almost vertically forward. The cranidium of *B. kimbellorum* tends to be relatively shorter and wider than that of *B. globosa*, with cranidial length equal to 55% (53-58) of the maximum width across the posterior fixigenae, versus 62% (55-69) in the latter. Glabellar furrows generally far more firmly impressed on internal moulds. Finally, the course of the posterior facial sutures differs. In *B. kimbellorum*, they are abruptly divergent near the palpebral lobe, so that the abaxial portion of the posterior fixigena is broad (exsag.). In contrast, the posterior branches are more gradually divergent in *B. globosa*, producing a narrower (exsag.), more evenly tapered distal termination to the posterior fixigenae.

Bynumina kimbellorum is the only species in which the external surface of the pygidium is preserved. Consequently, a full description of this sclerite is given. Pygidium (excluding articulating half-ring) subtrapezoidal in outline, length about half of maximum width; prominent articulating facet runs along lateral margin. Apart from convex anterior axial ring, axis is barely raised above level of pleural field; axial furrows effaced and axis defined only by termination of terrace ridges that traverse pleural field. Axis tapered backward, width at posterior slightly less than width at first ring; occupies about 40% of maximum pygidial width at first ring. Conspicuous articulating half-ring semielliptical in outline, longer than axial rings. Axial ring furrows very shallow grooves

Fig. 10. Bynumina kimbellorum sp. nov., Honey Creek Formation, Kimbell Ranch section, Comanche County, Oklahoma. All x12, except BB-DD (x13) and Y, EE (x15). All from collection KR2 42.25, except I-L, P-Q (collection KR2 42.75) and Z, BB, CC, EE (collection KR1 9.25). A-C, cranidium, dorsal, anterior and lateral views, OU 12349; E-G, cranidium, lateral, anterior and dorsal views, OU 12350 (holotype); G, cranidium, dorsal view, OU 12351; H, cranidium, dorsal view, OU 12352; I-K, cranidium, anterior, dorsal and lateral views, OU 12353; L, cranidium, dorsal view, OU 12354; M, cranidium, dorsal view, OU 12324; N, cranidium, dorsal view, OU 12355; O-Q, cranidium, lateral, dorsal and anterior views, OU 12356; R-T, cranidium, dorsal, lateral and anterior views, OU 12357; U-W, cranidium, anterior, lateral and dorsal views, OU 12358; X, cranidium, dorsal view, OU 12359; Y, cranidium, dorsal view, OU 12360; Z, cranidium, dorsal view, OU 12361; AA, cranidium, dorsal view, OU 12362; BB, CC, pygidium, posterior and dorsal views, OU 12363; DD, pygidium, dorsal view, OU 12364; EE, cranidium, dorsal view, OU 12365.

that lack sculpture; at least four present. First axial ring raised well above pleural field, carries several coarse, closely spaced terrace ridges that extend onto pleural field. Next three rings indistinct and each defined most clearly by one or two coarse terrace ridges that extend onto pleural field; terrace ridges crowded together near posterior tip of axis so that additional rings cannot be identified. Pleural field flexed strongly downward in posterior view; unfurrowed but with conspicuous sculpture of coarse, roughly transverse terrace ridges.

Discussion. *Bynumina kimbellorum* and *B. terrenda* are the only species that possess an anterior border on the external surface of the cranidium, and they also resemble each other in the course of the posterior branches of the facial suture, which are sharply divergent near the palpebral lobe before curving sharply backward (e.g., compare Figs 8L and 10A). The anterior border of the Oklahoman species is more convex than that of *B. terrenda*, standing well above the preglabellar field (e.g., Fig. 10E, K, S), and descends almost vertically at the anterior end of the cranidium. In *B. terrenda*, the border is less convex and barely differentiated from the preglabellar field (e.g., Fig. 8J-L). *Bynumina kimbellorum* has a glabella that is well defined, with shallow but clearly expressed axial and preglabellar furrows (Fig. 10A-N), whereas the margins of the glabella of *B. terrenda* are expressed largely as a change in slope of the transverse and sagittal profiles (Fig. 8C-D, H-K). The occipital ring is expressed on the external surface of *B. kimbellorum*, with a shallow occipital furrow evident on most specimens (e.g., Fig. 10J-M); the posterior margin of the glabella is nearly transverse. In contrast, the occipital ring is effaced on the external surface of *B. terrenda*, and the posterior glabellar margin is bowed backwards (e.g., Fig. 8H).

In the expression of the axial, preglabellar and occipital furrows on the internal mould (e.g., Fig. 10P), *B. kimbellorum* resembles the morphology of the holotype of *B. lirae* Kurtz (Fig. 9A-B, D). Comparisons between these two species are limited because the external surface of the latter is unknown. However, there are clear differences in the course of the posterior branches of the facial sutures. Near the palpebral lobe, the posterior branches of *B. kimbellorum* are abruptly divergent, running subparallel to the posterior cranidial margin before curving sharply backward. Consequently, the abaxial portion of the posterior fixigena is long (exsag.). In contrast, the posterior branches of *B. lirae* diverge more gradually backward, so that the posterior fixigena tapers uniformly abaxially, and is roughly triangular in outline.

Bynumina sp. nov. 1 (Fig. 9C, E-L)

1942 *Bynumina caelata*; Resser, p. 58, pl. 10, figs 18-21 [only].
1975 *Bynumina lirae*; Kurtz, p. 1032, pl. 2, fig. 5 [only].

Discussion. A few cranidia that were assigned to *Bynumina lirae* by Kurtz (1975) appear to represent a distinct species that is most similar to *B. caelata* Resser. Indeed, one specimen (Fig. 9E-F) was originally designated as a paratype of *B. caelata* by Resser (1942, p. 59). *Bynumina* sp. nov. 1 has a larger palpebral lobe that is located farther back on the cranidium than *B. caelata*, so that the post-palpebral fixigenal length (exsag.) is relatively shorter, equal to 37% (36-38) of cranidial length, rather than 50% (47-52) as in the latter. The preglabellar field is slightly longer in *B.* sp. nov. 1, occupying 23% (21-25), rather than 18% (16-21), of cranidial length, and the glabella is somewhat more convex. Although it is most likely new, it will not be named formally until more material becomes available.

ACKNOWLEDGEMENTS

This research was supported by National Science Foundation Grant grant EAR 0308685. Colt Nickel, Roger Burkhalter and Jennifer Eoff participated in field work in Oklahoma; Burkhalter also assisted in field work in Nevada and in processing samples in the laboratory. Jad Bean and David Schultz measured the Patterson Pass section and made collections in 2000; the section was redescribed and resampled by Westrop and Burkhalter in 2006. The Kimbell family of Wichita Falls, Texas, provided access to their ranch property in the Wichita Mountains, Oklahoma. Conrad Labandiera and Daniel Levin (National Museum of Natural History) and Susan Butts (Peabody Museum of Natural History) facilitated the loan of type material. Reviewers Pete Palmer and Brian Pratt provided helpful comments on an earlier draft of the manuscript.

REFERENCES

Adrain, J.M. & Westrop, S.R., 2004. A Late Cambrian (Sunwaptan) silicified trilobite fauna from Nevada. *Bulletins of American Paleontology 365*, 1-56.

Berkey, C.P., 1898. Geology of the St. Croix Dalles. *American Geologist 21*, 270-294.

Chatterton, B.D.E. & Ludvigsen, R., 1998. Upper Steptoean (Upper Cambrian) trilobites from the McKay Group of southeastern British Columbia, Canada. *Paleontological Society Memoir 49*, 1-43.

Clark, T.H., 1924. The paleontology of the Beekmantown Series at Levis, Quebec. *Bulletins of American Paleontology 10*, 1-134.

Clark, T.H., 1948. *Theodenisia*, new name, replacing *Denisia* Clark. *Journal of Paleontology 22*, 643.

Cössman, M., 1902. Rectification de la nomenclature. *Revue de Critique Paleozoologie 6*, 52.

Donovan, R.N., 1986. Geology of the Slick Hills. 1-12 in Donovan, R.N. (ed.), *The Slick Hills — Fragments of an Aulacogen?* Oklahoma Geological Survey Guidebook 24.

Fortey, R.A., 1983. Cambrian-Ordovician trilobites from the boundary beds in western Newfoundland and their phylogenetic significance. *Special Papers in Palaeontology 30*, 179-211.

Frederickson, E.A., 1948a. Clarification of Upper Cambrian stratigraphy in Oklahoma. *American Association of Petroleum Geologists Bulletin 32*, 1349-1355.

Frederickson, E.A., 1948b. Upper Cambrian trilobites from Oklahoma. *Journal of Paleontology 22*, 798-803.

Frederickson, E.A., 1949. Trilobite fauna of the Upper Cambrian Honey Creek Formation. *Journal of Paleontology 23*, 341-363

Fritz, W.H., Kindle, C.H. & Lespérance, P.J., 1970. Trilobites and stratigraphy of the Middle Cambrian Corner-of-the-Beach Formation, eastern Gaspé Peninsula, Quebec. *Geological Survey of Canada Bulletin 167*, 43-58.

Grant, R.E., 1965. Faunas and stratigraphy of the Snowy Range Formation (Upper Cambrian) in southwestern Montana and northwestern Wyoming. *Geological Society of America Memoir 96*, 1-171.

Hall, J. & Whitfield, R.P., 1877. Palaeontology. *United States Geological Exploration of the Fortieth Parallel 4*, 198-302.

Hintze, L.F. & Palmer, A.R., 1975. Upper Cambrian Orr Formation: Its subdivisions and correlatives in western Utah. *United States Geological Survey Bulletin 1405-G*, 1-25.

Hohensee, S.R. & Stitt, J.H., 1989. Redeposited *Elvinia* Zone (Upper Cambrian) trilobites from the Collier Shale, Ouachita Mountains, west-central Arkansas. *Journal of Paleontology 63*, 857-879.

Jaekel, O., 1909. Über die Agnostiden. *Zeitschrift der Deutschen Geologischen Gesellschaft 61*, 380-400.

Jell, P.A. & Adrain, J.M., 2003. Available generic names for trilobites. *Memoirs of the Queensland Museum 48*, 331-553.

Kellogg, H.E., 1963. Paleozoic stratigraphy of the southern Egan Range, Nevada. *Geological Society of America Bulletin 76*, 685-708.

Kobayashi, T., 1933. Upper Cambrian of the Wuhutsui Basin, Liaotung, with special reference to the limit of the Chaumitien (or Upper Cambrian) of eastern Asia and its subdivison. *Japanese Journal of Geology and Geography 11*, 55-155.

Kobayashi, T., 1938. Upper Cambrian fossils from British Columbia with a discussion of the isolated occurrence of the so-called "*Olenus*" Beds of Mt. Jubilee. *Japanese Journal of Geology and Geography 15*, 149-152.

Kobayashi, T., 1966. The Cambro-Ordovician formations and faunas of South Korea, Part 10. Stratigraphy of the Chosen Group in Korea and South Manchuria and its relation to the Cambro-Ordovician formations of other areas. Section B. The Chosen Group of North Korea and Northeast China. *Journal of the Faculty of Science, University of Tokyo, Section II, 16*, 209-211.

Kurtz, V.E., 1975. Franconian (Upper Cambrian) trilobite faunas from the Elvins Group of southeast Missouri. *Journal of Paleontology 49*, 1009-1043.

Loch, J.D., Stitt, J.H. & Derby, J.R., 1993. Cambrian-Ordovician boundary interval extinctions: implications of revised trilobite and brachiopod data from Mount Wilson, Alberta, Canada. *Journal of Paleontology 67*, 497-517.

Loch, J.D. & Taylor, J.F., 1995. High resolution biostratigraphy in the Upper Cambrian Ore Hill Member of the Gatesburg Formation, south-central Pennsylvania. 131-137 in Mann, K.O. & Lane, H.R. (eds), *Graphic Correlation*. Society for Sedimentary Geology Special Publication 23.

Loch, J.D. & Taylor, J.F., 2004. New trilobite taxa from Upper Cambrian microbial reefs in the central Appalachians. *Journal of Paleontology 78*, 591-602.

Lochman, C., 1953. Analysis and discussion of nine Cambrian trilobite families. *Journal of Paleontology 27*, 879-896.

Lochman, C. & Hu, C.-H., 1962. Upper Cambrian faunas from the north-west Wind River Mountains, Wyoming, part III. *Journal of Paleontology 36*, 1-28.

Ludvigsen, R., 1986. Revision of *Acheilus* and *Theodenisia* (Late Cambrian, Trilobita). *Journal of Paleontology 60*, 61-67.

McElmoyl, C., & Donovan, R.N., 2000. Unconformity in the lower part of the Honey Creek Limestone, Slick Hills, Oklahoma: candidate for a Grand Cycle boundary. 65-78 in Johnson, K.S. (ed.), *Platform Carbonates in the southern Midcontinent, 1996 symposium*. Oklahoma Geological Survey Circular 101.

Miller, B.M., 1936. *Brachyaspidion*, new name for *Brachyaspis* Miller (not Salter). *Journal of Paleontology 10*, 417.

Palmer, A.R., 1960. Trilobites of the Upper Cambrian Dunderberg Shale, Eureka District, Nevada. *United States Geological Survey Professional Paper 334-C*, 53-108.

Palmer, A.R., 1965. Trilobites of the Late Cambrian

Pterocephaliid Biomere in the Great Basin, United States. *United States Geological Survey Professional Paper 493*, 1-105.

Palmer, A.R., 1979. Biomere boundaries reexamined. *Alcheringa 3*, 33-41.

Palmer, A.R., 1982. Fossils of Dresbachian and Franconian (Cambrian) age from the subsurface of west-central Indiana. *Indiana Department of Natural Resources, Geological Survey Special Report 29*, 1-12.

Peng, S., Babcock, L.E. & Lin, H., 2004. *Polymerid trilobites from the Cambrian of northwestern Hunan, China. Volume 2, Ptychopariida, Eodiscida and undetermined forms*. Science Press, Beijing, 355 p.

Pratt, B.R., 1992. Trilobites of the Marjuman and Steptoean stages (Upper Cambrian), Rabbitkettle Formation, southern Mackenzie Mountains, northwest Canada. *Palaeontographica Canadiana 9*, 1-179.

Rasetti, F., 1963. Middle Cambrian ptychoparioid trilobites from the conglomerates of Quebec. *Journal of Paleontology 37*, 575-594.

Rasetti, F., 1965. Upper Cambrian trilobite faunas of northeastern Tennessee. *Smithsonian Miscellaneous Collections 148 (3)*, 1-127.

Raymond, P.E., 1924. New Upper Cambrian and Lower Ordovician Trilobita and Ostracoda from Vermont. *Geological Society of America Bulletin 48*, 1079-1146.

Resser, C.E., 1936. Second contribution to the nomenclature of Cambrian trilobites. *Smithsonian Miscellaneous Collections 95 (4)*, 1-29.

Resser, C.E., 1942. New Upper Cambrian trilobites. *Smithsonian Miscellaneous Collections 103 (5)*, 1-136.

Robison, R.A., 1964. Late Middle Cambrian faunas from western Utah. *Journal of Paleontology 38*, 510-566.

Robison, R.A., 1971. Additional Middle Cambrian trilobites from the Wheeler Shale of Utah. *Journal of Paleontology 45*, 796-804.

Robison, R.A., 1988. Trilobites of the Holm Dal Formation (late Middle Cambrian), central North Greenland. *Meddelelser om Grønland, Geoscience 20*, 23-103.

Roemer, C.F., 1849. *Texas. Mit besonderer Rücksicht auf deutsche Auswanderung und die physischen Verhältnisse de Landes*. Adolph Marcus, Bonn, 464 p.

Rozova, A.V., 1968. Biostratigraphy and trilobites of the Upper Cambrian and Lower Ordovician of the northwestern Siberian Platform. *Transactions of the Institute of Geology and Geophysics, Academy of Sciences of the USSR, Siberian Branch 36*, 1-243.

Shergold, J.H., 1991. Late Cambrian and Early Ordovician trilobite faunas of the Pacoota Sandstone, Amadeus Basin, Central Australia. *Bureau of Mineral Resources, Geology and Geophysics Bulletin 237*, 15-75.

Shumard, B.F., 1861. The primordial zone of Texas, with descriptions of new fossils. *American Journal of Science, 2nd Series 32*, 213-221.

Stitt, J.H., 1971. Late Cambrian and earliest Ordovician trilobites, Timbered Hills and lower Arbuckle Groups, western Arbuckle Mountains, Murray County, Oklahoma. *Oklahoma Geologic Survey Bulletin 110*, 1-83.

Stitt, J.H., 1977. Late Cambrian and earliest Ordovician trilobites, Wichita Mountains area, Oklahoma. *Oklahoma Geological Survey Bulletin 124*, 1-79.

Stitt, J.H., 1983. Enrolled Late Cambrian trilobites from the Davis Formation, southeast Missouri. *Journal of Paleontology 57*, 93-105.

Taylor, J.F., Loch, J.D. & Perfetta, P.J., 1999. Trilobite faunas from Upper Cambrian microbial reefs in the central Appalachians. *Journal of Paleontology 73*, 326-336.

Taylor, M.E., 1976. Indigenous and redeposited trilobites from Late Cambrian basinal environments of central Nevada. *Journal of Paleontology 50*, 668-700.

Taylor, M.E. & Cook, H.E., 1976. Continental shelf and slope facies in the upper Cambrian and lowest Ordovician of Nevada. *Brigham Young University Geology Series 23*, 181-214.

Walcott, C.D., 1884. The paleontology of the Eureka District, Nevada. *United States Geological Survey Monograph 8*, 1-298.

Walcott, C.D., 1916. Cambrian trilobites. *Smithsonian Miscellaneous Collections 64 (3)*, 157-258.

Walcott, C.D., 1924. Cambrian geology and paleontology V, no. 2, Cambrian and lower Ozarkian trilobites. *Smithsonian Miscellaneous Collections 75 (2)*, 53-60.

Westrop, S.R., 1986. Trilobites of the Upper Cambrian Sunwaptan Stage, southern Canadian Rocky Mountains, Alberta. *Palaeontographica Canadiana 3*, 1-179.

Westrop, S.R., 1992. Upper Cambrian (Marjuman-Steptoean) trilobites from the Port Au Port Group, western Newfoundland. *Journal of Paleontology 66*, 228-255.

Wilson, J.L., 1949. The trilobite fauna of the *Elvinia* Zone in the basal Wilberns Formation of Texas. *Journal of Paleontology 23*, 25-44.

Wilson, J.L., 1951. Franconian trilobites of the central Appalachians. *Journal of Paleontology 25*, 617-654.

Wilson, J.L., 1952. Upper Cambrian stratigraphy in the central Appalachians. *Geological Society of America Bulletin 63*, 275-322.