Upper lower Cambrian (provisional Cambrian Series 2) trilobites from northwestern Gansu Province, China

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Abstract. Upper lower Cambrian (provisional Cambrian Series 2) trilobites are described from three sections through the Shuangyingshan Formation in the Beishan area, northwestern Gansu Province, China. The trilobite fauna is dominated by eodiscoid and 'corynexochid' trilobites, together representing at least ten genera: *Serrodiscus*, *Tannudiscus*, *Calodiscus*, *Pagetides*, *Kootenia*, *Edelsteinaspis*, *Ptarmiganoides*?, *Politinella*, *Dinesus* and *Subeia*. Eleven species are described, of which seven are identified with previously described taxa and four described under open nomenclature. The composition of the fauna suggests biogeographic affinity with Siberian rather than Gondwanan trilobite faunas, and the Cambrian Series 2 faunas described herein and from elsewhere in northwestern China seem to be indicative of the marginal areas of the Siberian palaeocontinent. This suggests that the Middle Tianshan–Beishan Terrane may have been located fairly close to Siberia during middle–late Cambrian Epoch 2.

Key words: Trilobita, taxonomy, palaeobiogeography, lower Cambrian, Cambrian Series 2, Beishan, Gansu Province, China.

INTRODUCTION

China is a complex collage of continental blocks and accretionary belts, as well as several smaller blocks and terranes, including amalgamation of the North China plates and the southern marginal areas of Siberia. Fossils are of fundamental importance for interpretation of complex palaeogeographical situations, providing age and biogeographic constraints in formulation of tectonic models. This paper focuses on upper lower Cambrian (provisional Cambrian Series 2) trilobites from the Beishan area, northwestern Gansu Province of China. The trilobite fauna includes several palaeobiogeographically and biostratigraphically important taxa that are valuable for constraining early Cambrian plate configurations.

Fossiliferous Cambrian Series 2 rocks crop out sporadically in the Beishan area (Fig. 1A–D). During the Cambrian through Early Ordovician this area formed part of the Yining–Kawabulak–Beishan region (Zhou et al. 1996), which together with the Tekeli Depression of Apollonov & Patalakha (1989) may have formed an independent terrane within the Kazakhstan Mid-Plate (Kazakhstania). Following the closure of the Middle Tianshan Sea during the Darriwilian, this terrane was incorporated into the Tarim Plate (e.g. Zhou & Zhou 2006; Zhou & Zhen 2008). Several Ordovician terranes have been discriminated on the Kazakhstan side by Fortey & Cocks (2003). Among them, the Chu-Ili Terrane may be a western extension of the Yining–Kawabulak–Beishan Terrane, judging from shared stratigraphic and faunal patterns.

The trilobites described in this contribution were collected by Zhou Zhiqiang and Chinese colleagues from three measured sections through the Shuangyingshan Formation in Subei County, Beishan area, northwestern Gansu Province.

Section 1 is at 41°28′7″N and 96°33′54″E, 1 km southwest (225°) of Shuangyingshan Mountain (Fig. 1C). In descending order, the lithologies and occurrences of trilobites (Fig. 1D) are as follows:

Lowermost part of the Xishuangyingshan Formation: Black thin-bedded cherts with intercalated beds of a grey thin-bedded limestone.

———— conformity ————

Shuangyingshan Formation: Greyish white and grey thin-bedded and medium-bedded biocalcarenites with a thickness of 3.3 m.

Level BS6 (2.9 m above the base of the Shuangyingshan Formation): *Dinesus spinellosus* (Zhou), *Edelsteinaspis* sp., *Kootenia* sp., *Pagetides* (*Discomesites*) *huochengensis* (Zhang)?, *Ptarmiganoides*? sp. 1 and *Tannudiscus conicus* Zhou.

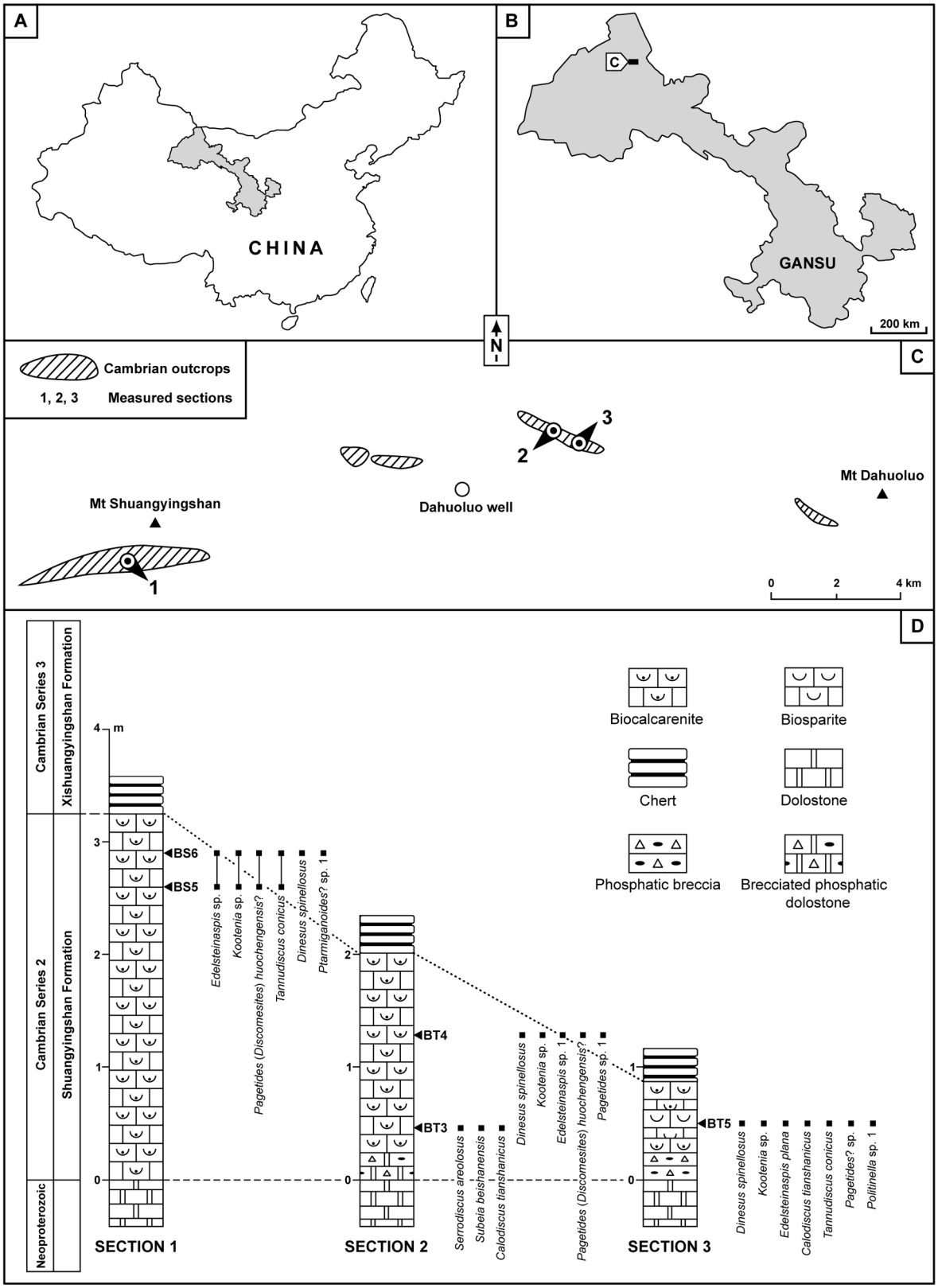

Fig. 1. A, **B**, sketch maps showing the location of the Beishan area, northwestern Gansu Province, China. **C**, distribution of major outcrop areas of Cambrian rocks and the location of measured sections (1–3) in the Beishan area. **D**, lithological successions and observed biostratigraphic distribution of trilobites in sections 1–3.

Level BS5 (2.6 m above the base of the Shuangyingshan Formation): *Edelsteinaspis* sp., *Kootenia* sp., *Pagetides* (*D.*) *huochengensis*? and *Tannudiscus conicus*.

———— disconformity ————

Xichangjing Group (Neoproterozoic): Greyish yellow thin-bedded dolostones.

Section 2 is at 41°29′36″N and 96°43′30″E, 3.4 km northeast (57°) of Dahuolou Well (Fig. 1C). In descending order, the lithologies and occurrences of trilobites (Fig. 1D) are as follows:

Lowermost part of the Xishuangyingshan Formation: Black thin-bedded to medium-bedded cherts with a thin-bedded micritic limestone at the top.

———— conformity ————

Shuangyingshan Formation, which can be subdivided into three units, in descending order:

1. Greyish biocalcarenites (1.1 m).

Level BT4 (1.28 m above the base of the Shuangyingshan Formation): *Dinesus spinellosus*, *Edelsteinaspis* sp. 1, *Kootenia* sp., *Pagetides* (*D.*) *huochengensis*? and *Pagetides*? sp. 1.

2. Greyish white biocalcarenites (0.7 m).

Level BT3 (0.46 m above the base of the Shuangyingshan Formation): *Calodiscus tianshanicus* Xiang & Zhang, *Serrodiscus areolosus* Zhou and *Subeia beishanensis* Li.

3. Dark grey to black brecciated dolostones with phosphate (0.2 m).

———— disconformity ————

Xichangjing Group (Neoproterozoic): Grey thin-bedded dolostones.

Section 3 is at 41°29′20″N and 96°44′8″E, 3.9 km northeast (68°) of Dahuolou Well (Fig. 1C). In descending order, the lithologies and occurrence of trilobites (Fig. 1D) are as follows:

Lowermost Xishuangyingshan Formation: Greyish black medium-bedded cherts.

———— conformity ————

Shuangyingshan Formation, which can be subdivided into two units, in descending order:

1. Greyish white and light pink biocalcarenites with intercalated beds of a biosparite (0.6 m).

Level BT5 (0.5 m above the base of the Shuangyingshan Formation): *Calodiscus tianshanicus*, *Dinesus spinellosus*, *Edelsteinaspis plana* Chernysheva, *Kootenia* sp., *Pagetides*? sp., *Politinella* sp. 1 and *Tannudiscus conicus*.

2. Greyish black phosphate-bearing conglomerates and breccias (0.2 m).

———— disconformity ————

Xichangjing Group (Neoproterozoic): Greyish yellow dolostones.

The base of the Xishuangyingshan Formation, overlying the Shuangyingshan Formation, bears the trilobite *Galahetes opimus* Zhang in Zhou et al. (1982, p. 231, pl. 59, figs 7–9) at a locality 13.5 km southwest (266°) of Section 1. The genus *Galahetes* Öpik, 1975a, known from Australia and Hainan Island of China, is indicative of the lower part of the traditional middle Cambrian (provisional Cambrian Stage 5).

Fossiliferous Cambrian Series 2 strata in the Beishan area were first discovered by Liu Guangxia and Chen Lijun (unpublished report from 1964). According to their report, lower Cambrian (Cambrian Series 2) strata that crop out around the Dahuoluo Well consist of greyish-white and white biosparites, occasionally with black chert interbeds. The succession has a total thickness of 21 m and has yielded trilobites of the genera *Bergeroniellus*, *Calodiscus*, *Dinesus* (= *Erbia*), *Kootenia* and *Serrodiscus*. Subsequently, Zhao Xiangshen and Ye Yu (unpublished stratigraphic report from 1966) restudied the Cambrian strata in this area and recovered some Cambrian trilobites. In an unpublished report (1967) they referred to lower Cambrian (Cambrian Series 2) strata as 'the Shuangyingshan Formation'. The Cambrian Series 2 trilobites collected by Zhao and Ye were described by Zhou Zhiqiang and Li Jinseng in the book *Paleontological Atlas of Northwest China, Shaanxi-Gansu-Ningxia Volume, Part 1* published in 1982. The trilobites include *Serrodiscus areolosus*, *Tannudiscus conicus*, *Dinesus spinellosus* and *Subeia beishanensis*. Further collections, which provided the bulk of the material for the present paper, were made by Zhao Xiangshen and Zhou Zhiqiang in 1982. A trilobite list and plate including the above-mentioned four species, *Kootenia* sp. and *Edelsteinaspis* sp. were published by Zhao et al. (1984).

BIOGEOGRAPHICAL ASSESSMENT

Xiang & Zhang (1985) and Zhang (1987) described an early Cambrian trilobite assemblage from the western part of the Xinjiang Uygur Autonomous Region, China. The assemblage comes from the Huocheng Formation at Guozigou and Akqat, Huocheng County (Fig. 2). The 2-m-thick Huocheng Formation consists mainly of light grey, thick-bedded micritic limestone with shell fragments. It is disconformably underlain by black silty, siliciclastic mudstones intercalated with limestone concretions and phosphate-bearing layers (Linkuanggou Formation), and disconformably overlain by phosphatic, argillaceous siliciclastic rocks intercalated with thin-bedded or lenticular limestones with trilobites of the genus *Xystridura* Whitehouse, 1936 (the lower part of the Kensay Formation). The trilobite assemblage from the Huocheng Formation includes six genera: *Calodiscus*,

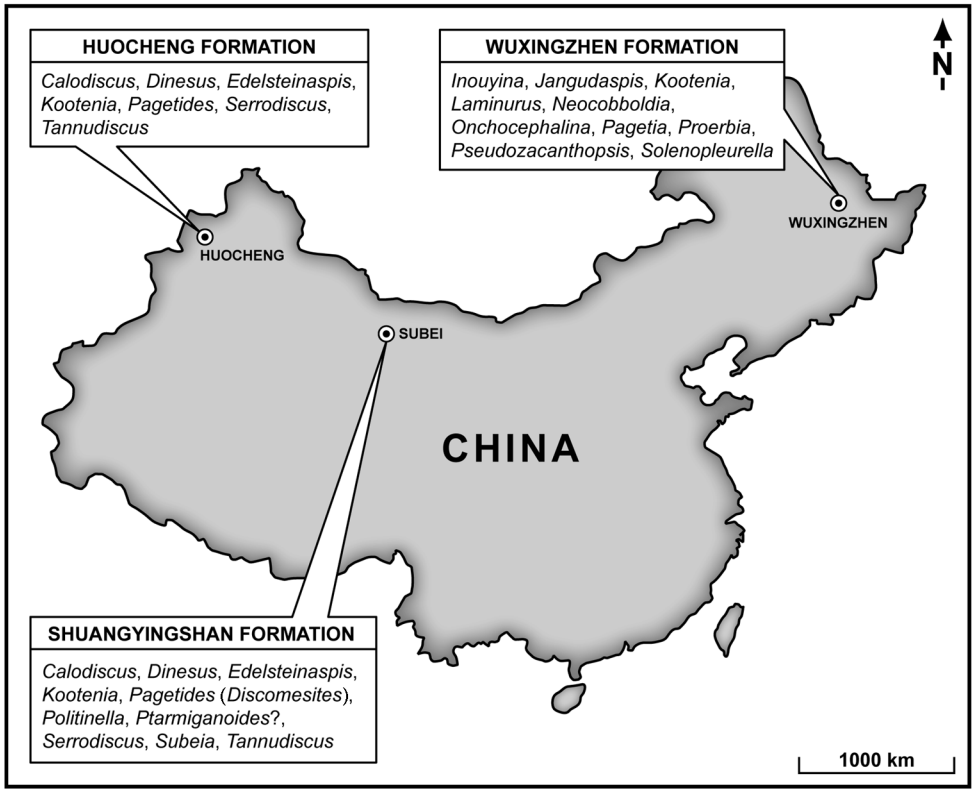

Fig. 2. Map of China showing the three so far known occurrences of Cambrian Series 2 faunas with north Asiatic affinities, all in northern China. One occurrence is in the Huocheng Formation at Guozigou and Akqat in Huocheng County, western Xinjiang Uygur Autonomous Region (Xiang & Zhang 1985; Zhang 1987). A second occurrence is in the Shuangyingshan Formation of Subei County, Beishan area, Gansu Province (Zhou et al. 1982; this paper). The third occurrence is in the Wuxingzhen Formation at Yichun City, Heilongjiang Province, northeastern China (Duan & An 2001).

Dinesus (= *Erbia*), *Edelsteinaspis*, *Kootenia*, *Pagetides* and *Tannudiscus* (Fig. 2). These are shared with the fauna in the Shuangyingshan Formation of Beishan.

Another related early Cambrian trilobite assemblage was discovered by Duan & An (2001) in a drill core recovered at Wuxingzhen Town, Yichun City, Heilongjiang Province, northeastern China (Fig. 2). The Wuxingzhen Formation is represented in the drill core and can be divided into three parts: (1) a lower part consisting of dark grey crystalline limestones and dolomitic limestones with an unknown thickness, (2) a middle part composed of a 100–150-m-thick succession with grey metamorphosed limestones (marble) intercalated occasionally with carbonaceous slates and silty slates and (3) an upper part comprising a 200-m-thick succession of dark grey carbonaceous and silty shales intercalated occasionally with micritic and bioclastic limestones. The bioclastic limestones have yielded trilobites of the genera *Inouyina*, *Jangudaspis*, *Kootenia*, *Laminurus*, *Neocobboldia*, *Onchocephalina*, *Pagetia*, *Proerbia* and *Pseudozacanthopsis* (Duan & An 2001; Fig. 2). The trilobite assemblage was considered by Duan & An to represent a fauna of late early Cambrian age (Lenian or Toyonian; provisional Cambrian Age 4) with Siberian affinity. Its composition differs, however, markedly from that of the fauna from the Shuangyingshan Formation. This distinction may result from a difference in both facies and age.

As mentioned above, parts of Northwest China, including at least the Middle Tianshan–Beishan Region of Zhou & Zhen (2008), are regarded as an extension of a geological region extending westwards into Kazakhstan. To the north, Repina (1972, pp. 297–299) recognized a Sayan–Altaj (also spelt Altai or Altay) province, in which limestones hold a trilobite fauna characterized by the genera *Kooteniella* (?= *Kootenia*), *Edelsteinaspis*, *Chondragraulos* and *Erbia* (i.e. *Dinesus*). Still further north, the evaporitic inner basinal part of the Siberian Platform had a '*Pseudoeteraspis–Poliella* biofacies' during the early–middle Toyonian (Repina 1972; Pegel 2000). The occurrences in northern China may represent the southern margin of this greater

Asiatic realm, recognized by Kobayashi (1972) as a North Asiatic subprovince (of an Asiatic–Mediterranean province) particularly rich in 'corynexochids' and 'ptychopariids'. However, the Middle Tianshan–Beishan Region has its own lithological and biofacies characters, although some species are shared with the Siberian province. The general aspect is certainly central Asiatic to Siberian rather than, for instance, Gondwanan, and, as noted by Zhou & Zhen (2008) and Álvaro et al. (2013), the Middle Tianshan–Beishan Terrane may have been located fairly close to the Siberian plate during late early Cambrian times (Cambrian Epoch 2).

SYSTEMATIC PALAEONTOLOGY

Because of the fragmentary state of the material, the genus *Kootenia* with at least five species is not treated herein. The morphological terminology used here follows that of Whittington in Kaesler (1997). Figured and cited specimens are deposited in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing (NIGP), and Xi'an Institute of Geology and Mineral Resources, Xi'an (XIGM).

Order EODISCIDA Kobayashi, 1939
Family WEYMOUTHIIDAE Kobayashi, 1943
Genus *Serrodiscus* Richter & Richter, 1941

Type species. *Eodiscus* (*Serrodiscus*) *serratus* Richter & Richter, 1941, from the lower Cambrian (Cambrian Series 2) *serratus*-Band in the Herrerías-Mergel (Herrerías Marlstone) Formation, near Cala, southern Spain; by original designation.

Remarks. The concept of *Serrodiscus* was recently discussed by Westrop & Landing (2011), who suggested that the genus as previously diagnosed is in fact paraphyletic. Their phylogenetic analysis indicates that *Serrodiscus sensu lato* should be restricted to include species with mostly entirely effaced glabellae.

Serrodiscus areolosus Zhou in Zhou et al. 1982
Figure 3A–K

1982 *Serrodiscus areolosus* Zhou et al., p. 220, pl. 57, figs 17–19.

Holotype. Cephalon XIGM Tr015 (Fig. 3I; Zhou et al. 1982, pl. 57, fig. 17), from the Shuangyingshan Formation, lower Cambrian (Cambrian Series 2) of Dahuoluo, Subei County, northwestern Gansu, China.

Paratype. Cephalon XIGM Tr016 (Fig. 3K; Zhou et al. 1982, pl. 57, fig. 18).

Other material. Three cephala (NIGP152225, 152226, 152229) and three pygidia [XIGM Tr017 (Fig. 3C, D; Zhou et al. 1982, pl. 57, fig. 19), NIGP152227, 152228], all from level BT3, Section 2.

Diagnosis. A species of *Serrodiscus* with a long, stout, upward and backwardly directed glabellar spine, and 11 pygidial axial rings with prominent median spines directed upwards and slightly backwards.

Description. The cephalon is semi-elliptical in outline and 80–90% as long (glabellar spine excluded) as it is wide. The preoccipital glabella is subconical in outline, rounded anteriorly, 68–72% of the cephalic length (glabellar spine excluded), and 30–35% of the cephalic width posteriorly. Three pairs of shallowly incised glabellar furrows are present; the anterior two pairs are transglabellar, whereas the posterior pair (S1) fades out medially. The anterior glabellar lobe is much longer than the other lobes. Transversely, the glabella is strongly convex. The anterior glabellar lobe slopes down strongly to the preglabellar depression. The posterior glabellar lobe (L1) widens rapidly backwards, raises upwards and extends into a large spine, which is directed upwards and slightly rearwards and overhangs the occipital ring. The occipital furrow is distinctly indicated abaxially, directed inwards and backwards, adaxially becoming shallower. The occipital ring (LO) is short (sag. and exsag.), with a backwardly arched posterior margin. The dorsal furrows are deeply incised; the preglabellar furrow is weak. The fixed cheeks are separated by a short and shallow preglabellar depression, convex (tr.) and strongly sloping down to the border furrow. The anterior and lateral border furrow is deep and rapidly widened forwards to form a crescentic depression on the anterior part of the cephalon. The border is narrow (tr.) posterolaterally, slightly widened anteriorly and carries seven pairs of low tubercles. The posterior border furrow is wide and deeply incised. The posterior border widens abaxially.

The pygidium is subtriangular in outline, rounded posteriorly and 85–91% as long as it is wide anteriorly. The axis is strongly convex (tr.), tapered backwardly at a uniform rate and terminates slightly in front of the border furrow. It consists of 10 rings and a terminal piece, each with a short but prominent median spine or spine-like tubercle directed upwards and slightly rearwards. These spines or turbercles decrease in size and length posteriorly. The ring furrows are well incised. The axial furrows are distinctly incised and rather broad. The pleural field is unfurrowed, sloping down strongly to the border furrow, slightly narrower than the axis and confluent behind the axis in a narrow strip. The border furrow is deeply incised. The border is

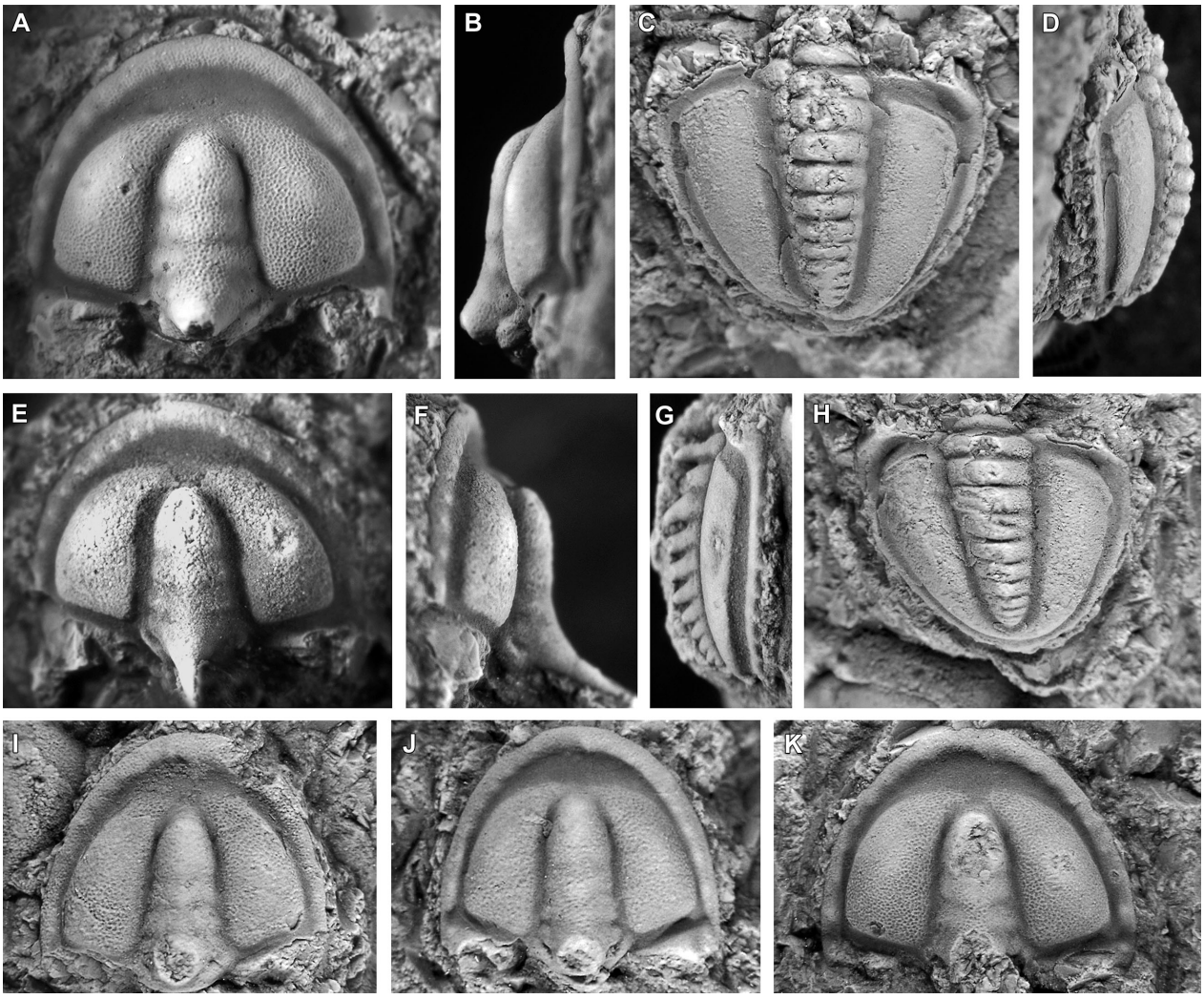

Fig. 3. *Serrodiscus areolosus* Zhou in Zhou et al. 1982. Dorsal and lateral views of cephala and pygidia. **A**, **B**, cephalon, NIGP152229, ×7. **C**, **D**, pygidium, XIGM Tr017, figured by Zhou (in Zhou et al. 1982, p. 220, pl. 57, fig. 19), ×8. **E**, **F**, cephalon, NIGP152226, ×7.6. **G**, pygidium, NIGP152228, ×7.8. **H**, pygidium, NIGP152227, ×6.6. **I**, holotype, cephalon, XIGM Tr015, figured by Zhou (in Zhou et al. 1982, p. 220, pl. 57, fig. 17), ×7.8. **J**, cephalon, NIGP152225, ×9.5. **K**, cephalon, XIGM Tr016, figured by Zhou (in Zhou et al. 1982, p. 220, pl. 57, fig. 18), ×6.6. All from level BT3.

narrow (tr.), slightly narrowing posteriorly and carries ten pairs of tiny border spines, directed posteroventrally.

The surface of the cephalon is strikingly ornamented with a fine, reticulate sculpture of narrow, low, raised ridges. Well-preserved specimens show that the external exoskeletal surface of the pygidium is covered with the same sculpture as the cephalon.

Remarks. New material permits a detailed supplement of the original description of this species (Zhou in Zhou et al. 1982, p. 220). It is easily distinguished from other *Serrodiscus* species by its large, nearly erected posterior glabellar spine and by its pygidial axial rings with prominent median spines or spine-like tubercles. Distinct median axial tubercles have also been described in pygidia of *S. bellimarginatus* (see, e.g., Rushton 1966, pl. 1, fig. 3a, b).

Species of *Serrodiscus* have been reported from various parts of North America inclusive of Greenland, Spitsbergen, Britain and central Europe, Spain, Morocco, Australia, Gansu in China, and Mt. Altaj in Russia (see Repina & Romanenko 1978 for the latter occurrence). They appear to be particularly common in the Taconic region of New York State (Rasetti 1966, 1967) and North Greenland (Blaker & Peel 1997).

Genus *Tannudiscus* Pokrovskaya, 1959

Type species. *Tannudiscus tannuolaicus* Pokrovskaya, 1959, from the Toyonian (Cambrian Series 2) of Tuva, Siberia; by original designation.

Tannudiscus conicus Zhou in Zhou et al. 1982
Figure 4A–H

1982 *Tannudiscus conicus* Zhou in Zhou et al., pp. 220–221, pl. 57, figs 20, 21.
1985 *Tannudiscus* sp.; Xiang & Zhang, p. 93, pl. 2, fig. 18.
1987 *Tannudiscus conicus* Zhou; Zhang, p. 44, pl. 1, figs 1–4.

Holotype. Cephalon XIGM Tr019 (Fig. 4E, F; Zhou et al. 1982, pl. 57, fig. 21), from the Shuangyingshan Formation, lower Cambrian (Cambrian Series 2) of Dahuoluo, Beishan area, northwestern Gansu, China.

Other material. Cephalon XIGM Tr018 (Fig. 4B; Zhou et al., 1982, pl. 57, fig. 20), from level BT5, Section 3; cephalon NIGP152232, from level BS6, Section 1; pygidium NIGP152233, from level BT5, Section 3; pygidium NIGP152234, from level BS5, Section 1.

Diagnosis. A species of *Tannudiscus* with a subconical frontal glabellar lobe, which reaches the anterior border furrow and is 52–61% the length of the posterior glabellar lobe. Cephalic border rapidly widened (sag. and exsag.) anteriorly. Pygidial axis tapered, much wider than pleural field, nearly reaching border furrow, with five weak ring furrows.

Description. The cephalon is subquadrate in outline, 85–110% as long as it is wide and broadly rounded anteriorly. The glabella is large, 74–80% as long as the cephalon, bilobed and reaches the border furrow anteriorly. The anterior lobe is subconical in outline, rounded anteriorly, 52–61% as long as the posterior lobe, strongly convex (tr.), anteriorly sloping down to the border furrow. The transglabellar furrow is narrow, deeply incised and curved slightly forward medially. The posterior lobe is subquadrate in outline, slightly widened rearwards, rounded posteriorly, rising steeply from cheeks and highest at the posterior 1/3 where it slopes steeply rearwards. An occipital furrow is absent. The dorsal and preglabellar furrows are narrow and deep, anteriorly joining the border furrow. The fixed cheek is moderately convex (tr.), sloping down to the border furrow. The border furrow is deep and anteriorly nearly transverse. The border is gently convex, wide, 18% of the cephalic length (sag.) and strongly narrowing rearwards.

The pygidium is semi-elliptical in outline, nearly as long as wide, with the anterior margin forwardly arched. The axis is strongly convex (tr.), tapered rearwards, nearly reaching the border furrow, and 79–84% of the

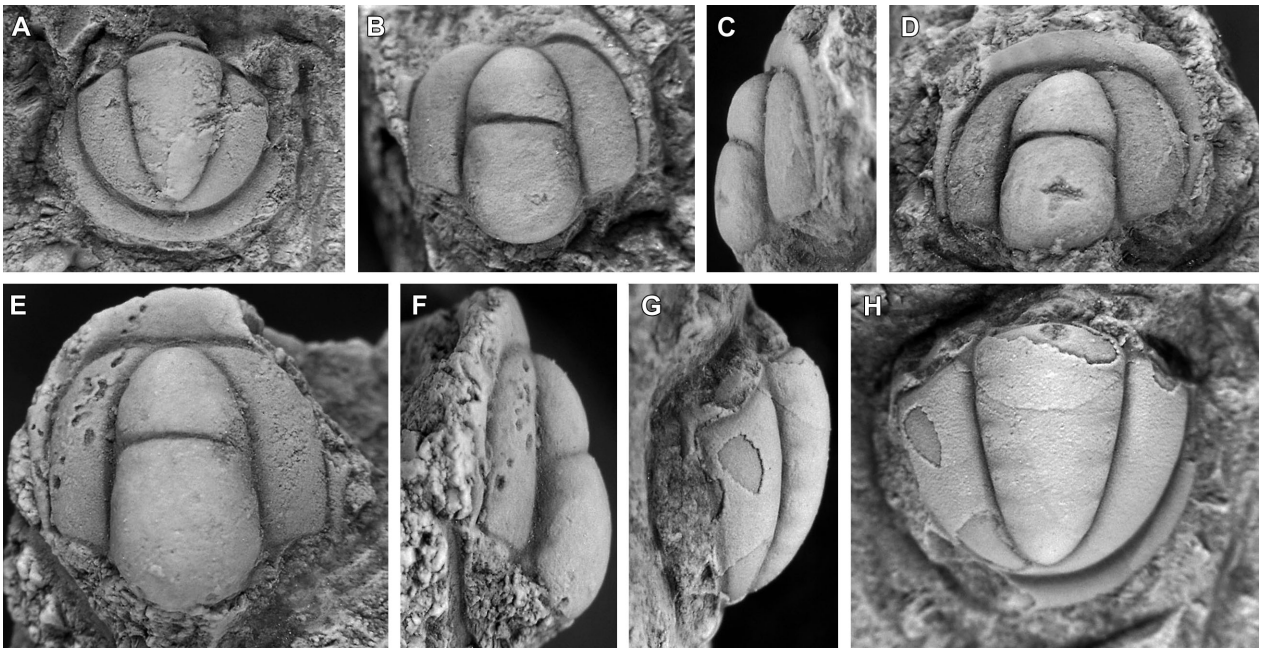

Fig. 4. *Tannudiscus conicus* Zhou in Zhou et al. 1982. Dorsal and lateral views of cephala and pygidia. **A**, pygidium, NIGP152234, level BS5, ×8.3. **B**, cephalon, XIGM Tr018, level BT5, ×8.4. **C**, **D**, cephalon, NIGP152232, level BS6, ×9.8. **E**, **F**, holotype, cephalon, XIGM Tr019, level BT5, ×10.2. **G**, **H**, pygidium, NIGP152233, level BT5, ×16.6.

pygidial length and 49–52% of the pygidial width anteriorly; its posterior part rapidly slopes down to the postaxial region. In addition to a narrow (sag.) articulating half ring, the axis is divided into five rings and a terminal piece. The ring furrows are shallow abaxially and almost invisible adaxially. The axial furrows are distinct and narrow. The pleural fields are strongly convex, steeply sloping down to the border furrow and rapidly narrowing backwards. The border furrow is deeply incised. The border is nearly flat, 10–11% of the pygidial length (sag.) and anterolaterally rapidly narrowing forwards.

All parts of the exoskeleton lack an apparent sculpture.

Remarks. The species that is most similar to *Tannudiscus conicus* appears to be *Tannudiscus tannuolaicus* Pokrovskaya (1959, p. 178, pl. 11, figs 16, 19, 20; see also Rushton 1966, text-fig. 8f). Features that are shared by both species are the glabella reaching the border furrow, a subconical anterior glabellar lobe and a cephalic border that widens anteriorly. Significant characters of *T. conicus*, which may separate it from *T. tannuolaicus*, include the shorter anterior lobe, being about 60% the length of the posterior lobe, a wider pygidial axis that does not reach the border furrow and the axial ring furrows of the pygidium that are visible abaxially. The species is like *T. altus* (Repina et al. 1964, p. 263, pl. 39, figs 1–3; Repina & Romanenko 1978, p. 111, pl. 2, figs 6–15) in having a subconical anterior glabellar lobe, a long and strongly convex posterior glabellar lobe and a pygidial axis not reaching the border furrow. It is distinguished by its glabella that reaches the anterior border furrow, its longer (sag.) cephalic border and its wider pygidial axis with shallow axial ring furrows laterally. *Tannudiscus balanus* Rushton, 1966 from England and SE Newfoundland is distinctive in having an expanded anterior glabellar lobe that is wider than the posterior lobe.

A *Tannudiscus* sp. was described from northern Tianshan by Xiang & Zhang (1985). Unfortunately their single illustration does not allow any comparison. *Tannudiscus conicus* is also known from Mt. Bolhinur in Xinjiang. As far as we can judge, it is indistinguishable from our material.

Family CALODISCIDAE Kobayashi, 1943
Genus *Calodiscus* Howell, 1935

Type species. *Agnostus lobatus* Hall, 1847, from the upper part of the lower Cambrian (Cambrian Series 2) Browns Pond Formation (formerly Schodack) at Troy in the Taconic region of New York State, USA; by original designation.

Calodiscus tianshanicus Xiang & Zhang, 1985
Figure 5A–G

1985 *Calodiscus xinjiangensis* Xiang & Zhang, p. 92, pl. 2, figs 14–17.
1985 *Calodiscus tianshanicus* Xiang & Zhang, p. 92, pl. 2, figs 5–11 only.

Holotype. Cephalon XGB T1363 (Xiang & Zhang 1985, pl. 2, fig. 5), from the Huocheng Formation, lower Cambrian (Cambrian Series 2) of Keguqin, Jinghe County, western part of northern Tianshan, Xinjiang, China.

Other material. Two cephala (NIGP152235, 152240) and one pygidium (NIGP152238) from level BT5, Section 3; one cephalon (NIGP152239) and one pygidium (NIGP152236) from level BT3, Section 2.

Description. The cephalon is semi-elliptical in outline and 82–87% as long as it is wide. The preoccipital glabella is subcylindrical in outline, slightly constricted medially, rounded anteriorly, 59–66% of the length and 26–29% of the width of the cephalon, convex (tr.) and rather strongly sloping down to the border furrow anteriorly. Two pairs of transglabellar furrows are very weak on the external exoskeletal surface, but clearly expressed on internal moulds. The anterior glabellar lobe is nearly as long as the total length of the posterior two glabellar lobes combined. The dorsal, preglabellar and occipital furrows are deeply incised. The occipital ring occupies 17.5% of the cephalic length (sag.) and is strongly narrowing abaxially with a strongly backwardly arched posterior margin, lacking a spine or node. The cheeks are nearly as wide as the preoccipital glabella posteriorly, convex (tr.) and abaxially downsloping to the border furrow. The border furrow is deep and broad; an ill-defined depression occupies the space between the glabella and the anterior border. The anterior border is narrow (sag.) and convex, slightly narrowing rearwards. The posterior border furrow is distinctly defined, and widened and anterolaterally curved outwards. The posterior border is convex and slightly widened laterally.

The pygidium is semi-elliptical and about 80% as long as it is wide. The axis is strongly convex (tr.), rising steeply from the pleural fields, gently tapered rearwards, rounded posteriorly, almost reaching the border furrow, 88% of the pygidial length and 42% of the pygidial width anteriorly; it is composed of four distinct rings and a very short terminal piece. The anterior three ring furrows are distinctly incised, while the rearmost is weak. The axial furrows are deep. The pleural fields are convex (tr.) abaxially, strongly sloping down to the border furrow and have three pairs of distinct pleural furrows excluding the deep anterior

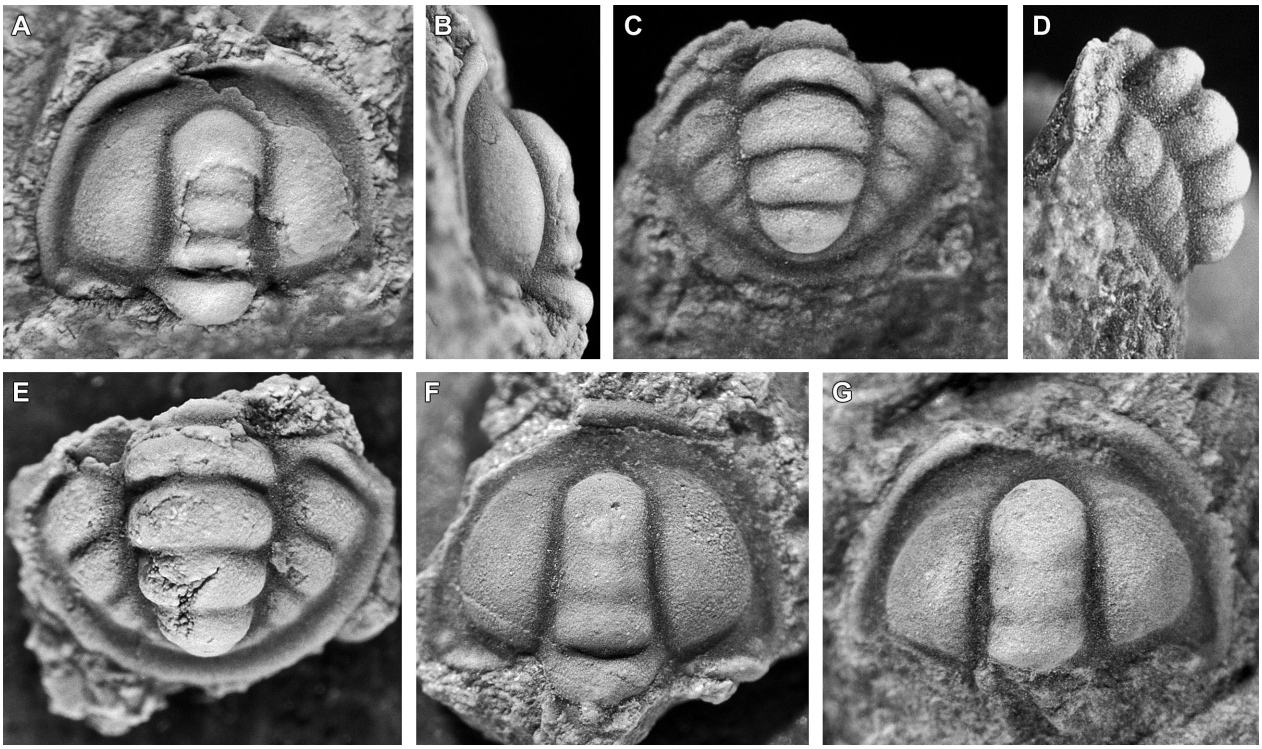

Fig. 5. *Calodiscus tianshanicus* Xiang & Zhang, 1985. Dorsal and lateral views of cephala and pygidia. **A**, **B**, cephalon, NIGP152235, level BT5, ×18.6. **C**, **D**, pygidium, NIGP152236, level BT3, ×19.5. **E**, pygidium, NIGP152238, level BT5, ×20.5. **F**, cephalon, NIGP152240, level BT5, ×16. **G**, cephalon, NIGP152239, level BT3, ×14.6.

border furrow. The interpleural furrows are very faint. The anterior pleural band has a fulcrum at about 1/2 the distance from the axial furrow to the lateral margin. The border furrow is distinct and of moderate depth. The border is low, gently convex, about 1/10 of the pygidial length, slightly serrated and provided with four or five pairs of very short, blunt spines.

The surface of the test is indistinctly granulated.

Remarks. The well-preserved cephala from the Shuangyingshan Formation illustrated here conform in all essential features with the holotype of *Calodiscus tianshanicus* (see Xiang & Zhang 1985, pl. 2, fig. 5), apart from showing two pairs of transglabellar furrows on an exfoliated cephalon, and we have no doubt that the same species is represented. Xiang & Zhang (1985, p. 92, pl. 2, figs 14–17) established *Calodiscus xinjiangensis* on the basis of four cephala from the Huocheng Formation of Keguqin, Jinghe County, Xinjiang. They considered that the only difference from *C. tianshanicus* Xiang & Zhang (1985, p. 92, pl. 2, figs 5–13) from the same formation is that *C. xinjiangensis* shows a forwardly expanded glabella. The differences between the two species are, however, both slight and intergradational. For example, the holotype of *C. xinjiangensis* bears a forwardly expanded glabella, while the other three cephala of this species have a nearly parallel-sided glabella. Therefore, *C. xinjiangensis* is here considered to be a junior subjective synonym of *C. tianshanicus*. The two pygidia assigned to *C. tianshanicus* by Xiang & Zhang (1985, pl. 2, figs 12, 13) are assuredly not that of a *Calodiscus*, since they have a too narrow axis and prominent nodes on axial rings. They should preferably be assigned to *Pagetides huochengensis* Zhang (Zhang 1987, p. 44, pl. 1, figs 5–7).

Calodiscus tianshanicus is similar to *C. lobatus* (Hall, 1847) (see Rasetti 1952, p. 441, pl. 51, figs 1–11; Rasetti 1967, p. 44, pl. 3, figs 2–6; Blaker & Peel 1997, p. 28, fig. 17; Cederström et al. 2009) in having a strongly convex (tr.) and wide pygidial axis with at least four rings plus a terminal piece, in having narrow pleural fields with three or four pairs of distinct pleural furrows and in having a well-defined pygidial border with four or five pairs of very short, blunt spines. Holaspid cephala of *C. lobatus* differ in having a more tapering glabella and in lacking transverse glabellar furrows. In these respects, *C. tianshanicus* is more similar to *C. agnostoides* (Kobayashi), now considered

to represent late meraspides of *C. lobatus* (e.g. Lochman 1956; Ahlberg 1983; Cederström et al. 2009) and *C. meeki* (Ford), although not fully conforming to any one of them (see Rasetti 1952, pl. 51, figs 16–21).

Family EODISCIDAE Raymond, 1913
Genus *Pagetides* Rasetti, 1945

Type species. *Pagetides elegans* Rasetti, 1945, from the lower Cambrian (Cambrian Series 2) Ville Guay conglomerate near Lévis, Quebec, Canada; by original designation.

Remarks. The relation between *Pagetides* and *Neopagetina* has been discussed for a long time (see Blaker & Peel 1997 for a review; see also Fletcher & Rushton 2007). According to the original definitions, the pygidial pleura should be smooth in the former genus but furrowed in the latter. Blaker & Peel (1997, pp. 34–37) summarized the discussion and illustrated specimens from North Greenland supposed to represent the type species of both genera. They concluded that there are in fact pleural furrows also in *Pagetides* and that there is no character that can be used for differentiating the two genera. However, the lectotype cranidium of the type species for *Neopagetina*, *N. rjonsnitzkii* (Lermontova, 1940), differs particularly in lacking the stout cephalic spine that is characteristic of *Pagetides* (Jell in Kaesler 1997, fig. 244:2a). We follow, however, Blaker & Peel (1997) in accepting the presence of pleural furrows in *Pagetides* and regard *Neopagetina* as a junior subjective synonym of *Pagetides*. As here defined, *Pagetides* is a geographically widely distributed genus that is known from several Cambrian palaeocontinents. It was recently described also from South China (Zhang & Clarkson 2012).

Subgenus *Pagetides* (*Discomesites*) Öpik, 1975b

Type species. *Pagetides* (*Discomesites*) *fragum* Öpik, 1975b, from the Cymbric Vale Formation of western New South Wales, Australia; by original designation.

Remarks. *Discomesites* was revised by Paterson (2005), who supported Palmer in Palmer & Rowell (1995) in treating it as a valid subgenus of *Pagetides*.

Pagetides (*Discomesites*) *huochengensis* (Zhang, 1987)?
Figure 6A–L, N?

?1987 *Pagetides huochengensis* Zhang, pp. 44–45, pl. 1, figs 5–7.

Material. Three cranidia (NIGP152242, 152244, 152247) and three pygidia, (NIGP152243, 152245, 152246) from level BS6, Section 1; two cranidia (NIGP152250, 152251) and one pygidium (NIGP152249) from level BT4, Section 2.

Description. The anterior border is evenly rounded and separated from the cheek rolls by a fairly narrow border furrow. It is slightly extended backwards medially. The elevated cheeks are separated by a median furrow in front of the glabella. The glabella is nearly parallel-sided, with a cone-shaped anterior end and a long, stout spine that is directed backwards and upwards. The glabellar furrows are distinct, but visible only laterally. The pygidium has a slightly tapering axis with six axial rings separated by narrow and deeply incised inter-ring furrows. At least the five anterior axial rings have a large, rounded median elevation. Since this elevation is truncated in all specimens, it is not clear if it represents a large node or the base of a stout spine. Five prominent pleural furrows are present. Interpleural furrows are obsolete. The external exoskeletal surface is coarsely granular.

Remarks. As with other species in this fauna, the material is meagre and species identification far from obvious. *Pagetides huochengensis* was described from three poorly preserved cranidia recovered from the Huocheng Formation in the Xinjiang Uygur Autonomous Region. Their overall morphology is similar to the cranidia illustrated here, but the poor quality of the material and illustration and the lack of illustrations of pygidia make the identification of our material uncertain. It also makes our associations of cranidia and pygidia uncertain.

A possible *Pagetides* species described from the Xinjiang Uygur Autonomous Region by Xiang & Zhang (1985) has a wider and smoother cephalic anterior border and does not represent any of the species from the Beishan area.

The general appearance contrasts with most *Pagetides* species, which as a rule have smooth or weakly furrowed pleural fields and lack median axial nodes or spines. It is difficult to find any similar species even in faunas that are comparatively rich in species of *Pagetides*. The overall morphology of our species is similar, however, to *Discomesites fragum* Öpik, 1975b, from the Cymbric Vale Formation of western New South Wales, Australia, particularly with respect to the pygidium. *Discomesites fragum* is the type species for the subgenus *Pagetides* (*Discomesites*) Öpik, 1975b, a subgenus that may be taken to include also our species.

A cranidium associated with a pygidium here referred to as *Pagetides*? sp. 1 is incomplete, lacking its posterior part and much of the glabella (Fig. 6N). The ornament is granular and the anterior border is extended backwards medially. It is here questionably assigned to *Pagetides* (*D.*) *huochengensis*.

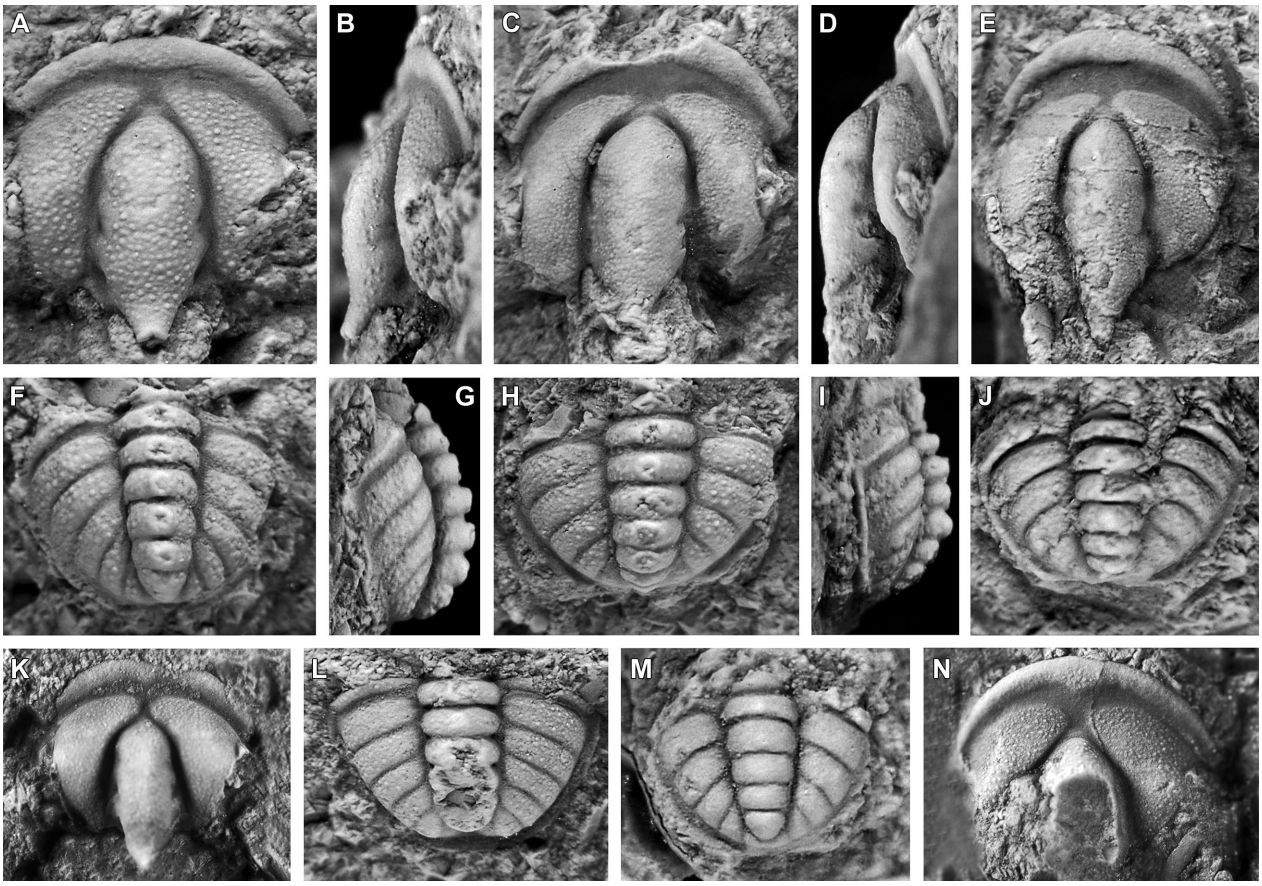

Fig. 6. A–L, N?, *Pagetides* (*Discomesites*) *huochengensis* (Zhang, 1987)?. Cranidia and pygidia in dorsal and lateral views. A, B, cranidium, NIGP152244, level BS6, ×13.7; C, D, cranidium, NIGP152242, level BS6, ×10; E, cranidium, NIGP152247, level BS6, ×8.4; F, G, pygidium, NIGP152243, level BS6, ×9.8; H, pygidium, NIGP152245, level BS6, ×9.4; I, J, pygidium, NIGP152246, level BS6, ×10.3; K, cranidium, NIGP152251, level BT4, ×9.1; L, pygidium, NIGP152249, level BT4, ×8.8; N, cranidium, NIGP152250, level BT4, ×11. **M**, *Pagetides*? sp. 1, pygidium, NIGP152252, level BT4, ×12.3.

Pagetides? sp. 1
Figure 6M

Material. One pygidium (NIGP152252) from level BT4, Section 2.

Remarks. The pygidium has a slightly tapering axis with four axial rings separated by narrow inter-ring furrows. The axial rings lack a medial elevation. Four pairs of distinct pleural furrows are present in addition to a pair of nearly effaced furrows behind the axis. Most species of *Pagetides* have unfurrowed or weakly furrowed pleural fields and a higher number of segments in the pygidium than in the pygidium at hand.

‘CORYNEXOCHIDS’

The key character of the ‘Corynexochida’ is fusion between the hypostome and the rostral plate, but the condition is often unknown and occasionally known to be different (for instance in *Ogygopsis* and dinesids; see also Hopkins & Webster 2009 and Robison & Babcock 2011). Other structural differences also indicate that the ‘corynexochids’ is a polyphyletic taxon (cf. Robison & Babcock 2011). Dorypygids and edelsteinaspidids share an inflated glabella with parallel glabellar furrows (when present), whereas in zacanthoidids and dolichometopids the glabellar furrows diverge from each other in their extension from the axial furrow. Dinesids, formerly assigned to the Corynexochida in Western literature (Moore 1959, pp. O230–231), do not resemble other ‘corynexochids’ and do not have a fused rostral-hypostomal plate. In Russian literature they are typically treated as solenopleuroids (e.g. Chernysheva 1961; Repina & Romanenko 1978), which seems more reasonable. The oryctocephalids are strikingly different from all others in their glabellar morphology with glabellar furrows typically consisting of pairs of pits not reaching the axial furrows.

Palmer & Halley (1979, pp. 77–78) described species of *Ptarmigania* and *Poliella*, two genera that are almost indistinguishable from each other although they are considered as representatives of the Zacanthoididae Swinnerton, 1915 and the Dolichometopidae Walcott, 1916, respectively. There is apparently a gradation between the two species associations, although in general one is more spiny than the other. There is thus good reason to regard Dolichometopidae as a junior synonym of Zacanthoididae or, at the most, as a subfamily of the latter.

The Edelsteinaspididae Hupé, 1953a similarly may be considered as a junior synonym of Dorypygidae Kobayashi, 1935. *Edelsteinaspis* differs from 'typical' dorypygids essentially only in having a more elevated frontal glabellar lobe, more deeply impressed glabellar furrows (which appear strongly arched because of the tilt imposed by the anteriorly elevated glabella) and wider pleural fields, features generally not useful in classification above species or perhaps genus level. However, we refrain from introducing any classificatory modifications herein.

As mentioned above, the fauna includes at least about five species of *Kootenia* (or *Kooteniella*) that are not dealt with here.

Family DORYPYGIDAE Kobayashi, 1935

As noted by, for instance, Blaker & Peel (1997), it is difficult to distinguish between the genera *Kootenia* and *Ogygopsis*. We follow here a practical approach in considering species with a fairly short pygidium as members of *Kootenia*. Hundreds of species of these two genera have been described, often based on disarticulated sclerites and insufficient characters (cf. Robison & Babcock 2011). For instance, information on the profile of the cranidium in lateral view is often missing. Pygidia are necessary for reliable identification (e.g. Geyer 1994, p. 1307). The material from Beishan includes three forms with comparatively long pygidia (with five segments plus a terminal piece) and three forms with short pygidia (with three segments plus a terminal piece). Species identification is in several cases hampered by deformation and poor preservation of the specimens. It seems likely that the material may comprise even more species, but additional findings are needed to confirm this suspicion.

Family EDELSTEINASPIDIDAE Hupé, 1953a

Genus *Edelsteinaspis* Lermontova, 1940

Type species. *Edelsteinaspis ornata* Lermontova, 1940 from the Elanskij Formation (Amgan), Kuznetsk Alatau, Russia; by original designation.

Edelsteinaspis plana Chernysheva, 1961

Figure 7D, F–M

1961 *Edelsteinaspis plana* Chernysheva, p. 109, pl. 10, figs 5–11.

1978 *Edelsteinaspis plana* Chernysheva; Repina & Romanenko, p. 166, pl. 16, figs 5–8.

Material. Five cranidia (NIGP152288, 152290–152293) and two pygidia (NIGP152287, 152289) from level BT5, Section 3.

Description. The glabella is nearly parallel-sided, with an evenly rounded front and three pairs of chevron-shaped glabellar furrows that are connected medially. The most anterior glabellar furrows have a characteristic course, almost V-shaped, giving the posterior part of the frontal lobe a strikingly triangular, almost pointed appearance. The angle between the eye ridge and the axial furrow is comparatively high and the palpebral lobe is strongly curved, which results in a wide, sub-triangular palpebral area. The entire exoskeletal surface is covered with granules of different sizes. The occipital furrow is nearly transverse and the occipital ring has a faint median node. No free cheeks are known.

The surface of the pygidium is covered with small tubercles, somewhat larger on the axial rings than on the pleural field, and with variation in tubercle size. The pleural and interpleural furrows in this species are different. The former are wide and shallow, the latter narrow but distinct. They fade some distance from the lateral margin. A border furrow is absent. The axis has four distinct segmental rings plus the terminal piece. The anteriormost ring has a median node.

Remarks. Of the two known species of *Edelsteinaspis* with four axial rings in the pygidium, the pygidial border is comparatively narrow in *E. gracilis* Lermontova, 1940, whereas it is distinctly wider in *E. plana*. This condition has effects on the position of the last axial ring, which is distinctly anterior to the mid-length of the pygidium in *E. plana*, but midways in *E. gracilis*. In these respects, our specimens correspond to *E. plana*. Co-occurring cranidia from BT5 are of two types. One has a gently curved palpebral lobe placed comparatively close to the glabella. The other has a more strongly bent palpebral lobe placed further away from the glabella. The latter configuration is identical to that in a specimen of *E. plana* illustrated by Suvorova (1964, pl. 6, fig. 6).

Edelsteinaspis sp. 1

Figure 7A–C, E

Material. One cranidium (NIGP152285) and one pygidium (NIGP152286) from level BT4, Section 2.

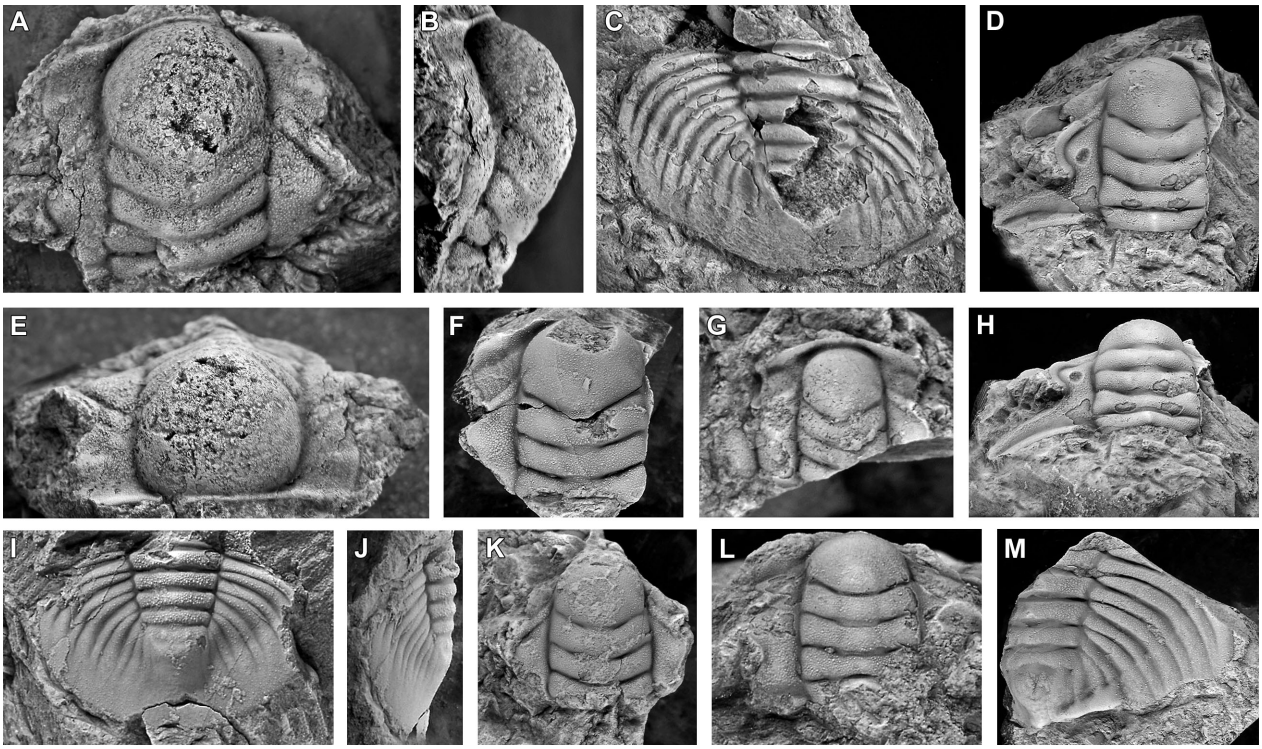

Fig. 7. A–C, **E**, *Edelsteinaspis* sp. 1 from level BT4. A, B, E, dorsal, left lateral and anterior view of cranidium, NIGP152285, ×1; C, dorsal view of pygidium, NIGP152286, ×0.9. **D**, **F–M**, *Edelsteinaspis plana* Chernysheva, 1961 from level BT5. D, H, dorsal and posterodorsal view of cranidium, NIGP152288, ×1.5; F, cranidium, NIGP152292, ×1.9; G, cranidium, NIGP152290, ×3.4; I, J, dorsal and left lateral view of pygidium, NIGP152289, ×2; K, cranidium, NIGP152293, ×2; L, cranidium, NIGP152291, ×4.9; M, pygidium, NIGP152287, ×4.4.

Description. A single cranidium was found in the section and level together with a pygidium referred to this species. They may belong to the same species. The surface sculpture is evenly granular. Unlike the cranidia referred to *E. plana*, the glabella expands slightly towards the front and is widest across the frontal lobe. The three pairs of glabellar furrows are simple, straight and regularly spaced, and the lateral lobes are of similar shape throughout. The frontal lobe is more subcircular in outline than in the cranidia assigned to *E. plana*. The eye ridge is straight and the palpebral lobe fairly strongly but evenly curved. The fixigena is fairly flat, but has a weak convexity inside the palpebral lobe. The free cheek is not known.

The thorax is not preserved, but the posterior morphology of the cephalon indicates that the hinge is probably quite short.

The pygidium has a fairly broad axis with six short segmental rings and a terminal piece without signs of segmentation. The pleural field has a broad, notably inclined border field which probably corresponds to the doublure. Pleural and interpleural furrows are almost equally developed and notably closely spaced, corresponding to the shortness of the axial rings. They almost extend to the margin, which lacks spines. Much of the pleural surface is smooth in detail, but the border has a pattern of faint wavy lines.

Remarks. The known species with six axial rings in the pygidium fall in two groups with regard to the pygidial morphology. *Edelsteinaspis ornata* Lermontova, 1940 and *E. compta* Suvorova, 1964 have a comparatively narrow pygidial border without apparent flattening. *E. biramjensis* Suvorova, 1964 and *E. altaica* Romanenko (in Repina & Romanenko 1978) have a distinctly wider pygidial border, which is apparently flattened. The drawing of Suvorova (1964, fig. 17b) is greatly misleading, showing a narrow border and the terminal piece of the axis too close to the posterior margin. Our six-segmented pygidium has a narrow border, as have the two former species. However, it looks more similar to the two latter species in having both interpleural and pleural furrows extending almost to the lateral margin, and possibly in having a greater topography. The glabella is distinctive in its forward expansion and the shape of the frontal lobe.

The pygidium most closely resembles those of the two latter species (*E. biramjensis* and *E. altaica*), but may also belong to still another, yet undescribed species. It is clear that the cranidium does not belong to any of the species mentioned above.

Family ZACANTHOIDIDAE Swinnerton, 1915
Genus *Ptarmiganoides* Rasetti, 1951

Type species. *Ptarmiganoides bowensis* Rasetti, 1951, from the Naomi Peak Limestone Member of the Langston Formation of the Canadian Rocky Mountains; by original designation.

Ptarmiganoides? sp. 1
Figure 8A, B, F, G

Material. Three cranidia (NIGP152294–152296) from level BS6, Section 1.

Description. The glabella is long and almost parallel-sided, expanding only slightly and gradually anteriorly, and broadly rounded in front. Its lateral profile is nearly evenly curved (Fig. 8B). In front of it there is a frontal furrow and a strongly raised marginal ridge. The most posterior glabellar furrow (S1) is forked, with the main branch extending inwards and strongly backwards adaxially. The occipital furrow is deeply incised and curved forwards abaxially. The occipital ring has a prominent axial spine extending backwards from the posterior edge. The fixigena has an almond-shaped rise from which the surface descends both towards the axial and the palpebral furrows. The palpebral lobe is long, arcuate and narrow, defined by a prominent palpebral furrow. The 2nd and 3rd glabellar furrows from behind are almost transverse and of similar length, whereas the 4th is shorter and directed inwards and slightly forwards adaxially. The entire surface is covered with tiny pits.

Remarks. Palmer & Halley (1979, pp. 94–95) stated that the genera *Paralbertella*, *Ptarmigania* and *Ptarmiganoides*, and even some other genera, differ from each other only in the pygidium. Similarly, Rasetti (1951, p. 179) noted that 'It is a common occurrence among dolichometopid trilobites to find almost identical cranidia associated with a great variety of pygidia ...'. In the absence of pygidia, our generic determination can therefore only be tentative. The combination of a strongly inclined S1 and a narrow preglabellar furrow separating the glabella from a 'border', which is merely a low, thin ridge, is shared with *Ptarmiganoides crassaxis* Palmer & Halley (1979, pl. 11, figs 12, 18). The two species also have a very similar occipital spine and similar fixigenae. This

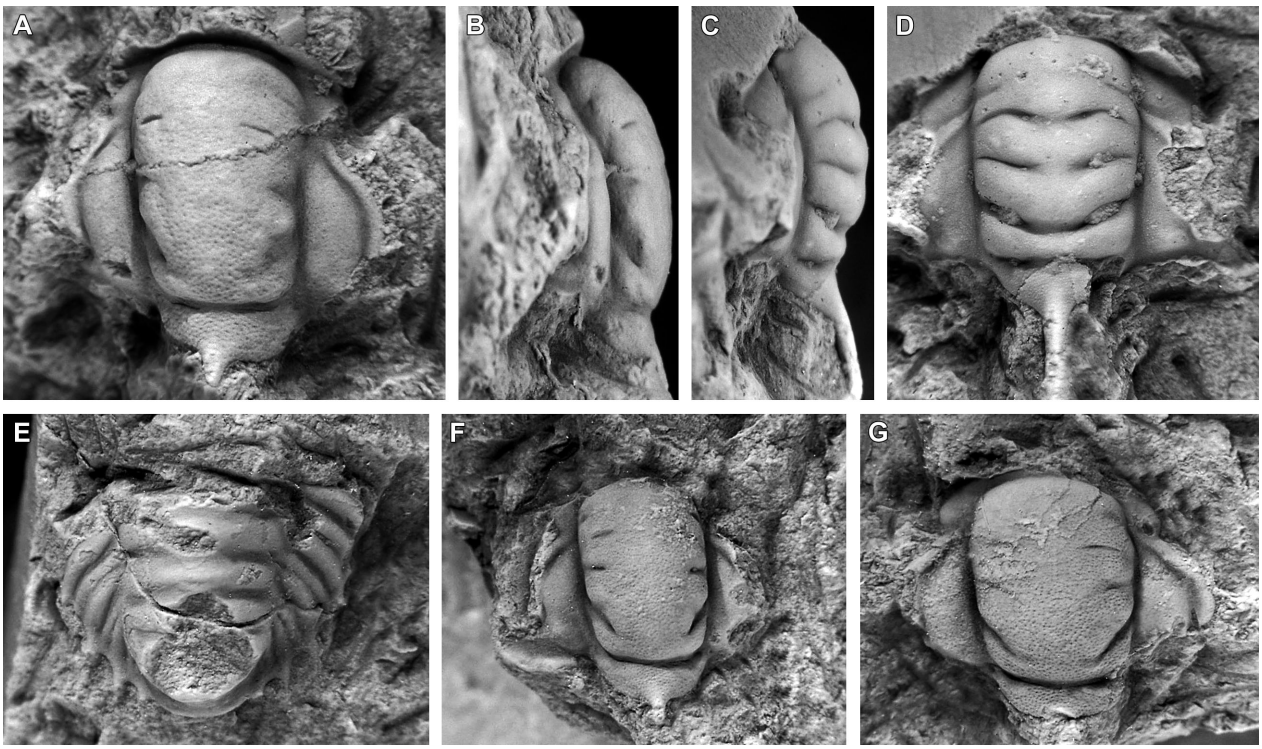

Fig. 8. A, **B**, **F**, **G**, *Ptarmiganoides*? sp. 1 from level BS6. A, B, cranidium in dorsal and left lateral views, NIGP152294, ×9; F, cranidium, NIGP152295, ×6.6; G, cranidium, NIGP152296, ×6.4; **C**–**E**, *Politinella* sp. 1 from level BT5. C, D, cranidium in left lateral and dorsal views, NIGP152298, ×7.8. E, pygidium, NIGP152297, ×6.6.

suggests that our species may belong to *Ptarmiganoides*. Information about the pygidium is, however, needed before a confident generic assignment can be made. So far, species of this genus have been restricted to the traditional middle Cambrian (*Albertella* Zone; provisional Cambrian Stage 5) of North America (Resser 1939; Rasetti 1951; Palmer & Halley 1979, including a thorough revision of Resser's determinations). In terms of the Siberian chronostratigraphy, the *Albertella* Zone can be correlated with the lower Amgan Stage (Blaker & Peel 1997; Geyer & Peel 2011).

Species assigned to *Zacanthoides* and *Zacanthopsis* differ in having a considerably longer (sag.) preglabellar area (e.g. Sundberg 1994 for *Zacanthoides*; Blaker & Peel 1997). *Wenkchemnia* (Dolichometopidae) and *Parkaspis* (Zacanthoididae) have a more expanding glabella (Sundberg 1994).

Prozacanthoides sp. undet. of Rasetti (1948, pl. 2, figs 20–24) differs distinctly from our material: the glabella expands steadily towards the anterior, and the preglabellar furrow is wide, with the anterior slope of it extended, although less than in *Zacanthoides*. The pygidium of Rasetti's species is somewhat *Kootenia*-like, with marginal spines.

Shaw (1955) illustrated a cranidium of *Prozacanthoides* sp. indet. As in Rasetti's specimens, the glabella is expanding, and there is a distinct preglabellar area.

Our species is also reminiscent of species of the genus *Poliella* Walcott, 1916, placed by Palmer & Halley (1979) in the family Dolichometopidae. They noted that the main difference between this family and Zacanthoididae is that there are intergenal and pygidial spines only in the latter. The intergenal corner is not visible in our material.

In the absence of a pygidium, we abstain from giving 'our' species a formal name, and the generic attribution is provisional.

Family DOLICHOMETOPIDAE Walcott, 1916
Genus *Politinella* Ivshin, 1979

Type species. *Poliellina* (*Politinella*) *bajanica* Ivshin, 1979, from the Bayanaulsk Horizon, central Kazakhstan; by original designation.

Discussion. Jell & Adrain (2003, p. 428) considered the subgenus to be enough separated from *Poliellina* (*Poliellina*) for it to warrant genus status.

Politinella sp. 1
Figure 8C–E

Material. One cranidium (NIGP152298) and one questionably assigned pygidium (NIGP152297) from level BT5, Section 3.

Description. The cranidium (exclusive of the occipital spine) is subquadrate, slightly wider than long. The glabella (excluding the occipital ring) is subcylindrical, with a somewhat bluntly rounded anterior end and evenly convex in lateral profile. There are four pairs of glabellar furrows, the three posterior ones being transglabellar. The most posterior furrow (S1) is deep and wide and begins at the axial furrow at 1/4 the length of the glabella. It arches back in a chevron-like figure. As a result, the most posterior glabellar lobe (L1) is narrow medially. The 2nd glabellar lobe from behind (S2) is still deep. It extends inwards and slightly rearwards from the axial furrow behind the mid-length of the glabella. The central portion is abruptly shallower than the lateral parts. The whole course is more gently curved than for S1. The 3rd glabellar furrow (S3) originates at the axial furrow 3/5 the length of the glabella from the occipital furrow (SO). It is deep and narrow and curves gently forwards from the axial furrow and then gently backwards to the shallow middle portion. The most anterior glabellar furrow (S4) extends inwards and slightly forwards from the axial furrow at a point about 4/5 the length of the glabella from the SO. It is short and distinct, although not deep. The SO is deeply incised laterally, shallower medially. It is nearly straight. The occipital ring (LO) is very narrow laterally, much widened medially, thus having a subtriangular outline. Medially it is produced backwards into a stout occipital spine. The anterior border is narrow and upturned and makes a gentle arch. It is well defined by a distinct and narrow border furrow. The fixigena is gently convex, about 1/3 the glabellar width medially. The eye ridge extends outwards and backwards from the axial furrow opposite the lateral end of the S4. The palpebral lobe is poorly preserved, but obviously long and gently curved. Where the exoskeleton is preserved (patches in the glabella and the occipital ring with spine) the surface has fine granules.

The pygidial axis is parallel-sided, wide and of constant width to the terminal piece. There are probably four axial rings in addition to the terminal piece, which is highly elevated above the posterior margin. The pleural field slopes strongly from the axis. The pleural and interpleural furrows are deep. Each pleural segment extends into a pointed spine, whereas the posterior end of the pygidium is rounded.

Remarks. The pygidium associated with the cranidium is unusually small for the family, but comparable in size and gross morphology to that in *Poliellina* and *Parapoliella*. The species closely resembles *Politinella bajanica* Ivshin (1979, p. 52, pl. 1, figs 1–12), from which it differs chiefly in the proportionately wider glabella, transglabellar S2 and S3, shallower S4 and a stout occipital spine. *Politinella* sp. 1 may represent a

new species, but open nomenclature is preferred here pending new discoveries.

Family DINESIDAE Lermontova, 1940
Genus *Dinesus* Etheridge, 1896

Type species. *Dinesus ida* Etheridge, 1896, from the Knowsley beds, Victoria, Australia; by original designation.

Dinesus spinellosus (Zhou in Zhou et al. 1982)
Figure 9A–M

1982 *Erbia spinellosa* Zhou in Zhou et al., p. 235, pl. 60, fig. 5.

Holotype. Cranidium XIGM Tr040 (Fig. 9F; Zhou et al. 1982, pl. 60, fig. 5) from the Shuangyingshan Formation, lower Cambrian (Cambrian Series 2) of Dahuoluo, Beishan area, northwestern Gansu, China.

Other material. Five cranidia (NIGP152299, 152301, 152302, 152304, 152308), one free cheek (NIGP152300) and two pygidia (NIGP152309, 152310) from level BT5, Section 3.

Description. The cranidium is subtrapezoidal in outline, with length smaller than width at mid-length. The glabella is parallel-sided, evenly rounded anteriorly. Transversely, the glabella is highly convex, sagittally it is strongly curved. There are three pairs of glabellar furrows. The anterior pair is very weak and transverse, and the middle pair is short, shallow and transverse. The posterior pair is deeply incised and extends inwards obliquely to the occipital furrow outlining raised subtriangular basal glabellar lobes. The occipital furrow is deeply incised and transverse. The occipital ring is convex (tr.), rapidly widened medially. Posteriorly it has a small axial spine directed rearwards and slightly upwards. The axial furrows and additional furrows, which extend anterolaterally from the axial furrow near the anterior end of the glabella to the anterior border furrow, are deep and wide and join the deep preglabellar furrow. The preglabellar field is narrow or almost absent in the sagittal line, rapidly expanding laterally to

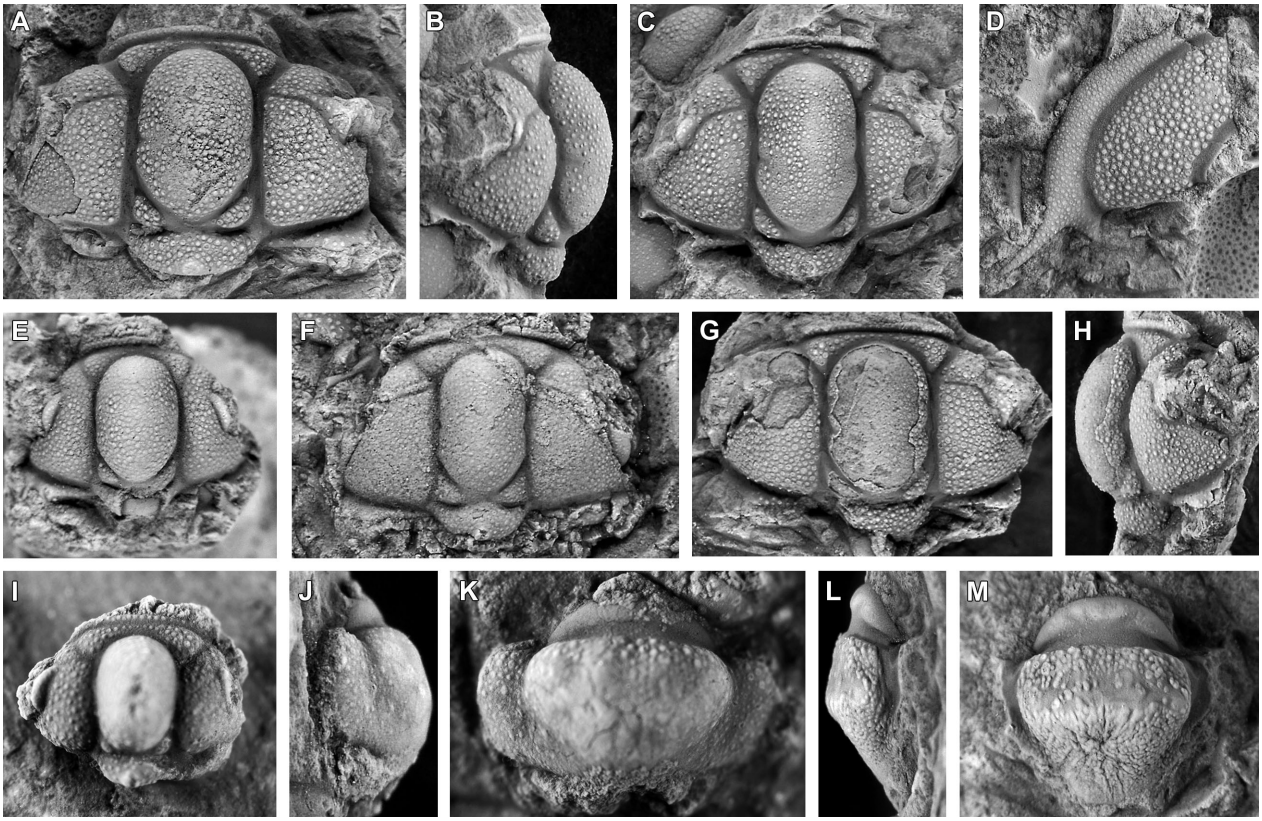

Fig. 9. *Dinesus spinellosus* (Zhou in Zhou et al. 1982) from level BT5. **A**, cranidium, NIGP152301, ×3.9. **B**, **C**, cranidium in left lateral and dorsal views, NIGP152302, ×3.4. **D**, dorsal view of left librigena, NIGP152300, ×5. **E**, cranidium, NIGP152308, ×5.9. **F**, holotype, cranidium, XIGM Tr040, ×4.7. **G**, **H**, cranidium in dorsal and right lateral views, NIGP152299, ×3.2. **I**, cranidium, NIGP152304, ×8.5. **J**, **K**, pygidium in left lateral and dorsal views, NIGP152309, ×12. **L**, **M**, pygidium in right lateral and dorsal views, NIGP152310, ×7.5.

form a pair of triangular raised lobes. The preocular field of the fixigena is wide (exsag.) and slopes down anteriorly and laterally. The anterior border is narrow (sag., exsag.), convex (sag., exsag.) and of nearly constant width, well defined by a deep and nearly transverse anterior border furrow. The eye ridge is distinct, slightly oblique rearwards, well defined by a distinct furrow behind the eye ridge on the larger specimens, but is faint on the smaller ones. The palpebral lobe is convex, short and situated anterior to the mid-length of the cranidium. The present material reveals that the palpebral lobe becomes relatively smaller during ontogeny. The anterior branches of the facial suture diverge slightly forwards and the posterior branches diverge strongly rearwards from the palpebral lobe. The palpebral area of the fixigena is convex (tr.), 61–65% of the glabellar width at mid-length. The postocular fixigena is broad and slopes strongly down laterally. The deep posterior border furrow widens and curves gently forwards laterally. The posterior border is convex (exsag.), widens outwards and has a distinct angularity directly behind the palpebral lobe, and is directed slightly forwards lateral to this angularity.

The librigena is broad and evenly convex (tr.). The lateral border, which is well defined by a deep and wide border furrow, is wide and gently convex and extends into a short genal spine directed backwards and outwards.

The pygidium as represented by NIGP152309 (Fig. 9J, K) is small, subsemicircular, 62% as long as wide and consists of a single ring only. The articulating half-ring is well developed and separated from the axial ring by a wide furrow. The axial ring is semielliptical, 62% as long as wide and much higher than the pleural field, with the moderately convex (tr.) inner part and steeply sloping peripheral part. Axial and postaxial furrows are very shallow. The pleural field is evenly convex, about 30% as wide as the axis, slopes down to the pygidial margin, without pleural, interpleural furrows and border. The postaxial field is narrow (sag.) and slopes down rearwards.

The pygidium NIGP152310 (Fig. 9L, M) differs from the one described above in having a larger pleural field, a larger articulating half-ring, a longer axis that is sub-conical, deeper axial furrows and more irregular tuberculation. However, there is certain similarity between this pygidium and the one attributed to *Dinesus spinellosus* in the lack of segmental axial rings, in the small convex pleura and in the ornament of tubercles of varying size. It may belong to a different species. On the other hand, species of *Dinesus* are fairly variable in their morphological characters. We therefore refer it to *D. spinellosus*, albeit with some uncertainty.

The surface of the cranidium and pygidium is densely ornamented with small- to medium-sized tubercles.

Remarks. Whitehouse (1936, p. 73, see also 1939, pp. 228, 231) suggested that *Dinesus* was present in the Cambrian of Siberia, being represented by *Solenoparia*? *sibirica* (Schmidt, 1886). Palmer (1968) compared the generotypes *Dinesus ida* and *Erbia sibirica* and concluded that they are generically different, the difference being the presence of a pair of isolated triangular elevated fields in front of the glabella only in *Dinesus*. All Siberian species referred to *Erbia* except for *E. sibirica* would probably belong to *Dinesus*. However, the difference is caused by a slight change in the forward extension of the glabella and we do not regard this as a character that can be used alone to distinguish a genus. We therefore regard *Erbia* Lermontova, 1940 as a junior synonym of *Dinesus* Etheridge, 1896 (cf. Gozalo et al. 2011). *Erbiella pjankovskia* Fedyanina, 1962 is indistinguishable on a generic level from *Dinesus*, and *Erbiella* is therefore a likely junior synonym of that genus.

Although differing in some respects, the species from Beishan has an overall resemblance to *Dinesus ida* Etheridge, 1896 (Whitehouse 1939, p. 229, pl. 24, figs 1–3), the type species of *Dinesus*. The outline of the glabella, shape of the anterior border, preglabellar field of the cranidium and librigena and the lack of a segmental pygidium are much similar in the two species. Features of *D. spinellosus* which distinguish it from *D. ida* are the shorter palpebral lobes, the presence of an occipital spine and the tubercular external surface on the exoskeleton.

Dinesus granulosus (Lermontova) is similar to our species but has a narrower fixed cheek and indistinct eye ridges (e.g. Lermontova 1951, pl. 16, fig. 3; Chernysheva 1961, pl. 30, figs 7–12). A few species have been described from the Russian part of the Altaj Mountains but the preservation of the specimens and the quality of the illustrations are not good enough for us to make a comparison. A specimen from Altaj, identified as *Erbia granulosa* Lermontova, is hardly determinable (Repina & Romanenko 1978, pl. 32, fig. 5).

Family ESTAINGIIDAE Öpik, 1975a

Genus *Subeia* Li in Zhou et al. 1982

Type species. *Subeia beishanensis* Li in Zhou et al. 1982, from the Shuangyingshan Formation, upper lower Cambrian (provisional Cambrian Series 2) of Dahuoluo, Beishan area, northwestern Gansu, China; by original designation.

Subeia beishanensis Li in Zhou et al. 1982
Figure 10A–E

1982 *Subeia beishanensis* Li in Zhou et al., p. 228, pl. 58, fig. 23.
2003 *Subeia beishanensis*; Jell & Adrain, p. 449.

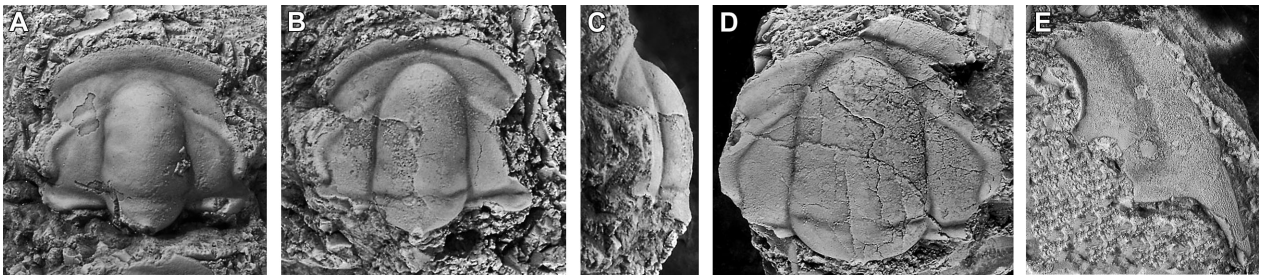

Fig. 10. *Subeia beishanensis* Li in Zhou et al. 1982 from level BT3. **A**, cranidium, NIGP152314, ×3.2. **B**, **C**, holotype, cranidium in dorsal and left lateral views, XIGM Tr029, ×2.3. **D**, cranidium, NIGP152312, ×1.7. **E**, right librigena, NIGP152311, ×1.7.

Holotype. Cranidium XIGM Tr029 (Fig. 10B, C; Zhou et al. 1982, pl. 60, fig. 5) from the Shuangyingshan Formation, upper lower Cambrian (provisional Cambrian Series 2) of Dahuoluo, Beishan area, northwestern Gansu, China.

Other material. Two cranidia (NIGP152312 and 152314) and one free cheek (NIGP152311) from level BT3, Section 2.

Description. The glabella decreases slightly in width towards the anterior and is somewhat acutely rounded in front. In one specimen there is a faint parafrontal band. Occasionally, three regular pairs of glabellar furrows are faintly indicated. The occipital furrow is somewhat shallower in the middle. The occipital ring is fairly long (sag.) in the middle, where it ends in a tubercle. The axial furrows are clearly defined. The ocular ridge is confluent with the palpebral lobe and curved gradually forwards to reach the glabella at the anterior glabellar furrow (S3). It is fairly wide, but may be narrower than the palpebral lobe. The latter is fairly long and extends backwards to a transverse line passing the posterior glabellar lobe (L1).

The cephalic border is comparatively wide, evenly curved and separated from the remainder of the cranidium by a narrow but distinct furrow. The preglabellar field tends to be slightly narrower than the border. The free cheek extends into a genal spine.

Discussion. This species is so far not known from outside the Beishan area. The parafrontal band has been taken as a characteristic of the subfamily Myopsoleninae. The value of the character is unknown, but *Subeia beishanensis* is closely comparable to the type species of *Myopsolenus*, *M. magnus* (Hupé 1953b, pl. 10, figs 11, 14, 15, and text-fig. 48:10). *Subeia beishanensis* differs in having less impressed glabellar furrows and a poorly defined parafrontal band. It is possible that *Subeia* is a junior synonym of *Myopsolenus*, but the lack of information on the thorax and pygidium hampers an analysis of their relationships.

Pocock (1964) noted similarities between *Estaingia* and genera such as *Bergeroniellus*, *Bergeroniaspis*, *Xystridura*, and the 'true' protolenids *Protolenus* and *Lusatiops*. He distinguished the protolenids on their tapering glabella, but this seems not to be a useful character. In the thorax, the fulcral knobs and deep pleural furrows are a similarity with ellipsocephalids. The deep furrows and marginal spines of the pygidium may just indicate a low degree of tagmosal difference between the thorax and the pygidium. *Subeia* may be regarded as a junior synonym of *Pararaia* Kobayashi, 1942, but the morphology of the thorax and the pygidium is not known in the latter genus.

A phyletic analysis by Paterson & Edgecombe (2006) has placed *Estaingia* close to *Ellipsocephalus*, and Paterson & Brock (2007) place the Estaingiidae as a family of the Ellipsocephaloidea.

Elicicola Jell, 1990 (see Jell 1990, fig. 193) is another ellipsocephaloid genus with similarities to *S. beishanensis*. It has a stronger relief of the cephalon and large muscle attachment areas rather than glabellar furrows.

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Loode-Hiina Gansu provintsi Alam-Kambriumi (provisoorne Kambriumi seeria 2) trilobiidid

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On kirjeldatud Hiina Gansu provintsi Beishani piirkonna kolme Alam-Kambriumi läbilõike Shuangyingshani kihistu trilobiidid. Nende hulgas domineerivad eodiscoidsed ja 'corynexochiidsed' trilobiidid kokku vähemalt kümne perekonna esindajatega (*Serrodiscus*, *Tannudiscus*, *Calodiscus*, *Pagetides*, *Kootenia*, *Edelsteinaspis*, *Ptarmiganoides*?, *Politinella*, *Dinesus* ning *Subeia*). See trilobiidikooslus viitab elustiku sarnasusele pigem Siberi laamaga kui Gondwanaga, millest on järeldatud, et antud piirkonna ehk Alam-Kambriumi Kesk-Tian Shani – Beishani laam paiknes tõenäoliselt Siberi laamale üsna lähedal.