New trilobite assemblage from the lower Cambrian (upper Stage 4) of the Lake Zone, western Mongolia

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Abstract.—The western Mongolian Lake Zone was a Neoproterozoic to early Paleozoic volcanic arc, where in addition to tuffs and lavas, fossiliferous siliciclastics and carbonates were accumulated during the early Cambrian. An uppermost Cambrian Series 2 (upper Stage

4) trilobite assemblage is described here from the Burgasutay Formation representing a continuous lower Cambrian succession at the Seer Ridge of the Great Lake Depression. The new assemblage is dominated by dorypygids and consists of 13 trilobite genera belonging to 9 families including *Catinouyia heyunensis* sp. nov. These fossils comprise the youngest and richest lower Cambrian trilobite assemblage in Mongolia. The composition of the Cambrian Stage 4 fauna of the Lake Zone suggests its biogeographic affinity with the Siberian Platform and Altay-Sayan Foldbelt, but the presence of inouyiids also implies a connection of this region with East Gondwana.

Introduction

The lower Cambrian faunas of western Mongolia display a very high level of diversity and disparity (Korobov, 1989; Esakova and Zhegallo, 1996; Zhuravlev and Naimark, 2005). This pattern is related to the highly complicated tectonic history of the Central Asian Orogenic Belt, which now includes Mongolia, Kazakhstan, the Altay-Sayan Foldbelt and Transbaikalia (Fig. 1.1). Two principal models for the development of this mosaic region have been developed. Both models attribute the tectonic development of Mongolia during the Neoproterozoic–early Paleozoic to the accretion and collision of several terranes, which were previously recognized as tectonic zones or provinces within the same marine basin (Amantov, 1963; Marinov, 1970; Blagonravov and Zaytsev, 1972; Marinov et al., 1973). The names of these zones are still in use, but their affinity to the same marine basin is rejected.

The first hypothesis suggests that Mongolia spanned a number of different volcanic arcs

(Lake, Khan-Khukhiy, Ider and Dzhida zones) and cratonic terranes (former Zavkhan and Khuvsgul zones), which originated as Precambrian crustal fragments, rifted from North China margin of East Gondwana, drifted across the Paleo-Asian Ocean and finally collided with and accreted to Siberia (Zonenshain et al., 1985; Mossakovsky et al., 1993; Zhou et al., 2018). Alternatively, the other hypothesis attributes the formation of the entire Central Asian Orogenic Belt to the growth of giant subduction-accretion complexes along a single migrating magmatic arc, which was formed during the rifting of the combined Baltica-Siberia craton (Sengör et al., 1993). However, the latter is neither supported by the distribution pattern of the facies or by faunal affinities, emphasizing a close similarity between faunas of different age in South China and Siberia. Terreneuvian small shelly fauna in South China and Mongolia shared much in common（Yang et al., 2015）. By contrast, later archaeocyaths and trilobites from Mongolia Cambrian Series 2 strata shared identical species with the Altay-Sayan Foldbelt, Transbaikalia and the Siberian Platform (Korobov, 1989; Debrenne et al., 1999). The suggestion that some Mongolian terranes originally belonged to South China and/or Tarim is further supported by a variety of tectonostratigraphic and paleomagnetic data (Levashova et al., 2011) and detrital and xenocrystic age spectra (Rojas-Agramonte et al., 2011). Although the paleotectonic situation is more complicated, some models suggest a long lasting and continuous sequence of events leading to accretion and amalgamation of numerous volcanic arcs, backarc/forearc basins and associated subduction complexes, crustal and other terranes the tectonic evolution of Mongolia (e.g. Badarch et al., 2002; Kheraskova et al., 2003; Janoušek et al., 2018). An underestimation of faunal data is has played a huge part in weakening tectonic models, thus suggestions made on the place of the origin and migration routes of terranes.

Thus, tectonic models need better paleontological grounds. The Neoproterozoic-lower Cambrian successions and the faunas of the Zavkhan terrane are relatively well studied (e.g. Voronin et al., 1982; Wood et al., 1993; Brasier et al., 1996; Smith et al., 2016; Yang et al., 2020; Steiner et al., 2021; Topper et al., 2022). On the contrary, our knowledge of facies and fossils from other former tectonic zones is still almost in its infancy. A few archaeocyaths and small shelly fossils from the Lake, Khan-Khukhiy and Khuvsgul regions have been clearly described (Vologdin, 1940; Zhuravleva, 1972; Voronin, 1988; Esakova and Zhegallo, 1996; Demidenko et al., 2003; Malakhovskaya, 2014) and some trilobite faunas were described from the Lake, Ider and Khuvsgul regions (Dumicz et al., 1970; Blagonravov et al., 1971; Korobov, 1980, 1989; Korovnikov and Lazarev, 2021). The youngest of these assemblages is represented almost exclusively by paradoxidid trilobites of the Khovd Aimak (region), the Mongolian Altay and assigned to the former middle Cambrian Amgan Stage of Siberia (Dumicz et al., 1970). They occur in a succession of mostly siliciclastic (sandstone and conglomerate) and volcanic (dolerite and doleritic tuff) strata and are restricted to siliceous shales. Unfortunately, they appear a separate block which is devoid of any older or younger fossils. At present, strata bearing similar trilobites in Siberia belong either to the uppermost Cambrian Stage 4, Series 2 or to the lower Wuliuan Stage, Miaolingian Series (Geyer, 2019). In addition, an undescribed oryctocephalid assemblage from the top of the Udzhigin-Gol Formation in Khuvsgul microcontinent (Korobov, 1980) may correspond to the uppermost of lower Cambrian. In fact, it is possible that an extreme rarity of trilobites younger than the early Cambrian Stage 4 in Mongolian terranes, possibly, was related to intense volcanic activity (Fig. 1.4).

Here we report a new uppermost Cambrian Series 2 trilobite assemblage from Seer Ridge

(Northwestern Mongolia) which occurs in a continuous fossiliferous Cambrian Series 2 succession of the Lake Zone and is the youngest rich Cambrian trilobite assemblage in Mongolia. It includes 13 genera of 9 families. Additionally, this assemblage provides new data on the paleobiogeographic affinities of Cambrian faunas of Mongolia.

Geological setting

The section, known as the Seer Southern Reef, lies on the northeast slope of the Seer Ridge, the Northern shore of the Khar-Us Lake in the Great Lake Depression, western Mongolia (Drozdova, 1980; Fig. 1.2). The basal lower Cambrian volcanic Tsol-Ula Formation and the lower, siliciclastic-carbonate, subformation of the Burgasutay Formation are not present here. The section comprises the upper Burgasutay Formation which only consists of five principal members delimited by a fault from below (Fig. 1.3, 1.4).

The lower member (~50 m in thickness) comprises of dark-green doleritic porphyry. It extends with a conformable contact by thick (~500-600 m) second member which is composed of alternating green doleritic porphyry, tuffs and fine- to medium-grained tuffstone and grey siliceous siltstone. The third member (15-20 m in thickness) overlays the volcanic layers with an erosive contact and is represented by dark-grey lenticular calcareous mudstone, sandy calcareous mudstone and wackestone with thin tuffaceous interbeds.

The fourth member (~200 m in thickness) lies conformably on red and brown fine- to medium-grained sandstone and siltstone. It is entirely represented by white archaeocyathan-calcimicrobial reefal limestone. A number of archaeocyaths occur in a growth position and are covered by abundant marine synsedimentary fibrous cement which displays a microwaved texture (up to 0.5 m thick) and rare calcimicrobial crusts to form an *in situ* framework (mostly cementstone). Archaeocyaths themselves are rarely coalesced to form a frame. Visually, large transversely folded *Orbicyathus* and chambered *Clathricoscinus* cups are recognizable among them. Such volumetric bioconstructions form mount-tops stretching in the meridional direction parallel to the northern shore of the lake over a distance of 12 km. In the topmost part of the reef, large cavities infilled with red argillaceous wackestone can be found, which contain complete skeletons of archaeocyaths, brachiopods, hyoliths, chancelloriides, hydroconozoans and branching khasaktiids (*Rackovskia*). In the middle of the reef, on its northern flank, reefal limestone is interbedded with green doleritic lava breccia up to several dozen square meters in area and up to 1.5 m in thickness, and bearing various angular reefal fragments (0.05–1.0 m in diameter). This lava tongue is the continuation of a sill and is overlain by a red argillaceous wackestone (0.1 m thick) bearing abundant skeletal fossils and passing up into white reefal limestone.

The fifth, upper, member (over 500 m in thickness) lies atop the reef with a slightly erosional concordant contact. This member consists of a frequent rhythmic alternation of blue calcareous mudstone, grey gravelstone with quarts gravels and carbonate intraclasts and calcareous cement, green to blueish-black shale and fine- to coarse-grained sandstone, and black doleritic tuffstone. Each of these layers is 0.05 to 0.2 m thick. Sandstone and siltstone interlayers bear abundant trilobite cranidia, pygidia and even intact carapaces restricted to the bedding surfaces being almost exclusively oriented up by their convex surfaces. These skeletal remains stand out from the host rock by bright yellow and orange colors and most are concentrated in the lower 10 m of the member which consists of intraclast-bearing sandy siltstone and black or green shale intercalated with thin limestone layers (Fig. 1.3, 1.4).

Age and paleobiogeographic affinities

Previously discovered trilobite faunas of the Lake Zone were assigned to earlier middle Atdabanian – early Toyonian or Cambrian Stage 3 – lower Stage 4 intervals (Korobov, 1980, 1989). Among them two youngest, lower Toyonian, trilobite assemblages or faunal beds were described by him, namely, *Kooteniella ventricosa–Chilometopus–Solontzella* beds in the upper Ak-Bashi Formation of the nearby Ak-Bashi Island, and the *Laminurus planus–Kootenina* and *Edelsteinaspis–Kooteniella ventricosa* beds in the middle Burgasutay Formation of Seer Ridge. These faunal beds yielded trilobites of the genera *Alokistocare*, *Chilometopus*, *Chondragraulos*, *Edelsteinaspis*, *Erkelina*, *Kootenia*, *Kootenina* (=*Olenoides*), *Kooteniella*, *Laminurus*, *Pegetides*, *Piriforma* (=*Dinesus*) and *Solontzella*. Also, an approximately coeval trilobite assemblage from the Khuvsgul terrane (Udzhigin-Gol Formation) was described (Korobov, 1989; Korovnikov and Lazarev, 2021). In both areas, trilobites are mostly represented by *Redlichia, Innouyina, Edelsteinaspis, Dinesus, Kootenia, Lermontoviella, Parapoulsenia*, *Chondragraulos* and *Onchocephalina* genera. This level is roughly correlated with the middle Cambrian Stage 4.

The new trilobite assemblage from Seer Ridge is found in the uppermost Burgasutay Formation and includes genera: *Amecephalus*, *Catinouyia*, *Chondragraulos*, *Dinesus*, *Eoptychoparia*, *Kootenia*, *Ogygopsis*, *Olenoides*, *Pagetides*, *Proerbia*, an uncertain antagmid, dorypygid and weymouthiid genera. Among fossils only assingend to genus level (*Dinesus*, *Eoptychoparia*, *Kootenia*, *Pagetides*, *Olenoides*, *Proerbia*), only *Eoptychoparia* and *Proerbia* have ranges within the Stage 4, and the others are abundant in both Wuliuan and the Stage 4. Fossils assingend to species level (*Amecephalus laticaudum*, *Chondragraulos minussensis*, *Ogygopsis virgata*) all have ranges within the Stage 4, and only *A. laticaudum* can be also extended to Wuliuan. Therefore, all these taxa are either known to range into, or have ranges entirely within the upper Stage 4 (*Lermontovia grandis* to *Ovatoryctocara-Schistocephalus* Zone, Egorova and Savitsky, 1969; Egorova et al., 1976; Korovnikov and Shabanov, 2016; Pegel et al., 2016), and it would seem more reasonable on the balance of evidences to suggest a Stage 4- age assessment. Because the index middle-late Toyonian trilobite genus *Edelsteinaspis* occurs in the *Edelsteinaspis–Kooteniella ventricosa* beds of the middle Burgasutay Formation, the new assemblage in upper part of this formation is thought to be younger than the Toyonian and rather represents the lower Amgan or the uppermost Cambrian Stage 4.

By the high diversity of dorypygids and the presence of *Amecephalus*, *Chondragraulos*, *Dinesus*, and *Proerbia*, the early Amgan fauna of the Lake Zone shows a close similarity to the Agata Horizon of the Altay-Sayan Foldbelt (e.g. Pokrovskaya 1959; Repina et al., 1964; Repina and Romanenko, 1978; Repina, 1980; Astashkin et al., 1995), as well as to the *Ovatoryctocara-Schistocephalus* Zone of the open marine (eastern) basin on the Siberian Platform (e.g. Chernysheva 1961; Khomentovsky and Repina, 1965; Egorova et al., 1976; Pegel, 2000). Although the majority of genera and even species occurred in a Siberian provenance (Siberian Platform and Altay-Sayan Foldbelt), the Lake Zone assemblage has its own biofacies identity.

While some lower Amgan index trilobites such as *Chondranomocare*, *Pseudanomocarina* and *Schistocephalus* are fairly common in Siberia, none of them appears in the Lake Zone. Instead, the local assemblage includes inouyiids, which represent a group previously being found only in East Gondwana (North and South China, Indian Himalaya) (Peng et al., 2009; Yuan et al., 2012, 2016). That means that the Lake Zone volcanic arc still was under influence of faunal migrations from East Gondwana even by the end of the early Cambrian. Extreme rarity of trilobites younger than the middle Cambrian Stage 4 (Wiliuan and upper stages) in Mongolian terranes, possibly, was related to intense volcanic activity (Fig. 1.4). The trilobite records of early Wuliuan Stage are limited to an *Eccaparadoxides* assemblage from the western accretionary wedge of the Lake Zone (Dumicz et al., 1970), and an undescribed oryctocephalid assemblage from the top of the Udzhigin-Gol Formation in Khuvsgul microcontinent (Korobov, 1980).

Palaeoecology

The Seer Sothern Reef locality is an interesting example of a large archaeocyathan reef lacking typical kalyptrate structure. No distinct smaller single or stacked mound-like buildups are recognized in the entire mount similar to those in Siberia, Australia or Laurentia (James and Kobluk, 1978; James and Gravestock, 1990; Kruse et al., 1995). Another specific feature of the Seer Reef is its principal composition of solitary archaeocyaths and synsedimentory fibrous calcite cement, enveloping their cups, with subdued calcimicrobal patches. Mud fillings are restricted to the reef top and some areas of lava breccia development only. Such composition indicates higher-energy conditions (James and Gravestock, 1990; Kruse et al., 1995).

Another important factor shaping the reef sedimentological and ecological composition could be a tectonically active regime, which led to a relatively rapid sinking of the entire island area with reefs. The presence of contemporary lava breccias bearing reefal fragments and covered with younger reefal strata shows that the reef was formed on an active island arc. Under such conditions, the reefal community survived by rapid growth only in order to escape submergence to the depths.

Muds are restricted mostly to the top of the buildup indicate that archaeocyath growth rates had slowed. Presumably, the island area drowned and finally became a site of massive volcanic-siliciclastic accumulation, while the reefal communities vanished. A new muddy environment, probably, enriched by particulate organic matter due to nutrient-rich volcanic dust fertilization, became a site for proliferation of an abundant and diverse trilobite fauna.

Probably, the reef was initiated during an episode when volcanic activity ceased allowing localized cementation and stabilization of seafloor sediments favoring archaeocyathan larval settlement.

Materials and methods

All specimens described in this paper were collected from the lower Cambrian Burgasutay Formation along the Seer Ridge section, Khovd region, western Mongolia (Fig. 1.2), and housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, China (NIGP 200755–200780). Light photographs were taken using a Nikon D810 camera fitted with a Nikon AF-S Nikkor 105 mm lens. Images were processed using Adobe Photoshop to adjust tone, contrast, and brightness. The morphological terminology employed here follows that of Whittington et al. (1997), and the systematic framework was based on Jell and Adrain (2002). Measurements were made parallel to and normal to the sagittal line, the directions of which are referred to as sagittal (sag.)/exsagittal (exs.) and transverse (tr.), respectively. The abbreviations for first to fifth lateral lobes are L0–L4, and first to fifth lateral glabellar furrows are S0–S4.

Repository and institutional abbreviation.—The following abbreviations of repositories are used below: Central Scientific Research Geological Exploration Museum (Chernyshev Museum), St. Petersburg, Russia (CNIGR); Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing, China (NIGP); Borissiak Palaeontological Institute, Russian Academy of Sciences, Moscow, Russia (PIN); United States National Museum, Washington, D.C., USA (USNM).

Systematic paleontology

Class Trilobita Walch, 1771

Order Eodiscida Kobayashi, 1939

Superfamily Eodiscoidea Raymond, 1913

Family Eodiscidae Raymond, 1913

Genus *Pagetides* Rasetti, 1945

Type species.—*Pagetides elegans* Rasetti, 1945, Cambrian, Series 2, Ville Guay Conglomerate, Québec, Canada.

Pagetides cf. *conicus* Korobov, 1989

Figure 2.1–2.10

cf. 1959 *Pagetides conicus* Korobov, p. 57–59, pl. I, figs. 10–12.

Holotype.—Cranidium PIN 4726/10 (Korobov, 1989, pl. XIII, fig. 10), Cambrian Series 2, lower Toyonian, *Laminurus planus–Kootenina* Zone, Burgasutay Formation, the Seer Ridge, western Mongolia.

Occurrence.—Cambrian Stage 4, Burgasutay Formation, Lake Zone, Seer Ridge, western Mongolia.*Material*.—Five cranidia and three pygidia (NIGP 200755a, 200755b, 200756a-c, 200759a, 200777, 200774a, 200774b and 200774a) from the Seer Ridge, western Mongolia.

Remarks.—Mongolia specimens has well-developed occipital furrow but no basal glabellar and pygidium axial spines, are highly resemble *Pagetides conicus* Korobov, 1989 discovered at the same site. The narrower pygidial axis probably preserved as internal model differs the new specimen from typical specimens. Moreover, some Mongolian pygidia show more obvious pleural furrows, suggesting that the expression of pygidial pleural furrows varies from individual to individual within the species, as previously recognized in other eodiscids (Blaker and Peel, 1997; Geyer and Peel, 2011). Becaure of the difference state of preservation between compacted and noncompacted specimens, it is appropriate to assign this specimen to a conformis of the type species *Pagetides conicus*. Some *Macannaia* (Resser, 1939b) from siberia such as *M. sibirica* and *M. spinosus* (Lazarenko, 1959) also resemble Mongolia specimens in has occipital furrow and short occipital spines, however, pygidium axis of *Macannaia* has teardrop-shaped back and hangs over the marginal border of the pygidium (Rasetti, 1966; Lazarenko, 1959; Jell, 1975).

Family Weymouthiidae Kobayashi, 1943

Weymouthiid gen. et sp. indet.

Figure 2.11, 12

Material.—Two pygidia (NIGP 200758, 200774d.)) from the Seer Ridge, western Mongolia.

Remarks.—Mongolian specimens are similar to *Cobboldites* Kobayashi, 1943 (possibly, including *Litometopus* Rasetti, 1966) in having effaced axial rings and pleural furrows, and deep border furrow. However, the Mongolian pygidia have a conical axis, which rather is a feature of *Runcinodiscus* Rushton in Bassett et al., 1976 and *Morocconus* Geyer, 1988. Notably, the Mongolian specimens also show a spine at the pygidial terminus. Therefore, new specimens may represent a new genus if a better material will be available.

?Order Corynexochida Kobayashi, 1935

Family Dorypygidae Kobayashi, 1935

Genus *Kootenia* Walcott, 1889

Type species.—*Bathyuriscus* (*Kootenia*) *dawsoni* Walcott, 1889, Cambrian, Miaolingian, Wuliuan, Stephen Formation, British Columbia, Canada.

Kootenia spp.

Figure 3

Material.—Two cranidia and seven pygidia (NIGP 200756d, 200757a, 200759b, 200762, 200763, 200764, 200765a, 200774e and 200778) from the Seer Ridge, western Mongolia.

Occurrence.—Uppermost Cambrian Stage 4, Burgasutay Formation, Lake Zone, Seer Ridge, western Mongolia.

Description.—Subrectangular glabella moderately convex, slightly expanding forward and well curved anteriorly; lateral glabellar furrows deep, reaches to anterior border furrow; occipital furrow well-defined, other glabellar furrows only faint indications. Anterior border narrow (sag.) and convex, anterior area reduced to narrow depression between border and eye ridge. Palpebral area of the fixigena moderate broad, transversely of ca. 50% the cranidial width across midlength. Palpebral lobes gently arcuate, defined by shallow furrow, centred at about glabellar midlength, length about 20% of the glabellar (sag.). Eye ridge short and faint. Posterolateral projections short (exs.) and narrow (tr.), subtriangular in outline. Pygidium semicircular except for marginal spines, length 5.6–25 mm (sag., n=6), about 53 to 63% of the width (tr.). Convex axis moderately tapering, extending to posterior margin, with four rings and a terminal piece; first three inter-ring furrows clearly defined, and the terminal one shallow and ill-defined. Pleural fields with four pairs of pleural furrows and and three weak interpleural furrows; furrows of small specimens nearly uniform in width and depth, and shallowing posteriorly in large specimens. Wide border with shallow furrow and five pairs of short to moderate length marginal spines; slender spines nearly uniform in length and subequally spaced, and the tip of 3d spines not extend beyond the smooth terminus of the pygidium. Surface smooth and without ornament.

Remarks.—The key characteristics of *Kootenia* from the Seer Ridge are: 1) pygidial axis displaying four rings and terminus; 2) five pairs of pygidial spines, short to moderate length, the tip of 3d spines does not extend beyond the smooth terminus of the pygidium. Korobov (1989) described *K. hirsuta* Suvorova, 1964, *K. rotundata* Rasetti, 1948, *K. tersa* Ergaliev in Ergaliev and Pokrovskaya, 1977 and his own new species *K. lata* from the Seer Ridge. However, most of these species were identified by cranidia, and only one pygidium possessing four pairs of spines was assigned to *K. hirsuta*. Therefore, the new specimen does not show similarity with known species of *Kootenia* from the same site. More than 30 species of *Kootenia* from the lower-middle Cambrian boundary interval are described in Siberia and adjacent areas (see list in Yuan et al., 2016), of which six species, *K. abacanica* (Poletaeva, 1936), *K. siberica* Lemontova, 1940, *K. florens* Suvorova, 1964, *K. rasilis* Suvorova, 1964, *K. mirabile* Ergaliev in Ergaliev and Pokrovskaya, 1977, and *K. tersa* Ergaliev in Ergaliev and Pokrovskaya, 1977 have five pairs of pygidial spines. *K. siberica* and *K. florens* are similar to Mongolian *Kootenia* in the length of pygidial spines, but these specimens differ from Mongolian ones in their longer occipital spine and tuberculate cranidia. Given over 100 species of *Kootenia* have been named (Sundberg, 1994; Yuan et al., 2016), this group needs a proper revision, and *Kootenia* from the Seer Ridge are left in open nomenclature.

Ogygopsis Walcott, 1889

Type species.—*Ogygia klotzi* Rominger, 1887, p. 12, Cambrian, Miaolingian, Wuliuan, Stephen Formation, British Columbia, Canada.

Ogygopsis virgata (E. Romanenko in Romanenko and Romanenko, 1962)

Figure 4.5–7

1962 *Kootenia virgata* E. Romanenko in Romanenko and Romanenko, p. 19, pl. 1, figs. 9–11.

1997 *Ogygopsis virgata*; Blaker and Peel, p. 80, figs. 46–48. *cum. syn.*

2011 *Ogygopsis virgata*; Geyer and Peel, p. 477, fig. 9C–H.

Holotype.—Original assignment has not been traced.

Material.—Two nearly complete pygidia (NIGP 200768, 200770) from the Seer Ridge, western Mongolia.

Occurrence.—Amgan Stage, Altay-Sayan Region; *Eoagnostus roddyi* – '*Arthricocephalus chauveaui*' Zone (upper Cambrian Stage 4), Henson Gletscher Formation, North Greenland.

Remarks.—The Mongolian pygidia show six pairs of wide pleural furrows, six axial rings, and two pairs of marginal spines, similar to Greenlandian *Ogygopsis* assigned to *O. virgata* (E. Romanenko in Romanenko and Romanenko, 1962) by Blaker and Peel (1997), and distinct from other species of this genus. The other specimen with similar furrows and axial rings has anterior marginal spines poorly preserved, but its undulated posterior margin is clear enough to support its assignment as *O. virgata*.

Ogygopsis sp. indet.

Figure 4. 4, 8, 9

Material.—Two uncomplete pygidia and a nearly complete exoskeleton (NIGP 200767, 200769, 200771) from the Seer Ridge, western Mongolia.

Remarks.—These specimens have smooth margins without spines and six pairs of pleural furrows, are reminiscent to *Ogygopsis batis* (Walcott 1916). However, except for the former two traits, another important character-numbers of axial rings- cannot be confirmed, and we suggest an open nonculture for the Mongolia specimens.

Olenoides Meek, 1877

Type species.—*Paradoxides? nevadensis* Meek, 1877, Cambrian, Miaolingian, Drumian, Wheeler Formation, Utah, USA.

Olenoides sp. indet.

Figure 4.1

Material.—A cranidium (NIGP 200760) from the Seer Ridge, western Mongolia.

Remarks.—The single Mongolia dorypygid cranidia material is characterized by a glabella with well-expressed lateral glabellar furrows. By these features, the cranidia under discussion have more in common with those of *Olenoides*. Over 80 species of *Olenoides* are identified primarily based on pygidial features (Yuan et al., 2002), thus it would more preferable to place the new specimen under a more open nonculture, and we tentatively assign it as *Olenoides* sp. indet.

Dorypygid gen. et sp. indet.

Figure 4.2, 3

Material.—Two cranidia (NIGP 200765b, 200766) from Seer Ridge, western Mongolia.

Remarks.—The smooth and broadly cylindrical glabella and extremely narrow preglabellar field suggest these specimens should be assigned to the Dorypygidae rather than another group.

The broad swollen glabella is reminiscent of *Kooteniella* Lermontova, 1940, but this genus has almost spherical glabella with the highest point and widest measure. The lack of pygidium also makes specific comparison difficult, thus the taxonomic placement is left open.

Family Dinesidae Lermontova, 1940

Proerbia Lermontova, 1940

Type species.—*Proerbia prisca* Lermontova, 1940, Cambrian Series 2, Stage 4, Kutorgina Formation, Siberian Platform, Russia.

Proerbia sp.

Figure 6.2, 3

Material.—Two incomplete cranidia (NIGP 200761, 200772b) from Seer Ridge, western Mongolia.

Remarks.—Cylindrical glabella with four well-expressed lateral furrows and wide preglabelar area with three swelling allow their identification as *Proerbia*. The Mongolian specimens differ from other *Proerbia* species in having a convex palpebral area obviously wider than glabellar, effaced eye ridges, and upturned palpebral lobes. Mongolian *Proerbia* sp. is somewhat similar to *P. angarensis* Dalmatov in Yazmir et al., 1975 from the Ogne Formation (Maolingian, Wuliuan) of western Transbaikalia, which differs by the flat palpebral area and long occipital spine. The wide and convex palpebral area suggests that *Proerbia* sp. possibly represents a new species. However, it would be a premature to establish a new species until better specimens preserving a complete anterior border and preglabellar area will be found.

Dinesus Etheridge, 1896

Type species.—*Dinesus ida* Etheridge, 1896, Cambrian, Miaolingian, Knowsley East Shale, Victoria, Australia.

Dinesus sp. indet.

Figure 5.9

Material.—Single cranidium (NIGP 200776) from the Seer Ridge, western Mongolia.

Remarks.—Axial furrows branching forward adjacent to the anterior part of the glabella, narrow or almost vanishing preglabellar area, effaced eye ridge, isolated triangular lobes adjacent to the anterior end of the glabella and the short palpebral lobe situated anterior to the mid-length of the cranidium support the placement of this single incomplete cranidium in *Dinesus*. However, due to the distortion of preglabellar area and the damage of palpebral lobe, it's difficult to assign this specimen to any species.

Order Unknown

Family Inouyiidae Zhang, 1963

Remarks.—Diagnostic of the Inouyiidae Zhang, 1963 is the faint or effaced border and furrow, wide preglabellar area with a periclinal swelling in front of glabella, and posterior border and border furrow bending backward opposite to the posterior end of palpebral lobe (Zhang, 1963; Yuan et al., 2016). The Bolaspididae Howell in Harrington et al., 1959 from the Miaolingian of Laurentia are also characterized by a swelling on the preglabellar field, but the inouyiids have a pair of wide shallow oblique furrows in the preglabellar field starting from the anterior lateral corner of the glabella. Currently, 13 genera are assigned to the Inouyiidae (Jell and

Adrain, 2002; Yuan et al., 2012, 2016), all of which are restricted to Cambrian strata of East Gondwana.

Catinouyia Zhang and Yuan, 1981

Type species.—*Catinouyia typica* Zhang and Yuan, 1981, Cambrian, Miaolingian, Wuliuan, *Kochaspis-Ruichengella* (=*Asteromajia hsuchuangensis*) Zone, Hulusitai Formation, North China.

Remarks.—*Catinouyia* is considered a junior synonym of *Inouyia* Walcott, 1911 by Peng (2021), since the principal difference between these two genera is merely the anterior margin. However, the anterior margin has always been regarded as an important character to distinguish genera within Inouyiidae (Yuan et al., 2012, 2016), so we consider that the *Catinouyia* is still valid. Except for the type species, two inouyiid species, *Catinouyia jiawangensis* Qiu et al., 1983 and *C. dasonglinensis* Yuan and Gao in Yuan et al., 2016, with convex and narrow anterior border were also assigned to *Catinouyia*.

Catinouyia heyunensis Sun, Yang and Zhao, new species

LSID urn:lsid:zoobank.org:act:BA072CF6-68A5-4FF8-ADA3-119404F1B3BF

Figure 5.1, 2, 4; 6.1

Holotype.—Cranidium (NIGP 200773) from uppermost Cambrian Stage 4, Burgasutay Formation, Lake Zone, Seer Ridge, western Mongolia.

Paratypes.—Three cranidia (NIGP 200775d, 200772a, 200779) from the type locality and stratum.

Etymology.—From the Chinese pinyin 'Heyun', the ancient Chinese word for the Lake Zone.

Diagnosis.—An inouyiid trilobite with rectangle cranidium, broad (tr.) frontal area, convex and narrow anterior border, straight border furrow, broad (tr.) palpebral area and straight eye ridges.

Description.—Cranidium obviously broad (tr.), moderately convex, rectangularl in outline; length (tr.) 11.1–12.3 mm, about 60 to 65% of the width at the palpebral lobes. Glabella moderately convex, truncated conical, occupying about 60% of total cranidial length and about 27% of total cranidial width; three pairs of lateral glabellar furrows (S0–S2) present, moderately deep, adjacent to the axial furrow slightly, progressively less well expressed from S0 to S2; S0 (occipital furrow) consisting of a pair of well-developed lateral sections and a median section slightly bending forward medially; S1 long, shallow and wide, directed backward from axial furrows and curved; S2 short, very shallow or indistinct; occipital ring convex, narrowing laterally, with a small occipital spine posteromedially; axial furrow moderately deep; preglabellar furrow deep, wide and straight, separated from the axial furrow by eye ridge. Preglabellar area long and wide, convex, nearly rectangular in outline, about 6 times as wide as anterior border, with faint caeca; two wide shallow furrows extending from anterior corner of glabella, separating from preocular field a low subrounded swelling; straight anterior border furrow well-defined, narrow and deep; anterior border narrow and gently convex. Palpebral area of the fixigena fairly broad, transversely of ca. 70% the cranidial width across S1; strongly convex, highest near palpebral lobe, slightly sloping down towards axial furrow. Palpebral lobes crescent shaped, upturned, clearly convex; anterior end located about opposite S2, posterior tips located about opposite L1. Eye ridges elevated, well developed, straight, moderately posteriorly directed from glabella, nearly horizontal from anterior corner of glabella. Posterior border furrow wide and deep, widening outward, posterior border narrow and convex; posterior border and border furrow bending backward opposite to posterior end of palpebral lobe. Anterior branch of facial suture convergent from palpebral lobe; posterior branch short, extending outwards and backwards.

Remarks.—*Catinouyia heyunensis* sp. nov. is distinguished from *C. typica* Zhang and Yuan, 1981 and *C. jiawangensis* Qiu et al., 1983 in having a wider preglabellar field, narrower anterior border and longer (tr.) eye ridges. *C. dasonglinensis* Yuan and Gao in Yuan et al., 2016 differs from the new species in having wider glabella with less forward taper, narrower palpebral areas, and eye ridge slightly directed more posterolaterally.

The palaeogeographic distribution of inouyiids has been confined to North China, the Yangtze Platform and Indian Himalaya (Peng et al., 2009; Yuan et al., 2012, 2016), therefore, the discovery of inouyiids in Mongolia reveals a wider distribution of this family.

Family Alokistocaridae Resser, 1939b

Amecephalus Walcott, 1924

Type species.—*Ptychoparia piochensis* Walcott, 1886, Cambrian, Miaolingian, Wuliuan, Chisholm Formation, Nevada, USA.

Amecephalus laticaudum (Resser, 1939a)

Figure 5.3, 5, 6

1939a *Alokistocare laticaudum* Resser, p. 17, pl. 4, figs. 15–19.

part 1939b *Alokistocare euchare* Resser, p. 51, pl. 2, figs. 11, 12.

part 1939b *Poulsenia granosa* Resser, p. 59, pl. 13, figs. 20, 21.

1962 *Alokistocare faceta* Lazarenko, p. 66, pl. VIII, figs. 12, 13.

1968 *Amecephalus laticaudum*; Fritz, p. 227, pl. 40, figs. 17–23.

1969 *Alokistocare faceta*; Egorova and Savitsky, p. 239, pl. 43, fig. 5.

1969 *Alokistocare laticaudum*; Egorova and Savitsky, p. 241, pl. 43, fig. 4.

1974 *Alokistocare faceta*; Repina et al., p. 175, pl. L, figs. 3, 4.

1976 *Alokistocare laticaudum*; Egorova et al., p. 128, pl. 11, fig. 21; pl. 16, figs. 1–3; pl. 18, figs. 10, 11; pl. 22, fig. 2.

2005 *Amecephalus laticaudum*; Sundberg, 2005, fig. 6.6, 6.12.

2011 *Amecephalus laticaudum*; Foster, fig. 7.4–7.7.

non 2015 *Amecephalus laticaudum*; Robison et al., fig. 63.

2016 *Alokistocare laticaudum*; Pegel et al., p. 126, pl. 27, figs. 1, 1a, 2.

Holotype.—Cranidium USNM 96517 (Resser, 1939a, pl. 4, fig. 18), Cambrian, Miaolingian, Wuliuan, Spence Shale, locality 55e, Wasatch Mountains, Utah, USA.

Material.—Three cranidia (NIGP 200762b, 200762c, 200774e) from the Seer Ridge, western Mongolia.

Occurrence.—*Albertella* to *Glossopleura* zones (lower Wuliuan), Pioche and Spence shales, Chisholm Formation, Great Basin, USA; *Lermontovia grandis* to *Ovatoryctocara-Schistocephalus* zones (upper Cambrian Stage 4), Sekten, Elanka, Udachny and Morgunovo formations, Siberian Platform, Russia; uppermost Cambrian Stage 4, Burgasutay Formation, Lake Zone, Seer Ridge, western Mongolia.

Remarks.—The cranidia from the Lake Zone are similar in size and overall morphology to those of *Amecephalus laticaudum* (Resser, 1939a) from the Siberian Platform (Egorova and Savitsky, 1969; Repina et al., 1974; Egorova et al., 1976; Pegel et al., 2016). The principal difference between the two sampling sets is that the Siberian specimens have a more well defined anterior border. However, this difference is ought to be result of preservation as the Siberian cranidia are mainly in carbonate lithologies while the Mongolian ones are flattened in siliciclastics. Siberian representatives of *A. laticaudum* have poorly defined anterior border furrow, concave anterior border, and swelling frontal area in anterior border furrow similarly to specimens of *Amecephalus* from Laurentia (Resser, 1939b; Fritz, 1968; Sundberg, 1999, 2005, 2020).

Family Utiidae Kobayashi, 1935

Chondragraulos Lermontova, 1940

Subgenus *Chondragraulos* Lermontova, 1940

Type species. *Chondragraulos minussensis* Lermontova, 1940, Cambrian Series 2, Stage 4, Kutorgina Formation, Siberian Platform, Russia.

Chondragraulos (*Chondragraulos*) *minussensis* Lermontova, 1940

Figure 5.8

1940 *Chondragraulos minussensis* Lermontova, p. 143, pl. XLIV, figs. 10, 10a.

1976 *Chondragraulos minussensis*; Egorova et al., p. 100, pl. XII, fig. 21, *cum. syn.*

2016 *Chondragraulos (Chondragraulos) minussensis*; Pegel et al., p. 111, pl. 23, figs. 7–10, *cum. syn.*

Lectotype.—Cranidium CNIGR 9182 (Lermontova, 1940, pl. XIV, figs. 10), Cambrian Series

2, Stage 4, “Potekhino limestone”, Kuznetsky Alatau, Altay-Sayan Foldbelt, Russia.

Material.—Single cranidium (NIGP 200775) from Seer Ridge, western Mongolian.

Occurrence.—*Lermontovia grandis* to *Ovatoryctocara-Schistocephalus* zones (upper Cambrian Stage 4), Amga, Erkeket, Elanka, Kharatas, Kutorgina, Nouyo, Sekten and Shumnoy formations, Siberian Platform, Russia; *Kooteniella-Edelsteinaspis* Zone to Mundybash Horizon (upper Cambrian Stage 4), Barangol and Karabulun formations, Altay-Sayan Foldbelt, Russia; uppermost Cambroan Stage 4, Yanguda Formation, Transbaikalia, Russia; uppermost Cambrian Stage 4, Burgasutay Formation, Lake Zone, Seer Ridge, western Mongolian.

Remarks.—*C. (C.) minussensis* Lermontova, 1940 is common in upper Cambrian Stage 4 strata of the Siberian Platform, Altay-Sayan Foldbelt and Transbaikalia. Another common species of this genus, *C. (C.) granulatus* Chernysheva, 1961 differs from the Mongolian species by a wide, less convex cranidium, distinct lateral glabellar furrows, and a sharper tapering of the glabella towards the preglabellar furrow.

Family Antagmidae Hupé, 1953

Antagmid gen. et sp. indet.

Figure 5.9.

Material.—Single cranidium (NIGP 200757b) from the Seer Ridge, western Mongolia.

Remarks.—The convex anterior border and deep, well-defined and continuous border furrow of this cranidium are typical features of antagmids. Unlike antagmids, previously reported from Siberia such as *Onchocephalina* Repina, 1960, the Mongolian specimen has a wider preglabellar area, but the broken palpebral area of the specimen prevents a precise taxonomic determination.

Family incertae sedis

Eoptychoparia Rasetti, 1955

Type species.—*Eoptychoparia normalis* Rasetti, 1955, boulders with Cambrian fossils within the Lévis Formation, near Lévis, Quebec, Canada.

Eoptychoparia sp. indet.

Figure 6.4–7.

Material.—Four cranidia (NIGP200755e, 200757c, 200774f, 200780) from the Seer Ridge, western Mongolia.

Remarks.—The absence of a distinct median swelling at the anterior border and a well enough expressed plectral swelling in front of the glabella in Mongolian specimens suggests their assignment to *Eoptychoparia* Rasetti, 1955 rather than to *Onchocephalus* Resser, 1937. Of several *Eoptychoparia* species reported from Siberia and adjacent areas (Geyer and Peel, 2011), Mongolian specimens are most similar with *E. manifesta* Lazarenko, 1962 in having a narrower glabella with only three lateral glabellar furrows. However, the distinctly upturned and brim-like anterior border commonly showed in *E. manifesta* cannot be observed in Mongolia specimens, due to their poor preservation. Thus, Mongolian specimens are not assigned to any definite species.

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