

Late Ordovician trilobites from the Zhusilenghaierhan area, Ejin Banner, western Inner Mongolia, China

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Late Ordovician (Caradoc) trilobites are for the first time described from the upper part of the Badainjaran Formation of the Zhusilenghaierhan area, Ejin Banner, western Inner Mongolia. The fauna comprises 10 families, 13 genera and 18 species, of which 7 are new, i.e. *Bulbaspis brevis*, *Collis rostratus*, *Erratencrinurus* (*Erratencrinurus*) *ejinensis*, *Flexicalymene peregrina*, *Phorocephala plena*, *Pliomerina serrata* and *Prophysemataspis zhengi*. The trilobite fauna shows a close relationship to coeval faunas of northern Tarim and Kazakhstan, being characteristic of a regional biogeographic unit. The unit may have been part of the *Eokosovopeltis-Pliomerina* Province of eastern Gondwana during the Caradoc. The trilobite fauna also exhibits some Baltican and Laurentian faunal aspects, as indicated by the occurrence of taxa assigned to *Flexicalymene*, *Erratencrinurus* and *Prophysemataspis*.

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THE ZHUSILENGHAIERHAN area lies about 55 km south of Yagan, about 10 km northwest of Zhusilenghaierhan Mountain and 135 km east of Ejin Banner town, western Inner Mongolia (Fig. 1A). According to Zhou *et al.* (1996a, b), geologically the area was part of the Yining-Kawabulak-Beishan region, which may extend westwards into Kazakhstan to connect with Apollonov & Patalakha's (1989) Tekeli Depression forming an independent terrane within the Kazakhstan Mid-Plate during the Cambrian-Early Ordovician; the terrane was then incorporated into the Tarim Plate following the closure of the Middle Tianshan Sea during the Darriwilian. Several Ordovician terranes have recently been distinguished on the Kazakhstan side by Fortey & Cocks (2003). Among them, the Chu-Ili Terrane is likely a western extension of the Yining-Kawabulak-Beishan Terrane, judging from the content of the stratigraphy and faunas.

Late Ordovician rocks outcrop sporadically in the area (Fig. 1B). The stratigraphic sequences were reported by Zheng *et al.* (1982, 1987), and a few trilobites of the middle Ashgill *Staurocephalus clavifrons* faunule were described by Zhou & Zhou (1982) from a 63 m light grey and greyish white limestone (upper part of the Badainjaran Formation), exposed at outcrop 3 (see Fig. 1B). Recently, some Hirnantian graptolites

(Ge *et al.* 1990; Rong *et al.* 2003) and middle Ashgill brachiopods (Rong *et al.* 2003) have been recorded, respectively, from the basal part of the Guaizihu Formation at outcrop 1, and from the upper part of the Badainjaran Formation at outcrop 2 (Fig. 1B).

STRATIGRAPHY AND AGE

The trilobites described in this paper were collected from a measured section throughout the Badainjaran Formation at 41°39'3"N and 102°36'8"E, or at 8.5 km northwest 298° of Zhusilenghaierhan Mountain and 135 km east of Ejin Banner town (Fig. 1B). According to Zheng *et al.* (1987), the underlying beds of the formation are not exposed at this locality and the top is conformably overlain by the *Dalmanitina* beds (Danmianshan Formation, Hirnantian in age; see Rong *et al.* 2003). Lithology and occurrence of trilobites and conodonts in this section (Fig. 2) are listed in descending order as follows:

Overlying beds: Danmianshan Formation: 0.7 m grey, medium-bedded limestone

————— Conformity —————

Badainjaran Formation (296.4 m)

11. Grey, medium-bedded, fine to medium-grained, calcareous sublitharenite. 7.9 m
10. Grey, thin-bedded, fine-grained sublitharenite.

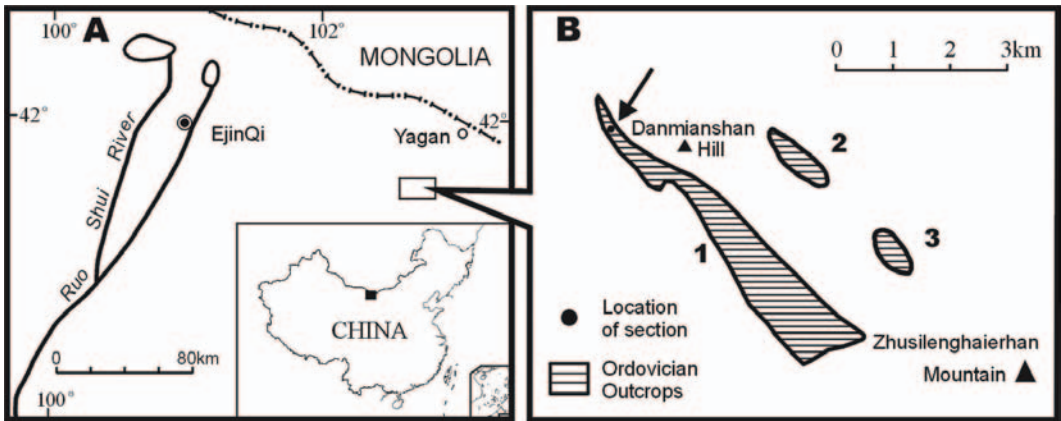


Fig. 1. A, Map of western Inner Mongolia showing the collection area. B, Geological map of Zhushilenghaierhan area showing Ordovician outcrops and the measured section from which collections have been made.

49.2 m

—————Fault—————

9. Purplish-grey, thin-bedded, calcareous, fine-grained sublitharenite intercalated with medium-bedded, sandy bioclastic limestone, yielding brachiopods, corals, trilobites and conodonts. 58.5 m

Zs6b (55 m above the base of the beds): trilobites *Amphilichas* sp., *Bulbaspis brevis* sp. nov., *Collis* cf. *parvulus* Koroleva, *C. rostratus* sp. nov., *Dionide* sp., *Erratencrinurus* (*Erratencrinurus*) *ejinensis* sp. nov., *Flexicalymene peregrina* sp. nov., *Phorocephala* sp., *Pliomerina rigida* Kolobova, *Prophysemataspis zhengi* sp. nov., *Basilicus* (*Basiliella*) sp. 2, *Remopleurides* sp. 1, illaenid gen. et sp. indet., cheirurid gen. et sp. indet., harpetid gen. et sp. indet.; conodonts (identified by An Taixiang) *Phragmodus* sp., *Aphelognathus* sp.

Zs6a (45 m above the base of the beds): trilobites *Nileus* sp., *Pliomerina serrata* sp. nov., *Phorocephala plena* sp. nov., *Remopleurides* sp. 2, *Sinocybele kazakhstanensis* (Koroleva), proetid gen. et sp. indet.

8. Greyish-purple, medium-bedded, sandy and argillaceous limestone, intercalated with thin-bedded, argillaceous, fine-grained sublitharenite, bearing corals (Zs5). 6.1 m
7. Greyish-purple, thin-bedded, calcareous siltstones and fine-grained sublitharenite, intercalated with thin-bedded, sandy bioclastic limestone near the top; containing brachiopods, corals, trilobites and conodonts (Zs4). Conodonts (identified by An Taixiang) *Belodina compressa* Branson & Mehl, *Panderodus* sp., *Phragmodus undatus* Branson & Mehl, *Aphelognathus* sp.; trilobites *Basilicus* (*Basiliella*) sp. 1. 26.9 m
6. Greyish-purple, medium-bedded calcarenite

and dolarenite with a few intercalations of yellowish-grey, thin-bedded, calcareous sandstone, yielding brachiopods and corals (Zs2, Zs3). 20.7 m

5. Greyish-purple, medium-bedded, coarse-grained sublitharenite intercalated with thin-bedded, fine- and medium-grained sublitharenite. 36.4 m
4. Purplish grey thin-bedded fine- to medium-grained sublitharenites intercalated with a few intercalated beds of purplish red fine-grained sublitharenite. 34.5 m
3. Purplish-red, thin-bedded, coarse-grained sublitharenite, bearing brachiopods at the base (Zs1). 17.2 m
2. Greyish-purple, thin-bedded sublitharenite with small-sized gravels. 18.2 m
1. Purplish-red, thin- to medium-bedded, coarse-grained, gravelly sublitharenite, interbedded with thin-bedded siltstone. 20.8 m

The co-occurrence of conodonts *Belodina compressa* and *Phragmodus undatus* in Layer 7 dates this interval to latest Gisbornian to early Eastonian (early-middle Caradoc) (Zhen Yong Yi personal communication, 2005). Most of the trilobites described in this paper occur in the upper part of Layer 9, about 70 m above Layer 7. This may suggest that the main horizon of the trilobite fauna could be late Caradoc-early Ashgill in age. However, as discussed below in the systematic description, the fauna exhibits a strong Caradoc aspect. In particular: *Sinocybele kazakhstanensis* (Koroleva, 1992) has previously been described from the Kalamolinskii strata (Caradoc) of the Stepnyakskii region, northern Kazakhstan; the genus *Collis* is restricted to the Caradoc; *Amphilichas* sp. is almost identical to *Amphilichas* sp. nov. A from the late Gisbornian (Caradoc) of Tasmania (Edgecombe *et al.* 2004) and close to

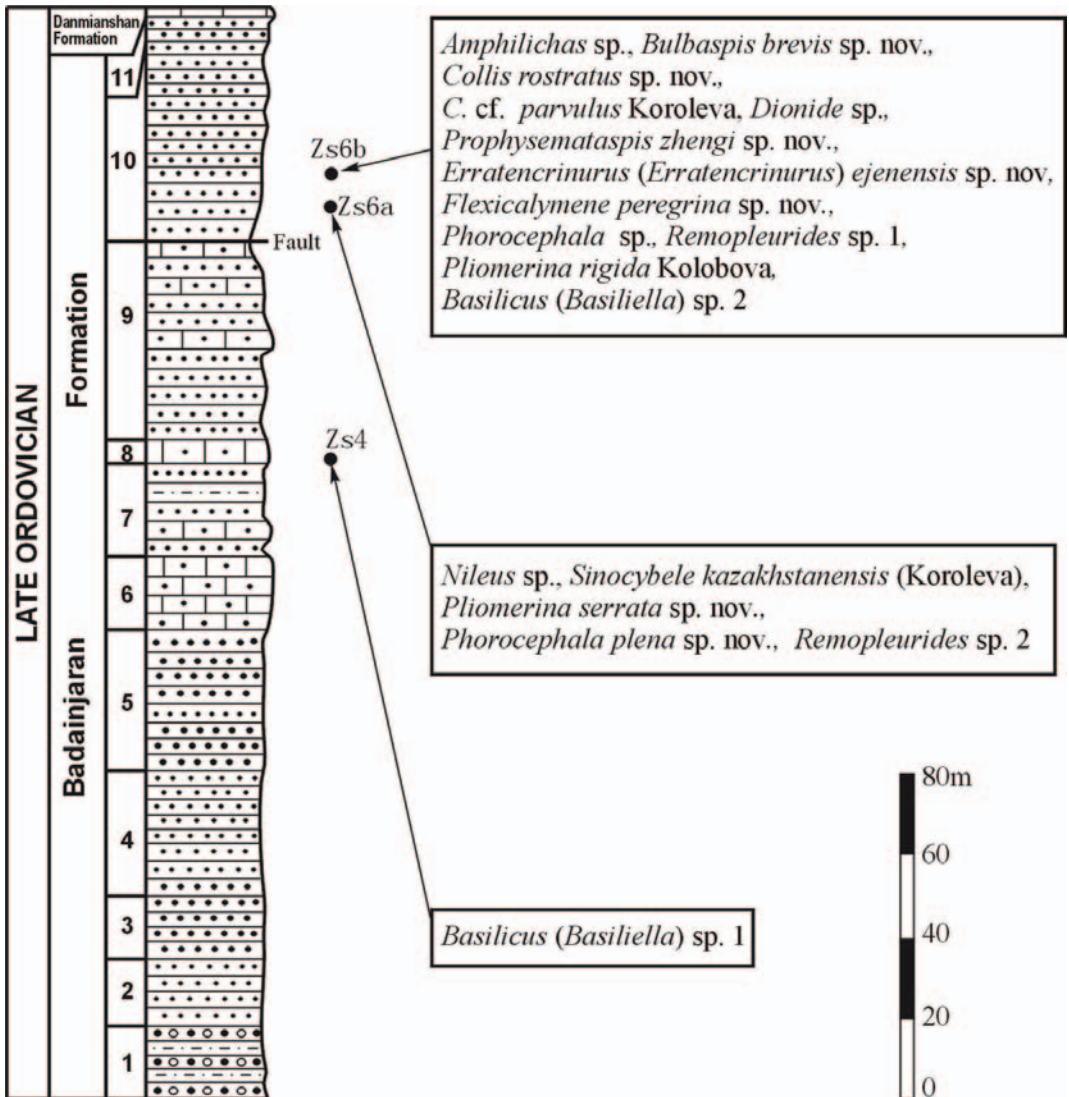


Fig. 2. Stratigraphic section of the Badainjaran Formation, measured at the point marked in Fig. 1B, showing the distribution of identified trilobite species.

Amphilichas ardmillanensis Reed, 1914 from the upper Balclatchie Group (lower Caradoc) of Scotland; and *Basilicus (Basiliella)* sp. 2 is closest to *Basiliella choii* Edgecombe, Banks & Banks, 2004 from the Gisbornian (Caradoc) of Tasmania and to *Isotelus levis* Chugaeva, 1958 from the Caradoc of the Chu-Ili Mountains of Kazakhstan. Therefore, at a closer estimate, it seems more likely that Layer 9 is of late Caradoc age.

The trilobite fauna consists of 13 identified genera, and 4 further indeterminate taxa. Of the 254 trilobite specimens collected, *Bulbaspis* makes up 22%, *Pliomerina* 19.7%, *Prophysemataspis* 12.5%, *Erratencrinurus (Erratencrinurus)* 7.8%, *Collis* 7.1%, *Flexicalymene* 7%, *Remopleurides* 5.4%, *Basilicus (Basiliella)* 4.5%, *Phorocephala*

2.4%, *Sinocybele* 1.4%, *Dionide* 1.4%, *Nileus* 0.7%, *Amphilichas* 0.7%, cheirurid 3%, illaenid 3%, proetid 0.7%, and harpetid 0.7%. *Bulbaspis* and *Pliomerina* dominate the fauna. All trilobites are disarticulated though not fragmentary, suggesting relatively high-energy conditions. The Badainjaran Formation consists largely of terrigenous deposits, and trilobites occur chiefly in intercalated sandy bioclastic limestones, which contain scattered coral reefs. The above evidence indicates that the *Bulbaspis-Pliomerina* association may characterise an inner shelf margin environment.

BIOGEOGRAPHIC RELATIONSHIPS

The 13 identified genera from Layers 7 and

9 may be divided into three groups. The first group includes *Amphilichas*, *Dionide*, *Nileus*, *Phorocephala*, *Remopleurides* and *Basilicus* (*Basiliella*), all of which are widespread during the Caradoc-middle Ashgill, but, except for *Remopleurides*, are mostly represented only by a few specimens. It is worth noting that the two asaphids described below as *Basilicus* (*Basiliella*) sp. 1 and 2 are respectively allied to *Pseudobasilicus? fortis* Webby, 1973 from the Caradoc of New South Wales, Australia, and to, as mentioned above, the coeval *Basiliella choii* from Tasmania and *Isotelus levis* from Kazakhstan.

The second group includes *Flexicalymene*, *Erratencrinurus* (*Erratencrinurus*) and *Prophysemataspis*. These genera occur commonly in Layer 9 and indicate a relationship to Late Ordovician Baltican and Laurentian faunas.

Flexicalymene Shirley, 1936 has been recorded from the Llanvirn-late Ashgill of Britain (Reed 1906; Shirley 1936; Dean 1963; Whittington 1965; Price 1974; Ingham 1977; Owen 1986), Ireland (Owen *et al.* 1986; Owen & Parkes 2000); Norway (Siveter 1977; Owen & Bruton 1980), Czech Republic (Barrande 1846; Hawle & Corda 1847; Shaw 2000), Kolyma, Siberia, Russia (Koren *et al.* 1983) and Ontario, Canada (Ludvigsen 1979).

Erratencrinurus (*Erratencrinurus*) Krueger, 1971 ranges from middle Caradoc to late Ashgill and occurs in the Lake District, England (Dean 1963; Ingham 1974; McNamara 1979), Baltica (Männil 1958; Krueger 1971, 1972, 2004; Owen 1981; Owen & Heath 1989) and North America (Hall 1847; Tripp 1974; Ludvigsen 1979; Lespérance & Desbiens 1995). However, one species, *Erratencrinurus trippi*, has recently been reported by Edgecombe *et al.* (1999a) from the middle-late Caradoc of Tasmania.

Prophysemataspis Lespérance & Desbiens, 1995 includes, apart from *Prophysemataspis zhengi* sp. nov., only *P. neuter* (Evitt & Tripp) and *E. uncatus* (Evitt & Tripp) from the Caradoc of Virginia, USA.

The third group shows strong Gondwanan affinities and contains *Bulbaspis*, *Pliomerina*, *Collis* and *Sinocybele*. All but *Sinocybele* are dominant forms in the fauna. They are diagnostic of the Badainjaran fauna and suggest a close relationship particularly to the eastern peri-Gondwanan faunas of Tarim, Kazakhstan and eastern Australia.

Bulbaspis Chugaeva, 1958, as revised below, includes, in addition to *B. brevis* sp. nov., *B. bulbifer* (Weber, 1932) from southern Kazakhstan, *B. sphaerornatus* Chugaeva, 1958 and *B. mirabilis* Chugaeva, 1958 from Chu-Ili Mountains of Kazakhstan, and *B. korlaensis* Zhang, 1981

from the northern Tarim Basin, Xinjiang, all of which are characterised by a subrhombic, carinate preoccipital glabella and a short pygidium; and are largely restricted to the Late Ordovician. The genus has also been reported from the Caradoc of the Langkawi Islands, Malaysia (Kobayashi & Hamada 1978) and southern Tasmania, Australia (Burrett *et al.* 1983), but specimens from both localities are too poor to make a precise generic assignment.

Pliomerina Chugaeva, 1956 has been described from the middle Arenig-early Ashgill (Zhou & Dean 1989) of North and Northwest China (Zhou & Fortey 1986; Chang & Jell 1983; Chu *et al.* 1979; Zhou *et al.* 1982); the Baoshan area of western Yunnan (part of the Sibumasu Terrane, see Zhou *et al.* 1998, 2001) (Reed 1917; Sheng 1974), China; South Korea (Kobayashi 1934a); the Chu-Ili Mountains and Chingiz Range of Kazakhstan (Weber 1948; Chugaeva 1956, 1958; Kolobova 1972; Apollonov 1975); Turkey (Dean 1973; Dean & Zhou 1988); central New South Wales (Webby 1971) and Tasmania, Australia (Corbett & Banks 1974; Edgecombe *et al.* 1999a); and the Precordillera of Argentina (Edgecombe *et al.* 1999b; Vaccari 2003). Recently, Edgecombe *et al.* (1999b) pointed out that *Parahawleia shengi* Xiang & Ji, 1988, from the early Ashgill of western Zhejiang, South China should be reassigned to *Pliomerina*.

Collis Koroleva, 1959 has previously been known only from the type species *C. parvulus* from the middle Caradoc of the Stepnyak area (part of the Chu-Ili Terrane, see Fortey & Cocks 2003, p. 289), northern Kazakhstan. *Malongullia oepiki* Webby, Moors & McLean (1970, p. 882, pl. 125, figs 1-2) from the Malongulli Formation (late Caradoc), New South Wales, Australia, however, is very similar to *C. parvulus*. It is possible that *Malongullia* may eventually prove to be a junior synonym of *Collis*, as suggested by Zhou *et al.* (1995, p. 63).

Sinocybele Sheng, 1974 ranges from the late Arenig to Ashgill and occurs in the Baoshan area of western Yunnan (Sheng 1974), South China (Lu in Lu & Chang 1974, as *Atractopyge sinensis* Lu; Lu 1975, as *Atractopyge sinensis* and *A. sp.*; Zhou *et al.* 1977, as *Atractopyge gaoluensis* Zhou; Qiu *et al.* 1983, as *Atractopyge gaoluensis* and *A. xianquaensis* Zhang; Zhou *et al.* 1984, as *Cybelurus? sinensis* (Lu) and *C.?* sp.; Ji 1986, as *Atractopyge lata* Ji; Tripp *et al.* 1989, as *Lyrapyge? gaoluensis* (Zhou); Chen & Zhou 2002; Turvey & Zhou 2002; Turvey & Zhou 2004; Zhou *et al.* 2005), northern Tarim (Zhang 1981), Turkey (Dean & Zhou 1988, as *Sinocybele? fluminis*), the Chalk'sky Range, Uzbekistan (Abdullaev & Khaletskaya 1970, as

Cybele pschemica), Kazakhstan (Weber 1948, as *Cybele planifrons* Weber, *Cybele weberi* Kolova, *Cybele* sp. 1 and *Cybele* sp. 2; Koroleva 1992, as *Koksorenus kazakhstanensis* Koroleva, see Chen & Zhou 2002) and New South Wales, Australia (Edgecombe & Webby 2006). It is significant that *Sinocybele kazakhstanensis* occurs in both the Zhusilenghaierhan area and Kazakhstan during the Caradoc.

Zhou & Dean (1989) indicated that Southeast Asia, China, Korea and Kazakhstan might have formed part of Gondwana during the Ordovician on the basis of trilobite evidence. Webby (1971, 1974, 1987, 1992), Webby *et al.* (2000) and Zhou *et al.* (1995) noted the close faunal relationships between eastern Australia, Tarim, South and Northwest China, and Kazakhstan during the Caradoc and proposed the *Eokosovopeltis-Pliomerina* Province to include these regions. Fortey & Cocks (2003) further outlined the global Ordovician palaeogeography and, on the basis of substantial new faunal information from Kazakhstan, indicated that the Tianshan, Chu-Ili and Chingiz terranes were all part of eastern peri-Gondwana at least in the Late Ordovician.

The genera *Bulbaspis*, *Pliomerina*, *Collis*, *Sinocybele* and *Basilicus* (*Basiliella*) are extremely diverse in Kazakhstan, especially in the Chu-Ili Terrane (*sensu* Fortey & Cocks, 2003), and some of these species are very similar to, or the same as, contemporaneous forms from the Zhusilenghaierhan area. A few trilobites, probably Caradoc in age, were described by Zhang (1981) from boreholes in the Korla area, northern Tarim Basin, Xinjiang, including *Bulbaspis korlaensis* (as *Bulbaspis* (*Parabulbaspis*) *korlaensis*), *Amphilichas konqihensis* (as *Cekovia konqihensis*), *Sinocybele* sp. (as *Atractopyge* sp.), and *Basilicus* (*Basiliella*) sp. (as *Basilicus* [*Basiliella*] cf. *yunnanensis* [Reed]). This is the only trilobite faunule that is close in composition to the Badainjaran fauna in China. It suggests that the Yining-Kawabulak-Beishan Terrane (Zhou *et al.* 1996a), of which the Zhusilenghaierhan area is a part, the Tarim Plate and the Kazakhstan terranes may have formed a single biogeographic unit at least during the Late Ordovician, supporting the view proposed by Zhou *et al.* (1996a). This unit may have been part of the *Eokosovopeltis-Pliomerina* Province.

SYSTEMATIC PALAEOLOGY

Eighteen species belonging to 10 families and 13 genera are described. Other elements, including an illaenid, cheirurid, harpetid and proetid, are too fragmentary to assign to a genus and are not described. All figured specimens were collected from Loc. 1 (Fig. 1B) and are housed in the

Nanjing Institute of Geology and Palaeontology (NIGP).

The terminology used here is essentially that of Whittington & Kelly (1997). The terminology for encrinurines follows that of Evitt & Tripp (1977), and the glabellar tubercle notation follows Strusz (1980). The term 'anterior part of preglabellar area' is employed in the description of *Flexicalymene* following Siveter & Chatterton (1996 p. 46). Systematic order is by family, following Fortey (1997).

Family LICHIDAE Hawle & Corda, 1847

Amphilichas Raymond, 1905

Type species. *Platymetopus lineatus* Angelin, 1854, from the Boda Limestone (Ashgill) of Dalarne, Sweden; by monotypy.

Amphilichas sp. (Fig. 3F)

Figured material. A cranidium NIGP140416, from horizon Zs6b.

Description. Cranidium approximately as long as wide, moderately convex (sag., tr.), strongly down-flexed forwards. Preoccipital glabella longer than wide, divided by a pair of longitudinal furrows into median lobe and a pair of lateral lobes. Longitudinal furrows deep and narrow, running forwards and slightly inwards from SO to 1/4 length of preoccipital glabella from back, then strongly diverging forwards in a smooth curve to anterior border furrow. Median lobe narrowest at about 1/4 length from back, where it is 55% as wide as basal glabellar width and 17% of anterior glabellar width. Lateral lobe kidney-shaped in outline, wider than base of median lobe, extending forwards to 73% of length of preoccipital glabella. SO deep, transverse medially, curving backwards behind lateral lobes. LO convex (tr.), 13% of cranial length (sag.), narrowing laterally. Axial furrows narrow and deep, weakly diverging forwards. Anterior border short and gently convex laterally, gradually narrowing inwards. Anterior border furrow deeper abaxially than adaxially. Fixigena poorly preserved, palpebral area convex. External surface closely covered with different sized tubercles and granules.

Remarks. The closest species to this form is *Amphilichas* sp. nov. A from the late Gisbornian (Caradoc) of Tasmania (Edgecombe *et al.* 2004, p. 75, fig. 12A-F). Although the latter has a slightly wider cranidium and a median lobe that is more rapidly expanded forwards in front of its narrowest part, the shape of the median lobe

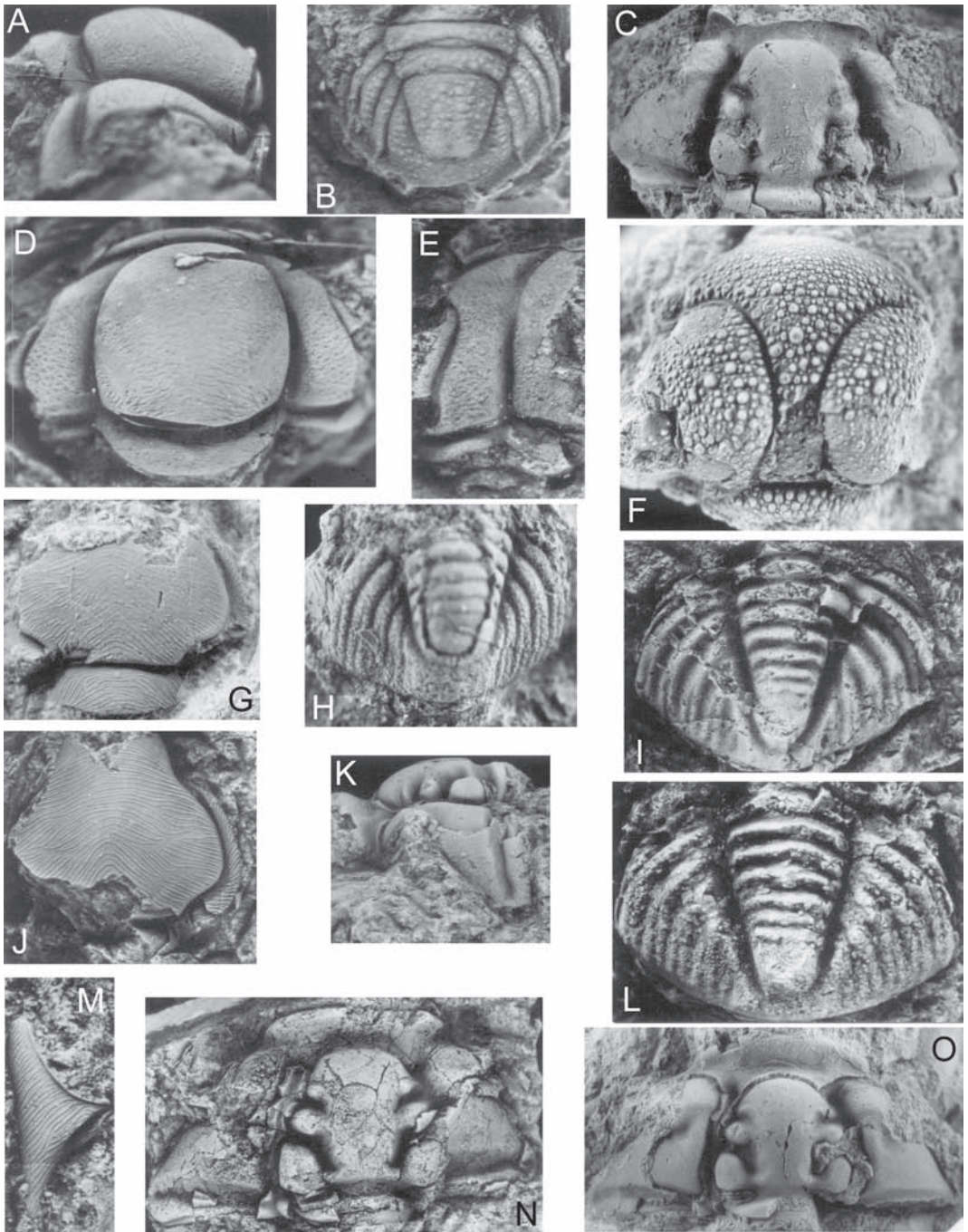


Fig. 3. A, B, D, *Phorocephala plena* sp. nov. from Horizon Zs6a. A, D, lateral and dorsal views of holotype cranidium, NIGP140412, $\times 10$. B, dorsal view of paratype pygidium, NIGP140413, $\times 12$. C, H, I, K, L, N, O, *Flexicalymene peregrina* sp. nov. from Horizon Zs6b. C, dorsal view of paratype cranidium, NIGP140414, $\times 4$. H, dorsal view of immature pygidium, NIGP140420, $\times 10$. I, dorsal view of paratype pygidium, NIGP140421, $\times 3$. K, O, lateral and dorsal views of holotype cranidium, NIGP140422, $\times 2.2$. L, dorsal view of pygidium, NIGP140423, $\times 4$. N, dorsal view of paratype cranidium, NIGP140424, $\times 1.7$. E, *Phorocephala* sp. from Horizon Zs6b, dorsal view of cranidium, NIGP140415, $\times 10$. F, *Amphilichas* sp. from Horizon Zs6b, dorsal view of cranidium, NIGP140416, $\times 3$. G, J, M, *Remopleurides* sp. 1 from Horizon Zs6b. G, dorsal view of cranidium, NIGP140417, $\times 5$. J, dorsal view of cranidium, NIGP140418, $\times 4$. M, dorsal view of librigena, NIGP140419, $\times 8$.

and lateral glabellar lobes and the pattern of the cranial surface sculpture of both are similar. The present form is also similar in many respects to *Amphilichas ardmillanensis* Reed (1914, p. 29, pl. 5, fig. 1; Tripp 1980, pl. 4, fig. 21) from the upper Balclatchie Group (lower Caradoc) of Scotland, but is distinguished by the more posteriorly expanded median lobe, and coarser cranial surface sculpture of tubercles and granules.

Family CALYMENIDAE Burmeister, 1843

Flexicalymene Shirley, 1936

Type species. Calymene blumenbachii var. *caractaci* Salter, 1865, from the Marshbrookian Stage (Caradoc), Shropshire, Britain; by original designation.

Flexicalymene peregrina sp. nov. (Fig. 3C, H-I, K-L, N-O)

Etymology. Latin *peregrinus*, strange, referring to the first record of the genus *Flexicalymene* in China.

Figured material. Holotype cranidium NIGP140422 (Fig. 3K, O). Paratypes: cranidia NIGP140414, 140424, pygidia NIGP140421, 140423, immature pygidium NIGP140420. All specimens from horizon Zs6b.

Diagnosis. A *Flexicalymene* species with weak S3; palpebral lobe small, situated opposite mid-length of L2 to S3; anterior part of preglabellar area 16-18% of cranial length, moderately upturned; pygidium relatively long, with maximum width 135-140% of the pygidial length (sag.).

Description. Except for those mentioned below, all specimens are preserved as internal moulds. Cranidium subtrapezoidal in outline, sagittal length about 3/4 width across palpebral lobes, with anterior margin very gently arched forwards. Preoccipital glabella bell-shaped, highly convex (tr.), becoming obviously narrower in front of S2, sagittal length 80-83% of basal width of preoccipital glabella, occupying 66-68% cranial length; frontal glabellar lobe steeply sloping toward broad preglabellar furrow, with rounded anterior margin. L1 large, subtriangular in outline, inflated, narrower (tr.) than central area of glabella; L2 subcircular, slightly more than half as long (exsag.) as L1, transversely directed; L3 small. Three pairs of lateral glabellar furrows present; S1 deep and wide (exsag.) at axial furrow, runs inwards and backwards, bifurcates at the inner end, longer posterior branch turning first

backward then inwards, extending on to median glabellar lobe as shallow depression; anterior branch directed forwards and inwards, confluent with weak longitudinal furrow which almost isolates L2 from median glabellar lobe; S2 short, deep, transverse, slightly backwardly directed adaxially; S3 short and weak, also transverse, close to S2. SO broad, shallow, weakly vaulted forwards behind central glabellar lobe, deep and narrow abaxially. LO arched (tr.), 15-17% of cranial length. Axial furrow deep and broad; anterior pit distinctly developed. Anterior border furrow broad and moderately deep. Anterior part of preglabellar area 16-18% of cranial length, gently upturned. Palpebral lobe small, situated opposite midlength of L2 to S3. Palpebral area arched (exsag., tr.), but lower than glabella, about 1/3 width of glabella across L2; posterior area of fixigena triangular in outline, about 4/5 the basal width of preoccipital glabella. Posterior border furrow broad and moderately deep. Anterior branches of facial suture slightly convergent forward; posterior branches run outwards for a short distance, then bend sharply backwards. External surface, as preserved in one specimen on the preglabellar furrow, anterior border and left posterolateral area of the fixigena (Fig. 3O), covered with closely-spaced granules of small to medium size. Surface of internal mould smooth.

Pygidium subrhombic in outline, widest across its anterolateral corners, where the width is 135-140% pygidial length. Axis strongly convex (tr.), occupying 88% pygidial length and 39-40% pygidial width anteriorly, tapering posteriorly, consisting of seven rings and a short terminal piece. First six ring furrows deeply incised, but the last shallower. Axial furrows deep; postaxial furrow much shallower. Pleural fields gently convex, steeply declined downwards abaxially, with five pairs of ribs delimited by deep pleural furrows in addition to articulating half ribs. Interpleural furrows deep abaxially, becoming shallower to mid-width of pleural fields and then effaced adaxially. Surface of internal mould smooth. External surface, as preserved on anterolateral part of a pygidium (Fig. 3I), bearing small granules. A juvenile pygidium (Fig. 3H) shows a wider, shorter and less tapering axis with six rings and a terminal piece, and granulose sculpture.

Remarks. The species resembles *Flexicalymene planimarginata* (Reed, 1906) (Whittington 1965, p. 60, pl. 17, figs 8-13, 16-17, 20-22) from the lower Bala Group (Caradoc) of Wales in the shape of the cranidium and glabella, the length of the anterior part of preglabellar area, and the number of pygidial segments, but differs in the

cranidium being slightly narrower (tr.) posteriorly, the frontal lobe of the glabella being slightly longer (sag.), the S3 weaker, the preglabellar furrow fainter, the palpebral lobe being more forwardly placed, and the pygidial axis being relatively narrower (tr.) and tapering backward more gently. *Flexicalymene declinata* (Hawle & Corda, 1847) from the Králův Dvůr Formation (Ashgill) of the Czech Republic (Shaw 2000, p. 381, pl. 3, figs 6-11; pl. 4, figs 1, 2) shares with *F. peregrina* the small L3, the long (sag.) and gently upturned anterior part of the preglabellar area, and the small and anteriorly placed palpebral lobe, but is distinguished by its shorter and weaker anterior branch of S1 and shorter pygidium with five axial rings.

Family PLIOMERIDAE Raymond, 1913

Pliomerina Chugaeva, 1956

Type species. Pliomerina martelli Reed, 1917, from the Shihtien Formation (Llanvirn) of Pupiao, Baoshan, western Yunnan, China; by original designation.

Pliomerina rigida Kolobova, 1972 (Fig. 4G-M, P-Q)

1972 *Pliomerina rigida*; Kolobova, p. 242, pl. 56, figs. 7-9.

Figured material. Cranidia NIGP140430, 140435, 140436, hypostome NIGP140433, pygidia 140431, 140432, 140434. All specimens from horizon Zs6b.

Description. Cranidium subtrapezoidal in outline, sagittal length 80-87% of width at midlength. Preoccipital glabella moderately convex (sag., tr.), subpentagonal in outline, expanded forwards, broadly rounded anteriorly, widest across L3, where the width is 119-122% the sagittal length and 130-137% the basal width. Three pairs of broad, deep lateral glabellar furrows initiated from axial furrows; S1 close to SO, directed inwards and slightly backwards and reaching 1/3 width of preoccipital glabella; S2 situated at 36-37% of length of preoccipital glabella from back, approximately parallel to and as long (tr.) as S1; S3 placed just in front of the anterolateral corner of the glabella, directed inwards and backwards at about 65° to sagittal line, slightly shorter (tr.) than S2. L2 longer than L1, and both slightly wider adaxially; L3 about twice as long as L2, shorter (exsag.) proximally than distally. Frontal lobe subrhombic in outline, occupying about 1/2 sagittal length of preoccipital glabella.

SO deep, gently forwardly arched medially. LO convex (tr.), 19% of cranial length, gradually shortening laterally. Axial furrows broad and deep; preglabellar furrow distinct abaxially, becoming shallower adaxially. Anterior border incompletely preserved, wider (exsag.) laterally. Palpebral area narrow and strongly convex (tr.); posterior area of fixigena triangular in outline, slightly narrower (tr.) than basal width of preoccipital glabella. Palpebral lobe situated opposite L2, well defined by palpebral furrow, about 1/4 length of preoccipital glabella. Anterior branches of facial suture diverge slightly forwards; posterior branches run backwards and outwards. Posterior border furrow deeply incised, transverse. Posterior border convex, widening slightly outwards. External surface covered with fine, closely spaced granules.

Hypostome subovoid in outline, almost as long as wide, sides converging backwards, posterior margin rounded. Median body moderately convex (sag., tr.); anterior margin strongly forwardly arched; lateral margin weakly backwardly convergent to mid-length of hypostome, then strongly tapering backwards; width slightly less than sagittal length of hypostome; weak lateral bulges present just in front of anterior wings; middle furrow deeply incised, with a pair of oval maculae on its posterior slope; posterior lobe subtriangular in shape, narrowly rounded posteriorly. Anterior border and wings not preserved. Lateral and posterior border furrows broad and deep. Lateral borders sloping towards border furrows; posterior border flattened, strongly widening backward. Surface of median body covered with sparse granules.

Pygidium subsemielliptical in outline, widest at mid-length, where the width is 140% of its sagittal length. Axis highly convex (tr.), anterior width 35-36% the maximum width of pygidium, tapering backward, consisting of five axial rings plus a terminal piece; five transverse ring furrows, all broad and deep except for the last that becomes shallower adaxially; terminal piece wedge-shaped, 33-35% of axial length, gently sloping backwards. Axial furrow broad and deep on internal mould, reaching pygidial margin posteriorly. Pleural field moderately convex (tr.) adaxially, strongly declining outwards, divided by deep, broad pleural furrows into five pleurae; each pleura with short, bluntly ended, down-flexed spine. First pleura transverse adaxially, sharply flexed at fulcrum, then extending backward; second and third pleurae running outward and backward; the fourth strongly backwardly curved; the last longitudinal, extending slightly beyond terminal piece of pygidial axis. Surface of internal mould covered with tiny pits. External surface as

preserved on the right first pleura (Fig. 4K, M) shows sparse, small granules.

Remarks. This species is remarkably similar to *Pliomerina yaoxianensis* Chen (in Zhou *et al.* 1982, p. 285, pl. 70, figs 13, 14) from the Taoqupo Formation (late Caradoc) of Yaoxian, central Shaanxi, China, particularly in the broad preoccipital glabella and the segmentation of the pygidium, but is distinguished by the following features: the L3 is more expanded abaxially; the pygidium more convex and subsemielliptical instead of subquadrate in shape; the first pleura sharply flexed at fulcrum; and each pleura having a bluntly ended, down-flexed spine.

***Pliomerina serrata* sp. nov.** (Fig. 4A-F)

Etymology. Latin *serratus*, serrated, in reference to the pygidial margin.

Figured material. Holotype cranidium NIGP140425 (Fig. 4A). Paratypes: cranidium NIGP140426, hypostome NIGP140427, pygidia NIGP140428, 140429. All specimens from horizon Zs6a.

Diagnosis. A *Pliomerina* species showing a relatively long frontal glabellar lobe, occupying about 1/2 length of preoccipital glabella. Palpebral lobe situated opposite L3. Hypostome longer than wide, sharply tapering backwards, with strongly convex (tr.) median body. Pygidium short and wide, with pleurae strongly widening outwards, ending in free, pointed tips.

Description. Cranidium subsemielliptical in outline, sagittal length 63% of posterior width. Preoccipital glabella highly convex (tr.), expanded forwards, attaining its maximum width at 54-57% of length of preoccipital glabella from back, this being 104-107% the sagittal length and 134-141% the basal width of preoccipital glabella; anterior margin broadly rounded. Three pairs of lateral glabellar furrows originating from axial furrows and deeply incised; S1 arises a short distance in front of SO, extending inward and slightly forward to 1/3 of glabellar width; S2 is situated at about 1/3 length of preoccipital glabella from back, directed inward and slightly backward, as long (tr.) as S1; S3 at 2/3 length of preoccipital glabella from back, running inward and backward at about 60° to the sagittal line, as long or slightly longer (tr.) than S2. Three pairs of lateral glabellar lobes successively increase in width anteriorly. Frontal lobe occupies about 1/2 length of preoccipital glabella, anterior part sloping down to preglabellar furrow. SO deep,

gently arched forwards. Axial furrows broad and deep; preglabellar furrow deeply incised abaxially, shallowing inwards and effaced adaxially. LO convex (tr.), occupying 18-19% of cranial length (sag.), gradually shortening (exsag.) laterally. Anterior border short (exsag.), only discernible laterally on dorsal surface, widening slightly outwards. Fixigena moderately convex (tr.), sloping outwards and forwards, subtriangular in outline, posterior width slightly less than basal width of preoccipital glabella. Palpebral lobe well defined by distinct palpebral furrow, rather prominent, situated at midlength of cranidium, occupying 23% of cranial length, directed backward and slightly outward. Posterior border gently widened outward, well defined by broad and deep posterior border furrow. Anterior branches of facial suture slightly anteriorly divergent; posterior branches extending outward and backward in sigmoidal curves. External surface covered with small, weak granules.

Hypostome longer than wide, sharply tapering backward, strongly arched forward anteriorly, narrowly rounded posteriorly. Median body pear-shaped in outline, expanded forwards, strongly convex (tr.), maximum width between anterior wings, this being 72% of its sagittal length. Middle furrow weak, situated at posterior 1/3 length of median body. Anterior border very short (exsag.), dying out medially. Anterior wing moderately wide, triangular, weakly depressed. Lateral border well defined by deep border furrow, narrow (tr.), upturned. Posterior border relatively long (sag.), occupying 9% of length of hypostome, flattened. External surface covered with small granules.

Pygidium semielliptical in outline, sagittal length 57% of anterior width. Axis occupies 37% of pygidial width anteriorly, tapering backward, with five axial rings plus a large terminal piece. Axial rings delimited by deep, transverse ring furrows, strongly convex (tr.), successively decreasing in length backward; terminal piece bounded by shallow posterior section of axial furrows, triangular in outline, occupying about 1/3 length of pygidial axis, gently convex and declining backward. Pleural field gently convex adaxially, strongly declining downward abaxially, with four pairs of deep pleural furrows. Five unfurrowed pleurae with free, bluntly pointed ends. First pleura rather abruptly flexed at fulcrum, outer part directed outward and strongly backward; second to fourth pleurae run outward and backward, strongly widening abaxially; last pleura almost longitudinal, with posterior end extending slightly beyond terminal piece of pygidial axis. External surface smooth.

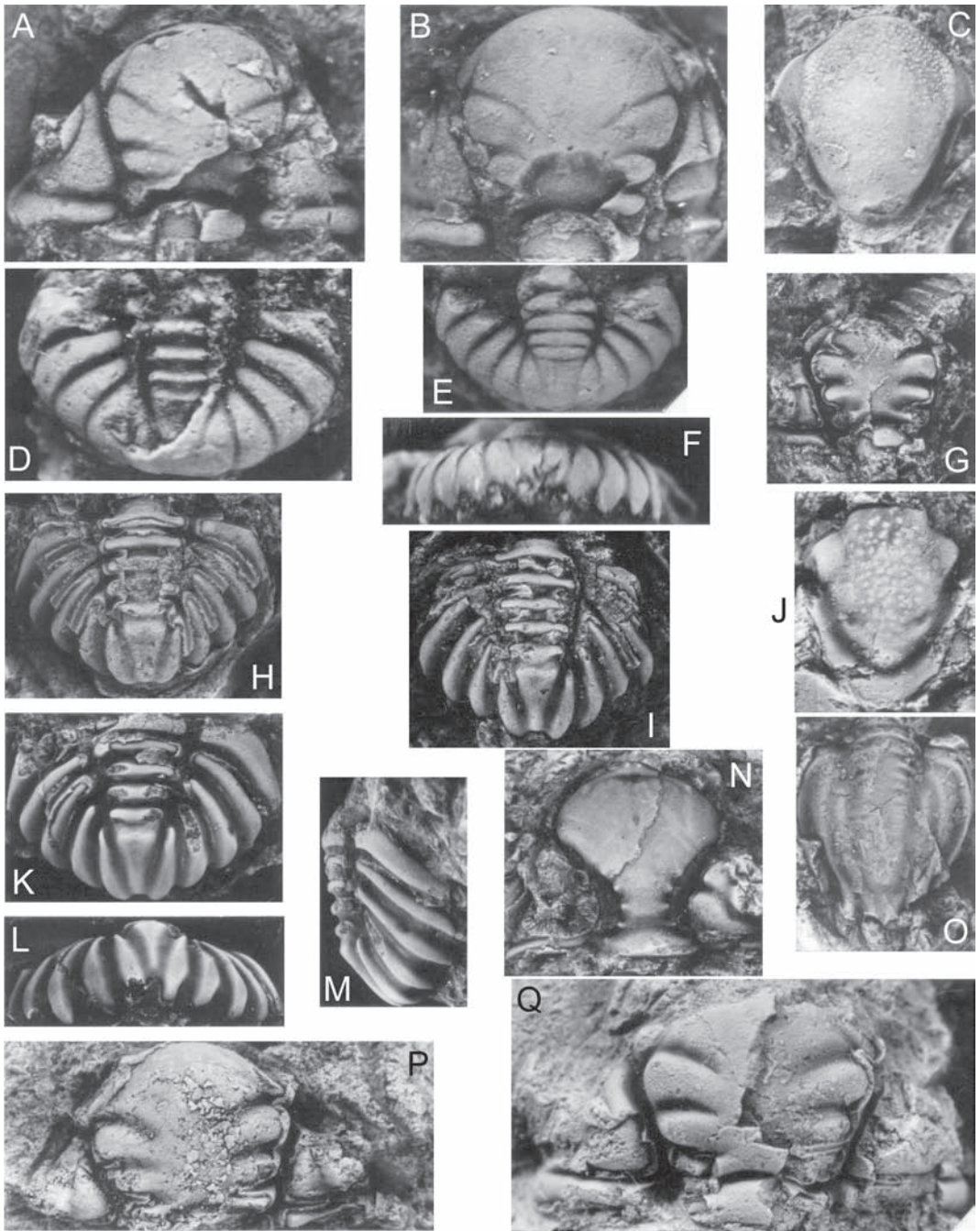


Fig. 4. A-F, *Pliomerina serrata* sp. nov. from Horizon Zs6a. A, dorsal view of holotype cranidium, NIGP140425, $\times 15$. B, dorsal view of paratype cranidium, NIGP140426, $\times 15$. C, ventral view of paratype hypostome, NIGP140427, $\times 12$. D, dorsal view of paratype pygidium, NIGP140428, $\times 15$. E, F, dorsal and posterior views of paratype pygidium, NIGP140429, $\times 15$. G-M, P, Q, *Pliomerina rigida* Kolobova, 1972 from Horizon Zs6b. G, dorsal view of cranidium, NIGP140430, $\times 3$. H, dorsal view of pygidium, NIGP140431, $\times 3$. I, dorsal view of pygidium, NIGP140432, $\times 3$. J, ventral view of hypostome, NIGP140433, $\times 5$. K-M, dorsal, posterior and lateral views of pygidium, NIGP140434, $\times 3$. P, dorsal view of cranidium, NIGP140435, $\times 3$. Q, dorsal view of cranidium, NIGP140436, $\times 4$. N, O, *Sinocybele kazakhstanensis* (Koroleva, 1992) from Horizon Zs6a. N, dorsal view of cranidium, NIGP140437, $\times 4$. O, dorsal view of pygidium, NIGP140438, $\times 4$.

Remarks. *Pliomerina serrata* strongly resembles *Pliomerina dulanensis* Chugaeva from the Dulankarin Horizon (late Caradoc to early Ashgill) of Dulankara, Chu-Ili Mountains, southern Kazakhstan (Chugaeva 1958, p. 102, pl. 11, figs 1-4) in glabellar shape, but differs in its longer and more oblique S3, wider and shorter pygidium with better defined fifth axial ring and terminal piece, and in having its pleurae ending in free, pointed tips. The new species is also comparable with *Pliomerina sanjuanina* (Vaccari 2003, p. 240, Fig. 3A-G, H?) from the upper part of the San Juan Formation (Llanvirm) of Precordillera, Argentina, especially in pygidial shape and segment number, but differs in having the second to fifth pygidial pleurae more strongly widening abaxially, in the more forwardly expanded glabella with much larger frontal lobe, and in the medial effacement of the anterior border furrow. It is readily distinguished from the younger species *P. rigida* Kolobova from Layer Zs6b in the same section by its proportionately longer glabella and frontal glabellar lobe, more strongly convex central body of the hypostome and shorter pygidium.

Family ENCRINURIDAE Angelin, 1854

Sinocybele Sheng, 1974

[=*Koksorenus* Koroleva, 1992, see Chen & Zhou 2002]

Type species. *Sinocybele baoshanensis* Sheng, 1974, from the Shihtien Formation (Llanvirm) of Baoshan, western Yunnan, China; by original designation.

Sinocybele kazakhstanensis (Koroleva, 1992) (Fig. 4N, O)

1992 *Koksorenus kazakhstanensis*; Koroleva, p. 123, fig. 1A-D.

Figured material. Cranidium NIGP140437, pygidium NIGP140438, from horizon Zs6a.

Description. Material preserved as internal moulds. Cranidium subsemielliptical in outline, about 67% as long as wide. Preoccipital glabella moderately convex (sag., tr.), clavate in outline, broadly rounded anteriorly, narrowest across L2, from which it is slightly expanded backwards to SO, but rapidly expanded forwards to attain its maximum width at about 1/3 length from anterior margin, where width is nearly equal to length of preoccipital glabella and about three times minimum width of preoccipital glabella. Four pairs of short lateral glabellar furrows are distributed on

flanks of posterior half of preoccipital glabella; S1 and S2 broad and deep; S3 as strong as S1 and S2, but slightly forwardly directed; S4 rather weak, parallel to S3. Four pairs of lateral glabellar lobes represented by small swellings; L1 the shortest; L4 poorly defined, slightly longer than others. SO gently arched forwards, broad and deep abaxially. LO rather convex (tr.), steeply sloping towards SO, 15% of length (sag.) of preoccipital glabella, tapering laterally, much wider than glabellar width across L1. Axial furrows broad and deep. Preglabellar furrow indistinct laterally, gradually becoming defined adaxially, sharply deepening and broadening medially. Anterior border gently convex, wider adaxially, produced into an obtuse angle anteriorly, surface covered with low and weak tubercles except for a pair of prominent tubercles on both sides of the sagittal line. Fixigena strongly convex, steeply sloping towards axial furrows; palpebral area narrow (tr.); posterior area as wide (tr.) as LO. Palpebral lobe vertical, situated opposite S2. Eye ridge thick, well defined by deep furrow posteriorly. Posterior border well defined by distinct border furrow, short (exsag.), gently curving backward abaxially.

Pygidium 78% as wide as long. Axis convex (tr.), tapering steadily rearwards, occupying 78% pygidial length (sag.) and 40% pygidial width anteriorly, divided into fourteen rings. First five axial ring furrows transverse, deeply incised laterally, becoming shallower adaxially; the remainder only faintly defined. Postaxial region short, triangular in form. Axial furrows broad and shallow; postaxial furrow weak. Pleural field gently convex adaxially, declined laterally, composed of three pleural ribs, each divided by deep pleural furrows into a short, depressed anterior band and a longer and more strongly convex posterior band; these posterior bands extend beyond the margins into short, inwardly and backwardly directed spines, the third pair close together at the posterior margin.

Remarks. Except for the anterior cranial border that shows a pair of prominent tubercles instead of small spines on both sides of the sagittal line, the material described here is identical with the type specimens of *Sinocybele kazakhstanensis* (Koroleva 1992, p. 123, fig. 1A-D) from the Kalamolinskii strata (Caradoc) of the Stepyakskii region of northern Kazakhstan. The species shows sharp differences from *Sinocybele gaoluensis* (Zhou) from the Linxiang Formation (early Ashgill), western Hubei (Zhou *et al.* 1977, p. 260, pl. 79, figs 1, 2; as *Atractopyge gaoluensis*) and the Tangtou Formation (late Caradoc-early Ashgill), southern Jiangsu (Tripp

et al. 1989, p. 62, figs 16a-g, j, m, n; 17a, i, j, o, u; as *Lyrapyge? gaoluensis*) in the more strongly forwardly expanded glabella, the shorter and unbranched glabellar furrows, the narrower fixigenae, the thicker eye ridges, and the longer and narrower pygidium.

Prophysemataspis Lespérance & Desbiens, 1995

Type species. *Encrinuroides uncatatus* Evitt & Tripp, 1977, from the Oranda Formation (Caradoc), northern Virginia, USA; by original designation.

Remarks. Edgecombe & Chatterton (1990) reviewed the history of classification of the genus *Encrinuroides* Reed, 1931. They considered that the diagnostic characters of *Encrinuroides* given by Reed (1931) are synapomorphies of a more inclusive group or are even more general, and some characters are not shared by species typically assigned to *Encrinuroides* by subsequent workers. They argued that the key characters proposed by Whittington (1950, 1965), Shaw (1968) and Evitt & Tripp (1977) are either plesiomorphies or undiagnostic. In their opinion, the more useful characters used to distinguish *Encrinuroides* from other encrinurines include the extreme abundance of small, irregularly arranged glabellar tubercles, an anterior cranial border of uniform length (sag., exsag.), the rostral plate with nearly equal width between the connective sutures, and the pygidium with continuous pygidial ring furrows and tubercles on each ring. Therefore, *Encrinuroides neuter* Evitt & Tripp and *E. uncatatus* Evitt & Tripp from the Caradoc of Virginia should be excluded from *Encrinuroides* (Edgecombe & Chatterton 1990), because both of them have coarser glabellar tubercles, a sagittally shorter anterior cranial border, discontinuous pygidial axial ring furrows, and no sagittal tubercles on each axial ring. Lespérance & Desbiens (1995, p. 11) established a new subgenus *Prophysemataspis* (*Prophysemataspis*) based on the type species *Encrinuroides uncatatus* and *E. neuter*. However, *Prophysemataspis* Evitt & Tripp, 1977 differs notably from *Prophysemataspis* in the bulbous and subcircular preoccipital glabella with obsolete lateral glabellar furrows and lobes, the larger and more inflated palpebral lobe, the smaller tubercles irregularly arranged on the surface of the preoccipital glabella, and the fewer segments in the pygidium (10-15 axial rings and 5-6 pleural ribs) with axial rings possessing paired tubercles. In this regard, *Prophysemataspis* Lespérance & Desbiens, 1995 is better considered as an independent genus.

More recently, Pärnaste (2006, p. 159) suggested that *E. uncatatus* and *E. neuter* are better assigned to *Erratencrinurus* Krueger, 1972, and that *Prophysemataspis* (*Prophysemataspis*) may be synonymous with *Erratencrinurus*. However, *Erratencrinurus* is distinguished from *Prophysemataspis* by having 20-40 larger glabellar tubercles [some of which may even merge into short horns or spines in some species of *E. (Erratencrinurus)*], a smooth rather than denticulate posterior hypostomal margin, and more pygidial segments (25-36 axial rings and 8-16 pleural ribs).

Prophysemataspis zhengi sp. nov. (Figs 5A, C-D, H, K-L, N-Q, 6B-C)

Etymology. After Professor Zheng Zhaochang, Ningxia Institute of Geology, who helped collect the specimens dealt with in this paper.

Figured material. Holotype cranium NIGP140439 (Fig. 5A, D). Paratypes: cranidia NIGP140443, 140444, 140455, librigena NIGP140454, pygidia NIGP140440, 140441, 140445. All specimens from horizon Zs6b.

Diagnosis. A *Prophysemataspis* species with rounded genal angle. Preoccipital glabella decorated with 48-56 dome-shaped tubercles of various sizes. L2, L3 and F4-3 occupied by coarse tubercles. Three pairs of lateral glabellar furrows short and moderately deep, anteromedian glabellar furrow distinct. Tubercle formula on posterior part of preoccipital glabella: 1L-1; 1S-0; 2L-3, 2, 1; 2S-0; 3L-2, 1. Anterior border of cranium with 8 tubercles and shallow anteromedian depression. Pygidium wider than long, with 17-19 axial rings and 8 pleural ribs. Axial ring without median tubercle, well defined by continuous furrows.

Description. Cranium subtriangular in outline, sagittal length 80-87% the width at midlength and 48-50% the posterior width of cranium. Preoccipital glabella convex (sag., tr.), expanded forwards, width across frontal lobe 164-175% width across L1 and 86-95% sagittal length. Three pairs of lateral glabellar furrows short and moderately deep; S1 longer (tr.) than S2 and S3, extending inwards and slightly forwards to almost 1/3 width of basal preoccipital glabella; S2 and S3 directed slightly forward. SO deeply incised, transverse. L1 composed of narrow (exsag.) ridge that runs inward and slightly forward from the axial furrow and becomes longer inward; L2 and L3 represented by coarse, elongate, subovoid tubercles. Frontal lobe 49-54% length of preoccipital glabella,

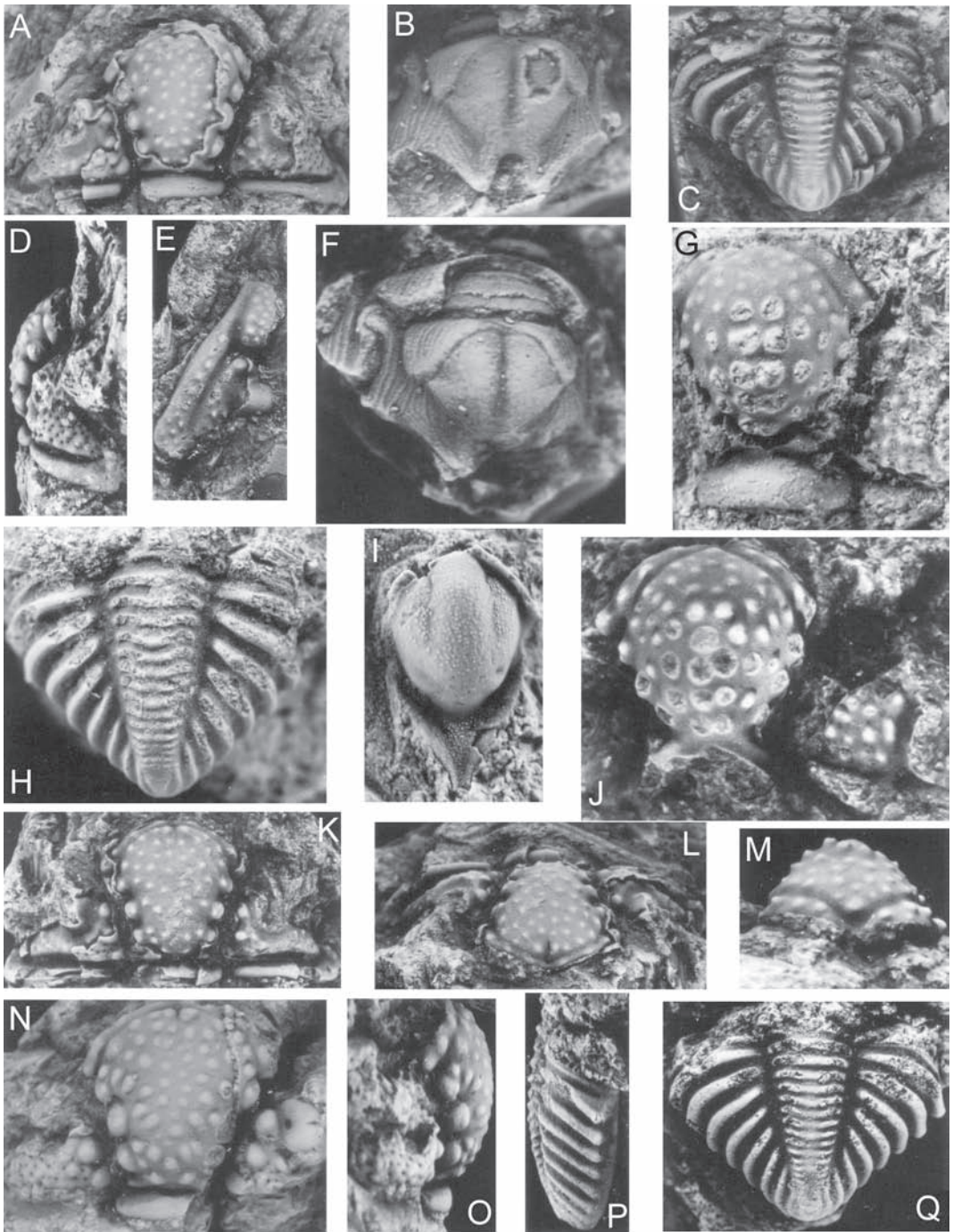


Fig. 5. A, C-D, H, K-L, N-Q, *Prophysemataspis zhengi* sp. nov. from Horizon Zs6b. A, D, dorsal and lateral views of holotype cranium, NIGP140439, $\times 3.5$. C, dorsal view of paratype pygidium, NIGP140440, $\times 5$. H, dorsal view of paratype pygidium, NIGP140441, $\times 5$. K, L, dorsal and obliquely anterior views of paratype cranium, NIGP140443, $\times 3$. N, O, dorsal and lateral views of paratype cranium, NIGP140444, $\times 5$. P, Q, lateral and dorsal views of paratype pygidium, NIGP140445, $\times 4$. B, F, *Remopleurides* sp. 2 from Horizon Zs6a. B, dorsal view of pygidium, NIGP140446, $\times 15$. F, dorsal view of pygidium, NIGP140447, $\times 15$. E, G, I, J, M, *Erratencrinurus* (*Erratencrinurus*) *ejinensis* sp. nov. from Horizon Zs6b. E, dorsal view of paratype librigena, NIGP140448, $\times 3$. G, dorsal view of paratype cranium, NIGP140449, $\times 8$. I, ventral view of paratype hypostome, NIGP140442, $\times 8$. J, M, dorsal and anterior views of holotype cranium, NIGP140450, $\times 7$.

semicircular in outline, F4-3 occupied by coarse tubercles, with a short, backwardly directed anteromedian glabellar furrow. LO convex (tr.), standing above the basal glabellar lobes, 12-13% of cranial length. Axial furrow broad and deep. Preglabellar furrow deep laterally, slightly shallowing inward. Anterior border of cranium short (sag., exsag.), moderately convex, forwardly arched, slightly wider laterally, with a shallow anteromedian depression on its posterior edge. Fixigenae triangular in outline, convex, with narrow (tr.) palpebral area and rather wide (tr.) and strongly outwardly declining posterior area. Palpebral lobes elevated, 20-21% of cranial length, with midpoint in line with the midlength of L3. Posterior border furrow deep. Posterior borders gently convex, strongly sloping outwards abaxially. Genal angle rounded. Anterior branches of facial suture poorly preserved; posterior branches run directly out from palpebral lobes, then curve backward and outward to cut posterior margin in front of genal angles.

Preoccipital glabella bears dome-shaped tubercles of various sizes, a total of 48-56, decreasing in size medially. Tubercle formula on posterior part of glabella: 1L-1; 1S-0; 2L-3, 2, 1; 2S-0; 3L-2, 1. Frontal lobe has 31-37 small and medium-sized tubercles: one pair of large tubercles (F4-3) on its abaxial ends; eight to ten medium-sized tubercles arranged in an arc along anterior margin of glabella; the remainder are randomly distributed. Tubercles 3L-2 are the largest pair, elongate ovoid, 8.6% the width of frontal glabellar lobe. 2L-3 and F4-3 also elongate ovoid in form, but slightly smaller than 3L-2. Fixigena with six to ten medium to large tubercles, of which 2-4 along axial furrow are larger than others; surface between the tubercles strongly pitted. Anterior border of cranium bears a row of 8 medium tubercles.

Librigena subtriangular in outline. Genal area broad, gently convex, with round pits of varying size, and small tubercles in between. Eye not preserved. Lateral border broad and flat, with a row of low, medium sized tubercles (at least 5). Lateral border furrow broad and moderately deep. Precranial lobe large, higher than lateral border, with small tubercles. Anterior border of cephalon continuous with lateral border, convex, sharply narrowing adaxially, lacking tubercles.

External surface of cephalon including tubercles densely covered with fine granules.

Pygidium triangular in outline, 74-78% as long as wide. Axis strongly convex (tr.), tapering backward almost to posterior margin, 30-34% the anterior width of pygidium, composed of 17-19 axial rings plus a terminal piece. A short, pointed postaxial ridge almost reaches posterior margin

and is surrounded by posterior pair of pleural ribs. Anterior 14 axial ring furrows deep laterally, but becoming shallower and gently backwardly bent medially; posterior 3 or 4 axial ring furrows shallow and dying out medially. Axial furrows beside anterior 14 axial rings are deep, shallowing backward. Pleural fields moderately convex (tr.), sloping steeply towards pygidial border. Eight pairs of pleural ribs defined by broad, deep, and successively more backwardly curving inter-rib furrows, with the eighth pair parallel to axis. Termination of pleural ribs rounded or truncated, overhanging narrow vertical border. Surface of internal mould without sculpture; external surface, as partly preserved on a pygidium (Fig. 5C), covered densely with tiny granules.

Remarks. *Prophysemataspis zhengi* sp. nov. resembles *P. neuter* (Evitt & Tripp 1977, p. 130, pl. 3, figs 7-9; pls 8-11; text-figs 9-11), especially in the shape of the preoccipital glabella and pygidium, the short and moderately deep lateral glabellar furrows, the L2, L3 and F4-3 covered by tubercles, the presence of tubercles 1L-1, 1S-0, 2L-2, 1, 3L-2, 1, and the numbers of axial and pleural ribs on the pygidium. It differs in several features: L1 is shorter (exsag.); the palpebral lobe is closer to the axial furrow; the anterior border of the cranium has smaller tubercles; the fixigena has no genal spine; the pygidial axis is more convex, with axial rings lacking median tubercles; and the pygidial axial ring furrows are continuous and sigmoid.

Erratencrinurus Krueger, 1971

Type species. *Erratencrinurus capricornu* Krueger, 1971, from glacial erratics of the Rakvere Stage (E) (middle Caradoc), Baltic shore near Binz (Rostock district), eastern Germany; subsequently designated by Krueger (1972, p. 858).

Erratencrinurus (Erratencrinurus) Krueger, 1971

Remarks. *Erratencrinurus* Krueger, 1971 and *Celtencrinurus* Evitt & Tripp, 1977 [type species *Encrinurus multisegmentatus* (Portlock, 1843)] are closely related. Temple & Tripp (1979, p. 24) suggested that the two taxa might best be expressed at subgeneric level. This view was supported in principle by Strusz (1980, p. 9). Owen (1981, p. 48) formally recognised *Erratencrinurus* and *Celtencrinurus* as subgenera of *Erratencrinurus*, an arrangement followed here. In our opinion there are sharp differences between these subgenera. *Erratencrinurus* (*Celtencrinurus*) shows coarse glabellar tubercles

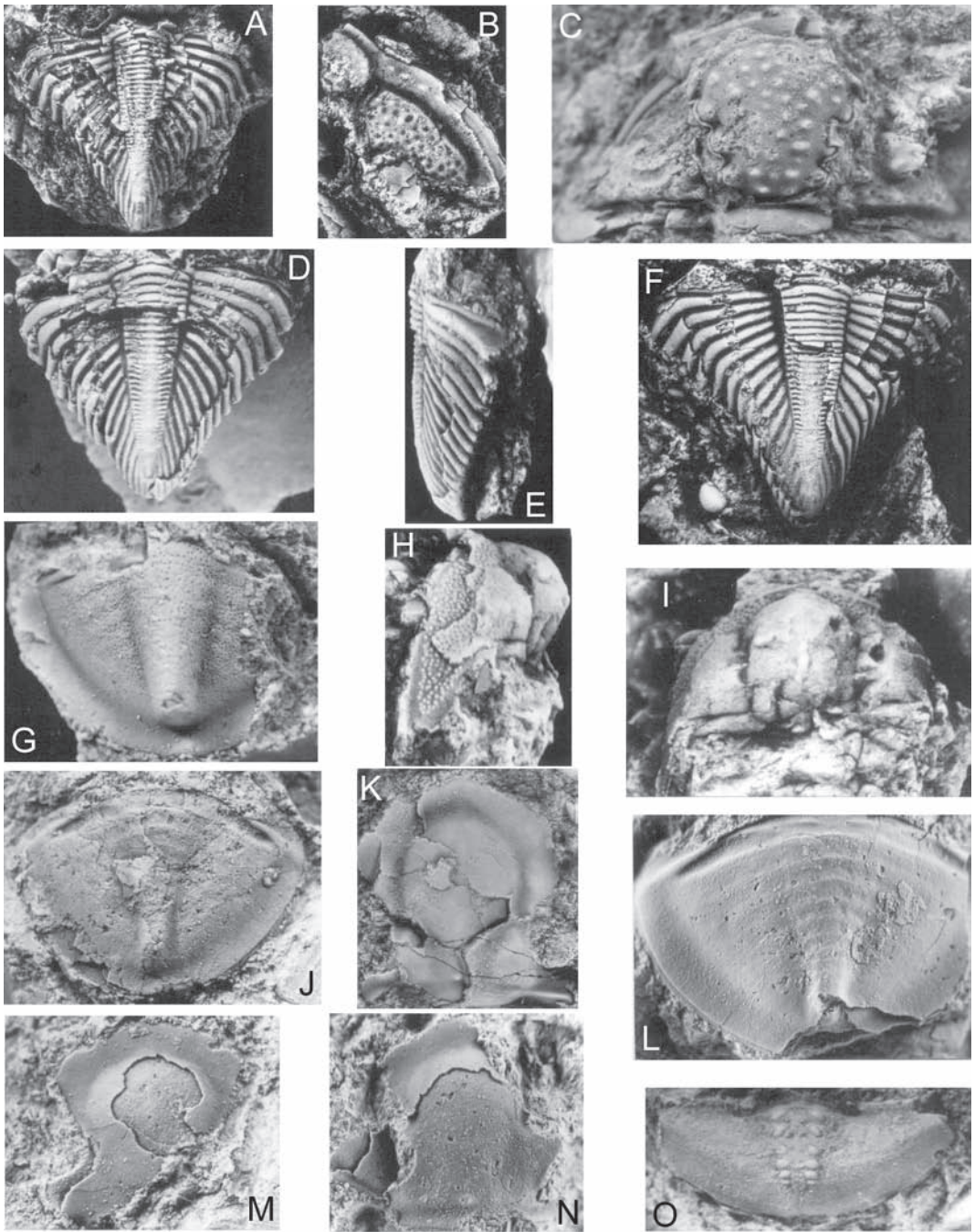


Fig. 6. A, D-F, *Erratencrinurus (Erratencrinurus) ejinensis* sp. nov. from Horizon Zs6b. A, dorsal view of paratype pygidium, NIGP140451, $\times 2.5$. D, E, dorsal and lateral views of paratype pygidium, NIGP140452, $\times 6$. F, dorsal view of paratype pygidium, NIGP140453, $\times 3.5$. B, C, *Prophysemataspis zhengi* sp. nov. from Horizon Zs6b, B, dorsal view of paratype librigena, NIGP140454, $\times 2$. C, dorsal view of paratype cranidium, NIGP140455, $\times 5$. G, J, L-N, *Basilius (Basiliella)* sp. 2 from Horizon Zs6b. G, dorsal view of pygidium, NIGP140456, $\times 8$. J, dorsal view of pygidium, NIGP140457, $\times 3$. L, dorsal view of pygidium, NIGP140458, $\times 3$. M, dorsal view of cranidium, NIGP140459, $\times 4$. N, dorsal view of cranidium, NIGP140460, $\times 4$. H, I, *Dionide* sp. from Horizon Zs6b, lateral and dorsal views of cephalon, NIGP140461, $\times 8$. K, *Basilius (Basiliella)* sp. 1 from Horizon Zs4, dorsal view of cranidium, NIGP140462, $\times 1.6$. O, *Bulbaspis brevis* sp. nov. from Horizon Zs6b, dorsal view of paratype pygidium, NIGP140463, $\times 6$.

that are closely spaced and almost uniform in size, with the tubercle 1L-0 invariably present, while *E. (Erratencrinurus)* lacks the tubercle 1L-0 and bears variably sized and more sparsely distributed glabellar tubercles, some of which may extend into short spines.

Erratencrinurus (Erratencrinurus) ejinensis sp. nov. (Figs 5 E, G, I-J, M, 6A, D-F)

Etymology. After Ejin Qi (Banner), an administrative area of Inner Mongolia, from which the material described here was collected.

Figured material. Holotype cranidium NIGP140450. Paratypes: cranidium, NIGP140449, librigena NIGP140448, hypostome NIGP140442, pygidia NIGP140451, 140452, 140453. All specimens from horizon Zs6b.

Diagnosis. Preoccipital glabella bearing 47-48 medium to large tubercles. Tubercle formula on posterior part of preoccipital glabella: 1L-1; 2L-3, 2, 1; 3L-3, 2, 1. Anterior border of cranidium shortening medially, divided by deep anteromedian furrow, with 8 medium-sized tubercles. Pygidium slightly wider than long, with 34 axial rings and 16 pleural ribs. Axial rings and pleural ribs without tubercles.

Description. Preoccipital glabella pear-shaped, except the basal part that is depressed, strongly convex (sag., tr.) and expanded forwards, widest at 1/3 of the distance from the anterior margin, where width is 79% sagittal length. Three pairs of lateral glabellar furrows short and shallow; S1 longer (tr.) than S2 and S3, runs inward and slightly forward. SO deeply incised, transverse. L1 strongly depressed abaxially, composed of narrow (exsag.) ridges, which extend inward and slightly forward from the axial furrows. L2, L3 represented by large tubercles. Frontal lobe 50-51% length of preoccipital glabella, semicircular in outline, slightly pointed anteromedially. LO convex (tr.), standing above basal glabellar lobes, 16% cranial length. Preoccipital glabella bears 47-48 dome-shaped, medium to large tubercles. The diameter of the biggest tubercle is 16.5-17% width of frontal glabellar lobe. Tubercle formula on posterior part of preoccipital glabella: 1L-1; 2L-3, 2, 1; 3L-3, 2, 1. Frontal lobe bears 33 medium to large tubercles: 10-11 medium tubercles arranged in arc along anterior margin of glabella; one pair of large tubercles (F4-3) on its abaxial ends; the remainder being randomly distributed. Axial furrow broad and very deep. Preglabellar furrow deep, with anterior part downwardly curving and forming a deep anteromedian furrow along

sagittal line. Anterior border of cranidium convex in cross-section, shortening medially, divided by median furrow, with eight medium sized tubercles. Librigena poorly preserved, moderately convex and much lower than glabella, covered with small and medium sized tubercles, weakly pitted in between.

Librigena broadly triangular in outline, steeply declined anterolaterally. Genal field gently convex; anterior part with three large tubercles close to lateral border furrow; posterior part with a few small tubercles. Eye elevated, supported by short socle. Lateral border broad, convex; bearing eight medium sized tubercles in one row, in addition to five small tubercles adaxially distributed on the posterior part. Lateral border furrows broad and moderately deep. Precranial lobe large, more convex than lateral border, with two irregular rows of large tubercles. Anterior border of cephalon continuous with lateral border, very short anteriorly, without tubercles.

Hypostome subrhombic in outline, 62% as wide as long, with maximum width at 26% of hypostomal length from anterior margin; its anterior margin forms an angle of about 100°, with posterior end sharply pointed. Median body strongly swollen, elongately ovate. Rhynchos strongly convex (tr.), defined by two longitudinal furrows, occupying 52% of width and 58% of length of median body. Median furrow shallow, placed on posterolateral part of median body; maculae faint. Borders short (exsag.), upturned, extending to the posterior end, well defined by deep border furrows. Posterior tongue 1/3 of hypostomal length, with pointed tip. Surface densely covered with small granules.

Pygidium triangular in outline, slightly wider than long. Axis convex (tr.), narrow (tr.), tapering backwards, extending to 90% of pygidial length, consisting of about 34 axial rings and a terminal piece occupying 15% of axial length. First 14 axial ring furrows deep throughout; others moderately deep laterally but shallowing or effaced medially. Pleural field moderately convex (tr.), steeply sloping towards pygidial margin. Sixteen pairs of pleural ribs defined by deep inter-rib furrows, which are successively more backwardly curving; posterior three pairs longitudinally extended. Termination of pleural rib rounded or truncated, overhangs narrow vertical border. External surface densely covered with tiny granules, but surface of internal mould smooth.

Remarks. Owen & Heath (1989) divided species of *Erratencrinurus* into five species groups: the *E. (E.) capricornu* group and *E. (E.) nebeni* group within *E. (Erratencrinurus)*; the *E. (Celtencrinurus) kiaeri* group and *E. (Celtencrinurus) multisegmentatus*

group in *E. (Celtencrinurus)*, and an unnamed *Erratencrinurus (sensu lato)* species group. They suggested that *E. (E.) capricornu* group and *E. (E.) nebeni* group might eventually be separated at subgeneric level. The *E. (E.) nebeni* species group is typified by the pentagonal arrangement of tubercles/spines at 1L-1 (or 1S-1), 2L-1, 0 and 2S-0, while the *E. (E.) capricornu* species group is characterised by the very sparse tuberculation on the posteromedial part of the preoccipital glabella, and by the absence of the tubercles 1L-1 and 1L-0. The new species *ejinensis* exhibits a tubercle formula on posterior part of preoccipital glabella as 1L-1, 2L-3, 2L-2, 2L-1, 3L-3, 3L-2, 3L-1, and, therefore, is not assignable either to the *E. (E.) nebeni* species group or the *E. (E.) capricornu* species group. With regard to the cranial characters, it seems to be referable to the unnamed *Erratencrinurus (sensu lato)* species group, but it has more pygidial segments than in species of that group (34 axial rings and 16 pleural ribs cf. 21-26 axial rings and 6-12 pleural ribs). For the time being, we provisionally refer *ejinensis* to *Erratencrinurus (Erratencrinurus)*, pending further research.

Species assigned to the unnamed *Erratencrinurus (sensu lato)* species group include *E. (s.l.) spicatus* (Tripp), *E. (s.l.) kingi* (Dean), *E. (s.l.) melzensis* Krueger, *E. (s.l.) striatus* Angelin, *E. (s.l.)* sp. A (= *Encrinurus* sp. of Tripp 1974), *E. (s.l.)* sp. B (= *Erratencrinurus (s.l.)* sp. of Lespérance & Tripp 1985) and *E. trippi* Edgecombe *et al.*, 1999a. Among those, the cranidium of *E. (E.) ejinensis* is most like that of *Erratencrinurus (Erratencrinurus)* sp. from the Galena Formation (Middle Caradoc) of Iowa, USA (Tripp 1974, p. 487, pl. 1, figs. 9-10; see Edgecombe & Chatterton 1990, p. 825) in the size of glabellar tubercles, the tubercle array in 1L, 2L, 3L and 4F rows, the anterior border of the cranidium with eight tubercles and deep anteromedian furrow, but is distinguished by the absence of tubercles 2S-0 and 3S-0, and the smaller glabellar tubercles on the anterior border of the cranidium. The pygidium of *E. (E.) ejinensis* is easily distinguishable from the American form by its narrower pygidial axis with more segments (34 axial rings and 16 pleural ribs). *Erratencrinurus (E.) ejinensis* shares many characters with that of *E. trippi* Edgecombe, Banks & Banks from the Ida Bay Limestone and Benjamin Limestone (middle-upper Caradoc) of Tasmania (Edgecombe *et al.* 1999a, p. 245, figs. 7A-E, G, H, 9I-L) including the strongly depressed L1, the presence of tubercles L1-1, the wide axial furrow, the deep preglabellar furrow, and the size of the glabellar tubercles, but differs in the anterior border of the cranidium having 8

instead of 10 tubercles, the longer (sag.) LO, the lateral border of librigena with eight medium-sized tubercles in one row, the narrower pygidial axis with more rings (34 cf. 28-30), and the pygidial pleurae with more ribs (16 cf. 10-11) that are less backwardly curved. This species is also comparable with a Baltoscandian upper Harjuan (Ashgill) form *E. (s.l.) melzensis* (Krueger 1971, p. 1149, pl. 8, fig. 6; Krueger 2004, p. 112, pl. 15, fig. 1-8), but differs in having tubercles L2-3 and L3-3, 33 instead of 26 tubercles on the frontal lobe of the glabella, 8 smaller tubercles on the anterior border of the cranidium, and more pygidial segments (34 axial rings and 16 pleural ribs cf. about 23 axial rings and 11 pleural ribs).

Family TELEPHINIDAE Marek, 1952

Phorocephala Lu in Lu *et al.*, 1965

[= *Phorocephala (Paraphorocephala)* Li & Xiao, 1984]

Type species. Phorocephala typa Lu in Lu *et al.*, 1965, from the Siliangssu Formation (late Arenig), southern Shaanxi, China; by original designation.

Phorocephala plena sp. nov. (Fig. 3A, B, D)

Etymology. Latin *plenus*, full, in reference to the swollen glabella.

Figured material. Holotype cranidium NIGP140412 (Fig. 3A, D), paratype pygidium NIGP140413, from horizon Zs6a.

Diagnosis. A *Phorocephala* species with subrectangular preoccipital glabella, displaying maximum width at midlength equal to 106% of sagittal length. Pygidium subpentagonal, 120% as wide as long; axis wide, truncated conical, with two rings plus a large terminal piece; pleural lobe strongly declining towards border, with two furrowed and backwardly directed pleurae; third pair of pleurae confluent with postaxial area; border short, weakly depressed; surface of cranidium covered with pits and discontinuous raised ridges; surface of pygidium with small and medium sized granules.

Description. Cranidium subtrapezoidal in outline, sagittal length 70% of width across midlength of palpebral lobes. Preoccipital glabella strongly convex (sag., tr.), subrectangular in outline, broadly rounded anteriorly, subparallel-sided but slightly expanded outwards, widest at midlength, where the width is 114% basal width and 106% sagittal length. Two pairs of muscle scars represented by

smooth patches on external surface; anterior pair short, pear-shaped, originating from axial furrows at 1/3 length of preoccipital glabella from back, directed inward and rapidly inwardly widening; posterior pair longer (tr.), subrectangular, running inward and strongly backward from axial furrow at 43% length of preoccipital glabella from back, widening adaxially, dying out before reaching SO. SO broad and deep, curving forward laterally. LO strongly convex (tr.), 14% cranial length (sag.), slightly shortening laterally, gently arched backward, with a weak median tubercle. Axial and preglabellar furrows continuous, deeply incised. Anterior border furrow deep, almost transverse. Preglabellar field absent. Anterior border strongly convex (tr.), steeply upturned, rather short (sag., exsag.), with gently forwardly arched anterior margin. Fixigena convex (tr.), steeply sloping forward and outward, 23% cranial width across palpebral lobes. Posterior border furrow narrow (exsag.) and deep; posterior border widening outward. Palpebral lobe defined by deep and narrow palpebral furrow, gently inwardly curving, 40% as long as preoccipital glabella. Anterior branches of facial suture converge slightly forward; posterior branches run outward and backward. Surface of preoccipital glabella densely covered with pits and weak, discontinuous and forwardly arched raised ridges; fixigenae and LO covered with dense pits and irregular raised ridges; anterior border covered with fine terrace lines parallel to anterior margin.

Pygidium subpentagonal in outline, widest across its anterolateral corners, where the width is about 120% sagittal length, slightly outwardly and strongly backwardly curving laterally and rounded posteriorly. Axis strongly convex (tr.), very wide, occupying 58% pygidial width anteriorly and 81% sagittal length of pygidium, tapering uniformly backwards to truncate tip, consisting of a short (sag.) articulating half-ring, two rings and a large terminal piece. Two axial rings well defined by sharp, transverse ring furrows, each occupying 16% axial length; terminal piece 63% axial length. Axial furrows narrow and deep; postaxial furrow shallower. Pleural fields steeply sloping towards border, having three pairs of pleurae. Pleural and interpleural furrows deeply incised, extending slightly outward and strongly backward. Anterior pair of pleural furrows and two pairs of interpleural furrows extending to pygidial margin; second pair of pleural furrows dying out before reaching border. Anterior pleural band slightly longer (exsag.) than posterior pleural band. Third pair of pleurae confluent with postaxial area. Border short (sag., exsag.), weakly depressed, defined by shallow border furrow. External surface covered with densely

spaced, small to medium granules, in addition to two files of medium granules distributed beside sagittal line on terminal piece of axis.

Remarks. This species closely resembles *Phorocephala athleta* (Dean 1971, p. 48, pl. 23, figs 2-9; pl. 24, figs 1-4, 6, 8, 11) from the Chair of Kildare Limestone (Ashgill) of eastern Ireland, from which it is chiefly distinguished by the proportionally longer preoccipital glabella and pygidium, the longer trapezoidal rather than semielliptical terminal piece of the pygidial axis, the pygidial postaxial area being confluent with the third pair of pleurae, and by the pygidial surface having coarser granules.

Phorocephala sp. (Fig. 3E)

Figured material. One damaged cranidium NIGP140415, from horizon Zs6b.

Remarks. This incomplete cranidium has a surface sculpture similar to *P. plena* sp. nov., but differs in having a straight-sided preoccipital glabella, less inwardly curved palpebral lobe, and forwardly diverging instead of converging anterior branches of the facial suture.

Family ASAPHIDAE Burmeister, 1843

Basilicus Salter, 1849

Type species. *Asaphus tyrannus* Murchison, 1839.

Basilicus (Basiliella) Kobayashi, 1934b

Type species. *Asaphus barrandi* Hall, 1851, the Black River Group (Caradoc), near Platteville, Wisconsin, USA; by original designation.

Remarks. Jaanusson (in Moore 1959) considered *Basiliella* as a subgenus of *Basilicus* (type species: *Asaphus tyrannus* Murchison, 1839, from the Llandeilo of South Wales). Zhou & Fortey (1986) regarded *Parabasilicus* as an effaced *Basiliella* and referred it to *Basilicus* as the third subgenus. Lee & Choi (1992) further confirmed that *Parabasilicus* is a junior synonym of *Basiliella*, on the basis of a restudy of the type species, *P. typicalis* Kobayashi, 1934b, from the Jigunsan Formation (Llanvirn) of South Korea. As noted by Zhou & Fortey (1986), there are no characters to distinguish *Basilicus* and *Basiliella*. Some specimens including effaced or distinctly furrowed cranidia are tentatively assigned to *Basilicus (Basiliella)*.

Basilicus (Basiliella) sp. 1 (Fig. 6K)

Figured material. One cranidium NIGP140462, from horizon Zs4.

Description. Cranidium slightly longer than wide. Preoccipital glabella moderately convex (tr.), divided by shallow, inwardly and backwardly directed S1 into a large, pear-shaped frontal lobe and a pair of triangular basal lobes, with a median tubercle close to SO. SO rather shallow. LO gently convex (tr.), short (sag.), constricted abaxially. Axial furrows gently converge forward to meet with shallow preglabellar furrow; weak beside basal lobes, deep and subparallel in front of S1. Preglabellar area almost flattened, occupies 15% sagittal length of cranidium. Palpebral lobes backwardly placed. Anterior area of fixigena slightly swollen, widened forwards; posterior area triangular in outline, rather short (tr.). Posterior border defined by shallow border furrow, short (exsag.). Facial sutures of isoteliform type. External surface smooth.

Remarks. This cranidium compares with that of *Pseudobasilicus? fortis* Webby, 1973 from the Cliefden Caves Limestone (Caradoc) of New South Wales (Webby 1973, p. 461, pl. 53, figs 11-24, pl. 54, figs 1-4), but differs in its shallower S1, longer preglabellar area, and in the absence of surface sculpture of raised lines. As noted by Webby (1973, p. 465-467), the Australian form exhibits some characters that are undiagnostic of the genus *Pseudobasilicus* (*s.l.*), such as a shorter (sag.) preglabellar area, longer preoccipital glabella, slightly more anteriorly placed palpebral lobe, less pointed, backwardly curving thoracic pleurae, and narrower pygidial doublure. All of these are, however, indicative of the genus *Basilicus*. The Australian species has a relatively short pygidium, and is probably better assigned to the subgenus *Basiliella*.

Basilicus (Basiliella) sp. 2 (Fig. 6G, J, L-N)

Figured material. Two broken cranidia NIGP140459, 140460, two pygidia NIGP140457, 140458, one immature pygidium NIGP140456, from horizon Zs6b.

Description. Cranidium longer than wide. Preoccipital glabella ill-defined, moderately convex, and divided by shallow and broad S1 into large, pear-shaped frontal lobe and a pair of triangular basal lobes, with a weak median tubercle situated immediately in front of SO. Axial furrows almost obsolete behind palpebral lobes, very shallow and forwardly divergent in front

of palpebral lobes, continuous with shallow and forwardly arched preglabellar furrow. S1 weak, extending inward and strongly backward from axial furrow opposite anterior end of palpebral lobe. LO 8% of cranial length, gently convex (tr.); SO shallow. Preglabellar area almost flat, moderately long (sag.), bluntly pointed in front, occupies 15% cranial length (sag.). Palpebral lobe large, subsemicircular, backwardly placed. Facial sutures isoteliform. External surface smooth.

Pygidium semielliptical in outline, 70-74% as long as wide. Axis moderately convex (tr.), occupying 28-31% anterior width and 85% length of pygidium; funnel-shaped in outline, with anterior half strongly backwardly tapering and posterior half gently backwardly tapering. Ten axial rings and a terminal piece well defined by broad, shallow ring furrows in internal mould. Articulating half ring short (sag.), broadly arched forwards, defined by shallow, wide furrow. Axial furrows rather shallow and wide. Pleural field gently declining towards border furrow with, in addition to the deep first pair, five pairs of faint pleural furrows. Anterior half rib ridge-like, with broad (tr.) facet. Border flat, 15% pygidial length, well defined by broad and shallow border furrow. Surface of axis and pleural field punctate.

Remarks. This species of *B. (Basiliella)* is similar to *Basiliella choii* Edgecombe *et al.* (2004, p. 66, figs 7-9) from the Gisbornian (Caradoc) of Tasmania, and to *Isotelus levis* Chugaeva, 1958 from the Caradoc of the Chu-Ili Mountains of Kazakhstan (Chugaeva 1958, p. 50, pl. 5, figs 6-10), in having an ill-defined preoccipital glabella with effaced furrows, and a poorly segmented pygidium with a broad, flat pygidial border. It differs from the Australian form in having a shorter cranidium with a proportionally longer preglabellar area and palpebral lobe, and a funnel-shaped instead of conical pygidial axis; and from the Kazakhstan form in having a shorter preglabellar area, a more strongly expanded frontal lobe, and a funnel-shaped and shallowly furrowed pygidial axis. The presence of posterolateral glabellar furrows and larger and more backwardly sited palpebral lobes indicate that *Isotelus levis* should be excluded from the genus *Isotelus* DeKay, 1824. We regard it as an effaced representative of *Basilicus (Basiliella)*.

Family REMOPLEURIDIDAE Hawle & Corda, 1847

Remopleurides Portlock, 1843

Type species. *Remopleurides colbii* Portlock,

1843; from the middle Caradoc of Ireland; subsequently designated by Miller (1889).

Remopleurides sp. 1 (Fig. 3G, J, M)

Figured material. Two incomplete cranidia NIGP140417, 140418, one librigena NIGP140419, from horizon Zs6b.

Description. Preoccipital glabella urceolate in shape, moderately convex (tr.), widest across abaxial ends of S1; anterior tongue wide, with its basal width about 56% maximum width of glabella, gently convergent and declining forwards. Three pairs of equally spaced, lateral glabellar furrows directed inward and backward, developed as smooth impressions interrupting sculpture on external surface of glabella. S1 and S2 arising close to axial furrow, long (tr.) and gently curved backward; S3 short, sub-oval in outline, isolated from axial furrow. LO well defined by deep, transverse SO, as convex as preoccipital glabella, relatively long, with small median occipital tubercle set close to SO. Palpebral lobes strip-like, of typical remopleuridid form, well defined by deep axial furrow, narrow (tr.), widening backward. Surface of preoccipital glabella covered with fine raised lines arranged in Bertillon pattern, arched forward strongly on posterior half but gently on anterior half and frontal tongue. Raised lines on LO broadly curved backwards, and on palpebral lobes running inward and backward.

Librigena triangular in outline, narrow anteriorly but strongly widening backwards, gently convex, with broad-based, posterolaterally directed genal spine. Lateral border furrow completely effaced; posterior border furrow deep, dying out before reaching genal spine. Genal notch absent. Surface covered with raised lines that are almost transversely arranged.

Remarks. This form exhibits slightly wider palpebral lobes and more densely crowded raised lines on the cranidial surface, but otherwise is similar to *R. acer* Webby, 1973 from the Cliefden Caves Limestone (Caradoc), New South Wales (Webby 1973, p. 457, pl. 53, figs 1-10).

Remopleurides sp. 2 (Fig. 5B, F)

Figured material. One pygidium NIGP140446, one pygidium with attached thoracic segment NIGP140447, from horizon Zs6a.

Description. Pygidium convex (tr.), subrectangular in outline, wider than long, with lateral margins diverging slightly backward. Axis triangular

in outline, tapering backward onto posterior marginal ridge. Articulating half-ring well defined by deep articulating furrow, relatively short (sag.). Axis moderately convex (tr.), sloping outward and backward. First axial ring very short (sag.), widened strongly abaxially; second axial ring large, subrhombic in outline, 76% sagittal length of axis, divided by deep median longitudinal furrow into two triangular areas. Axial furrows deeply incised, postaxial furrow effaced. Two pairs of pleural ribs produced abaxially into short pleural spines; the first pair diverging slightly outward, the second extending backward and slightly inward to embrace a deep, U-shaped median notch. Prominent fulcral process developed on anterolateral corner of pygidium. Raised lines run backward and slightly outward on first axial ring and first pleural rib, directed inward and backward on second pleural rib, but absent on second axial ring.

The attached thoracic segment shows a broad and convex (tr.) axial ring, and a relatively narrow, backwardly directed pleura, which bears a deep, almost longitudinal pleural furrow and a deep fulcral socket, being covered with thick, raised lines directed backward and slightly outward.

Remarks. The pygidium is close to that of *Remopleurides saenuros* Webby, 1973 from a Late Ordovician limestone at Billabong Creek, New South Wales (Webby 1973, p. 451, pl. 52, figs 1-28), and is only distinguished by the first axial ring being more strongly expanded laterally, and by the second axial ring having a more forwardly arched anterior margin. However, the lack of a cranidium renders further comparison difficult.

Family NILEIDAE Angelin, 1854

Nileus Dalman, 1827

Type species. *Asaphus (Nileus) armadillo* Dalman, 1827, from the uppermost Arenig-lower Llanvirn of Östergötland, Sweden; by monotypy (see Nielsen 1995).

Nileus sp. (Fig. 7N)

Figured material. One incomplete cranidium NIGP140473, from horizon Zs6a.

Remarks. Diagnostic features of this form are not clear, owing to the paucity and fragmentary preservation of material. The only cranidium is gently convex (tr.), having a straight anterior margin, a large, subsemicircular right palpebral lobe and an effaced right axial furrow, with forwardly diverging anterior branches of the facial

suture and a smooth external surface.

Family DIONIDIDAE Gürich, 1907
[=Tongxinaspidae Zhou, 1981, see Fortey & Shergold 1984]

Dionide Barrande, 1847

Type species. *Dione formosa* Barrande, 1846, from the Zahořany Formation (middle Caradoc) of the Czech Republic; by original designation.

Dionide sp. (Fig. 6H, I)

Figured material. One poorly preserved cephalon NIGP140461, from horizon Zs6b.

Description. Cephalon subsemicircular in outline, 44% as long as wide. Preoccipital glabella strongly convex (sag. and tr.), longer (sag.) than wide, occupying about 40% breadth of cephalon, parallel-sided, with a median tubercle placed at 1/3 sagittal length from its rear. Longitudinal glabellar furrows extend from SO to about 1/3 length of preoccipital glabella from back, lateral lobe much narrower than central lobe. Preglabellar furrow shallower than axial furrows. LO poorly preserved. Gena moderately convex. Preglabellar field occupies about 10% sagittal length of cephalon. Anterior and lateral borders ridge-like. Fringe densely pitted, sloping steeply forward and laterally, extended backwards into a pair of prolongations. Posterior border furrow deep. Posterior border short (exsag.).

Remarks. This cephalon resembles that of *Dionide regalis* Lu & Zhou (1981, p. 17, pl. 7, figs 4-11; Tripp *et al.* 1989, p. 51, fig. 12a-c, f, g, u, v) from the upper Tangtou Formation (early Ashgill) of Tangshan, Jiangsu, but the latter possesses a wider preoccipital glabella, shorter longitudinal glabellar furrows, and a longer (sag.) fringe. The shape and size of the glabella is comparable to that of *D. decorata* Kielan (1960, p. 163, pl. 31, figs 1-3) from the middle Ashgill of Brzezinki, Poland. The latter, however, differs mainly in having an additional anterior median glabellar tubercle, shorter longitudinal glabellar furrows, longer cephalic border, and in lacking a pair of fringe prolongations.

Family RAPHIOPHORIDAE Angelin, 1854

Bulbaspis Chugaeva, 1958
[=*Bulbaspis* (*Parabulbaspis*) Zhang, 1981, see Yuan & Zhou (1997, p. 179)]

Type species. *Ampyx bulbifer* Weber, 1932,

from the Djebagly 'horizon' (Llandeilo) of the Djebagly Range, southern Kazakhstan; by original designation.

Diagnosis. A raphiophorid genus with subrhombic preoccipital glabella that protrudes considerably beyond anterior margin of fixigenae and projects into an anterior bulb. Thorax with five segments. Pygidium short, faintly segmented, with border steeply sloping downwards.

Remarks. Exclusive of the poorly preserved forms recorded from Malaysia (Kobayashi & Hamada 1978), southern Gansu, northwest China (Zhou & Dean 1986), and Tasmania (Burrett *et al.* 1983), species previously assigned to *Bulbaspis* can be divided into two morphological groups: the Arenig-Llanvirn *ovulum* species group, and Llandeilo-Ashgill *bulbifer* species group.

The *ovulum* group includes *B. ovulum* (Weber) (Weber 1948, p. 15, pl. 11, figs 12, 13; Chugaeva 1958, p. 26, pl. 2, figs 6-10) from the Llanvirn of Kazakhstan, *B. ordosensis* Lu (Lu *et al.* 1976, p. 73, pl. 13, figs 6,7) from the Klimoli Formation (Llanvirn), Zhuozishan Mountains, Inner Mongolia, and *B. lageniformis* Zhou (Zhou *et al.* 1982, p. 279, pl. 69, figs 9, 10) from the uppermost part of Zhuozishan Formation (late Arenig), Miboshan Mountains, central Ningxia. Zhou & Zhou (2006, p. 112) suggested that all these listed species are *Ampyx*-allied and should be reassigned to a new genus *Abulbaspis* (type species: *B. ordosensis* Lu in Lu *et al.*, 1976), which is characterised by a clavate glabella projecting over the anterior margin of the fixigenae for only a short distance, the absence of a sagittal carina on the preoccipital glabella, a six-segmented thorax, and a relatively long pygidium with a well defined, narrow (tr.), multisegmented (7 to 14 rings) axis.

The *bulbifer* group includes, in addition to *B. brevicollis* sp. nov. described below, *B. bulbifer* (Weber) (Weber 1932, p. 5, pl. 4, figs 38-41; Weber 1948, p. 15, pl. 2, figs 9, 10) from the Llandeilo of southern Kazakhstan, *B. mirabilis* Chugaeva (1958, p. 28, pl. 3, figs 1-4) from Caradoc-early Ashgill, southern Kazakhstan, *B. sphaerornatus* Chugaeva (1958, p. 29, pl. 2, figs 11-16) from the Caradoc of southern Kazakhstan, and *Bulbaspis* (*Parabulbaspis*) *korlaensis* Zhang (Zhang 1981, p. 201, pl. 74, figs 1-4; Yuan & Zhou 1997, p. 173, pl. 1, fig. 7, as *Bulbaspis mirabilis* Chugaeva) from the Late Ordovician of the northern Tarim Basin, Xinjiang. Species of the *bulbifer* group are considered to represent real members of *Bulbaspis*, having evolved probably from *Lonchodomus*. When compared with *Abulbaspis*, *Bulbaspis* differs in having a

rhombic, carinate preoccipital glabella, which protrudes much beyond the anterior margin of the fixigenae, a five-segmented thorax, and a shorter, poorly segmented pygidium.

Bulbaspis brevis sp. nov. (Figs 6O, 7G, H, J-M, O)

Etymology. Latin *brevis*, short, in reference to the short anterior part of the glabella.

Figured material. Holotype cranidium NIGP140468 (Fig. 7G). Paratypes: cranidia NIGP140470, 140471, immature cranidium NIGP140469, pygidia NIGP140463, 140472, all specimens from horizon Zs6b.

Diagnosis. A *Bulbaspis* species with large anterior glabellar bulb, which is about as long and as wide as the preoccipital glabella in mature cranidia. Anterior part of glabella short, forwardly converging. Pygidial axis poorly defined, reaching mid-length of border, with three shallow ring furrows. Pygidial pleural field with two pairs of pleural furrows, first pair shallow, second faint. Border wide, steeply sloping downwards.

Description. Cranidium subtriangular in outline, sagittal length 83-87% posterior width. Preoccipital glabella convex (tr.), subrhombic in outline, forwardly expanded to attain its maximum width at about 80% sagittal length (exclusive of glabellar bulb) from back, which is 120% sagittal length and 160-180% basal width of preoccipital glabella, then convergent forwards to anterior bulb. The bulb strongly overhangs the ventral part of the glabella, which slopes downwards steeply to the shallow preglabellar furrow. Anterior cranial border short (sag.) and gently sloping downwards. Surface of internal mould shows three pairs of muscle scars tightly arranged on flanks of posterior part of preoccipital glabella, located close to axial furrows; anterior pair elongate-ovate, as long as 30-34% length of preoccipital glabella, situated slightly anterior to midlength of preoccipital glabella; posterior and second pairs subcircular, each 15-16% length of preoccipital glabella. Anterior bulb large, subspherical, as long as 46-48% cranial length and approximately as wide as maximum width of glabella. Axial furrows broad, extending forwards to anterior margin of fixigenae and then strongly downwards to connect with preglabellar furrow. LO gently convex (tr.), defined by shallow and transverse SO, about 9% cranial length. Fixigena triangular in outline, about 170% as wide as preoccipital glabella posteriorly, declining steeply forwards and moderately outwards. Posterior border furrow

distinctly incised, abruptly dying out close to axial furrow, slightly sigmoidal. Posterior border short (exsag.), sloping toward border furrow and slightly outward. External surface of cranidium smooth. An immature cranidium (Fig. 7H) shows longer glabella, and a much smaller and subrhombic anterior bulb with a rounded median pit on its posterior margin.

Pygidium short, broad, semielliptical in outline, sagittal length 37% anterior breadth. Axis poorly defined by faint axial furrows, gently convex (tr.), occupying 30-31% pygidial width anteriorly and 82% pygidial length, extending to midlength of border. On external surface only three ring furrows shallowly impressed; on internal mould there are six pairs of subovoid muscle scars present on flanks of axis. Pleural field flattened, with two pairs of pleural furrows, the first shallow, the second faint, both almost transverse. Border long (sag.), 33-34% pygidial length (sag.), steeply sloping downwards, narrowing rapidly outwards, surface covered with closely spaced terrace lines parallel to posterior margin.

Remarks. *Bulbaspis brevis* sp. nov. closely resembles *Bulbaspis korlaensis* Zhang (1981, p. 201, pl. 74, figs 1-6; Yuan & Zhou 1997, p. 173, pl. 1, fig. 7, as *Bulbaspis mirabilis* Chugaeva) from the late Ordovician of the northern Tarim Basin, Xinjiang, but is distinguished by its proportionally broader cranidium, its less convex preoccipital glabella with shorter anterior part, its shallower axial furrows, and its relatively longer (sag.) LO.

Collis Koroleva, 1959

Type species. *Collis parvulus* Koroleva, 1959, from the upper Maylsor horizon (middle Caradoc) of the Stepyak area, northern Kazakhstan; by original designation.

Diagnosis. A raphiophorid genus having a pear-shaped preoccipital glabella with moderately convex posterior lobe and extremely upwardly vaulted frontal lobe. Bacculae kidney-shaped. Eye tubercle weak, adjacent to anterior tip of baccula. Preglabellar field steeply forwardly declining.

Remarks. This genus was founded on only a few cranidia. Koroleva (1959) assigned *Collis* to the family Trinucleidae Hawle & Corda, 1847 and did not compare it with related genera of the Raphiophoridae Angelin, 1854. As noted by Zhou *et al.* (1995, p. 63), its cranidium agrees in almost all respects with that of *Malongullia* Webby *et al.* 1970, based on the type species *M. oepiki* from the Malongulli Formation (late

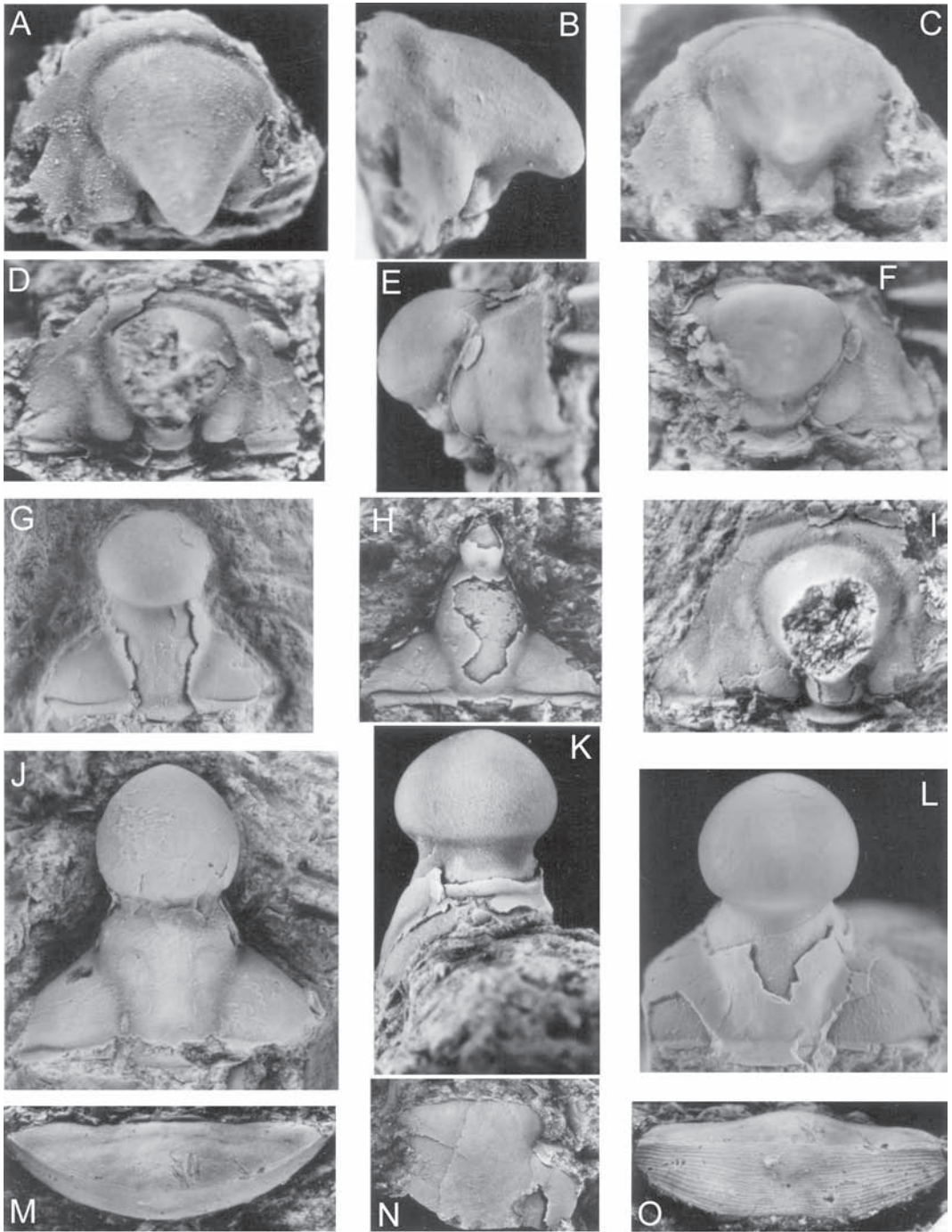


Fig. 7. A-D, I, *Collis rostratus* sp. nov. from Horizon Zs6b. A-C, obliquely dorsal, lateral and dorsal views of holotype cranidium, NIGP140464, $\times 10$. D, dorsal view of cranidium, NIGP140465, $\times 10$. I, dorsal view of cranidium, NIGP140465, $\times 8$. E, F, *Collis* cf. *parvulus* Koroleva, 1959, lateral and dorsal views of cranidium, NIGP140467, $\times 10$. G, H, J-M, O, *Bulbaspis brevis* sp. nov. from Horizon Zs6b. G, dorsal view of holotype cranidium, NIGP140468, $\times 2$. H, dorsal view of immature cranidium, NIGP140469, $\times 8$. J, dorsal view of paratype cranidium, NIGP140470, $\times 4$. K, L, lateral and dorsal views of paratype cranidium, NIGP140471, $\times 4$. M, O, dorsal and obliquely posterior views of paratype pygidium, NIGP140472, $\times 6$. N, *Nileus* sp. from Horizon Zs6a, dorsal view of cranidium, NIGP140473, $\times 3$.

Caradoc), New South Wales, Australia (Webby *et al.* 1970, p. 882, pl. 125, figs 1-12). However, as no associated thorax and pygidium have yet been found for *Collis*, it remains unclear whether both genera are synonymous.

***Collis rostratus* sp. nov.** (Fig. 7A-D, I)

1959 *Collis* sp.; Koroleva, p. 1313, fig. 2d-f.

1965 *Collis* sp.; Koroleva, p. 151, pl. 1, fig. 8a-d.

Etymology. Latin *rostratus*, beaked, in reference to the shape of the frontal glabellar lobe.

Figured material. Holotype cranidium NIGP140464 (Fig. 7A-C). Paratypes: cranidia, NIGP140465, 140466. All specimens from horizon Zs6b.

Diagnosis. Frontal glabellar lobe strongly projected upwards and slightly backwards to form an aquiline nose, and overhanging posterior glabellar lobe. Transverse glabellar furrow absent. Preglabellar field with a pair of small nodes close to preglabellar furrow on either side of sagittal line.

Description. Cranidium subsemielliptical in outline, sagittal length 58% posterior width. Preoccipital glabella pear-shaped in outline; posterior lobe occupies about one-third of length of preoccipital glabella, subcylindrical in outline, narrow (tr.), moderately convex (tr.); frontal lobe strongly expanded forward, with rounded anterior margin, highly projected upward and slightly backward to form an aquiline nose, and overhanging posterior lobe of glabella. Posterior sections of axial furrows distinctly incised beside posterior lobe of glabella, subparallel, ending in a pair of pits; anterior sections shallow and strongly divergent forwards; preglabellar furrow distinct. SO broad and deep, transverse. LO short (sag.), convex (tr.), steeply sloping towards SO. Fixigenae moderately wide, gently convex (tr.), united in front of glabella, steeply sloping downwards. Bacculae defined by shallow furrows abaxially, moderately convex, kidney-shaped, about half length of preoccipital glabella, close to axial and posterior border furrows. Eye tubercles subovoid in outline, rather weak, situated near axial furrows just in front of bacculae. Preglabellar field 10% cranidial length, with a pair of small nodes close to preglabellar furrow on either side of sagittal line. Anterior border short (sag., exsag.), well defined by distinct anterior border furrow. Posterior border short (exsag.); border furrow distinct and transverse. Facial suture gently bending inwards

and forwards to meet anteriorly in a broad curve. External surface of cranidium smooth.

Remarks. The new species differs from the type species *Collis parvulus* (Koroleva 1959, p. 1313, fig. 2a-c; Koroleva 1965, p. 151, pl. 1, figs 6, 7a-c) in having the frontal glabellar lobe projecting strongly upward and slightly backward to form an aquiline nose overhanging the posterior glabellar lobe, lacking a transverse glabellar furrow, in having wider bacculae and a pair of small nodes on the preglabellar field.

***Collis cf. parvulus* Koroleva, 1959** (Fig. 7E, F)

Figured material. An incomplete cranidium NIGP140467, from horizon Zs6b.

Description. Cephalon subsemicircular in outline. Preoccipital glabella pear-shaped in outline, divided into two lobes by a broad, shallow transverse furrow; posterior lobe moderately convex (tr.), occupying about 1/4 length of preoccipital glabella, half as wide (tr.) as frontal lobe, subparallel-sided; frontal lobe strongly expanded forwards, highly convex and forwardly bent down to preglabellar field, with a prominent, apically placed median tubercle. Axial furrows deeply incised beside posterior lobe of glabella, becoming shallower beside frontal lobe to meet distinct preglabellar furrow. SO broad and deep, transverse. LO short (sag.), convex (tr.), steeply sloping towards SO. Fixigenae wide, moderately convex (tr.), steeply sloping downwards, united with moderately long (sag.) preglabellar field. Anterior border flat, well defined by distinct, narrow (sag., exsag.) border furrow. Baccula kidney-shaped, gently convex, defined by shallow furrow outwards, about half length of preoccipital glabella, extending along axial furrow and ending close to posterior border furrow. Eye tubercles weak, situated near axial furrows, just in front of bacculae. Posterior border short (exsag.), well defined by distinct and transverse border furrow. External surface smooth.

Remarks. The cranidium is much like that of *Collis parvulus* except for the wider bacculae.

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