ORDOVICIAN TRILOBITES FROM THE DAWANGOU FORMATION, KALPIN, XINJIANG, NORTH-WEST CHINA

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ABSTRACT. Sixteen trilobite taxa are described from the type section of the Dawangou Formation (late Arenig–early Llanvirn) at Dawangou, Kalpin, north-western Tarim, Xinjiang, north-west China. They include two new genera: the asaphine *Mioptychopyge* and the pterygometopine *Yanhaoia*. Evidence from the lithofacies and from the composition and taphonomy of the assemblages suggests that the fauna lived in a generally calm, upper slope environment. More than 80 per cent. of the species are common, or closely allied, to coeval forms in the Yangtze region, indicating a close palaeogeographical relationship between the Tarim and South China blocks during the late early Ordovician. Some genera, such as *Birmanites*, *Eccoptochile*, *Ovalocephalus* and *Pseudocalymene*, are typical of Gondwanan faunas, and it is likely that the Tarim Block formed part of peri-Gondwana in the Ordovician.

EIGHT trilobite species were previously recorded from the Upper Qiulitag Group in the Kalpin area (Zhang 1981), all from the uppermost part of the group (Zhou, *in* Zhou and Chen 1990, 1992), recently referred by Zhou *et al.* (1991) to a new rock unit, the Dawangou Formation. The specimens described herein were mostly collected in 1987 from the measured section at the stratotype of the formation at Dawangou, about 9 km north-west of Yingan village, Kalpin County (Text-fig. 1). The work formed part of an extensive field investigation of the periphery of the Tarim Basin by geologists of the Nanjing Institute of Geology and Palaeontology, Academia Sinica, and the 05 Project Administration, Bureau of Petroleum Geology of Southwest China. The large, new collection includes representatives of 16 genera and provides evidence for the range of variation in species previously known from limited material, as well as a more complete knowledge of faunal composition and species diversity in the type Dawangou Formation.

AGE AND STRATIGRAPHICAL SUMMARY

The Dawangou Formation is exposed extensively along the north-western margin of the Tarim Basin and is composed of grey, medium- to thinly-bedded biocalcilutites, biocalcarenites and nodular biocalcilutites, some of which contain glauconite and masses and bands of chert (Text-fig. 2). The formation is conformably underlain by the Upper Qiulitag Group and overlain by the Saergan Formation.

Three conodont zones have been recognized in the Dawangou Formation (Zhou *et al.*, *in* Zhou and Chen 1990, 1992) at Dawangou; they are, in ascending order, *Baltoniodus* aff. *navis*, *Amorphognathus variabilis* and *Eoplacognathus suecicus*. The *Baltoniodus* aff. *navis* Zone was established in the upper part of the Dawan Formation in the Nanjing Hills, Jiangsu, and in the upper part of the Meitan Formation at Qijiang and Huayingshan, Sichuan, in the Yangtze area (An 1987), where its horizon lies between the *Amorphognathus variabilis* and *Paroistodus originalis* zones. As An (1987, p. 75) pointed out, the *B.* aff. *navis* Zone may correspond to the *Microzarkodina parva* Zone of Baltoscandia. The *A. variabilis* and *E. suecicus* zones were founded in the North Atlantic Ordovician conodont province. In the Yangtze area both have been recognized in, respectively, the uppermost Dawan Formation to lowermost Kuniutan Formation, and the lower part of the Kuniutan Formation (An 1987). Graptolites from the overlying lower part of the Saergan

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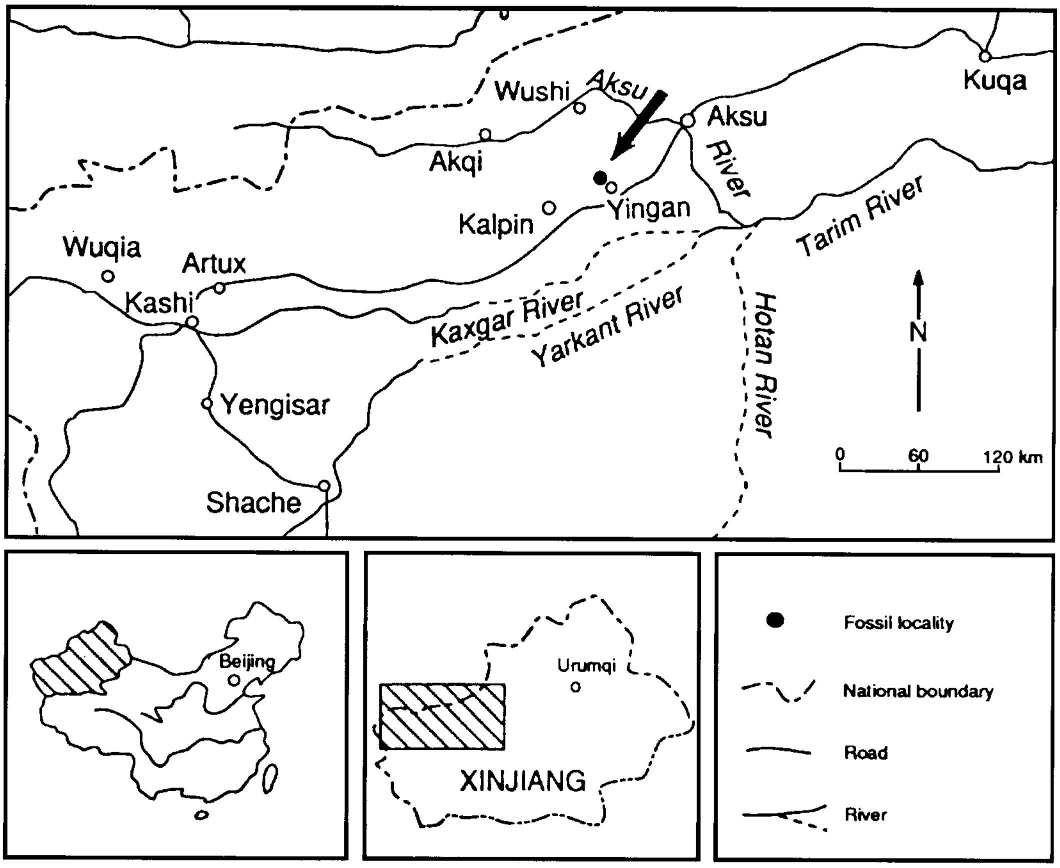


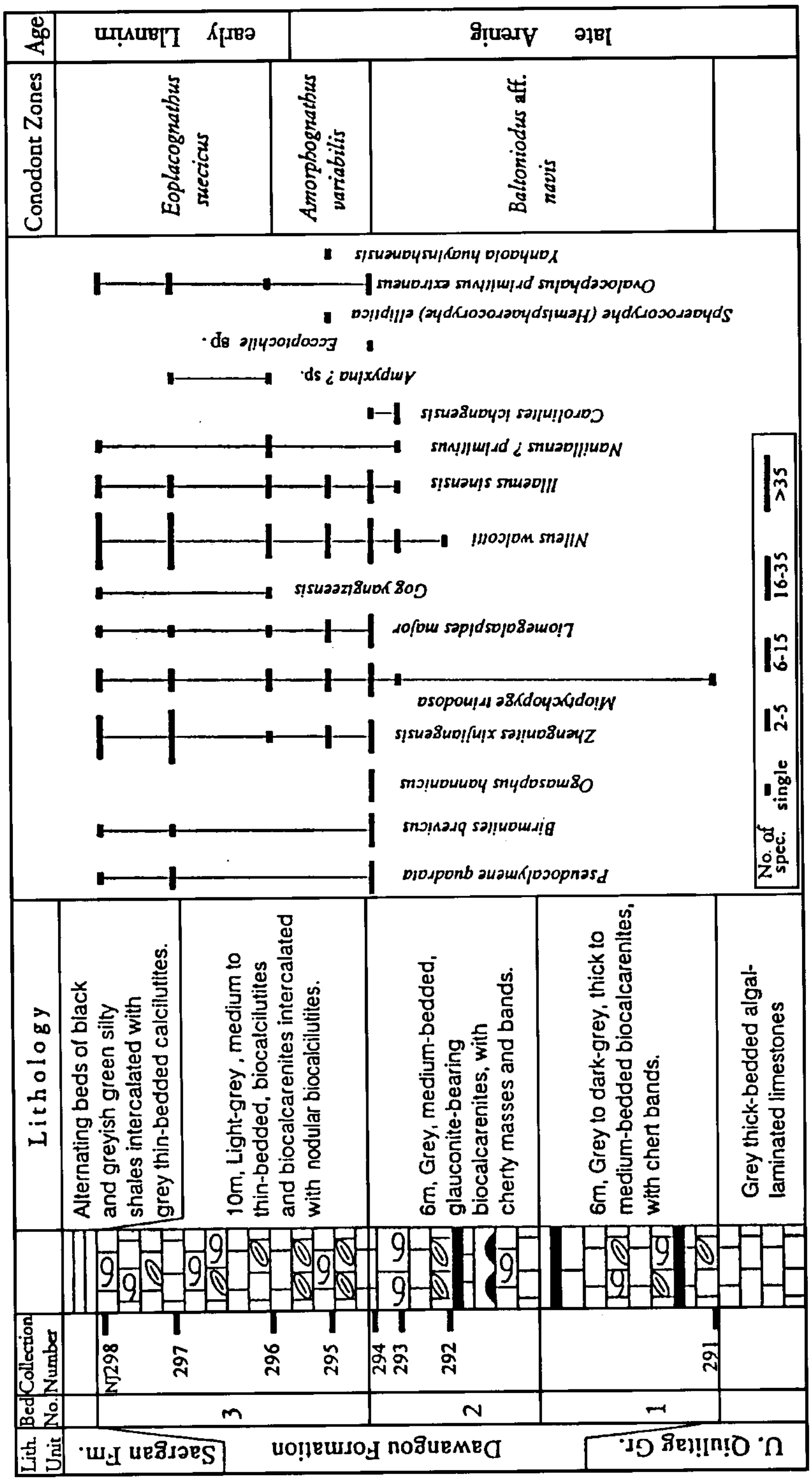
TEXT-FIG. 1. Outline maps showing location of the measured section through the Dawangou Formation.

Formation include, amongst others, *Pterograptus elegans* Holm, *Amplexograptus confertus* (Lapworth) and *Isograptus lyra* Ruedemann, which belong to the *Pterograptus elegans* Subzone of the *Didymograptus murchisoni* Zone (Zhou *et al.* 1990, 1992).

Evidence from conodonts and graptolites indicates that the Dawangou Formation is of late Arenig–early Llanvirn age in terms of the British chronostratigraphical standard advocated by Fortey *et al.* (1995). It is correlated with the upper part of the Dawan Formation and the lower part of the Kuniutan Formation, or coeval beds, in the Yangtze area, south China. Chen and Bergström (1995) suggested that the *Undulograptus austrodentatus* Zone may well be the basal unit of the Darriwilian or 'Llanvirn' in terms of the international Ordovician chronostratigraphical scheme. The *U. austrodentatus* interval has been referred approximately to the *M. parva* conodont zone and the lower part of the *A. variabilis* Zone (Bergström and Wang, *in* Chen and Bergström 1995). It is likely that the base of the *U. austrodentatus* Zone corresponds approximately with that of the Dawangou Formation.

BIOFACIES AND ENVIRONMENTAL IMPLICATIONS

Trilobites occur mostly in the upper part of the Dawangou Formation. The fauna includes six species of Asaphidae, two of Illaenidae, two of Cheiruridae, one of Nileidae, one of Leiostegiidae,



TEXT-FIG. 2. Columnar section of the Dawangou Formation at Dawangou, near Yingan, Kalpin, Xinjiang, showing vertical ranges of identified trilobite species. Fm = Formation; Gr. = Group; No. of spec. = Number of specimens.

one of Hammatocnemidae, one of Raphiophoridae, one of Pterygometopidae and one of Telephinidae. Species diversity is 16. Of the 350 trilobite specimens collected, *Nileus walcotti* makes up 47 per cent., asaphids (*Zhenganites xinjiangensis* 22 per cent., *Mioptychopyge trinodosa* 8 per cent., *Liomegalaspides major* 4·7 per cent., *Birmanites brevicus* 3 per cent., *Ogmasaphus hannanicus* 1·7 per cent., *Gog yangtzeensis* 0·6 per cent.) 40 per cent., and illaenids (*Illaenus sinensis* 7 per cent., *Nanillaenus*? *primitivus* 1 per cent.) 8 per cent.; other forms are rare. The association of species indicates the Nileid Biofacies (cf. Nileid Community of Fortey 1975*a*). On the basis of analyses of Arenig–Llanvirn lithofacies and faunal composition in Spitsbergen, Fortey (1975*a*) suggested that the lower depth limit of the nileid fauna might be some 100 m (corresponding roughly to the oxidizing-reducing boundary) but it may extend shorewards to overlap with the illaenid-cheirurid assemblage, which was typically distributed along the platform margin, in carbonate build-ups deposited in a shallow-water environment at or near wave-base (Fortey 1980*a*). The mingling of a considerable number of illaenids and a few cheirurids with the present nileid assemblage indicates that the fauna inhabited an area not far from the platform.

More than 30 per cent. of specimens in our collection, especially the nileids, illaenids and asaphids, are articulated exoskeletons. Most are randomly distributed and poorly sorted on the bedding surface. The evidence suggests that the association is mainly an autochthonous benthonic fauna which lived in a generally calm environment, normally below storm-wave base (> 70 m). Biodebris-bearing flags occur only occasionally in the Dawangou Formation and contain fragments of trilobites, nautiloids and cystids, all poorly sorted and probably transported by storm-induced debris flows from the adjacent platform edge.

The occurrence of benthic trilobites in relation to a shallow- to deeper-water environment gradient in north-western Tarim has been discussed by Zhou *et al.* (*in* Zhou and Chen 1990, 1992). Based on the late Arenig–early Llanvirn palaeogeographical map (Zhou *et al.*, *in* Zhou and Chen 1990, 1992, text-fig. 3-13), the fossiliferous section at Dawangou lies only about 30 km north of the platform-marginal reef-facies belt. A few algal-bound bioclastic limestones recently found in the Dawangou Formation (Zhou *et al.* 1991) indicate the presence of sparse, small, lenticular carbonate mounds in the Kalpin area in the late Arenig–early Llanvirn. They may have formed exceptional ecological niches on the sea-floor, and a few specimens of *Illaenus sinensis* and *Nanillaenus*? *primitivus* from the bioherm 'pockets' show much coarser terrace ridges on the dorsal surface than specimens from surrounding beds.

According to Zhou *et al.* (1990, 1992), the sea on the Tarim Block deepened gradually during the early Ordovician and, following the late Arenig transgression, the platform edge shifted shorewards so that the previous platform in the Kalpin area deepened to a shallow shelf slope. The above evidence suggests that the slope was fairly gentle with a depth generally little more than 70 m during the interval represented by the Dawangou Formation.

FAUNAL AFFINITIES AND PALAEOGEOGRAPHICAL RELATIONSHIPS

Of the 16 species described here, half are new to the Kalpin area, and the fauna exhibits strong affinities with that of the Yangtze region, the shallower part of the South China Block. On the basis of the new material, nine species are common to both areas: *Pseudocalymene quadrata*, *Birmanites brevicus*, *Ogmasaphus hannanicus*, *Gog yangtzeensis*, *Nileus walcotti*, *Illaenus sinensis*, *Carolinites ichangensis*, *Sphaerocoryphe* (*Hemisphaerocoryphe*) *elliptica* and *Yanhaoia huayinshanensis*. Four forms (*Zhenganites xinjiangensis*, *Mioptychopyge trinodosa*, *Liomegalaspides major* and *Ovalocephalus primitivus extraneus*) are closely allied to coeval taxa from the Yangtze region (*Zhenganites guizhouensis* Yin, *in* Yin and Lee, 1978, *Mioptychopyge suni* (Endo, 1935), *Liomegalaspides blackwelderi* (Weller, 1907), *Ovalocephalus primitivus primitivus* (Lu, 1975)). It is concluded that the Tarim and South China blocks formed a single palaeogeographical unit during the late early Ordovician. Biotic evidence from the rest of the Palaeozoic shows that Tarim, an independent block, was situated very close to the South China Block, and the two were not separated by large oceanic basins (Zhou and Chen 1990, p. iv; 1992, p. ii; Zhou *et al.* 1996, pp. 11, 20).

Of the 15 trilobite genera and one subgenus in the Dawangou Formation, four are endemic to the Tarim and Yangtze regions, namely *Zhenganites*, *Mioptychopyge* gen. nov., *Liomegalaspides* and *Yanhaoia* gen. nov. A small number of trilobites such as *Pseudocalymene*, *Birmanites* and *Ovalocephalus* are found only in Ordovician Gondwanaland (Zhou and Dean 1989); *Eccoptochile*, typically known elsewhere from the upper Llanvirn–Ashgill of Spain, Portugal, France, Bohemia and, probably, Morocco and Turkey (Rabano 1990), is also referred to this group.

Carolinites is an epipelagic genus which occurs in North America, Greenland, Spitsbergen, Siberia, Tasmania, Australia, South China and, uncommonly, northern Baltica, Turkey and Argentina, a distribution suggesting Ordovician lower latitudinal zones (Fortey 1985). *Nileus* is also widespread but is mainly restricted to the Nileid Biofacies belts or slope areas adjacent to carbonate platforms in the Ordovician tropical to temperate zones (Fortey 1975*a*; Zhou *et al.* 1989). The occurrence of *Gog* is linked to the Nileid Biofacies, although it has been found elsewhere only in Spitsbergen, Sweden, the north Arctic Urals (Fortey 1975*b*) and the western marginal area of the North China platform (Zhou *et al.* 1982).

Illaenus has a world-wide distribution, and is especially predominant in carbonate build-ups (Fortey 1975*a*; Mikulic 1980; Zhou *et al.* 1989). *Nanillaenus*, recorded from North America, Scotland and Argentina, and *Sphaerocoryphe* (*Hemisphaerocoryphe*), known from Baltoscandia, Australia and the Yangtze region, are both members of the Illaenid-Cheirurid Association. However, judging from their occurrences in China, all three genera may have tolerated a wide range of environments, from platform to upper slope.

Excluding those genera that are endemic, pelagic and facies-restricted, the trilobite fauna shows strong Gondwanan affinities, and the Tarim Block may have formed part of Ordovician Gondwanaland. This landmass, extending from the South Pole to north of the equator during the Ordovician, was large enough to account for the considerable faunal differences between the cold and warm areas, and there appears to be no evidence for the presence of oceanic barriers that might have prevented migration and dispersal of trilobites between different areas (Zhou and Dean 1989; Cocks and Fortey 1990). Palaeomagnetic data show that the Kalpin area was located at 19·6° S (Zhou and Zheng 1990).

The trilobites from the Dawangou Formation include largely warm-water elements, with some, such as *Eccoptochile* (see Přibyl *et al.* 1985), that were once considered as cold-water forms. Asaphids have a strong Baltoscandian aspect: *Ogmasaphus*, previously thought to be endemic to Scandinavia; *Gog*, recently recorded from Sweden; *Liomegalaspides*, considered by Lu (1975) to be derived from *Megalaspides*; and others, such as *Zhenganites* and *Mioptychopyge*, which are closely related to *Ptychopyge* (*s.l.*) and *Pseudobasilicus* (*s.l.*). Baltoscandia is widely considered to have been located in the temperate zones, at least during the early Ordovician. The mixture of trilobites from different temperature zones in the Dawangou fauna may suggest ecological conditions appropriate to an upper slope environmental gradient.

Interestingly, the oldest recorded species of *Nanillaenus*, *Eccoptochile* and *Sphaerocoryphe* (*Hemisphaerocoryphe*) occur in the Dawangou fauna, and a probably new raphiophorid is referred questionably to *Ampyxina*, a principally North American form. If the latter determination is correct, it may lend support to the view (Fortey 1984; Dean 1985) that faunal exchange between Laurentia and Gondwanaland may have started in the early Ordovician.

SYSTEMATIC PALAEONTOLOGY

The terminology used here is essentially that of the first edition of the *Treatise on invertebrate paleontology* (Harrington *et al.*, *in* Moore 1959), with the modifications proposed in the second edition (Whittington and Kelly 1997). Repositories of described and cited specimens are: NI, Nanjing Institute of Geology and Palaeontology, Academia Sinica; USNM, National Museum of

Natural History, Washington, D.C.; XTR, Regional Geological Survey Team of Xinjiang; YI, Yichang Institute of Geology and Mineral Resources, Academy of Geological Sciences of China.

Family LEIOSTEGIIDAE Bradley, 1925

Remarks. We follow Fortey and Shergold (1984) in considering Eucalymenidae Lu, 1975 to be a junior synonym of Leiostegiidae.

Genus PSEUDOCALYMENE Pillet, 1973
(= *Eucalymene* Lu, 1975, p. 245)

Type species. Pseudocalymene superba Pillet, 1973.

Remarks. Eucalymene was established by Lu (1975) mainly on the basis of the type species *E. quadrata*, and the diagnostic features, including small eyes, lack of cephalic border, and the presence of interpleural furrows on the pygidium agree well with the definition of *Pseudocalymene*. Pillet's (1976) suggestion that the two genera are synonymous is followed here. Except for the type species, *P. superba* Pillet (1973, p. 36, pl. 6, figs 6–8; pl. 7, figs 1–6; pl. 8, fig. 9) from the Ordovician of eastern Iran, other forms of the genus have been recorded from the upper Arenig–Llanvirn of the Yangtze region (Li *et al.* 1975; Lu 1975; Zhou *et al.* 1977; Lee 1978; Xia 1978; Yin and Lee 1978; Zhou *et al.* 1982; Sun 1984) and of Tarim (Zhang 1981), China.

Pseudocalymene quadrata (Lu, 1975)
Plate 1, figures 1–3

1975 *Eucalymene quadrata* Lu, p. 460, pl. 48, fig. 15; pl. 49, figs 1–10; pl. 50, figs 1–5.
1975 *Eucalymene quadrata* Lu; Li *et al.*, p. 148, pl. 13, fig. 13.
1977 *Eucalymene quadrata* Lu; Zhou *et al.*, p. 264, pl. 80, fig. 1a–d.
1978 *Eucalymene quadrata* Lu; Xia, p. 183, pl. 36, fig. 18.
1981 *Pseudocalymene quadrata* (Lu); Zhang, p. 212, pl. 79, figs 1–3.
1982 *Pseudocalymene quadrata* (Lu); Zhou *et al.*, p. 289, pl. 71, figs 5–6.
1984 *Pseudocalymene quadrata* (Lu); Sun, p. 419, pl. 54, figs 7–8.

Holotype. Enrolled exoskeleton (NI 16987), figured Lu (1975, pl. 59, figs 1–5), Zhou *et al.* (1977, pl. 80, fig. 1a–d) and Sun (1984, pl. 154, figs 7–8), from the uppermost Dawan Formation (latest Arenig) at Fenxiang, Yichang, western Hubei.

Figured specimens. Two pygidia (NI 80715–80716) and a juvenile librigena (NI 80714), from Bed 2.

EXPLANATION OF PLATE 1

Figs 1–3. *Pseudocalymene quadrata* (Lu, 1975); Bed 2. 1, NI 80714; small right librigena; ×6. 2, NI 80715; pygidium; ×1·5. 3, NI 80716; pygidium; ×1·5.

Figs 4–11. *Birmanites brevicus* Xiang and Zhou, 1987; Bed 2. 4, NI 80717; cephalon with thorax. 5, NI 80718; cephalon with thorax. 6–7, NI 80719; enrolled exoskeleton, dorsal views. 8, 11, NI 80720; incomplete exoskeleton, lateral views. 9, NI 80721; incomplete cephalon with thorax. 10, NI 80722; thorax and pygidium of complete exoskeleton. All ×1·5.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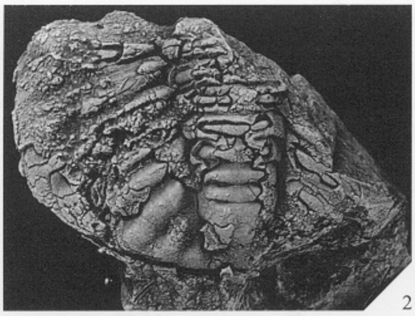
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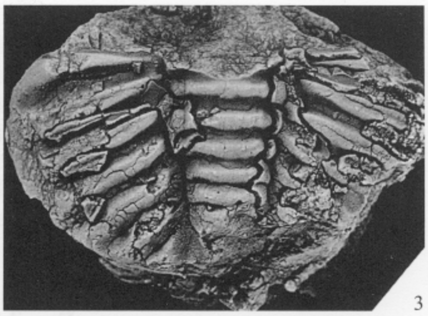
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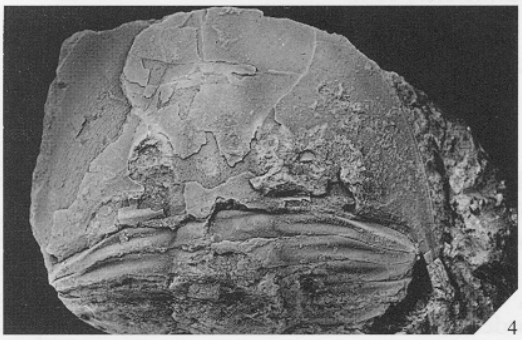
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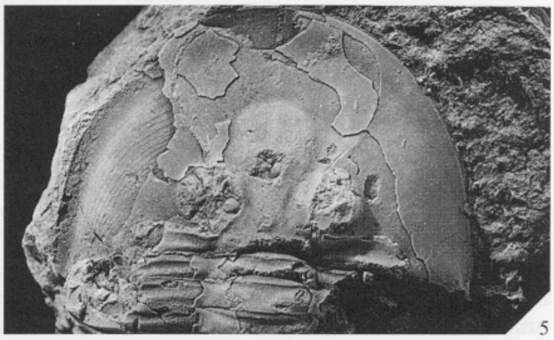
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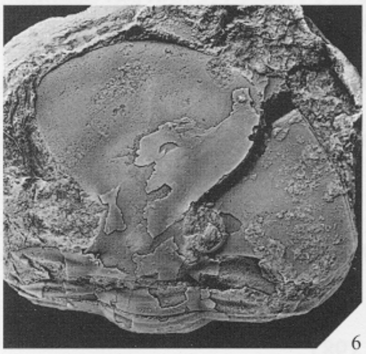
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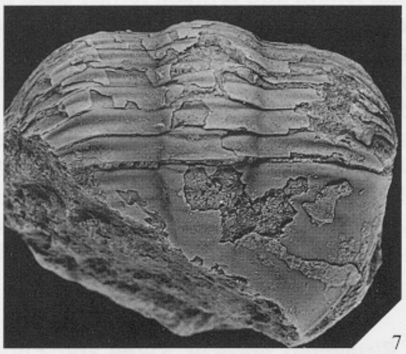
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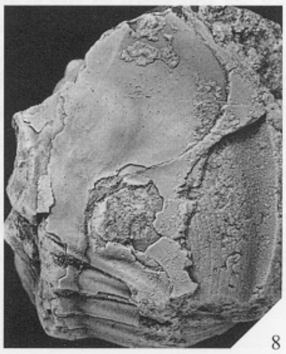
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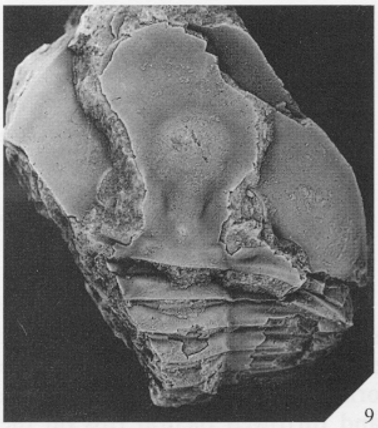
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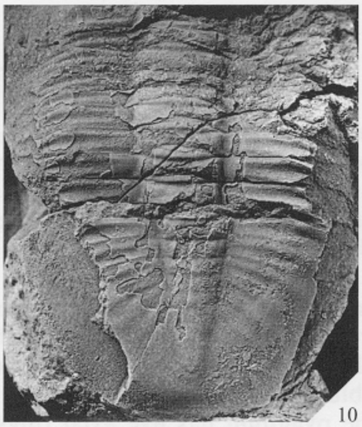
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ZHOU *et al.*, *Pseudocalymene*, *Birmanites*

Remarks. The species was described fully by Lu (1975, p. 460) and the present pygidia, although poorly preserved, agree with his account. Two enrolled exoskeletons and a pygidium from the same horizon and locality were referred to the species by Zhang (1981, p. 212, pl. 79, figs 1–3). An associated juvenile librigena shows five widely spaced terrace ridges on the strongly convex border; surface is covered with distinct scattered tubercles in adaxial part of genal field, coarsely granular in anterior part of border, and otherwise smooth, but in the holotype, the whole surface of the librigena is densely granular. These differences are considered as intraspecific and may represent morphological changes during ontogeny.

Family ASAPHIDAE Burmeister, 1843
Subfamily ASAPHINAE Burmeister, 1843
Genus BIRMANITES Sheng, 1934

Type species. Ogygites birmanicus Reed, 1915.

Remarks. As noted by Zhou *et al.* (1984), Zhou and Dean (1986) and Tripp *et al.* (1989), *Ogygites* de Tromelin and Lebesconte, 1876, *Pseudobasilicus* Reed, 1931, *Birmanites* Sheng, 1934, *Opsimasaphus* Kielan, 1960 and *Nobiliasaphus* Přibyl and Vaněk, 1965 are closely similar and may prove to be synonymous. Recently, Rabano (1990) suggested that *Ogygites* should be used solely for the type species, *Ogygia desmaresti* Brongniart, 1822. *Pseudobasilicus* differs from *Birmanites* only in the shorter preglabellar field. A species recorded below shows a frontal area that occupies 36–39 per cent. of the cranidial length and is much longer than that of *Ptychopyge lawrowi* Schmidt, 1898 (p. 31, fig. 7), type species of *Pseudobasilicus*; for the time being we refer it to *Birmanites*.

Birmanites is a widely distributed Ordovician genus in Asia. In addition to the type species, the following are included, although some are based on inadequate material, or on pygidia only, and need to be further revised: *Ogygites yunnanensis* Reed, 1917, *Birmanites hupeiensis* Yi 1957, *Ogygites almatyensis* Chugaeva 1958, *Ogygites kolovae* Chugaeva 1958, *Birmanites dabashanensis* Lu, *in* Lu and Chang, 1974, *Birmanites yangtzeensis* Lu, 1975, *Birmanites politus* Lu, 1975, *Birmanites carinatus* Lu, *in* Lu *et al.*, 1976, *Birmanites sichuanensis* Lee, 1978, *Birmanites sanduensis* Yin, *in* Yin and Lee, 1978, *Birmanites juxianensis* Ju, *in* Qiu *et al.*, 1983; *Birmanites brevicus* Xiang and Zhou, 1987, *Birmanites elongatus* Xiang and Zhou, 1987 and *Birmanites yichangensis* Xiang and Zhou, 1987.

Birmanites brevicus Xiang and Zhou, 1987

Plate 1, figures 4–11

1983 *Birmanites brevicus* Xiang and Zhou, *in* Zeng *et al.*, pl. 7, fig. 12 [*nomen nudum*].
1987 *Birmanites brevicus* Xiang and Zhou, p. 312.

Holotype. Exoskeleton (YI 70260), figured Xiang and Zhou, *in* Zeng *et al.* (1983, pl. 7, fig. 12), from the Kuniutan Formation (Llanvirn) at Huanghuachang, Yichang, western Hubei.

Figured specimens. Three exoskeletons (NI 80719–80720, 80722) and three cephala with attached thoracic segments (NI 80717–80718, 80721) from Bed 2.

Remarks. The present specimens agree well with the holotype of *B. brevicus*, described formally by Xiang and Zhou (1987). The frontal area is 36–39 per cent. of the cranidial length and 150 per cent. of the width between palpebral lobes, the pygidium is sub-trapezoidal in outline and, based on the new material, the pygidial doublure is narrower than in known forms, about half the pleural width along the anterior margin. The pygidium has five axial rings and furrowed pleural ribs on the external surface, but up to ten are visible on the internal mould, as described by Xiang and Zhou (1987, p. 312).

B. brevicus is closely allied to *B. hupeiensis* Yi (1957, p. 552, pl. 3, fig. 1a–g), a Llandeilo–early Caradoc species described from the Miaopo Formation of western Hupei and the Shihtzupu Formation of northern Guizhou by Lu (1975, p. 319, pl. 7, figs 14–15; pl. 8, figs 1–7) and Zhou *et al.* (1984, p. 17, fig. 3c–f, i–j, m). Except for the much wider pygidial doublure, the latter species differs mainly in its longer frontal area (up to 50 per cent. the cranidial length). The pygidium of *B. hupeiensis* is mostly semi-elliptical, but a few specimens have a trapezoidal outline (see Lu 1975, pl. 8, fig. 5) like that in *B. brevicus*. In pygidia of the younger species the length varies from 60–75 per cent. of the width, and the length of the axis is 55–70 per cent. of the pygidium. Corresponding figures for a complete pygidium (Pl. 1, fig. 10) of *B. brevicus* are 62 per cent. and 73 per cent., and fall almost within the range of variation in *B. hupeiensis*.

Genus OGMASAPHUS Jaanusson, 1953

Type species. Asaphus praetextus Törnquist, 1884.

Ogmasaphus hannanicus (Lu, 1975)

Plate 2, figures 1–5

1975 *Pseudoasaphus* [*sic*] *hannanicus* Lu, p. 311, pl. 5, fig. 24.

Holotype. Incomplete cephalon with three attached thoracic segments (NI 16487), figured Lu (1975, pl. 5, fig. 24), from a horizon of Llanvirn age in the Siliangssu Formation, at Liangshan, Hanzhong, southern Shaanxi.

Figured specimens. One exoskeleton (NI 80725), one cephalon with five attached thoracic segments (NI 80724) and one pygidium with two attached thoracic segments (NI 80723) from Bed 2.

Description. Exoskeleton oval in outline with semicircular cephalon and pygidium of equal length; frontal area fairly narrow. Glabella convex, broadly rounded anteriorly, hourglass-shaped, constricted opposite palpebral lobes, from which it expands more gently forwards than backwards; no S0, but pair of indentations present close to axial furrows; median glabellar node posteriorly situated, about in line with posterior edge of palpebral lobes; median ridge faintly visible on exfoliated surface, extending forwards from median node; posterolateral furrow distinct, deeper than axial furrows, dies out adaxially. Low posterolateral glabellar lobe small, triangular. Anterior glabellar lobe shows four pairs of muscle scars on exfoliated surface: posterior scar is triangular, directed backwards, close to posterolateral glabellar furrow; remaining scars are oval, transverse, located on glabellar flank anterior to posterolateral furrow and adjacent to axial furrow. Palpebral lobe large, more than one-third cranidial length, crescentic in form, elevated above fixigena, well defined by broad palpebral furrow. Anterior sections of facial suture diverge forwards in broad curve, submarginal anteriorly; posterior sections extend outwards and slightly backwards in gently sigmoidal curve. Palpebral area of fixigena gently convex, as wide as long; posterior area short (exsag.), strip-like, with raised border which narrows adaxially, defined by shallow border furrow. Librigena without border but has raised edge; genal area transversely convex; eye socle vertical, narrow; eye large, length (exsag.) half that of cephalon (sag.); doublure wide, covered with dense terrace ridges, part of its inner margin close to eye socle.

Thoracic axis is bounded by distinct axial furrows that are gently curved adaxially, and occupies about 40 per cent. of overall width; rectangular axial ring moderately convex (tr.). Pleurae extend horizontally for short distance to the fulcrum, then curve gently down and slightly backwards. Pleural furrows distinct, but die out both abaxially and adaxially on external surface.

Pygidium broadly rounded posteriorly, 60–67 per cent. as long as wide. Axis convex, conical, occupies 37 per cent. of anterior width of pygidium and 87 per cent. of its sagittal length; it is well defined by broad axial furrows, including eight faintly defined rings and a small, rounded terminal piece in addition to a wide (sag.)

articulating half ring as shown in exfoliated specimens. Pleural region evenly convex, without defined border; inner part weakly displays four to five furrowed ribs on exfoliated surface; articulating half-rib ridge-like, faceted anterolaterally; first pleural furrow deeply incised. Doublure fairly broad, about half pleural width anteriorly; inner margins lightly convex adaxially except where indented around posterior part of axis (including seventh and eighth rings and terminal piece).

Remarks. Our specimens show a pair of shorter posterolateral glabellar furrows and an almost effaced occipital furrow, but otherwise agree well with the holotype, an internal mould. In our opinion these superficial differences are probably due to preservation. The species shares some features, such as the absence of a cephalic border and the more or less effaced S0, with both *Ogmasaphus* and *Asaphus* (*Neoasaphus*). Some Scandinavian species are intermediate between the two latter and, as Henningsmoen (1960, p. 236) believed, further work may prove *Ogmasaphus* to be no more than a subgenus of *Asaphus*. Reassignment of the present species to *Ogmasaphus* is suggested by the extremely narrow (sag.) frontal area of the cranidium and the fairly wide pygidial doublure, although the large eye and poorly defined pygidial border and pleural ribs are more similar to those of known species of *A*. (*Neoasaphus*).

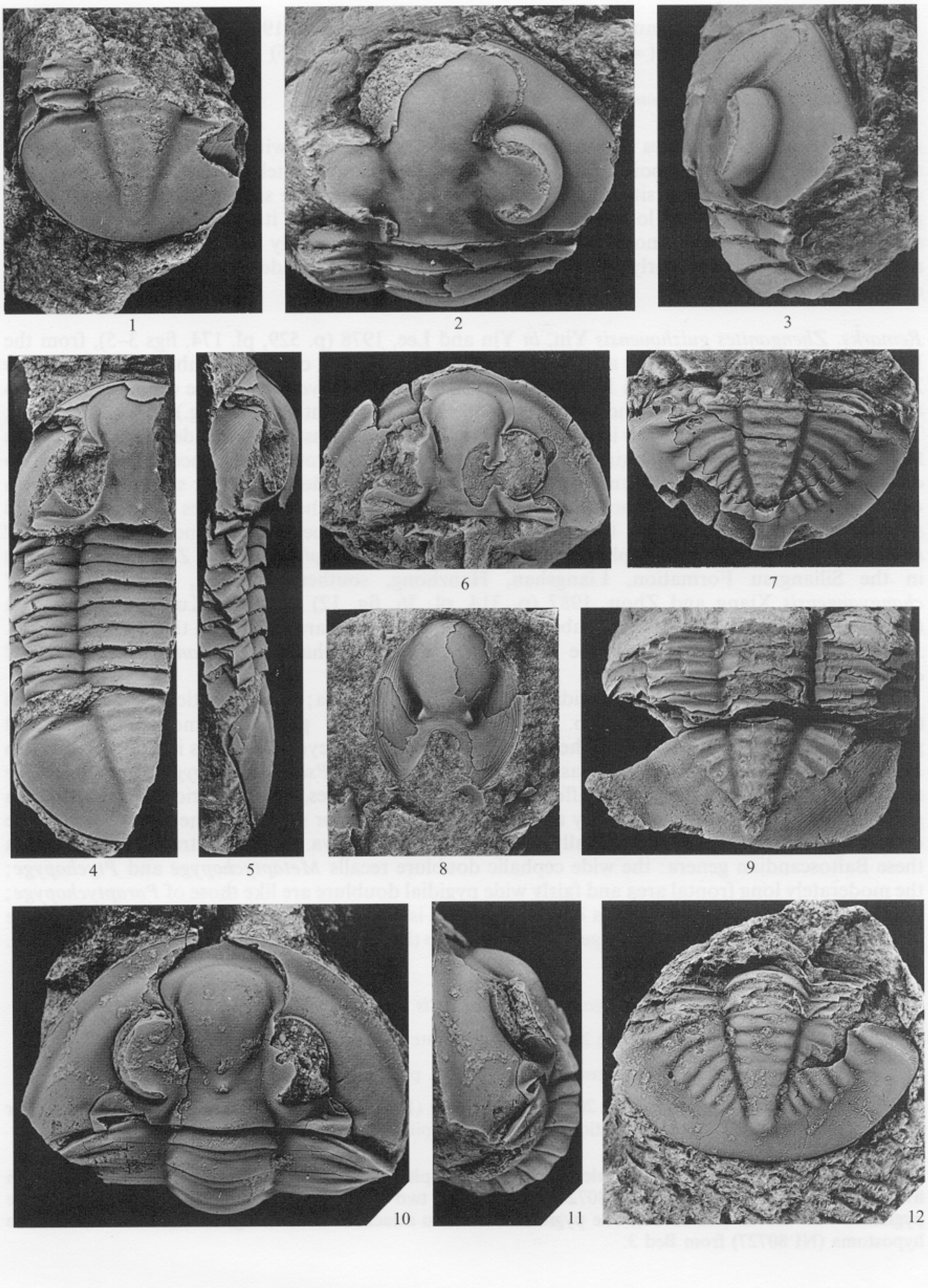
Compared with *O. praetextus* (Törnquist) (see Jaanusson 1953, p. 427, pl. 5, figs 1–8) and *O. costatus* Jaanusson (1953, p. 433, pl. 6, figs 3–9; pl. 7, figs 1–4) from the middle Ordovician of Scandinavia, *O. hannanicus* has larger eyes, broader cephalic doublure and the anterior part of the glabella expands forwards more gently. The absence of a defined pygidial border, the weakly defined ribs, and the presence of librigenal spines (see Lu 1975, pl. 5, fig. 24) in *O. hannanicus* may also distinguish it from the Scandinavian species, although the features are shared by exceptional specimens of *O. costatus* (see Jaanusson 1953, pl. 6, figs 6, 9).

Several Chinese species strongly resemble *O. hannanicus*, especially in the extraordinarily large eyes (length half that of the cephalon), and may form a closely related species group. They include *Ogmasaphus* [*Asaphus*] *fenhsiangensis* (Yi 1957, p. 532, pl. 2, fig. 2a–b) (see Xiang and Zhou 1987, p. 309, pl. 35, fig. 11), *Ogmasaphus* [*Opsimasaphus*] *fusiformis* (Xia 1978, p. 161, pl. 29, fig. 10) [= *Opsimasaphus xilingxiaensis* Xia 1978, p. 161, pl. 29, figs 8–9 = *Pseudasaphus limbatus* Xia 1978, p. 162, pl. 30, fig. 4 only, *non* fig. 5; see Xiang and Zhou 1987, p. 310, pl. 33, fig. 5, pl. 35, fig. 8] and *Ogmasaphus triangularis* Xiang and Zhou 1987 (p. 311, pl. 35, fig. 7), all from the Miaopo Formation (Llandeilo–early Caradoc) of the Yichang area, western Hubei; and possibly also *Asaphus nebulosus* Gortani (1934, p. 76, pl. 18, fig. 1a–b) from the upper lower Ordovician of Karakorum. Among the listed species, only *Ogmasaphus fenhsiangensis* is well founded. The cranidium as described by Yi (1957) is almost indistinguishable from that of *P.*? *hannanicus*, but the thorax and pygidium recently illustrated by Xiang and Zhou (1987) differ considerably in the narrower thoracic axis (about as wide as the adjacent pleura), the even narrower pygidial axis (one-fifth to one-sixth the frontal breadth of the pygidium) with ten instead of eight defined axial rings, and the more distinct pleural furrows on the pygidium.

EXPLANATION OF PLATE 2

Figs 1–5. *Ogmasaphus hannanicus* (Lu, 1975); Bed 2. 1, NI 80723; pygidium with two attached thoracic segments; ×2·5. 2–3, NI 80724; cephalon with five attached thoracic segments, dorsal and lateral views; ×3. 4–5, NI 80725; incomplete exoskeleton, dorsal and lateral views; ×2.

Figs 6–12. *Zhenganites xinjiangensis* (Zhang, 1981). 6–7, NI 80726; Bed 2; enrolled exoskeleton, dorsal views; ×1·5. 8, NI 80727; Bed 3; hypostoma; ×2. 9, NI 80728; Bed 2; pygidium and five attached thoracic segments, showing pygidial doublure; ×1. 10–11, NI 80729; Bed 3; enrolled exoskeleton, dorsal and lateral views; ×2. 12, NI 80730; Bed 3; pygidium with attached thorax; ×1·5.



ZHOU *et al.*, *Ogmasaphus*, *Zhenganites*

Genus ZHENGANITES Yin, *in* Yin and Lee, 1978
(= *Eosoptychopyge* Zhang, 1981, p. 185)

Type species. Zhenganites guizhouensis Yin, *in* Yin and Lee 1978.

Diagnosis. Asaphine trilobites with narrow (tr.) glabella. Cephalon with flat border and librigenal spines; cranidium bluntly pointed frontally; frontal area moderately long; bacculae elongate, constricted; eyes very large, sited posteriorly; median glabellar node sited in front of line through posterior ends of palpebral lobes; cephalic doublure wide, part of its inner margin close to eye socle. Hypostoma deeply notched posteriorly. Pygidium broadly rounded posteriorly; axis markedly narrower posteriorly; pleural region with abaxially rounded ribs and distinct border; doublure fairly broad.

Remarks. Zhenganites guizhouensis Yin, *in* Yin and Lee, 1978 (p. 529, pl. 174, figs 3–5), from the Kuniutan Formation (Llanvirn) at Anchang, Zhengan, Guizhou, closely resembles *E. xinjiangensis* Zhang (1981, p. 185, pl. 68, figs 1–2), the type species of *Eosoptychopyge*. The cephala of the two are almost indistinguishable, although the preglabellar field is slightly wider (sag.) in *Z. guizhouensis*. The pygidium of *Z. guizhouensis* is incomplete but, from Yin's illustration and description, it differs from that of *E. xinjiangensis* mainly in the shallower pleural furrows. Differences between the two do not seem generically significant, and *Eosoptychopyge* is considered a junior subjective synonym of *Zhenganites*. The above diagnosis is based on the holotype of the type species and well preserved specimens of *Z. xinjiangensis* from our collection. Other species may include *Ptychopyge*? *hankiangensis* Lu, 1975 (p. 311, pl. 6, figs 7–9), from the *Ningkianolithus welleri* Zone (latest Arenig) in the Siliangssu Formation, Liangshan, Hanzhong, southern Shaanxi, and *Ptychopyge*? *changyangensis* Xiang and Zhou, 1987 (p. 314, pl. 36, fig. 12) from the Kuniutan Formation (Llanvirn), Yichang area, western Hubei. The pygidium is comparable in both these species and *Z. xinjiangensis*, and the three may be conspecific, but the cephala of *P. hankianensis* and *P.*? *changyangensis* is as yet unknown.

Zhenganites has an elongated cranidium and a narrow glabella; characteristic post-ocular nodes (or bacculae, see Fortey 1980*b*, p. 258) are absent but a pair of homologous elongated protuberances is well developed on the fixigena just behind the eye. The genus is closely related to *Ptychopyge* and allied genera (see Balashova 1964, 1976) such as *Pseudoptychopyge*, *Paraptychopyge* and *Metaptychopyge*. *Zhenganites* differs in the much larger eyes, more anteriorly placed median glabellar node, and the more broadly rounded concave posterior margin of the hypostoma. Some other characters considered generically important by Balashova (1964) are transitional between these Baltoscandian genera: the wide cephalic doublure recalls *Metaptychopyge* and *Ptychopyge*; the moderately long frontal area and fairly wide pygidial doublure are like those of *Paraptychopyge*; the bluntly pointed anterior margin of the cranidium is close to that of *Pseudoptychopyge*; and the more deeply notched hypostoma is generally similar to that of *Paraptychopyge* and *Metaptychopyge*.

Zhenganites xinjiangensis (Zhang, 1981)

Plate 2, figures 6–12; Plate 3, figures 1, 3

1981 *Eosoptychopyge xinjiangensis* Zhang, p. 185, pl. 68, figs 1–2.

Holotype. Enrolled exoskeleton (XTR 206), figured Zhang (1981, pl. 68, fig. 1a–b), from the topmost Upper Qiulitag Group [= Dawangou Formation] at Subaxi, Kalpin, north-western Tarim, Xinjiang.

Figured specimens. One enrolled exoskeleton (thorax incompletely exposed) (NI 80726) and one pygidium with five attached thoracic segments (NI 80728) from Bed 2; two cephala with thorax (NI 80729, 80731), one pygidium with thorax (NI 80730), one pygidium with two attached thoracic segments (NI 80732) and one hypostoma (NI 80727) from Bed 3.

Description. Cephalon about as wide and long as pygidium, gently convex, with librigenal spines; length 40–50 per cent. of width (longer in the small specimen); cephalic border low, flat, about 8–10 per cent. of cephalic length (sag.) and narrows moderately backwards. Glabella elongate, convex, broadly rounded frontally, slightly constricted opposite palpebral lobes, well defined by axial furrows, with prominent medial note sited in front of line through rear of palpebral lobes; distinct posterolateral furrows shallow towards median node; posterolateral lobes triangular, with two pairs weakly defined transverse depressions in exfoliated specimens; largely effaced S0 traceable near axial furrows on exfoliated surface opposite posterior ends of palpebral lobes. Baccula elongate, ridge-like, poorly defined abaxially, sited between posterior end of palpebral lobe and adaxial end of posterior border furrow. Large, semicircular palpebral lobe 45 per cent. the cranidial length, ill defined by obsolete palpebral furrow. Anterior sections of facial suture diverge gently until opposite anterolateral corners of glabella, where curve adaxially to meet in bluntly pointed ogive; each posterior section forms a sigmoidal curve. Frontal area usually 9–13 per cent. of cranidial length, being relatively shorter in larger specimens. Preglabellar field much narrower (sag.) than anterior border and declines gently to border furrow. Anterior area of fixigena slightly swollen, narrows backwards; palpebral area higher than adjacent part of glabella; posterior area narrow (exsag.), widens abaxially, and convex posterior border is well defined by deep border furrow. Librigena with convex (tr.) genal field and vertical eye socle; large crescentic eye up to 50 per cent. cranidial length; posterior border poorly defined; doublure wide, inner margin subparallel to lateral border furrow and, in part, close to eye socle. Hypostoma forked, longer than wide; sub-hexagonal middle body strongly convex, clearly delimited by deep, wide lateral border furrows and shallow posterior border furrow; posterolateral maculae distinct; lateral border widens posteriorly, with margin adaxially curved; posterior fork broadly based, bluntly pointed; broadly rounded median notch 30 per cent. overall length of hypostoma; borders covered with widely-spaced ridges subparallel to margin.

Thorax parallel-sided, with convex, uniformly wide axis about one-third overall width. Axial furrow deep, broad. Pleurae transverse as far as fulcra, where curve gently backwards and down, each narrowing to a pointed tip. Pleural furrow runs slightly backwards abaxially, shallowing adaxially on external surface.

Pygidium has length 50–53 per cent. width and is broadly rounded posteriorly. Convex axis has frontal width about 25 per cent. that of pygidium, tapering gently to the fourth ring furrow and then strongly to rounded tip, reaching inner margin of border; there are seven axial rings and terminal piece in addition to short (sag.) articulating half ring; ring furrows shallow on external surface, deep on exfoliated surface, and become fainter posteriorly. Axial furrow deep. Pleural field vaulted, with seven or eight ribs divided by deep, broad pleural furrows which end at inner margin of border; ribs convex, faintly furrowed, well rounded abaxially; articulating half-rib ridge-like, with broad (tr.) facet. Border slightly declined towards margins, occupies 17–20 per cent. pygidial length at sagittal line and widens gradually abaxially; no border furrow, but border well defined by change in convexity. Concave doublure 50–55 per cent. of frontal width of pleural region and is densely covered with terrace ridges subparallel to margins; inner margins of doublure diverge forwards from abaxial ends of sixth ring furrow, and extend backwards along the axial furrows to meet at tip of axis.

Genus MIOPTYCHOPYGE gen. nov.

Derivation of name. Mio (Greek, less) with *Ptychopyge*, a well known Baltoscandian asaphine genus.

Type species. Ptychopyge trinodosa Zhang, 1981.

Diagnosis. Cephalon semi-elliptical with broadly based librigenal spines; frontal area quite long (sag.); border flat, well defined; doublure wide (sag.). Cranidium bluntly pointed frontally; glabella relatively narrow; bacculae elongate, very narrow; preglabellar field shorter (sag.) than border; anterior sections of facial sutures diverge forwards slightly, intramarginal anteriorly; posterior sections sigmoidal. Eyes moderately large, located posteriorly. Hypostoma forked. Tips of thoracic pleurae extend into short, backwardly directed spines. Pygidium with uniformly tapered axis; inner part of pleural region with furrowed ribs; border slopes gently at periphery with no border furrow; doublure fairly broad, its inner margins diverging forwards from ends of sixth ring furrow.

Remarks. Some closely related Chinese species have in common a combination of characters transitional between *Ptychopyge* (*s.l.*) and *Pseudobasilicus* (*s.l*). Baltoscandian species formerly included in these two groups were reassigned by Balashova (1964, 1971, 1976) to several genera and subgenera, but relevant Chinese forms do not fit readily into any of them and the present group of species is sufficiently distinct to warrant allocation to a new genus. *Mioptychopyge* includes, in addition to the type species, the following Chinese taxa: *Asaphus suni* Endo, 1932 (p. 112, pl. 39, figs 11–17; 1935, p. 218; provisionally reassigned to *Ptychopyge* by Lu *et al.* 1965 and to *Ningkianites* by Chang and Jell 1983), *Basiliella zhenbaensis* Zhou, *in* Li *et al.*, 1975 (p. 150, pl. 18, figs 3–5) and *Pseudobasilicus taotsaotzensis* Lu, *in* Lu *et al.*, 1976 (p. 63, pl. 10, fig. 3). *Ptychopyge thebawi* Reed, 1915 (p. 32, pl. 6, figs 5–8) from the Hwe Mawng Beds (lower Ordovician), Northern Shan States, Burma, is also referable to the genus. Among the listed species, *Mioptychopyge zhenbaensis* and *M. suni* are both based on material from the same horizon (probably latest Arenig–Llanvirn) in the Siliangssu Formation of southern Shaanxi, and original specimens of *M. suni*, refigured by Chang and Jell (1983, fig. 4A–F) are virtually identical to those of *M. zhenbaensis*. The latter species differs only in having deeper pleural furrows on the pygidium, a character insufficient to justify specific separation.

Several late early Ordovician species from the Yangtze region, such as *Pseudobasilicus dawanicus* Lu, 1975 (p. 312, pl. 6, figs 1–3; pl. 7, figs 1–2), *Pseudobasilicus pseudodawanicus* Lu, 1975 (p. 314, pl. 5, fig. 25; pl. 6, figs 4–6), *Ptychopyge neichiensis* Kobayashi, 1951 (p. 30, pl. 2, figs 5–6), *Ptychopyge orientalis* Kobayashi, 1951 (p. 29, pl. 2, figs 3–4) and *Pseudobasilicus xiaotanensis* Zhang, *in* Qiu *et al.*, 1983 (p. 203, pl. 67, fig. 11) are believed to be allied, or even belong, to *Mioptychopyge*. However, they are founded either on juvenile specimens (*P. dawanicus*, *P. xiaotanensis*) or on inadequate or imperfectly preserved material (*P. orientalis*, *P. neichiensis*, *P. pseudodawanicus*). These forms are insufficiently well known for adequate revision.

Pseudobasilicus (*s.l.*) resembles *Mioptychopyge* especially in the presence of thoracic pleural spines, the fairly broad pygidial doublure (see, for example, Schmidt 1904, pl. 4, figs 3, 5, 7, for the type species of *Pseudobasilicus*, *P. lowrowi*) and the deeply and broadly indented posterior margin of the hypostoma. But it differs in the more divergent anterior sections and less sigmoidal posterior sections of the facial suture; the shorter frontal area; the absence of bacculae; the proportionally wider cephalon, librigena and pygidium; the narrower cephalic doublure; the stouter cranidium; the more posterior position of the eye (which almost reaches the posterior border furrow); the long (tr.), narrower (exsag.) posterior area of the fixigena, which narrows abaxially (cf. widens in *Mioptychopyge*); and the flatter pygidial border.

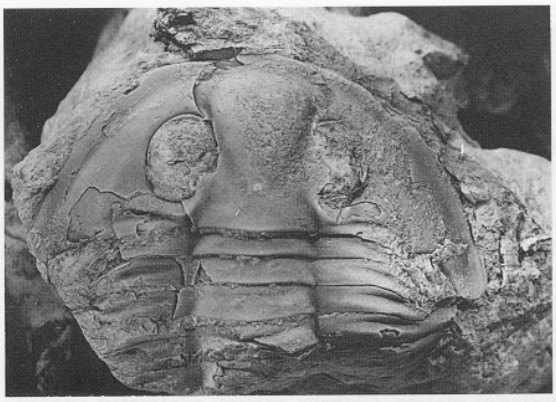
The relatively elongate cranidium, the strongly sigmoidal posterior sections and gently divergent anterior sections of the facial suture, and the postocular bacculae of the new genus are suggestive of *Ptychopyge* (*s.l.*); but in the latter there are no thoracic pleural spines, the posterior notch of the hypostoma is narrower (tr.) than that of *Mioptychopyge suni* (Endo) (see Zhou, *in* Li *et al.* 1975, p. 18, fig. 4), and the pygidial border is generally flat and well defined. Some other features of *Mioptychopyge* are shared with genera of the *Ptychopyge* group (*Ptychopyge s.s.*, *Pseudoptychopyge*, *Paraptychopyge*, *Metaptychopyge*) as follows: the broad cephalic doublure in *Mioptychopyge* is comparable to that of *Ptychopyge* (*s.s.*) and *Metaptychopyge*; the course of the anterior sections of the facial suture is similar to that in *Pseudoptychopyge*; the length of the frontal area and the position of the palpebral lobe compare to those of *Ptychopyge* (*s.s.*); and the broad pygidial doublure agrees with that of *Paraptychopyge*. The exoskeleton of *Mioptychopyge* is, in our opinion, closer to *Ptychopyge* (*s.l.*) than to *Pseudobasilicus*.

EXPLANATION OF PLATE 3

Figs 1, 3. *Zhenganites xinjiangensis* (Zhang, 1981); Bed 3. 1, NI 80731; cephalon with thorax; ×1·2. 3, NI 80732; pygidium, with two attached thoracic segments; ×1.

Figs 2, 4–10. *Mioptychopyge trinodosa* (Zhang, 1981). 2, NI 80733; Bed 3; pygidium; ×2. 4–5, 7. NI 80734; Bed 2; exoskeleton, dorsal and lateral views; ×2. 6, NI 80735; Bed 2; pygidium, showing doublure; ×1. 8, NI 80736; Bed 2; pygidium with thorax; ×2. 9, NI 80737; Bed 3; pygidium; ×1. 10, NI 80738; Bed 3; small pygidium; ×4.

PLATE 3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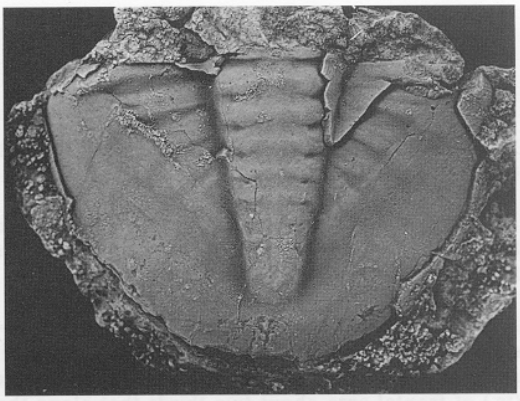
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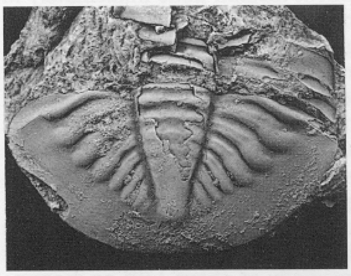
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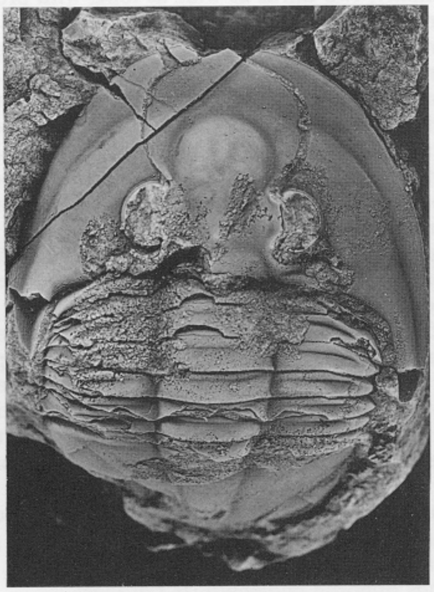
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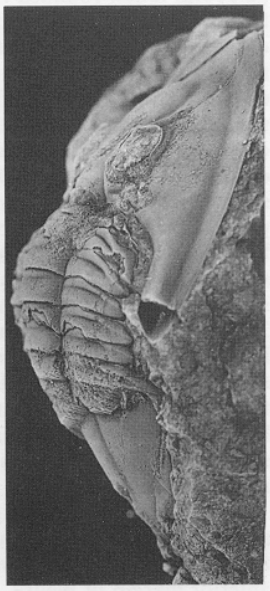
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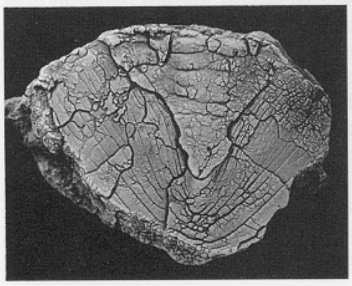
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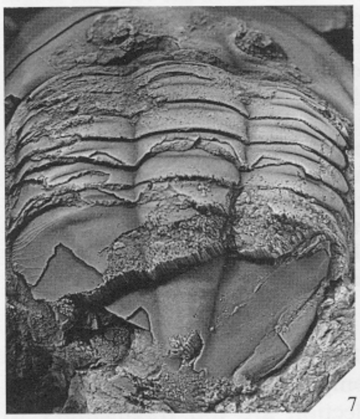
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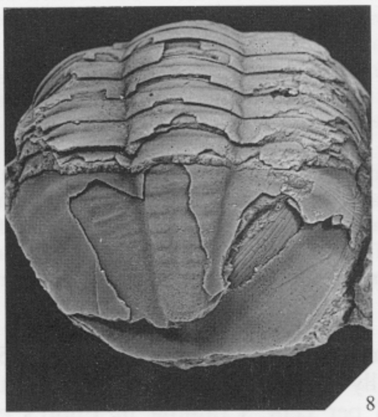
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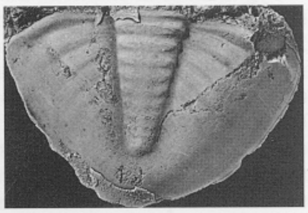
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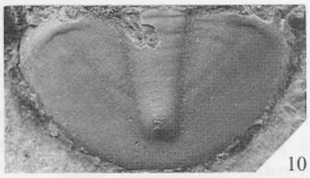
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ZHOU *et al.*, *Zhenganites*, *Mioptychopyge*

Mioptychopyge trinodosa (Zhang, 1981)

Plate 3, figures 2, 4–10; Plate 4, figure 1

1981 *Ptychopyge trinodosa* Zhang, p. 185, pl. 65, fig. 10a–c

Holotype. Exoskeleton (XTR 202), figured Zhang (1981, pl. 65, fig. 10a–c), from the topmost Upper Qiulitag Group (= Dawangou Formation) at Kanlin, Kalpin, north-western Tarim, Xinjiang.

Figured specimens. One exoskeleton (NI 80734), one pygidium with thorax (NI 80736), one pygidium (NI 80735), and one cephalon with three attached thoracic segments (NI 80739) from Bed 2; three pygidia (NI 80733, 80737–80738) from Bed 3.

Description. Exoskeleton oval, gently convex. Semi-elliptical cephalon as long as pygidium, its length 55 per cent. the posterior width; cephalic border flat, one-fifth the cephalic length (sag.), narrows gradually abaxially and posteriorly, well defined by distinct, broad border furrow. Cranidium slightly wider than long, with width (tr.) of frontal area about two-thirds that along the posterior margin. Glabella convex, contracted opposite palpebral lobes, rounded frontally, two-thirds as wide as long, with prominent median node immediately in front of weak S0. Posterolateral furrows shallow, running backwards and abaxially from line through front end of palpebral lobe to meet at mid-point of S0; posterolateral lobe low, triangular. Three pairs of sub-triangular, smooth muscle-attachment areas on anterior part of preoccipital glabella are elongate and closely spaced; they extend adaxially forwards from axial furrows and become successively fainter and narrower (exsag.) anteriorly; second pair is opposite anterior end of palpebral lobe. Auxiliary impressions densely grouped in central part of frontal lobe demarcate an axially extended, spear-shaped ridge. Occipital ring uniformly wide (sag.), 14 per cent. of glabellar length. Distinct axial furrows shallower opposite palpebral lobe. Well preserved specimens show narrow (tr.), elongate baccula ill-defined abaxially, running between posterior end of palpebral lobe and proximal end of posterior border furrow. Palpebral lobe semicircular, 22 per cent. of cranidial length; distance between its posterior end and cranidial margin about one-eighth cranidial length. Anterior sections of facial suture run in broad curves on to border and then turn adaxially to meet medially at about 130° on margin; sigmoidal posterior sections cut posterior margin closer to axial furrow than to lateral margin. Frontal area 30 per cent. of cranidial length (sag.); preglabellar field shorter (sag.) than anterior border and slightly convex longitudinally. Palpebral area higher than posterolateral glabellar lobe; posterior area short (exsag.), narrows adaxially, and convex border well defined by deep border furrow. Librigena has wide, gently convex librigenal field; posterior border faintly defined; eye crescentic, 25 per cent. cranidial length; eye socle narrow, vertical; lateral and posterior borders and librigenal field narrow posteriorly, continuous with broadly based librigenal spine, sub-rhombic in cross section; doublure wide, its inner margin subparallel to lateral cephalic margin and, in part, close to eye socle.

Thoracic axis convex, slightly tapered, a little narrower (tr.) than adjacent pleura, delimited by broad, deep axial furrows. Axial rings uniformly wide (sag.); proximal part of each pleura parallel-sided, horizontal, but faceted distal part narrows abaxially to form moderately long spine; pleural furrow deep, subparallel to anterior margin of pleura, ends opposite midlength (tr.) of facet.

Pygidium semi-elliptical, moderately convex, without well defined border; width 60–82 per cent. the length (relatively longer in larger specimens). Convex, evenly tapered axis occupies 74–80 per cent. pygidial length, 24–32 per cent. anterior width, and is defined by deep axial furrows; there are six to ten axial rings and a rounded terminal piece, separated by shallow, broad ring furrows; segmentation more weakly developed on external surface than on exfoliated surface; each ring, when exfoliated, shows pair of oval muscle scars laterally; articulating half ring narrow (sag.), broadly rounded anteriorly. Pleural region moderately convex, declines laterally and posteriorly to pygidial margin; articulating half-rib ridge-like, widens to facet; incised first pleural furrow does not reach margin; five pairs of broad pleural furrows seen adaxially on exfoliated surface cross paradoublural line and die out; five pairs of ribs faintly furrowed. Doublure fairly broad; inner margins reach sixth ring furrow along axial furrows and then diverge forwards to attain frontal width 36–60 per cent. of pleural region; surface covered with terrace lines subparallel to margin. There are very fine transverse ridges on surface of axis and pleural region, and roughly transverse, fine anastomosing ridges on anterolateral angles.

Remarks. The present species most resembles *M. suni* (Endo, 1935), the type specimens of which have a pygidium with proportionally shorter (sag.) postaxial region, only 10–16 per cent. of pygidial length compared with 20–26 per cent. Cranidia in Endo's collection are too fragmentary to interpret, but a sagittal muscle scar and auxiliary pit-like depressions seen on exfoliated surface of preoccipital part of the glabella are exactly comparable. An exfoliated cranidium of *M. suni* described by Zhou (*in* Li *et al.* 1975, p. 150, pl. 18, fig. 3) as *Basiliella zhenbaensis* (see above) compares closely to the present species except for the narrower (sag.) frontal area (21 per cent. length of cranidium) and deeper posterolateral glabellar and occipital furrows. However, the depth of furrows in trilobites, particularly asaphids, may vary with preservation.

The cranidium and pygidium of *M. trinodosa* recall *M. tatzaoensis* (Lu, *in* Lu *et al.* 1976), from the upper Ordovician of Ninglang, north-western Yunnan, and the Burmese species *M. thebawi* (Reed, 1915) (see above). But *M. thebawi* has a shorter (sag.) cephalic border and frontal area, *M. tatzaoensis* has a shorter (sag.) pygidial axis, and both have a longer glabella and deeper pleural furrows on the pygidium. *M. trinodosa* also resembles *Pseudobasilicus pseudodawanicus* Lu from the upper Dawan Formation (late Arenig) of western Hubei in many respects. The holotype (Lu 1975, pl. 5, fig. 25) of the latter has more divergent anterior sections of the facial suture, the front of the cranidium is more bluntly pointed, and the median node sited slightly more forwards, but some supposedly distinguishing characters are due to preservation. Specimens of the Hubei species are poorly preserved and further comparison is impossible. *P. pseudodawanicus* should be attributable to *Mioptychopyge* if its cephalic doublure and pygidium prove similar to those of *M. trinodosa.*

Subfamily ISOTELINAE Angelin, 1854

Genus LIOMEGALASPIDES Lu, 1975

Type species. Isotelus usuii Yabe, *in* Yabe and Hayasaka, 1920.

Liomegalaspides major (Zhang, 1981)

Plate 4, figures 2–7, 9

1981 *Ptychopyge major* Zhang, p. 185, pl. 65, figs 11–12.

Holotype. Pygidium (XTR 203), figured Zhang (1981, pl. 65, figs 11–12), from the topmost Upper Qiulitag Group (= Dawangou Formation) at Kanlin, Kalpin, north-western Tarim, Xinjiang.

Figured specimens. Three pygidia (NI 80742–80744) from Bed 2; one incomplete cranidium (NI 80741) and one pygidium (NI 80740) from Bed 3.

Description and remarks. The species was based by Zhang (1981) on two large pygidia. The holotype has a narrow doublure but no defined border, indicating that the species is referable to *Liomegalaspides* or *Megalaspides* rather than to *Ptychopyge.* Based on the new material we add the following description: (1) glabella is broadly rounded anteriorly, constricted between palpebral lobes and poorly defined on exfoliated surface; (2) frontal area is short (7 per cent. of cranidial length (sag.)) and flat; (3) palpebral lobe higher than glabella, its length about 20 per cent. that of cranidium and its anterior margin opposite centre of cranidium; (4) posterior area of fixigena short (exsag.), with no trace of posterior border furrow on external surface; (5) pygidial axis has short articulating half-ring, 11 rings and a small, posteriorly rounded terminal piece seen on exfoliated surface; (6) pleural regions gently convex with pair of articulating half-ribs defined by deep pleural furrows; (7) up to nine pairs of weakly furrowed ribs visible on internal mould; (8) pygidial doublure concave, narrow, uniformly wide, covered with fine terrace ridges, its inner margin subparallel to pygidial margin and just reaches end of axis; (9) length of pygidium 70–90 per cent. of width, and large specimens are more elongated. *L. major* differs from the type species of *Megalaspides*, *M. dalecarlicus* (Holm) from its named zone in the Arenig of Sweden (see Tjernvik 1956, p. 247, pl. 8, figs 4–13, text-figs 39C, 40A), in the longer sub-triangular pygidium, an hourglass-shaped rather than parallel-sided glabella, a shorter frontal area, and more divergent anterior sections of the facial suture. All these characters are diagnostic of *Liomegalaspides.*

The name *Liomegalaspides* as first proposed by Lu (*in* Lu and Chang 1974) was a *nomen nudum*, with no diagnosis or designation of type species. The genus was formally established by Lu (1975, p. 327) to include *L. hupeiensis* (Sun, 1931, p. 4, pl. 1, fig. 3a–h; Kobayashi 1951, p. 16, pl. 4, fig. 3 only; Lu, *in* Lu and Chang 1974, p. 126, pl. 49, figs 15–16; Lu 1975, p. 328, pl. 13, figs 8–10), from the *Azygograptus suecicus* Zone (mid Arenig) of Hubei and Sichuan, in addition to the type species *L. usuii* (Yabe, *in* Yabe and Hayasaka, 1920, p. 57, pl. 18, fig. 9; pl. 19, fig. 8; Kobayashi 1951, p. 27, pl. 2, figs 7–8; Lu, *in* Lu and Chang, 1974, p. 126, pl. 50, figs 1–2; Lu 1975, p. 328, pl. 13, figs 1–7), from the uppermost Dawan Formation (latest Arenig), western Hubei.

Other species from the upper lower Ordovician of the Yangtze Region possibly referable to the genus are: *Megistaspis* sp. of Li *et al.* (1975, p. 145, pl. 10, fig. 6), *Liomegalaspides huayingshanensis* Lee, 1978 (p. 239, pl. 102, figs 2–4), *L. banqiaoensis* Yin, *in* Yin and Lee, 1978 (p. 531, pl. 175, fig. 4), *Megalaspides zhenganensis* Yin, *in* Yin and Lee, 1978 (p. 530, pl. 174, figs 11–12), *M. xinhuangensis* Liu, 1982 (p. 327, pl. 223, fig. 9) and *M. yichangensis* Xiang and Zhou, 1987 (p. 315, pl. 36, fig. 14). Some of these are, however, based on poorly preserved specimens and require further revision.

Isoteloides liangshanensis Lu, 1957 (p. 279, pl. 152, figs 1–2; 1975, p. 322, pl. 9, figs 6–10, pl. 10, figs 1–11; Zhou *et al.* 1982, p. 263, pl. 65, fig. 16) from the *Ningkianolithus welleri* Zone (latest Arenig) in the Siliangssu Formation at Hanzhong, southern Shaanxi, is closely similar to the contemporaneous *L. usuii*, although the latter has less well defined furrows. Accurate comparison is difficult due to their different preservation, the former in shale and the latter in limestone. It is likely that *I. liangshanensis* is referable to *Liomegalaspides*, and the narrow cranidial border and more acute posterior area of the fixigena preclude its assignment to *Isoteloides*. Fortey (1979, p. 69) was inclined to reassign the species to *Stegnopsis* Whittington, 1965, but the type species, *S. solitarius* Whittington, 1965 (p. 344, pl. 20, figs 1–11; pl. 21, figs 1–4, 6; text-fig. 3) from the Table Head Formation of western Newfoundland, has a much wider cephalic border, more divergent anterior sections of the facial suture, a more posteriorly located palpebral lobe, and a much narrower (exsag.) postocular area of the fixigena.

Of the 12 asaphid species recorded by Weller (1907, 1913) from the upper lower Ordovician of northern Sichuan and southern Shaanxi, *Asaphus blackwelderi* Weller, 1913 (p. 286, pl. 26, figs 21–22; Chang and Jell 1983, fig. 3B, H) and *A. asiaticus* Weller, 1913 (p. 287, pl. 26, fig. 5; Chang and Jell 1983, fig. 3I) are indistinguishable from *L. liangshanensis* and we believe that all should be included in *L. blackwelderi*, the first described of the three.

L. major generally resembles the type species, *L. usuii*, but the latter has a proportionally shorter pygidium which is almost featureless except for a faint trace of axial furrows. *L. blackwelderi* compares closely with *L. major* in almost every respect, but has a shorter pygidium (length = 67–77 per cent. of width), a difference which may fall within the range of intraspecific variation, but this cannot yet be confirmed.

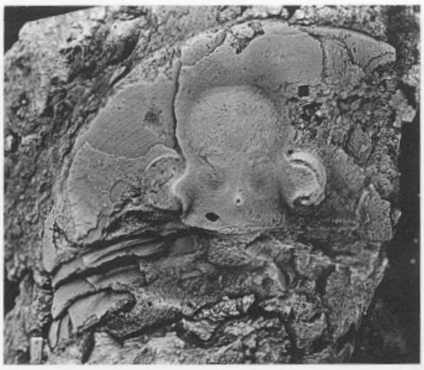
EXPLANATION OF PLATE 4

Figs 1. *Mioptychopyge trinodosa* (Zhang, 1981); Bed 2. NI 80739; incomplete cephalon with three attached thoracic segments; × 1·5.

Figs 2–7, 9. *Liomegalaspides major* (Zhang, 1981). 2–3, NI 80740; Bed 3; pygidium, dorsal and lateral views; × 2. 4, NI 80741; Bed 3; incomplete cranidium; × 2·5. 5, NI 80742; Bed 2; pygidium, showing part of doublure; × 1·5. 6, NI 80743; Bed 2; pygidium; × 0·66. 7, 9, NI 80744; Bed 2; pygidium, lateral and dorsal views; × 1.

Figs 8, 11–13. *Nileus walcotti* Endo, 1932. 8, NI 80746; Bed 3; cephalon of enrolled exoskeleton, × 1·5. 11–12, NI 80747; Bed 3; cephalon and thorax of enrolled exoskeleton, dorsal and lateral views; × 1·5. 13, NI 80748; Bed 2; cephalon with four attached thoracic segments; × 2.

Fig. 10. *Gog yangtzeensis* (Lu, 1975); NI 80745; Bed 3; incomplete pygidium; × 1.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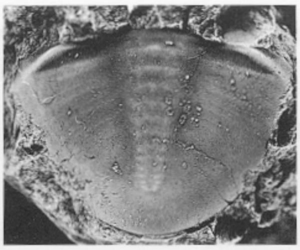
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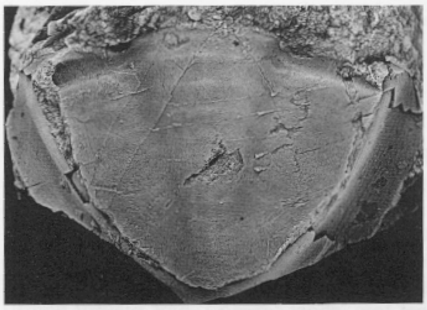
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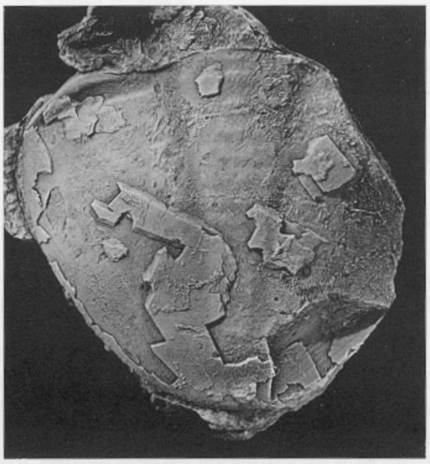
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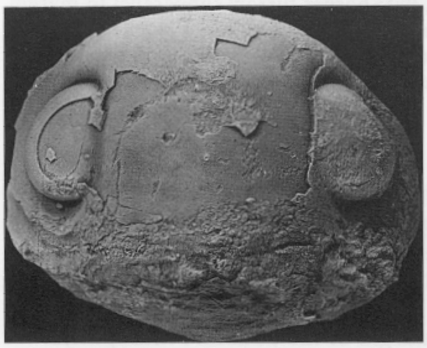
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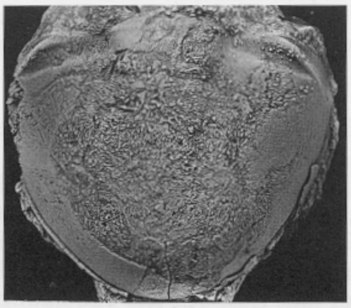
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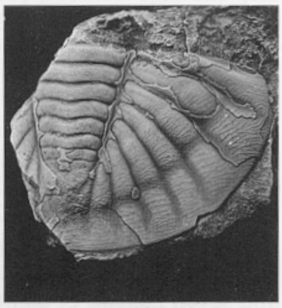
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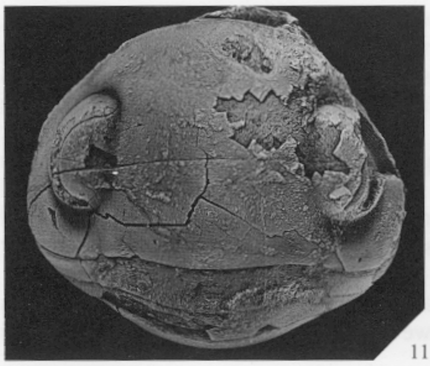
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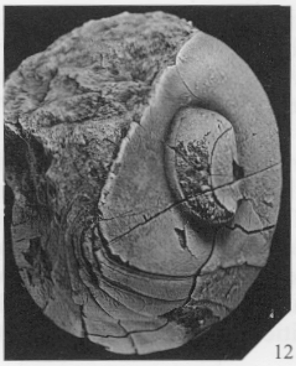
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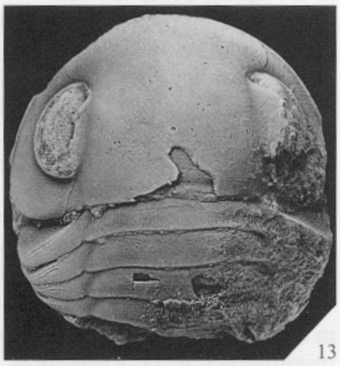
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ZHOU *et al.*, Ordovician trilobites

Subfamily NIOBINAE Jaanusson, *in* Moore, 1959

Genus GOG Fortey, 1975*b*

Type species. *Gog catillus* Fortey, 1975*b*.

Gog yangtzeensis (Lu, 1975)

Plate 4, figure 10

1975 *Niobe yangtzeensis* Lu, p. 332, pl. 15, figs 4–5.
1977 *Niobe yangtzeensis* Lu; Zhou *et al.*, p. 214, pl. 63, fig. 13.
1984 *Niobe yangtzeensis* Lu; Sun, p. 379, pl. 147, figs 12–13.

Holotype. Pygidium (NI 16618), figured Lu (1975, pl. 15, fig. 4), from the upper Dawan Formation (late Arenig) at Tangya, Fenxiang, Yichang, western Hubei.

Figured specimen. Incomplete pygidium (NI 80745) from Bed 3.

Description. Semicircular pygidium has length 37 per cent. of width. Tapered convex axis is 77 per cent. of pygidial length and does not reach border furrow; seven well defined axial rings with ring furrows curved backwards medially; axial furrows deep; triangular terminal piece poorly delimited by weak axial furrows on exfoliated surface but merges with seventh pair of pleural ribs on external surface. Pleural region gently convex, with articulating half-rib and seven prominent, distally rounded ribs; deep, wide pleural furrows cross paradoublural line and border furrow almost to pygidial margin, and are successively more backwardly deflected. Articulating half-rib convex, widens (exs.) abaxially; facet low, short (exsag.), half pleural width; weak interpleural furrows seen on exfoliated surface. Border wide, flat; border furrow subparallel to margin, deep and wide from first pair of pleural furrows but shallows abruptly medially. Doublure reaches sixth ring furrow; inner margin slightly undulating, subparallel to border furrow. Surface of pleural region covered with dense anastomosing ridges, subparallel to margin, which become even finer and denser inside paradoublural line.

Remarks. Apart from its slightly greater width and broader border, the pygidium agrees well with that of *Gog explanatus* (Angelin, 1851, pl. 11, fig. 4; Fortey 1975*b*, pl. 4, fig. 2), from black limestone (probably late Arenig) at Skåne, Fågelsång, Sweden. It differs from that of *G. catillus* Fortey, 1975*b* (p. 26, pl. 1, fig. 1; pl. 2, fig. 1; pl. 3, figs 4–6), from the Olenidsletta Member (mid Arenig), Spitsbergen, and *G. pileiformis* Zhou, *in* Zhou *et al.*, 1982 (p. 264, pl. 66, figs 4–5), from the Miboshan Formation (Llanvirn), Tongxin, Ningxia, mainly in having a well defined border furrow and seven instead of eight or nine ribs. The less undulating margin of the doublure in *G. pileiformis* is, however, comparable.

The figured pygidium is identical with the holotype of *Niobe yangtzeensis*, described by Lu (1975, p. 332) as having six pairs of ribs, though a small seventh pair is present in the type material. The species recalls several Scandinavian early Ordovician forms of *Niobe*, such as the type species *N. frontalis* (Dalman, 1827) (Bohlin 1955, p. 143, pl. 6, figs 5–9), *N. insignis* Linnarsson, 1869 (Moberg and Segerberg 1906, p. 94, pl. 6, figs 6–9; Tjernvik 1956, p. 224, pl. 4, fig. 10, text-fig. 36A), *N. emarginula* Angelin, 1851 (Tjernvik 1956, p. 226, pl. 4, figs 14–17, text-fig. 36C) and *N. incerta* Tjernvik, 1956 (p. 225, pl. 4, figs 11–13, text-fig. 36B), in the broad pygidial doublure and well defined pygidial border but differs mainly in the pleural furrows, which almost reach the pygidial margin before dying out. In addition, the first three of these Scandinavian species have six rather than seven pairs of ribs and the last three have straight or medially straight ring furrows.

As *Niobe yangtzeensis* Lu was based on only two pygidia, and there is no associated cranidium in our collection, its generic position remains uncertain, but we reassign it to *Gog* because of its close resemblance to *G. explanatus*.

Family NILEIDAE Angelin, 1854

Genus NILEUS Dalman, 1827

Type species. Asaphus (*Nileus*) *armadillo* Dalman, 1827.

Nileus walcotti Endo, 1932

Plate 4, figures 8, 11–13; Plate 5, figures 1–11

1932	*Nileus walcotti* Endo, p. 113, pl. 39, fig. 10.
1934	*Nileus armadillo* Dalman; Gortani, p. 73, pl. 17, figs 2–3, *non* 4.
1934	*Nileus armadillo* var. *expansus* Gortani, p. 76, pl. 17, fig. 5a–c.
1975	*Nileus liangshanensis* Lu, p. 353, pl. 23, figs 7–11; pl. 24, figs 1–3.
1975	*Nileus liangshanensis* Lu; Li *et al.*, p. 147, pl. 13, fig. 7.
1981	*Nileus liangshanensis* Lu; Zhang, p. 189, pl. 71, figs 1–2.
1981	*Nileus armadilloformis* Lu; Zhang, p. 189, pl. 71, figs 4–6.
1983	*Nileus armadillo* Dalman; Chang and Jell, p. 206, fig. 6A–B.

Holotype. Incomplete cephalon with thorax (USNM 83770), figured Endo (1932, pl. 39, fig. 10) and Chang and Jell (1983, fig. 6A–B), from a Llanvirn horizon in the Siliangssu Formation, near Ningqiang, southern Shaanxi.

Figured specimens. One cephalon with four attached thoracic segments (NI 80748), one pygidium with thorax (NI 80753) and one hypostoma (NI 80752) from Bed 2; four enrolled exoskeletons (NI 80746–80747, 80749, 80755), two cephala (NI 80750–80751), one cranidium (NI 80754), and one pygidium with attached thorax (NI 80756) from Bed 3.

Description and remarks. Kobayashi (1951, p. 39) considered *Nileus walcotti* to be a synonym of *N. armadillo*, from the upper Arenig and lower Llanvirn of Sweden. However, the holotype of *N. walcotti*, recently refigured by Chang and Jell (1983), shows a smaller, more anteriorly sited palpebral lobe and a longer (exsag.) posterior area of the fixigena compared with the specimens of *N. armadillo* described by Schrank (1972, p. 365, pl. 6, figs 1, 3, 5–6). In addition, the type species has the median glabellar node situated farther back, the posterior sections of the facial suture are more divergent posteriorly, and the axial furrows more weakly defined. The two species are probably distinct. *N. liangshanensis* Lu, 1975, from the same horizon as *N. walcotti* in southern Shaanxi, matches that species closely and is considered a synonym.

N. walcotti was fully described (as *N. liangshanensis*) by Lu (1975), and we add the following on the basis of new material: (1) the median glabellar node seen on internal moulds is opposite the rear of the palpebral lobe, about 40 per cent. of glabellar length from posterior margin in palpebral view; (2) hypostoma is 64 per cent. as long as wide, broadly notched posteriorly; convex middle body occupies 40 per cent. of overall frontal width, is longer than wide, tapers backwards and is bluntly pointed posteriorly, defined by deep, wide lateral furrows, with pair of depressed, oval maculae sited on lateral margins opposite centre of hypostoma; anterior wing small, triangular; border gently convex, bounded by almost uniformly narrow rim; lateral border narrows posteriorly and has broadly rounded margin. Short (sag.) posterior border tripartite with triangular median projection; surface covered with coarse, transverse terrace ridges; (3) pygidium is 52–63 per cent. as long as wide. Large pygidia, except for axis, have surface covered by coarse, anastomosing terrace ridges which extend more or less transversely on the border but are slightly concave forwards on pleural region; in small pygidia, up to seven finer ridges seen behind articulating facet are subparallel to anterolateral margin (Pl. 5, fig. 6).

Juvenile specimens (Pl. 5, figs 3, 7, 10) resemble large individuals, but the glabella is wider, more strongly declined anteriorly; palpebral area of fixigena is longer (exsag.), only weakly defined by faint axial furrow; and anterior part of librigena is narrower (tr.). The first two of these also characterize *N. armadilloformis* Lu, 1975 (p. 351, pl. 21, figs 1–12; pl. 22, figs 1–7) from the upper part of the Dawan Formation, western Hubei, which may be closely related to the present species.

Zhang (1981) recorded *N. liangshanensis* and *N. armadilloformis* from the same horizon and locality as the new material but his account of the latter species was based largely on a juvenile exoskeleton (Zhang 1981, pl. 71, fig. 5a–c). On the basis of our material we believe that only a single species, *N. walcotti*, is present in Zhang's collection.

Specimens from the uppermost Arenig–lower Llanvirn of Karakorum, described by Gortani (1934) as *Nileus armadillo* Dalman and *N. armadillo* var. *expansus* Gortani, match those of *N. walcotti*, as noted by Kobayashi (1951). We agree with this conclusion except for one cephalon (Gortani 1934, pl. 17, fig. 4a–b) in which the glabella expands uniformly forwards, has the axial glabellar node situated further back, and is well defined by deep axial furrows; the specimen is probably referable to *Symphysurus*.

N. liangshanensis has also been reported from the lower middle Ordovician of western Hubei (Sun 1984, p. 384, pl. 155, fig. 4) and upper lower Ordovician of Hexian, Anhui (Qiu *et al.* 1983, p. 212, pl. 71, figs 1–2), but the cranidia from both localities are quite different from Lu's original material. *N. liangshanensis sensu* Qiu *et al.* has the median glabellar node and palpebral lobe sited further back, and the axial furrows are distally convex opposite the palpebral lobe; in *N. liangshanensis sensu* Sun the glabella is defined by deep axial furrows and is strongly constricted opposite the mid-point of the palpebral lobe, which is again more posteriorly placed. Both species should probably be excluded from the synonymy of *N. walcotti*, but the specimens are too poorly preserved for confident assignment.

N. walcotti is closely related to the Swedish Arenig species *N. exarmatus* Tjernvik, 1956 (p. 209, pl. 2, figs 16–21; Schrank 1972, p. 358, pl. 2, figs 1–10; pl. 3, figs 3–11, 14) and *N. orbiculatoides orbiculatoides* (Schrank, 1972, p. 361, pl. 4, figs 1–5; pl. 5, figs 1–2, as *N. exarmatus orbiculatoides*; see Fortey 1975*b*, p. 43) on the evidence of the hypostoma, librigena, cephalic doublure and the shape of the glabella and pygidium. But the Swedish forms differ in the intramarginal instead of marginal anterior sections of the facial suture, the subangular rather than rounded anterior cranidial margin, the larger palpebral lobe, the more posteriorly placed median glabellar node, and the shorter, more divergent posterior sections of the facial suture.

In shape of posterior area of fixigena, size and position of palpebral lobe, and location of median glabellar node, the Chinese form is also comparable to *N. porosus* Fortey, 1975*b* (p. 44, pl. 12, figs 1–14) from the higher part (latest Arenig–early Llanvirn) of the Profilbekken Member on Spitsbergen. Characteristic of the latter are: (1) fainter axial furrows parallel opposite eyes (cf. distinct and progressively divergent backwards in *N. walcotti*); (2) cephalic doublure wider (sag.); (3) librigena lacks lateral border; (4) smooth hypostoma has wider but more weakly defined middle body, and lateral margins are almost parallel as far as posterolateral angles (cf. evenly curved); (5) cranidial surface punctate; and (6) pygidial border rather poorly defined.

Family ILLAENIDAE Hawle and Corda, 1847

Genus ILLAENUS Dalman, 1827

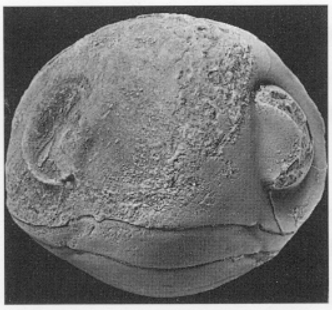
Type species. *Entomostracites crassicauda* Wahlenberg, 1818.

EXPLANATION OF PLATE 5

Figs 1–11. *Nileus walcotti* Endo, 1932. 1–2, NI 80749; Bed 3; enrolled exoskeleton, dorsal views; ×1·5. 3, NI 80750; Bed 3; small cephalon, lateral view; ×6. 4, 9, NI 80751; Bed 3; cephalon, lateral and dorsal views; ×3. 5, NI 80752; Bed 2; hypostoma; ×3. 6, NI 80753; Bed 2; pygidium with thorax; ×3. 7, 10, NI 80754; Bed 3; small cranidium, lateral and dorsal views; ×6. 8, NI 80755; Bed 3; enrolled exoskeleton, showing cephalic doublure; ×1·5. 11, NI 80756; Bed 3; pygidium with thorax, showing pygidial doublure; ×1·5.

Figs 12–13. *Illaenus sinensis* Yabe, *in* Yabe and Hayasaka, 1920; NI 80757; Bed 2; exoskeleton, dorsal and lateral views; ×2.

PLATE 5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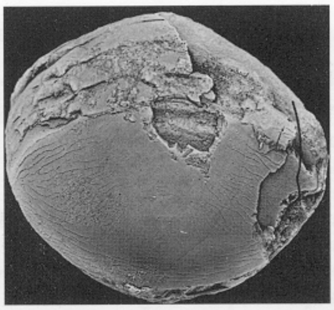
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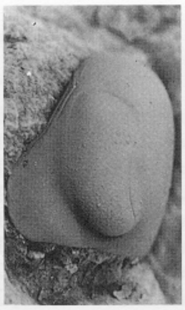
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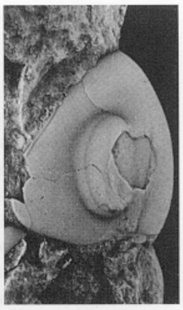
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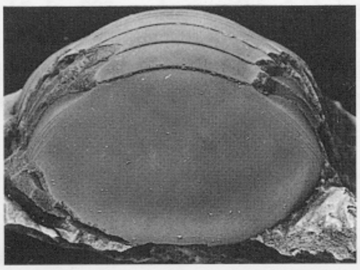
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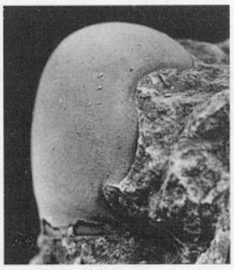
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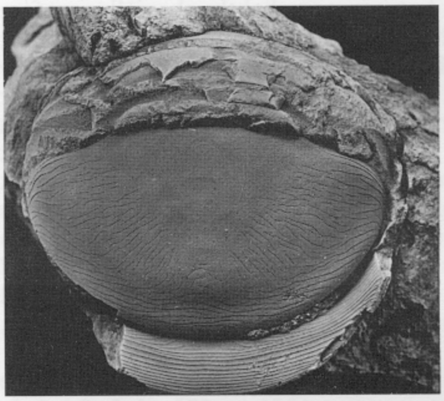
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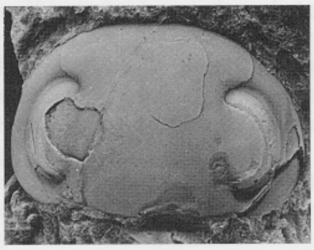
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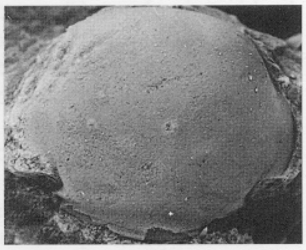
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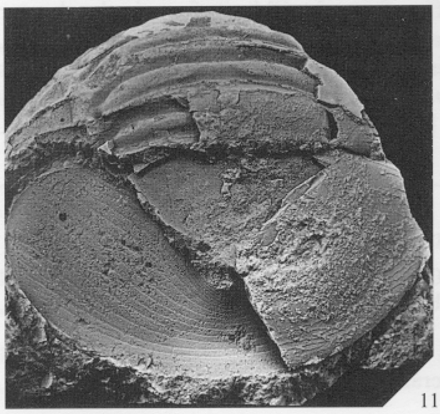
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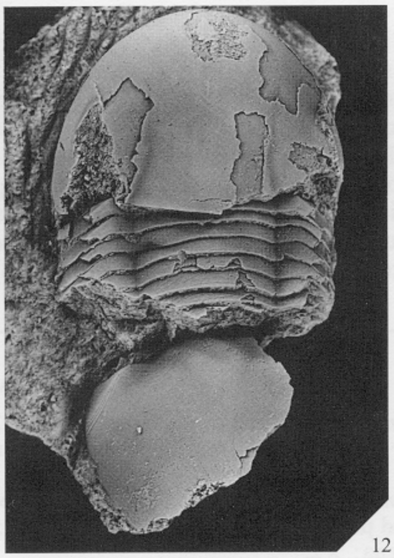
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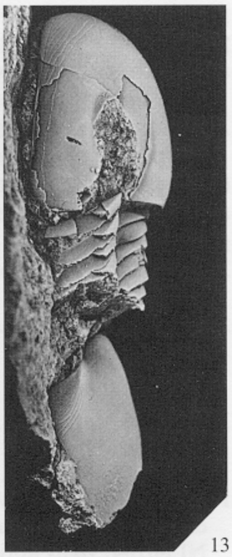
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ZHOU *et al.*, *Nileus*, *Illaenus*

Illaenus sinensis Yabe, *in* Yabe and Hayasaka, 1920

Plate 5, figures 12–13; Plate 6, figures 1–4, 6, 9

1920	*Illaenus sinensis* Yabe, *in* Yabe and Hayasaka, p. 58, pl. 18, fig. 10.
1951	*Illaenus sinensis* Yabe; Kobayashi, p. 35, pl. 2, figs 1–2.
1957	*Illaenus sinensis* Yabe; Lu, p. 289, pl. 150, figs 1–4.
1965	*Illaenus sinensis* Yabe; Lu *et al.*, p. 561, pl. 118, figs 8–13.
1974	*Illaenus sinensis* Yabe; Lu and Chang, p. 128, pl. 51, figs 4–5.
1975	*Illaenus sinensis* Yabe; Lu, p. 380, pl. 31, figs 1–10; pl. 32, figs 1–5.
1977	*Illaenus sinensis* Yabe; Zhou *et al.*, p. 236, pl. 71, fig. 11a–c.
1978	*Illaenus sinensis* Yabe; Xia, p. 169, pl. 32, figs 7–9.
1981	*Illaenus sinensis* Yabe; Zhang, p. 194, pl. 72, fig. 9a–b.
1983	*Illaenus sinensis* Yabe; Qiu *et al.*, p. 220, pl. 74, fig. 7a–c.
1984	*Illaenus sinensis* Yabe; Sun, p. 390, pl. 150, figs 9–11.

Holotype. Cephalon and attached thorax, figured Yabe (*in* Yabe and Hayasaka 1920, pl. 18, fig. 10) and Kobayashi (1951, pl. 2, figs 1–2) from the uppermost Dawan Formation (latest Arenig), Yichang, western Hubei.

Figured specimens. One exoskeleton (NI 80757) from Bed 2; one exoskeleton (NI 80758), two pygidia (NI 80759, 80761) and one cephalon (NI 80760) from Bed 3.

Remarks. The species was redescribed by Lu (1975) using well-preserved specimens from the type area and horizon. Additional characters based on the new material are as follows: (1) pygidial doublure is about 60 per cent. length (sag.) of pygidium but narrows slightly abaxially; surface covered with widely spaced terrace lines subparallel to the margins but without medial groove; anterior margin broadly bicuspid; (2) pair of low, elliptical lunettes sited opposite eyes and abaxially adjacent to axial furrows, but less well defined on external surface than on internal mould; similar structures are also visible in well-preserved specimens from the Yangtze region figured by Lu (1975, pl. 31, fig. 3) and by Qiu *et al.* (1983, pl. 74, fig. 7a–c); (3) prosopon variable; in most specimens dorsal axis is traversed by distinct, anastomosing ridges, slightly curved, convex forwards, whilst similar, almost transverse ridges occur on genal region, subparallel to axial furrows on thoracic pleurae, and to pygidial margin on anterior part of pleural region; a small proportion of specimens have similar but much finer ridges on external surface of thorax, whilst cephalon and pygidium are almost smooth except for a few ridges along anterior flange of cephalon and pygidium; one exceptional but partly preserved cephalon (Pl. 6, fig. 6) is covered with coarse, anastomosing terrace ridges.

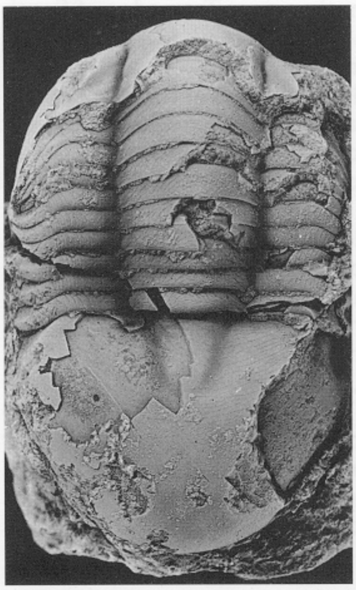
The bicuspid anterior margin of the pygidial doublure indicates that *I. sinensis* belongs to the *I. sarsi* species-group of Jaanusson (1957, p. 110). *I. sarsi* Jaanusson, 1954 (p. 575, pl. 2, figs 1–2; 1957, p. 114, pl. 4, figs 1–9), from the Llanvirn of Sweden, differs from the Chinese form in the shorter (sag.) pygidium and doublure, wider (tr.) fixigena, almost parallel posterior sections of facial suture, and less convex posterior part of glabella, but is otherwise similar. Two other members of the species group which closely resemble *I. sinensis* are: *I. hinomotoensis* Kobayashi, 1934 (p. 560, pl. 3, figs 22–29; Zhou and Fortey 1986, p. 193, pl. 10, figs 3–11, 13) [= *I. semioviformis* Kobayashi, 1934, p.

EXPLANATION OF PLATE 6

Figs 1–4, 6, 9. *Illaenus sinensis* Yabe, *in* Yabe and Hayasaka, 1920; Bed 3. 1–3, NI 80758; exoskeleton, dorsal and lateral views; ×1·5. 4, NI 80759; pygidium, showing doublure; ×1·5. 6, NI 80760; cephalon; ×2. 9, NI 80761; pygidium; ×2.

Figs 5, 7–8, 10–11. *Nanillaenus*? *primitivus* Zhang, 1981; Bed 3. 5, 7, NI 80762; pygidium of enrolled exoskeleton, dorsal and posterior views; ×3. 8, 11, NI 80763; cranidium, dorsal and lateral views; ×1. 10, NI 80764; right librigena; ×2.

PLATE 6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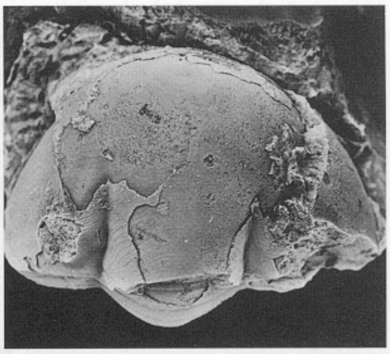
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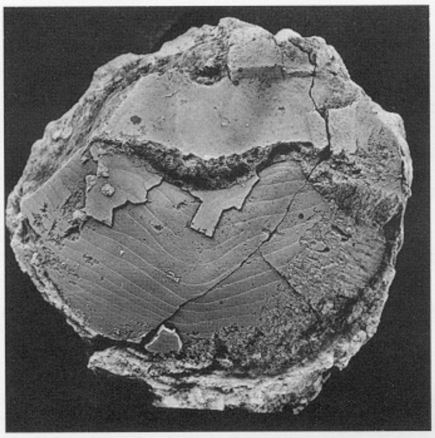
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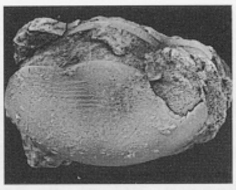
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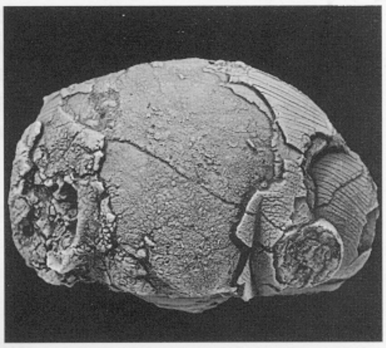
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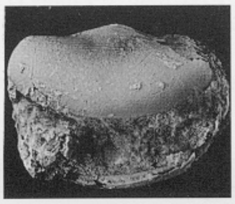
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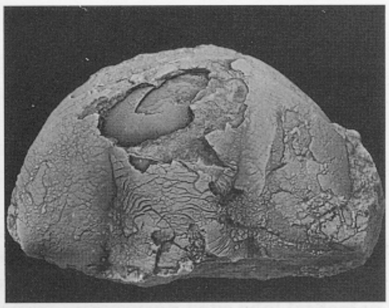
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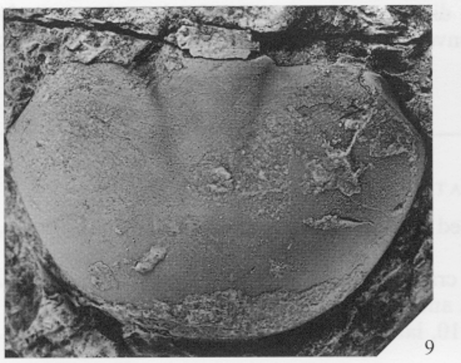
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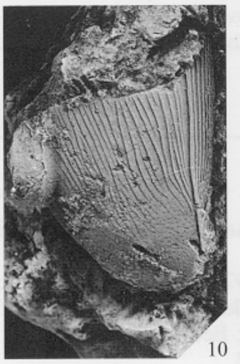
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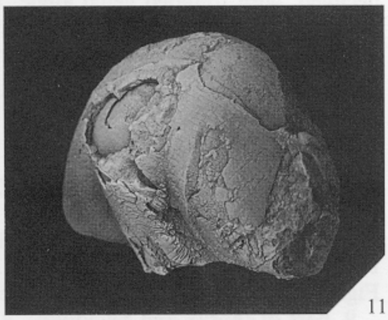
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ZHOU *et al*., *Illaenus*, *Nanillaenus*?

561, pl. 3, figs 30–31], the oldest species of *Illaenus* yet known, from the upper Tremadoc of South Korea and North China; and *I. tingi* Sun, 1931 (p. 10, pl. 2, fig. 3a–b; Zhou *et al.* 1984, pl. 20, fig. 4l–o) from the Llandeilo of Zunyi, Guizhou. The latter's cranidium agrees with that of *I. sinensis* but its pygidium is shorter (sag.), with broader axis, and the doublure occupies about 40 per cent. (cf. 60 per cent.) of pygidial length (sag.). The former species has a comparable pygidium but the doublure is shorter (sag.), crossed by a shallow median groove; the cranidium is longer, more gently declined; palpebral lobes are sited further forwards; and anterior sections of facial suture are subparallel instead of divergent forwards.

Illaenus sinensis is superficially similar, especially in its relatively long pygidium with narrow axis, to *I. spitiensis* Reed, 1912 (p. 95, pl. 14, figs 4–14; Gortani 1934, p. 88, pl. 19, fig. 3a–b) from the middle Ordovician of the central Himalayas and Karakorum, but in the latter the cranidium is more elongate, with completely defined glabella; the pygidium is less broadly rounded posteriorly with coarsely pitted external surface; the pygidial axis is much shorter (sag.), triangular, well defined posteriorly, and the pygidial doublure is much narrower (sag.), probably of *I. excellens* type (Jaanusson 1957, p. 111). A single cephalon referred by Gortani (1934, p. 83, pl. 43, fig. 7a–c) to *I. esmarki* (Schlotheim) [= *I. wahlenbergi* (Eichwald); see Jaanusson 1957, p. 139] from the upper lower Ordovician of Karakorum has a narrower glabella than *I. wahlenbergi* but is almost identical with that of *I. sinensis*. We omit it from our synonymy because the pygidium is unknown and, as Kobayashi (1951) noted, the posterior part of the glabella is less convex.

Genus NANILLAENUS Jaanusson, 1954

Type species. Illaenus conradi Billings, 1859.

Nanillaenus? *primitivus* Zhang, 1981

Plate 6, figures 5, 7–8, 10–11; Plate 7, figures 1–2, 6

1981 *Nanillaenus*? *primitivus* Zhang, p. 194, pl. 70, figs 5a–b, 6a–e.

Holotype. Incomplete exoskeleton (XTR 259), figured Zhang (1981, pl. 70, fig. 5a–b), from the topmost Upper Qiulitag Group (= Dawangou Formation), Kanling, Kalpin, north-western Tarim, southern Xinjiang.

Figured specimens. Two enrolled exoskeletons without librigenae (NI 80762, 80765), one cranidium (NI 80763) and one librigena (NI 80764) from Bed 3.

Description. Cranidium about 60 per cent. as long as wide, broadly rounded anteriorly, strongly curved down in front of line joining anterior ends of palpebral lobes. Axis convex (tr.) posteriorly, where it occupies 40 per cent. cranidial width; broad axial furrows converge and shallow forwards and die out frontally. Medium-sized palpebral lobe sited posteriorly; palpebral area protrudes strongly abaxially. Anterior sections of facial suture long, gently convergent forwards; posterior sections short, divergent. Librigena sub-triangular, steeply declined, with rounded genal angle; librigenal field slightly convex; eye semicircular and eye socle vertical; lateral border narrows posteriorly.

EXPLANATION OF PLATE 7

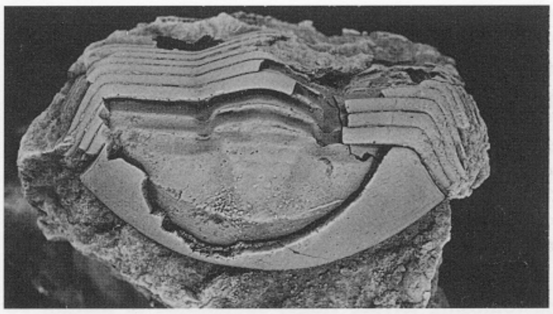
Figs 1–2, 6. *Nanillaenus*? *primitivus* Zhang, 1981; NI 80765; Bed 3; enrolled exoskeleton without librigenae, dorsal views; ×3.

Figs 3–4. *Carolinites ichangensis* Lu, 1975; Bed 2. 3, NI 80766; cranidium; ×5. 4, NI 80767; cranidium; ×6.

Figs 5, 7. *Ampyxina*? sp.; NI 80768; Bed 3; cranidium, dorsal and lateral views; ×4.

Figs 8–10. *Eccoptochile* sp.; NI 80769; Bed 2; exoskeleton. 8, 10, lateral and dorsal views of cephalon; ×3. 9, part of thorax and pygidium; ×4.

PLATE 7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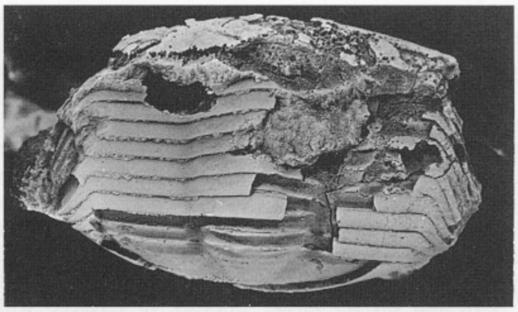
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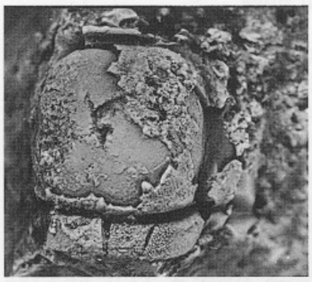
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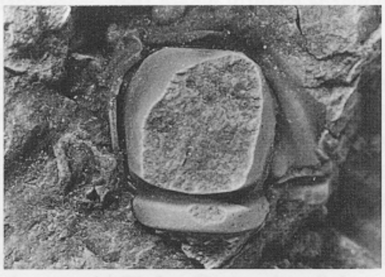
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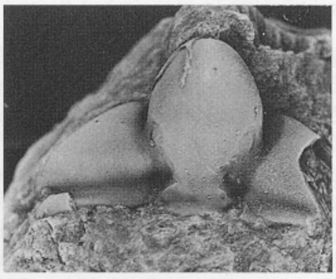
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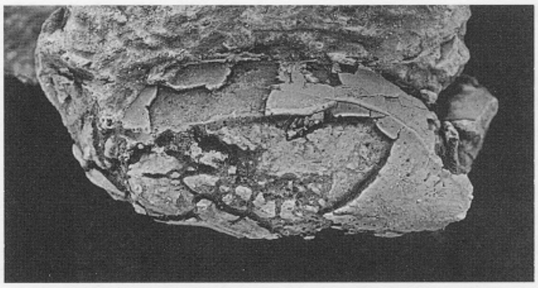
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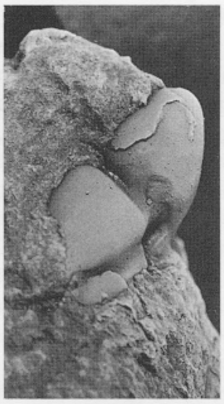
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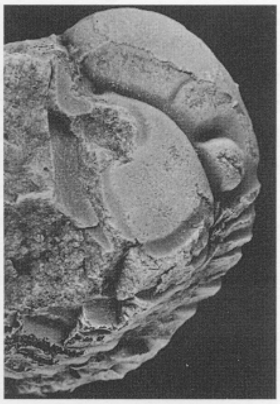
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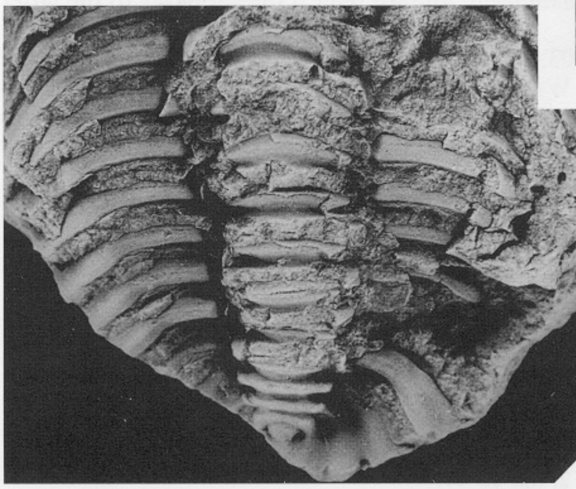
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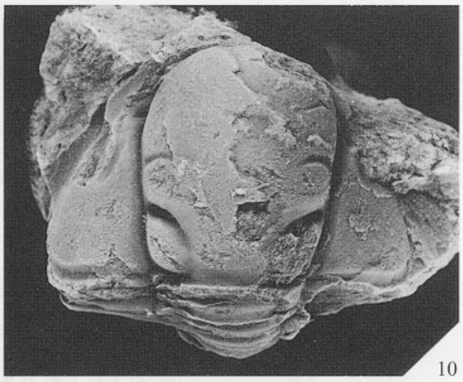
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ZHOU *et al.*, Ordovician trilobites

Thorax of ten segments. Axis convex, about one-third overall width, slightly tapered backwards; axial furrows shallow. Pleural region featureless; inner part of each pleura horizontal, uniformly wide (exsag.); outer part (about one-fifth pleural width) faceted, bent down, and narrows to pointed tip.

Pygidium broadly rounded, 40–45 per cent. as long as wide, its width more than 70 per cent. that of cephalon; its anterior margin is straight as far as facet and then turns down sharply. Axis convex, tapered, occupies one-third frontal width of pygidium and merges posteriorly with pleural field; internal mould shows three poorly defined rings, narrow (sag.) articulating half ring delimited by shallow articulating furrow, and triangular terminal piece which is defined posterolaterally by pair of small oval muscle scars and is produced to form a postaxial ridge. Axial furrows broad. Pleural regions gently declined laterally and posteriorly; only broad first pleural furrow seen on internal mould. Doublure uniformly wide (tr.), equal to about one-quarter pygidial length (sag.); inner margin parallel to that of pygidium, just behind muscle scars medially.

External surface either smooth, or covered with anastomosing terrace ridges subparallel to margin on cephalon, and a few transverse ridges on pygidium. Doublure carries dense, fine terrace ridges, mostly subparallel to margin but flexing backwards slightly where they cross postaxial ridge.

Remarks. Apart from its smaller palpebral lobe and proportionally smaller pygidium with larger facets, the species could be referred to *Illaenus. I. angusticollis* Billings, 1859 (see Raymond and Narraway 1908, p. 245, pl. 61, figs 1–5), from the middle Ordovician of Quebec and Ottawa, Canada, closely resembles *N.? primitivus*, but differs in having a still smaller pygidium with posteriorly defined axis, eight or nine thoracic segments, and short librigenal spines. *I. angusticollis* was assigned by Jaanusson (1954) to *Nanillaenus*, in addition to the type species, *I. conradi* Billings (Raymond and Narraway 1908, p. 245, pl. 60, figs 9–10). Other species referred, some questionably, to *Nanillaenus* have been recorded from the middle Ordovician of North America (Shaw 1968, 1974; Chatterton and Ludvigsen 1976) and Scotland (Reed 1944; see also Tripp 1980, p. 132), and the Llanvirn of Argentina (Harrington and Leanza 1957). None is closely related to *N.? primitivus*, but *N.? punctatus* (Raymond 1905, p. 347, pl. 13, fig. 10; see Shaw 1968, p. 49, pl. 20, figs 17, 19, 21–28; 1974, p. 16, pl. 4, figs 3–4, 8, 10–18) resembles it in the fairly wide cranidium, the glabella well defined posteriorly by convergent axial furrows, the rounded genal angles, the ten thoracic segments, and the large pygidial facets; the Canadian species is distinguished by the better defined pygidial axis and anterior part of the glabella, the wider (sag.) pygidial doublure with bicuspid anterior margin and shallow median groove (instead of ridge), and the mostly pitted dorsal surface.

Shaw (1968, p. 49) considered *Nanillaenus* transitional between *Thaleops* and *Illaenus*, whilst Jaanusson (1954) regarded its eight-segmented thorax as distinctive of the genus; but according to Whittington (1963, p. 68) and Shaw (1968, p. 52) the number of thoracic segments is not a reliable generic criterion in illaenid classification. Chatterton and Ludvigsen (1976, p. 30) believed that *Nanillaenus* and *Thaleops* may prove synonymous with *Illaenus*. The present species exhibits characters intermediate between *Illaenus* and *Nanillaenus*, and we refer it questionably to the latter pending revision of the group.

Nanillaenus wuxiensis Lee, 1978 (p. 255, pl. 103, fig. 5) was based on a single pygidium from the uppermost Dawan Formation (latest Arenig), Wuxi, eastern Sichuan, and its generic position is uncertain in the absence of cephalon and thorax. The specimen differs from that of *N.? primitivus* in its broader, longer axis, well defined posteriorly, and in the faceted distal part of the anterior margin, which curves backwards only slightly.

Family TELEPHINIDAE Marek, 1952

Genus CAROLINITES Kobayashi, 1940

Type species. Carolinites bulbosus Kobayashi, 1940.

Carolinites ichangensis Lu, 1975

Plate 7, figures 3–4

1975 *Carolinites ichangensis* Lu, p. 288, pl. 2, figs 16–17.

1977 *Carolinites ichangensis* Lu; Zhou *et al.*, p. 187, pl. 55, figs 16–17.
1978 *Carolinites zunyiensis* Yin, *in* Yin and Lee, p. 507, pl. 169, fig. 13.
1983 *Carolinites ichangensis* Lu; Qiu *et al.*, p. 166, pl. 54, fig. 10.
1984 *Carolinites ichangensis* Lu; Sun, p. 367, pl. 146, fig. 11, *non* figs 12–14 [? = *C. bulbosus* Kobayashi, 1940].
1987 *Carolinites ichangensis* Lu; Xiang and Zhou, p. 306, pl. 34, figs 1–3.

Holotype. Cranidium (NI 16411), figured Lu (1975, pl. 2, fig. 16) from the uppermost Dawan Formation (latest Arenig), Tangya, Fenxian, Yichang, western Hubei.

Figured specimens. Two incomplete cranidia (NI 80766, 80767) from Bed 2.

Remarks. Specimens from Tarim match the holotype from the Yangtze region and show, in addition, that the surface of the cranidium is densely covered with fine granules. The species closely resembles *C. ekphymosus* Fortey, 1975*b* (p. 110, pl. 39, figs 1–13), from the upper Arenig of Spitsbergen, in the moderately large baccula, the finely granulate surface of the cranidium, the four-segmented pygidial axis, and the shape and proportions of the glabella. Further comparison is difficult owing to different size and preservation of figured specimens, but *C. ichangensis* has the fixigena apparently slightly wider than that of *C. ekphymosus*.

Carolinites [*Bathyurus*] *minor* (Sun, 1931, p. 19, pl. 3, fig. 1; see also Lu 1975, p. 290, pl. 2, fig. 20 and Sun 1984, p. 368, pl. 146, figs 9–10) and *C. subcircularis* Lu, 1975 (p. 289, pl. 2, figs 18–19) were both founded on small specimens from the middle–upper Dawan Formation (mid–late Arenig) of western Hubei, and differ from *C. ichangensis* in their broader fixigena and smaller baccula. These characters are in turn diagnostic of *C. transversus* Zhang, *in* Qiu *et al.*, 1983 (p. 167, pl. 54, figs 11–13) from the Shinianpan Formation (mid Arenig), Hexian, Anhui, and of the specimens from the corresponding horizon in western Hubei that Sun (1984, pl. 146, figs 12–14) referred to *C. ichangensis*. Evolutionary trends in *Carolinites* proposed by Fortey (1975*b*) suggest that the association of cranidial features seen in these Chinese forms is possessed only by *C genacinaca* Ross (*s.l.*), an early representative. The pygidium described for *C. subcircularis* and *C. transversus* has a three-segmented axis, and the librigena assigned to *C. transversus* has a very long, abaxially curved genal spine, suggesting that this group of closely related species belongs with *C. genacinaca genacinaca* Ross, 1951 (p. 84, pl. 18, figs 25–26, 28–36; Fortey 1975*b*, p. 112, pl. 37, figs 1–15, pl. 38, figs 1–3). Legg (1976, p. 5) and Henderson (1983, p. 146) recorded the type species *C. bulbosus* Kobayashi from the Arenig of, respectively, the Canning Basin and north-eastern Queensland, Australia, and suggested that *C. genacinaca* (*s.s.*) is a junior subjective synonym of the Australian species. We believe that *C. minor*, *C. subcircularis* and *C. transversus* may all prove to be junior synonyms of *C. bulbosus*, but further material from the Yangtze area is needed to clarify the nomenclature.

C. punctatus Zhang, *in* Qiu *et al.*, 1983 (p. 167, pl. 54, fig. 14), from the Xiaotan Formation (late Arenig–Llanvirn) strongly resembles *C. ichangensis* in the narrow fixigena and general form of the glabella, but is distinguished by the larger baccula and the dense, coarse granulation on the fixigena.

Family RAPHIOPHORIDAE Angelin, 1854
Subfamily RAPHIOPHORINAE Angelin, 1854

Genus AMPYXINA Ulrich, 1922

Type species. *Endymionia bellatula* Savage, 1917.

Ampyxina? sp.

Plate 7, figures 5, 7

Figured specimen. A cranidium (NI 80768) from Bed 3.

Description. Cranidium triangular, 54 per cent. as long as wide. Glabella extends for 37 per cent. of its length in front of fixigena, widest between front ends of fixigenae, where the width is 62 per cent. the sagittal length; occipital ring weakly convex, slightly arched backwards, defined by shallow S0; preoccipital portion of glabella strongly convex, broadly carinate, rounded and with tiny median tubercle anteriorly. Behind deeply incised, oval S1 the glabella is narrow (tr.) and expands over the short distance to S0; node-like L1 sited opposite adaxial end of posterior border. In front of S1, glabella is rhomboidal in outline, with four pairs of lateral muscle scars: two rearmost scars are large, sub-circular, depressed, close to each other; the anterior two are small, shallow, oval to triangular, closely spaced, with fourth scar just behind anterolateral angle of glabella. Baccula elongate, low, narrow (tr.), weakly defined abaxially and extends from end of S0 to point opposite anterior end of second muscle scar. Axial furrow deep, wide, shallower beside baccula. Fixigena triangular, moderately convex. Posterior border furrow deep, broad, transverse, ends at baccula opposite S1; almost parallel-sided posterior border is wide (exs.), convex. Facial suture gently curved, abaxially concave.

Remarks. According to Owen and Bruton (1980, p. 25) *Ampyxina* and *Raymondella* Reed, 1935 differ mainly in the thorax and pygidium. However, two cranidia in our collection have a rhomboidal rather than hemispherical glabella and elongate (exsag.) bacculae but lack anastomosing ridges on fixigena; for Whittington (1950, p. 559; 1959, pp. 487–488), these features are typical of *Ampyxina* rather than *Raymondella*, and we refer our specimens questionably to the former.

The Chinese form differs from other species of *Ampyxina* in its poorly defined, narrow (tr.), strip-like baccula, narrow (exsag.) fixigena, and the more forwardly protruding glabella. The anterior portion of the glabella in *Ampyxina lanceola* Whittington, 1959 (p. 486, pl. 34, figs 14–28; pl. 35, figs 26–35), from the Edinburg Formation (middle Ordovician) of Virginia, USA, is somewhat similar in outline but more rounded anteriorly, with a short frontal spine in the holotype instead of a tubercle, although the present specimen is larger. The latter may represent a new genus but is insufficient for formal definition.

Family CHEIRURIDAE Hawle and Corda, 1847
Subfamily ECCOPTOCHILINAE Lane, 1971

Genus ECCOPTOCHILE Hawle and Corda, 1847

Type species. *Cheirurus claviger* Beyrich, 1845.

Eccoptochile sp.

Plate 7, figures 8–10; Plate 8, figure 1; Text-figure 3

Figured specimen. Exoskeleton (NI 80769) from Bed 2.

Description. Exoskeleton elongate, oval in plan. Cephalon semi-elliptical, 32 per cent. overall length, 72 per cent. as long as wide, strongly convex. Highly convex glabella inflated, broadly rounded anteriorly, 70 per cent.

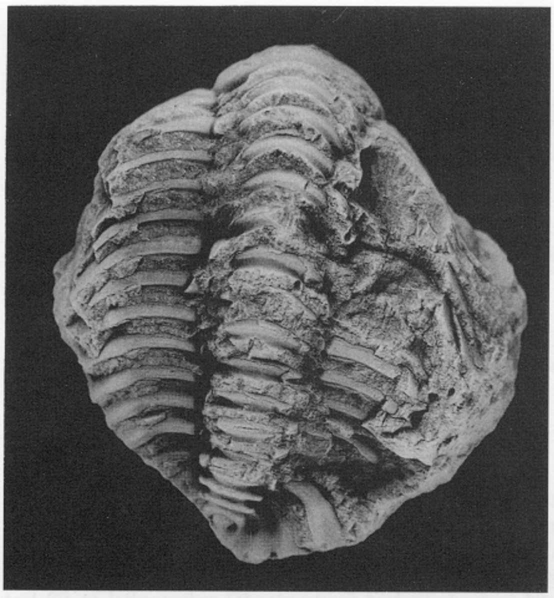
EXPLANATION OF PLATE 8

Fig. 1. *Eccoptochile* sp.; Bed 2; exoskeleton (see Pl. 7, figs 8–10), showing pygidium and thorax; × 3.

Figs 2–3, 6. *Sphaerocoryphe* (*Hemisphaerocoryphe*) *elliptica* (Lu, 1975); NI 80770; Bed 3; cephalon with thorax, dorsal and lateral views; × 5.

Figs 4–5. *Yanhaoia huayinshanensis* (Lu, 1975); NI 80774; Bed 3; cephalon with eight attached thoracic segments, dorsal and lateral views; × 3.

Figs 7–9. *Ovalocephalus primitivus extraneus* (Lu and Zhou, 1979); Bed 2. 7, NI 80771; cranidium. 8, NI 80772; pygidium. 9, NI 80773; pygidium with attached thoracic segments. All × 4.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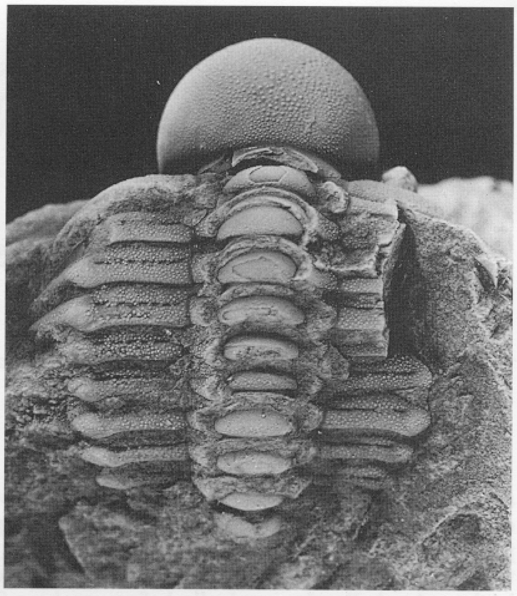
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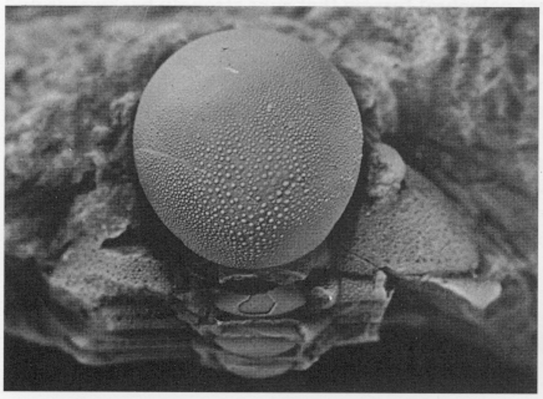
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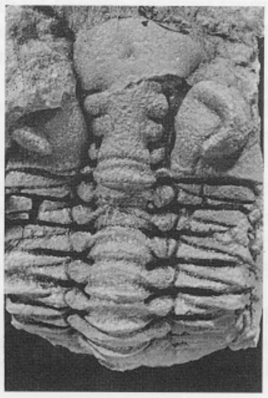
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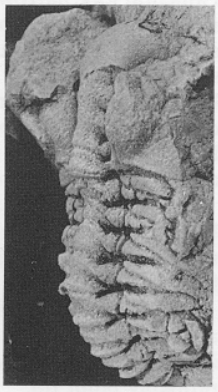
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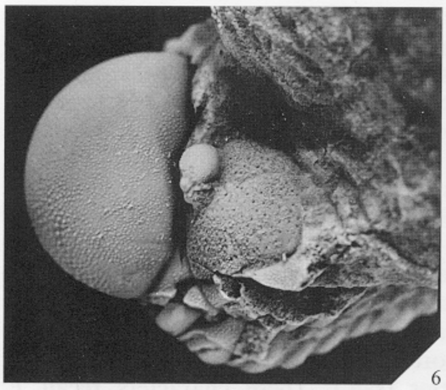
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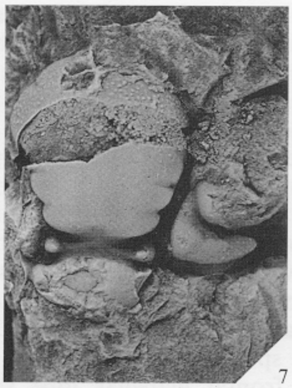
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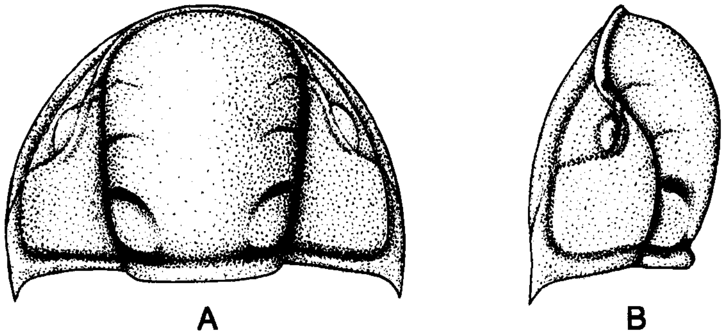
ZHOU *et al.*, Ordovician trilobites



TEXT-FIG. 3. Reconstruction of cephalon of *Eccoptochile* sp., based on NI 80769. A, dorsal view; B, lateral view; ×3.

as wide as long, expands gently forwards to S3, where maximum width is 125 per cent. that of the base; occipital ring incompletely preserved; S0 broad, deep behind L1, shallow medially; frontal lobe overhangs deep preglabellar furrow; L1–L3 relatively narrow (tr.), subequal in length and width; L1 slightly bulbous, subtriangular, 22 per cent. glabellar length and 25 per cent. basal glabellar width; S1 deep, wide, curved strongly backwards, shallowing markedly before reaching S0; S2 incised, arched forwards; S3 subparallel to S2 but shallower, with abaxial end behind fossula or anterolateral angle of glabella. Axial furrows wide, very deep. Palpebral lobe narrow, almost vertical, defined by distinct palpebral furrow that runs strongly backwards and slightly outwards, opposite frontal part of L2 and rear part of L3. Ocular ridge short, ends close to S3. Anterior sections of facial suture slightly convergent, meeting anterior cephalic margin in a broad curve; posterior sections run abaxially into lateral border, and curve through almost a right-angle to cut it obliquely. Anterior border narrow, upturned. Posterior area of fixigena rectangular, 30 per cent. of cephalic width, strongly declined abaxially; posterior border convex; posterior border furrow deep, wide, slightly narrower adaxially; lateral border furrow shallow. Palpebral and anterior areas sub-triangular, narrow (tr.). Librigena triangular, acutely angular to front and rear; doublure slightly concave.

Thorax of twelve segments, 57 per cent. length of exoskeleton. Axis strongly convex (tr.), narrows gently backwards, each ring about 30 per cent. width (tr.) of whole segment. Axial furrows deep, wide. Pleurae unfurrowed; proximal portion flat with median row of pits; distal portion curves backwards and down from fulcrum.

Pygidium short, broad, its length 11 per cent. that of carapace. Tapered, highly convex axis comprises articulating half ring, three axial rings and triangular terminal piece. Pleural region with two pairs of broad interpleural furrows and three pairs convex pleurae; each pleura widens backwards to short spine with probably blunt tip.

Remarks. The present species is probably new but we leave it in open nomenclature as only a single exoskeleton is available. Although it is well preserved, the pygidium is incomplete and the fixigenal spines are missing, but we believe the specimen can be assigned with confidence to *Eccoptochile*. Species of the genus were listed by Rabano (1990) from the upper Llanvirn–Ashgill of Europe and, probably, Morocco and Turkey. Of these, the present form most resembles the type species, *E. clavigera* (Beyrich) (see Hawle and Corda 1847, p. 130, pl. 6, fig. 69; Barrande 1852, p. 772, pl. 40, figs 1–9 only; Prantl and Přibyl 1948, pl. 6, figs 1–2; Horný and Bastl 1970, pl. 14, fig. 1) from the Letná Formation (Caradoc; see Štorch *et al.* 1993) of Bohemia, especially in the shape of the glabella, and size and location of the palpebral lobe; the cranidium figured by Horný and Bastl (1970) shows that S1 shallows abruptly rearwards but reaches S0 as in *E.* sp. However, in the present species S1 curves further backwards and L1–L3 are narrower, with L1 only one-quarter the basal glabellar width, compared with one-third in *E. clavigera*. Other features separating the Chinese form from the type species include: glabella more convex (sag., tr.); S2 more arched forwards and shorter; and frontal glabellar lobe shorter (sag.). These characters recall *E.*

almadenensis Romano, 1980 (p. 610, pl. 78, figs 8–9; pl. 79, figs 1–7; text-fig. 2a–c) [see also Hammann 1974, p. 105, pl. 11, figs 188–191; pl. 12, figs 192–198; text-fig. 39, as *E. mariana* (de Verneuil and Barrande, 1856); Henry 1980, p. 46, text-fig. 14, as *E.* cf. *mariana* (de Verneuil and Barrande); Rabano 1990, p. 158, pl. 28, figs 1–10] from the upper Llanvirn–Llandeilo (–?Caradoc) of Spain, Portugal, France and probably southern England; but apart from the wider (tr.) L1 and more or less sigmoidal S1, the eyes are sited further back (posterior ends level with S1) and the glabella of less deformed specimens is more narrowly rounded frontally in the European form. In addition, the holotype (Hammann 1974, pl. 12, fig. 192a–c) of *E. almadenensis*, a well-preserved cephalon, shows in dorsal view an angle between the anterior border of the cranidium and the lateral border of the librigena due to a sharp change in convexity (compare evenly rounded cephalic margin of *E. sinica*).

Subfamily DEIPHONINAE Raymond, 1913

Genus SPHAEROCORYPHE Angelin, 1854

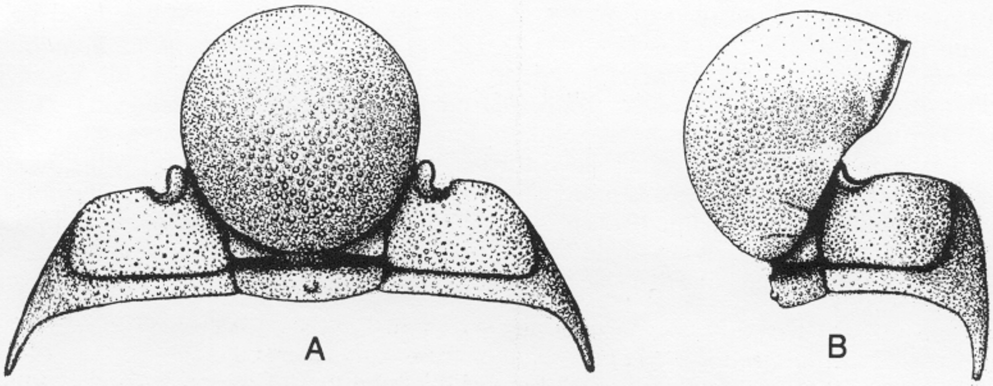
Type species. Sphaerocoryphe dentata Angelin, 1854.

Subgenus HEMISPHAEROCORYPHE Reed, 1896
(= *Ellipsocoryphe* Lu, 1975, p. 428)

Type species. Sphaerexochus pseudohemicranium Nieszkowski, 1859.

Remarks. As noted by Přibyl *et al.* (1985), *Ellipsocoryphe* Lu, 1975 is indistinguishable from, and synonymous with *Hemisphaerocoryphe*, previously considered as a probable junior synonym of *Sphaerocoryphe* by Lane (1971) and by Holloway and Campbell (1974). Comparing *Hemisphaerocoryphe pseudohemicranium* (see Öpik 1937, p. 113, pl. 15, figs 1–2), from the middle Ordovician of Estonia, with *Sphaerocoryphe dentata* Angelin, 1854 (p. 66, pl. 34, figs 6, 6a; Kielan-Jaworowska *et al.* 1991, p. 234, figs 10–11), from the upper Ordovician (Ashgill) of Sweden, the most obvious difference is the development in the former species of a shorter (sag.) preoccipital depression, a term introduced by Holloway and Campbell (1974) to include S0 and part of the glabellar lobes. Silicified material of *Sphaerocoryphe ludvigseni* Chatterton (1980, p. 43, pl. 13, figs 1–30; text-fig. 9A–F) and *S. robusta* Walcott (Ludvigsen 1979, p. 44, pl. 18, figs 33–54) suggests that L1 and L2 (or most of it) are incorporated into the preoccipital depression; this may be an important character for all typical members of *Sphaerocoryphe* (Holloway and Campbell 1974). The specimen described below has a cranidium typical of *Hemisphaerocoryphe*; the swollen anterior part of the glabellar portion has traces of S1–S4 furrows or impressions. In most other typical members of the genus, including, in addition to the type species, *H. inflata* Nikolaisen, 1961 (p. 292, pl. 1, figs 11–12), *H. granulata* (Angelin, 1854, p. 76, pl. 39, figs 4, 4a; Warburg 1925, p. 388, pl. 10, figs 35–39; Männil 1958, p. 178, pl. 5, figs 4–7) and even *Sphaerocoryphe* sp. ind. of Reed (1906, p. 77, pl. 5, fig. 26) from the lower Ordovician of the Northern Shan States, Burma, S3 (level with palpebral lobe) and S4 are also visible, although S1 and S2 are usually indistinguishable owing to either poor preservation or effacement. Possibly only part of L1 is incorporated in the preoccipital depression of *Hemisphaerocoryphe*.

As the lateral glabellar furrows are visible with difficulty in most species of both *Sphaerocoryphe* and *Hemisphaerocoryphe*, it is more practical to consider the latter a subgenus of the former, as suggested by Přibyl *et al.* (1985). Additional differences between the subgenera include the more forwardly situated palpebral lobe and the anterior glabellar portion, which overhangs the preoccipital depression more strongly in *Sphaerocoryphe*, but neither is of generic importance. The only known pygidium of *Hemisphaerocoryphe* was described as *Sphaerocoryphe exserta* Webby,



TEXT-FIG. 4. Reconstruction of cranidium of *Sphaerocoryphe* (*Hemisphaerocoryphe*) *elliptica* (Lu, 1975), based on NI 80770. A, dorsal view; B, lateral view; × 5.

1974 (p. 237, pl. 33, figs 1–9) from the Caradoc of New South Wales, Australia and closely resembles that of *Sphaerocoryphe*. Přibyl *et al.* (1985) considered the presence of a pair of free points between the largest spines to be distinctive, but as Tripp *et al.* (1997) pointed out, the points are only hyperextended ventral forks like those found in all species of *Sphaerocoryphe*.

Sphaerocoryphe (*Hemisphaerocoryphe*) *elliptica* (Lu, 1975)

Plate 8, figures 2–3, 6; Text-figure 4

1975 *Ellipsocoryphe elliptica* Lu, p. 429, pl. 43, figs 12, 14; text-fig. 46.
1978 *Ellipsocoryphe elliptica* Lu; Lee, p. 266, pl. 107, fig. 6a–b.

Holotype. Cranidium (NI 16932), figured Lu (1975, pl. 43, figs 12–14), from the upper Meitan Formation (late Arenig–earliest Llanvirn) of Huayingshan, north-east of Chongqing, Sichuan.

Figured specimen. Incomplete cephalon with nine attached thoracic segments (NI 80770) from Bed 3.

Description. Cranidium 60 per cent. as long as wide in plan, excluding fixigenal spines. Anterior portion of glabella spherical, slightly longer than wide, partly overhangs preoccipital depression and cheeks; it occupies 84 per cent. of glabellar length, 47 per cent. of cranidial width, excluding fixigenal spines, and is defined posteriorly by deep transverse furrow which may represent posterior branch of bifurcate S1. S1–S4 short, faint: S1 (probably its anterior branch) curves back slightly at posterolateral corner of the isolated anterior glabellar portion and merges abaxially with transverse furrow; S2 adaxially directed, opposite anterior end of preoccipital depression; S3 and S4 appear as smooth areas sited, respectively, level with palpebral lobe and at anterolateral corner of glabella. Preoccipital depression almost joins occipital furrow medially, with abaxial pair of flat, triangular preoccipital lobes which are weakly inflated adjacent to axial furrows to form small, rounded nodes covered with dense, fine granules. Occipital ring convex, 70 per cent. width of anterior glabellar portion and defined by deep S0; small median node visible on holotype is not seen on exfoliated surface of the present specimen. Axial furrows deep, wide. Fixigena sub-rectangular, abaxially declined; palpebral lobe L-shaped, vertical, its front end in-line with mid-point of anterior glabellar portion and close to axial furrow. Posterior and lateral borders broad, widening towards genal angle where they meet at base of fixigenal spine. Border furrow distinct. Anterior section of facial suture runs forwards and down; posterior section transverse, cuts lateral border at point opposite S3. Librigena triangular; eye socle vertical; eye spherical in lateral view, reniform in plan, its length 16 per cent. that of anterior glabellar portion.

Thorax of nine segments. Axis almost parallel-sided, occupies 44 per cent. width of thorax and is transversely convex, bounded by distinct axial furrows. Proximal part of pleura flat, rectangular, 74 per cent. of overall width (tr.) and with incised, intermittent, transverse median pleural furrow; distal part forms broad-based tubular spine which narrows backwards and slightly down.

Surface densely and finely granulose, with scattered, coarser granules medially on posterior half of anterior glabellar portion; finer granules on cheeks, with sparsely distributed pits on intervening areas.

Remarks. The holotype is a tiny, slightly deformed cranidium, from which the new specimen differs in the wider anterior portion of the glabella, but this may result from changes during ontogeny. An occipital node seen on the holotype which cannot be verified as the occipital ring is exfoliated in the present specimen. Compared with the type species and other typical members of *Hemisphaerocoryphe*, *S*. (*H*.) *elliptica* is characterized mainly by the more flattened preoccipital segment with a pair of rather poorly demarcated lateral nodes. The species is probably the oldest known representative of the Deiphoninae, a subfamily interpreted as being derived from the cheirurid lineage *Laneites–Ceraurinella* (Přibyl *et al*. 1985) or from early cheirurids such as *Krattaspis* Öpik, 1937 (Chatterton 1980), although Lane (1971) considered that both Cheirurinae and Deiphoninae may have come from a common stock. The morphology of *S*. (*H*.) *elliptica* is highly specialized, and without evidence of its ontogeny the species cannot be used to support either of the above hypotheses.

Family HAMMATOCNEMIDAE Kielan, 1960

Genus OVALOCEPHALUS Koroleva, 1959

(= *Hammatocnemis* Kielan, 1960, p. 141)

Type species. *Ovalocephalus kelleri* Koroleva, 1959.

Remarks. Zhou and Dean (1986) pointed out that differences between *Ovalocephalus* and *Hammatocnemis* Kielan, 1960 fall within the range of intrageneric variation, and more recently the two were considered synonymous by Dean and Zhou (1988), Tripp *et al*. (1989) and Hammann (1992).

Ovalocephalus primitivus extraneus (Lu and Zhou, 1979)

Plate 8, figures 7–9

1979 *Hammatocnemis primitivus extraneus* Lu and Zhou, p. 426, pl. 1, figs 1–13; pl. 2, figs 1–8; text-fig. 5a–c.
1981 *Hammatocnemis primitivus* Lu; Zhang, p. 209, pl. 77, figs 3–4.

Holotype. Cephalon (NI 56541), figured Lu and Zhou (1979, pl. 1, figs 1–9), from the uppermost Zotzeshan Formation (latest Arenig) at Laoshidan, Haibowan, Nei Mongol.

Figured specimens. One cranidium (NI 80771), one pygidium with attached thoracic segments (NI 80773), and one pygidium (NI 80772) from Bed 2.

Description. Glabella convex, two-thirds as wide as long, anterior portion gently expanded and broadly rounded frontally; lenticular occipital ring twice as wide as long, 20 per cent. length of glabella, and wider than preoccipital ring, well defined by deep S0; preoccipital ring low, ridge-like, arched forwards medially and widens (tr.) abaxially to form pair of convex elliptical lobes; preoccipital furrow transverse, deep abaxially; anterior glabellar portion carries four pairs lateral furrows; S1–S3 short, equally spaced, successively shallower; S1 runs slightly back adaxially, S2 directed adaxially, S3 extends slightly forwards and located opposite front end of palpebral lobe; S4 in front of anterolateral glabellar angle and directed backwards. Axial furrow deep, wide. Palpebral lobe high, narrow, carries distinct palpebral furrow, its posterior end level with L1. Palpebral area triangular; posterior area sub-rectangular, distal part declined abaxially.

Pygidium about twice as wide as long; gently tapered low axis has four rings, broadly rounded terminal piece, and ring furrows that are successively shallower; axial furrows distinct frontally but shallow around tip of axis. Pleural region declined abaxially, comprising four pleurae separated by deep interpleural furrows; first three pleurae extend slightly backwards beyond margin and end in free points (see Zhang 1981, pl. 77, fig. 4b). Surface of glabella and pygidium densely granulose.

Remarks. The new material is identical with specimens from the same horizon and area, described as *Hammatocnemis primitivus extraneus* by Lu and Zhou (1979, pl. 2, figs 5–8) but as *H. primitivus* by Zhang (1981). We refer them here to *O. primitivus extraneus* as the occipital ring is much longer (sag.) than that of *O. primitivus primitivus* (Lu, 1975, p. 441, pl. 45, figs 4–14). *O. primitivus extraneus* has been regarded as the ancestral form of Species group 2 of *Ovalocephalus* (Zhou and Dean 1986), characterized by having the entire median preoccipital ring between the preoccipital lobes. Diagnostic of the subspecies are: shorter (exsag.) posterior area of fixigena; palpebral lobe longer, sited further back; glabella less constricted at L1; S4 present; first three pygidial pleurae extend beyond posterior margin as short free points. These are considered as primitive characters in the *O. primitivus extraneus*–*O. tetrasulcatus* evolutionary lineage (Lu and Zhou 1979) and have proved useful in distinguishing older forms from related younger species such as *O. intermedius* (Lu and Zhou, 1979), *O. obsoletus* (Zhou and Dean, 1986), *O. kanlingensis* (Zhang, 1981), *O. tetrasulcatus* (Kielan, 1960), *O. kelleri* Koroleva, 1959 and *O. globosus* Abdullaev, 1972.

Family PTERYGOMETOPIDAE Reed, 1905

Subfamily PTERYGOMETOPINAE Reed, 1905

Genus YANHAOIA gen. nov.

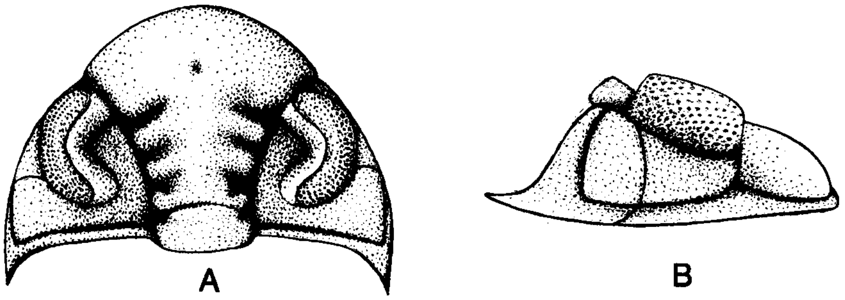
Derivation of name. After Professor Lu Yanhao, author of the type species, which is the only known pterygometopine in China.

Type species. Pterygometopus huayinshanensis Lu, 1975.

Diagnosis. Cephalon with short fixigenal spines and large eyes. Glabella has three pairs of deep glabellar furrows; S1 bifurcate, S2 and S3 parallel, anteriorly directed adaxially; L1–3 of subequal length. Frontal glabellar lobe with shallow medial depression. Anterior section of facial suture runs along preglabellar furrow.

Remarks. Pterygometopus huayinshanensis Lu, 1975 (p. 462, pl. 50, figs 6–10; Zhou *et al.* 1982, p. 292, pl. 72, fig. 4), from the upper lower Ordovician of Sichuan and southern Shaanxi, displays some typical pterygometopine characters, such as: frontal glabellar lobe strongly expanded laterally; L1 and L2 of almost equal length; palpebral lobe stands very high above glabella; and frontal margin of large eye reaches anterior part of axial furrow (see Ludvigsen and Chatterton 1982; Jaanusson and Ramsköld 1993). The pygidium is not yet known, but the straight S3, directed slightly backwards abaxially, and short (exsag.) L3 suggest that this is an aberrant form whose affinities with other pterygometopine species are uncertain (cf. Zhou and Dean 1989, p. 137), and we follow Jaanusson and Ramsköld (1993, p. 745) in considering it to represent a new, as yet monotypic genus.

Pterygometopus Schmidt, 1881 differs from *Yanhaoia* in the following characters: wider cephalon and frontal glabellar lobe; posterior part of glabella more strongly tapered; preglabellar furrow more distinct; genal angles rounded; curved S3 runs slightly backwards adaxially; longer L3; eyes smaller; anterior section of facial suture runs in front of, instead of inside, preglabellar furrow; and posterior section runs along a sulcus described by Whittington (1950, p. 539) as 'the continuation of the palpebral furrow out to the lateral border'. *Yanhaoia* resembles *Ingriops* Jaanusson and Ramsköld, 1993, from the Llanvirn of northern Estonia and Östergötland, Sweden, in several respects, especially the glabellar outline, bifurcate S1, large eyes, presence of genal spines, and the siting of the anterior section of the facial suture in the preglabellar furrow. The Baltoscandian genus



TEXT-FIG. 5. Reconstruction of cephalon of *Yanhaoia huayinshanensis* (Lu, 1975), based mainly on holotype, NI 16991 (Lu 1975, pl. 50, figs 6, 9). A, dorsal view; B, lateral view; ×4.

is distinguished by the more pointed front of cephalon and glabella; adaxial extension of S3; longer L3; and triangular, rather than trapezoidal, frontal glabellar lobe, which lacks a median depression.

Yanhaoia huayinshanensis (Lu, 1975)

Plate 8, figures 4–5; Text-figure 5

1975 *Pterygometopus huayinshanensis* Lu, p. 462, pl. 50, figs 6–10.
1978 *Pterygometopus huayinshanensis* Lu; Lee, p. 280, pl. 107, fig. 14.
1982 *Pterygometopus huayinshanensis* Lu; Zhou *et al.*, p. 292, pl. 72, fig. 4.

Holotype. Cephalon (NI 16991), figured Lu (1975, pl. 50, figs 6–10), from the lower part of the Neichiashan Series (probably Llanvirn) at Huayingshan, north-east of Chongqing, Sichuan.

Figured specimen. Incomplete cephalon with eight attached thoracic segments (NI 80774) from Bed 3.

Description. Cephalon semi-elliptical, about three-quarters as long as wide, declined anteriorly and laterally, with short genal spines. Convex glabella broadly rounded frontally, narrows forwards to S1 and then expands strongly so that anterior width is twice that across L1; occipital ring lenticular with pair of rounded lateral lobes; distinct S0 deepens abaxially; S1–S3 deeply incised; S1 bifurcate, S2 and S3 parallel, straight, directed adaxially forwards; L1–L3 of almost equal length (exsag.); L1 rounded, L2 and L3 directed abaxially backwards, and L3 slightly wider (tr.) than L2; frontal lobe trapezoidal, expanded forwards, with small median depression; axial furrow deep, broad. Palpebral lobe high, with distinct palpebral furrow, its length (sag.) about half that of glabella; front end of lobe reaches axial furrow immediately in front of S3, and posterior end opposite L1. Palpebral area of fixigena declines adaxially and anteriorly. Posterior section of facial suture sigmoidal. Eye large, crescentic, with vertical eye socle.

Thorax subparallel-sided, strongly convex transversely. Axis about two-fifths the thoracic width, well defined by distinct axial furrows. Axial ring rectangular, with pair of rounded axial nodes visible on internal mould. Inner part of pleura horizontal, with deep, wide, diagonal pleural furrow; outer part declines steeply to pointed tip.

Remarks. Only two specimens of the species were previously known, the holotype and a well-preserved cephalon with five attached thoracic segments, from the middle part (Llanvirn) of the Siliangssu Formation at Nanzheng, southern Shaanxi (Zhou *et al.* 1982). The new specimen, although incomplete, compares closely with both; the tiny fixigenal spine on the right side of the cephalon can also be distinguished on the holotype.

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