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Late Devonian (Famennian) phacopid trilobites from western Xinjiang, Northwest China

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Abstract. An early Famennian trilobite fauna represented by phacopids is recorded and illustrated from the lower member of the Hongguleleng Formation (*crepida* conodont Zone) near the Bulongguoer Reservoir in northwestern Xinjiang, northwestern China. In this area, the Hongguleleng Formation is rich in diverse faunas and exposes bioclastic argillaceous limestones and marls, intercalated with green calcareous shales of Famennian shallow marine shelf deposits formed in a volcanic arc-related setting. The studied material is most often incomplete, often poorly preserved as internal **molds**. Due to insufficient preservation of well-preserved cephalae, additional material is required. However, among faunas, the Hongguleleng Formation contains specimens of *Clarksonops junggariensis* gen. nov. sp. nov., a so-far endemic **taxon**, which **is** the first known and described representatives of trilobites from **lower** Famennian deposits of northwestern China; and *?Houseops cf. olonbulagensis*, a **taxon** encountered in western Mongolia. Their affinities with known other sighted species of the same age are discussed.

Keywords. Trilobites, Phacopidae, **lower** Famennian, Hongguleleng Formation, Biodiversity, Taxonomy

Statements and Declarations

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1. Introduction

Trilobites were relatively abundant and diverse in the mid-Paleozoic marine habitats. During the mid-Paleozoic time, dynamic long-term climate change (Algeo and Scheckler 1998; Stein et al. 2007; Becker et al. 2016) triggered significant biodiversity changes and major biotic crises (Sepkoski 1996; Racki 2005; Bond and Graspy 2017). Among changes in trilobites, eye reduction leading to a forward shift of the eye lobe became a common phenomenon in the Upper Devonian series with the development of the main groups of reduced-eyed or blind phacopid trilobites in deeper offshore cephalopod limestones. After a severe diversity limitation triggering one of the highest extinction rates in the mid-Palaeozoic (Lerosey-Aubril and Feist 2012; Crônier et al. 2013; Crônier and François 2014), Feist (2019) recognized a rather important diversification of phacopids during the early Famennian.

Even if the trilobite record in shallow near-shore environments remains scarce (Feist et al. 2009; Crônier et al. 2021), some diversity hotspots have been recognized in the Central Asian Orogenic Belt and neighboring areas (Waters et al. 2003; Waters and Webster 2009; Ernst 2013; Waters et al. 2021; Nazik et al. 2021; Crônier et al. 2021). In northwestern China, the Hongguleleng Formation is one of the few highly fossiliferous Famennian localities in the world deposited in a shallow marine setting. Abundant benthic organisms, i.e., brachiopods (Chen et al. 2009; Chen and Yang 2011; Zong and Ma 2012), rugose corals (Liao and Cai 1987), echinoderms (Hou et al. 1993; Lane et al. 1997; Waters et al. 2003; Waters and Webster 2009), trilobites (Zong et al. 2016), and nektonic organisms, i.e., ammonoids (Wang 1983; Liang and Wang 1988) have been described, as well as micro-organisms, i.e., ostracods (Song et al. 2018), conodonts (Wang et al. 2016), and trace fossils (Fan and Gong 2016). Trilobites reported by Zong et al. (2016) although coming from the same formation in the same region, are encountered in the *Palmatolepis marginifera* conodont Biozone unlike the described trilobites in the present work, which come from the *Palmatolepis crepida* conodont Biozone.

Such diversity hotspots may be related to specific palaeoenvironmental settings (Waters et al. 2003; Waters and Webster 2009; Ernst 2013; Waters et al. 2021; Nazik et al. 2021). Previous works point out that the northwestern China sections were deposited on a volcanic island arc complex during the Palaeozoic (Jahn et al. 2000; Cocks and Torsvik 2007; Windley et al. 2007; Wainwright et al. 2011; Xiao et al. 2010; Gong and Zong 2015). In this Paleo-Tethyan island arc complex, Carmichael et al. (2014, 2016), Fan and Gong (2016) recognized that the Hongguleleng Formation was deposited with intermittent periods of volcanic activities. Lane et al. (1997), Waters et al. (2003), Waters and Webster (2009), as McGhee et al. (2013) hypothesized that this

formation may have served as Famennian refugium in the aftermath of major biotic extinction events. [Carmichael et al. \(2014\)](#) recognized and documented the Upper Kellwasser Anoxia Event through multiple proxies although black shales are missing in episodic dysoxia shallow water and the rebound of shallow marine ecosystems in the early Famennian. Somewhere else, in Western Australia (northern Canning Basin), [Feist et al. \(2009\)](#) demonstrated the origin of post-event phacopids from shallow water environments.

To evaluate the hypotheses that trilobite faunas expanding from shallow-water habitats support the idea of specific palaeoenvironmental settings as refugia or radiation centers, a systematic trilobite study has been performed from the shallow-water setting in western Junggar that belonged to the Kazakhstan Block, western Xinjiang, Northwest China, where the Hongguleleng Formation is exposed.

The present paper contributes to the systematic study of the early Famennian phacopids. The discovery of new occurrences assigned to *Clarksonops junggariensis* gen. nov. sp. nov., and *?Houseops cf. olonbulagensis* [Crônier in Crônier et al., 2021](#) from Northwest China, provides the opportunity to get a better understanding of these post-event phacopids. No members of other trilobite families have been found associated with the studied phacopids at this stage of the investigations. Interestingly, in order to get a better understanding on the distribution of Late Devonian faunas at the interface of palaeogeography and palaeoecology, a comparison of our trilobite fauna with those from the western Mongolia has been performed.

2. Geological setting and material

The Central Asian Orogenic Belt (CAOB) associated with the closure of a part of the Palaeo-Asian Ocean prior to the end of the Carboniferous ([Buckman and Aitchison 2004](#)), covers a huge area ([Fig. 1a](#)) that extends between the Siberian platform to the north, the Cathaysian terranes and the North China–Tarim Craton to the south ([Jahn et al. 2000](#); [Cocks and Torsvik 2007](#); [Windley et al. 2007](#); [Choulet et al. 2012](#); [Gong and Zong 2015](#)). CAOB includes a complex amalgamation of intra-oceanic island arcs and continental margin arc terranes including Palaeozoic deposits of western Junggar area of northwest Xinjiang-Uygur Autonomous Region as part of this complex tectonic framework ([Xiao et al. 2008, 2010](#); [Xiao and Santosh 2014](#); [Li et al. 2017](#); [Yang et al. 2019](#)). [Most](#) of the middle Palaeozoic [reconstructions](#) hypothesized for CAOB ([Windley et al. 2007](#); [Xiao et al. 2010](#)) locate the Hongguleleng Formation at approximately 25 to 30 degrees north, in a tropical setting ([Filippova et al. 2001](#)), which is consistent with echinoderm communities ([Waters et al. 2003](#)) within a back-arc basin.

Fig1.jpg (from corel draw)

The mid-Palaeozoic deposits well developed in the Xinjiang-Uygur Autonomous Region are located in the northwestern part of China; the Xinjiang-Uygur Autonomous Region being composed of several plates, microcontinents, and accretionary wedge (Sengör et al. 1993; Zhao 1994; Han and Zhao 2018). The Late Devonian Hongguleleng Formation is a part of this accretionary wedge, whose outcrops are relatively small and sporadically distributed. Ma et al. (2013) recognized several subunits of the Hongguleleng Formation, which indicate lateral facies changes, including some proximal storm deposits, during the Late Devonian in western Junggar.

The Hongguleleng Formation is of Famennian age (Ma et al. 2017) based on conodont and brachiopod data. Geochemical evidence for anoxia events occurs near the base of the section at Bulongguoer Reservoir (Carmichael et al. 2014) and near the top of the formation (Carmichael et al. 2016). Based on the conodont biostratigraphy in Suttner et al. (2014), anoxia at the base of the section was interpreted as the Upper Kellwasser Event. Similarly, the event near the top was interpreted as the Hangenberg event. More recent studies on the conodonts from Bulongguoer Reservoir question the presence of the Frasnian / Famennian boundary in the Hongguleleng Formation (Zhang et al. 2021), and dismiss the geochemical signal of anoxia as diagenetic. Critical geochemical signals of anoxia (data from pyrite framboids) are not particularly sensitive to diagenesis. Resolution of this issue is beyond the scope of this paper.

The Hongguleleng Formation near the Bulongguoer Reservoir (stratotype section) is characterized by an abundant, a very well preserved and diverse marine faunal assemblage (Zong and Ma 2012; Waters et al. 2003; Suttner et al. 2014; Zong et al. 2014; Zong and Gong 2017; Song et al. 2018) including trilobites. Most of them have only been listed in the Geological Survey Reports from the 1960s to the 1980s or first described in the Atlas of Paleontology of Northwest China (Zhang 1983). From previous published works, two subspecies of phacopid trilobites were described from the upper Famennian, i.e., *Omegops accipitrinus mobilis* Xiang, 1981, and *Phacops (Phacops) circumspectans tuberculosus* Yuan and Xiang, 1988, associated with many brachiopods and corals in the type Bulongguoer section (Xiang 1981; Yuan and Xiang 1988), in the upper part of the Hongguleleng Formation according to the stratigraphical range from Ma et al. (2011) or in the 'Hebukehe' Formation from Suttner et al. (2014) and Carmichael et al. (2016).

The studied material (sampled by J.A.W. in 1995 and 2005) belonging to the Hongguleleng Formation (Fig. 2) originates from two localities located near the Bulongguoer Reservoir in northwestern Xinjiang, NW China

(Fig. 1b): the type locality and Aomage locality (Fig. 1b). The Hongguleleng Formation is approximately 200 m thick and is divided into two stratigraphically distinct echinoderm assemblages: a fauna dominated by crinoids from the lower part comprising the studied trilobites and a fauna dominated by blastoids from the upper part of the Hongguleleng Formation (Waters et al. 2003). In the lower part of the Hongguleleng Formation, no trilobite specimens have yet been illustrated or described. Some phacopids (with an equivalent age to the Mongolian phacopids; Crônier et al. 2021) have been found with a mixed fauna of very small crinoids, brachiopods, corals and bryozoans in the lower part of the section from an interval of very thin-bedded limestone with shale and volcanoclastic rocks within the *crepida* Biozone. These shallow marine faunas may document the rapid recovery from the Kellwasser extinction and represent an important window into a critical interval of earth history.

The type locality of the Hongguleleng Formation (Latitude 46°45.16'N, Longitude 86°08.49'E) is 3 km west of Bulongguoer Reservoir. This section exposes the marly beds of the lower part of the Hongguleleng Formation, with abundant marine organisms including the studied trilobites (bed 5, collected in 1995 and 2005), and dark bryozoan-rich shales and coarse crinoidal grainstones from the upper part of the Hongguleleng Formation.

The Aomage locality (Latitude 46°37.59'N, Longitude 86°00.25'E in the vicinity of Aomage) exposes the lower limestones and marly beds of the lower part of the Hongguleleng Formation. This section is very fossiliferous, with abundant brachiopods, bryozoans, corals, few phacopids trilobites and only one crinoid, *Chinacrinus* Lane et al., 1997, the most abundant crinoid in the Xinjiang faunas (Webster et al. 2003).

The collected trilobite material assigned to the Phacopidae family is the result of a field campaign in 1995 and 2005. Phacopids include disarticulated molting remains as well as partially enrolled specimens. Phacopid remains are more or less well preserved with some distortion due to some abrasion features because of sediment transport. The material described and figured herein is stored at Nanjing, China under repository numbers NIGP/180500-180511.

Fig2.jpg (from corel draw).

3. Systematic palaeontology (by C. Crônier)

The illustrated specimens were coated with ammonium chloride before photographed using a digital camera Nikon. The morphological terminology follows Chlupáč (1977) and Crônier et al. (2011).

Order Phacopida [Salter, 1864](#)

Superfamily Phacopoidea [Hawle and Corda, 1847](#)

Family Phacopidae [Hawle and Corda, 1847](#)

Subfamily Phacopinae [Hawle and Corda, 1847](#)

Genus *Clarksonops* gen. nov.

Type species: *Clarksonops junggariensis* gen. nov. sp. nov.

Species included: Type species: Famennian (*Palmatolepis crepida* conodont Biozone), northwestern China.

Etymology: For Euan Clarkson (Edinburgh, Scotland), in honor of all his work on Devonian trilobites.

Diagnosis: As for the species.

Stratigraphical range: **Lower** Famennian. *crepida* conodont Zone

Occurrence: NW-China (Western Junggar, Xinjiang).

Remarks: The configuration of cephalic and pygidial features assign the new taxon to the Phacopidae. However, the combined set of features observed in the type species, i.e., the reniform visual complex close to the posterior border, the subocular librigenal field relatively narrow at the front of the eye, larger and concave backwards with a weak subocular pad, the preoccipital ring not reduced (sag.) and the configuration of the ridge-like anterior border, not seen in any other early Famennian phacopids, justify its assignment to the new genus. **The newly large-eyed phacopine *Feistops* Crônier in Crônier et al., 2021 from the Famennian of Mongolia represented by three species differs in having a lowered glabella with a narrow base, and a cephalic border without marginulation.** The large-eyed phacopine *Magreanops monachus* [van Viersen and Vanherle, 2018](#) from the middle Frasnian of Belgium differs in having a lowered glabella, a longer (sag.) eye with a lower edge of the eye in the lateral border furrow. The newly described large-eyed phacopine *Cronierella* [Feist and Klapper, 2022](#) from the latest Givetian (Upper *disparilis?*) *norrissi* Zone **through** lower Frasnian Zone 6 in Europe differs in

having low eyes remaining below the level of the glabella and the outline of the visual field which is “pointed” behind, and a pygidium with a narrow, low axis and a postaxial ridge that does not reach the posterior edge. Meanwhile *Omegops* Struve, 1976 encountered in the late Famennian differs in having a typical reduced preoccipital ring and an anterior border not overhanging (see next ‘comparison’ section). The new genus shares a very short (sag., exsag.), ridge-like anterior border, projecting slightly forwards as *Phacops* but differs in having a subocular librigenal field relatively narrow at the front of the eye, larger and concave backwards with a weak subocular pad (see next ‘comparison’ section).

Clarksonops junggariensis gen. nov. sp. nov.

Fig. 3a-s, Fig. 4a-b

Etymology: After the area of northwestern China.

Holotype: Cephalon, NIGP/180506 (Fig. 3k-m).

Paratype: Cephalon, NIGP/180505 (Fig. 3a-j, n-p); Pygidia, NIGP/180507-180509 (Fig. 3n, q-s).

Type locality: Type locality of the Honggueleng Formation (Latitude 46°45.16'N, Longitude 86°08.49'E), 3 km west of Bulongguoer Reservoir, northwestern Xinjiang, NW China.

Type stratum: Honggueleng Formation, lower part of the lower member, lower Famennian, *Palmatolepis crepida* conodont Biozone, Late Devonian.

Material: Twenty three cephalon, one cephalothorax, one complete enrolled exoskeleton with displaced sclerites, one complete but damaged exoskeleton, 5 pygidia, and 15 thoracopyga.

Diagnosis: Cephalon narrow; glabella bounded by low divergent axial furrows; L1 with subquadrate lateral lobes; reniform visual complex with 15 vertical lens files and maximum five lenses per file; inter-lensar sclera thickened dorsally and more slightly ventrally; inflated palpebral lobe; palpebral furrow distinct and strongly convex (abax.); anterior border relatively short, ridge-like, projected slightly forward and sloping

posteroventrally; marginulation extending to genal angle; subocular librigenal field relatively narrow at the front of the eye, larger and concave backwards; weak subocular pad. Pygidium rather long with a rather narrow and long pygidial axis, composed of eight clear rings plus terminal piece; pygidial pleural field with five well-defined ribs; deep pleural furrows; indistinct interpleural furrows. Medium-sized to coarse tubercles dense to moderately dense on cephalon; small granules on pygidium.

Fig3.jpg (from corel draw)

Description: *Cephalon:* Narrow, length/width ratio about 0.60. *Dorsal view:* Glabellar ratio of width at L1/maximum width of frontal lobe about 0.48, narrow at base. Glabella bounded by relatively deep axial furrows that are low divergent (57-59°). Frontal outline parabolic anteriorly. Frontal lobe overhanging a deep preglabellar furrow. S2 and S3 distinct. S1 continuous and slightly curved in its middle part, subparallel to S0, and becoming deeper in its distal portions. L1 shorter (sag.) than L0 (barely more than half length of L0) and with a wide (tr.) median portion relative to its total width. Median portion of L1 inflated, with tubercles. L1 with subquadrate lateral lobes, not strongly inflated, separated from its median part by a weak exsagittal furrow. S0 distinct and almost transverse/ hardly curved in its middle portion. L0 wide (tr.) with lateral lobes not defined. Reniform visual surface with 15 dorso-ventral files of lenses and a maximum of 5 lenses per file (Fig. 4b), with smaller lenses in the anterior part. Inter-lensar sclera thickened dorsally and more slightly ventrally. Palpebral furrow distinct and strongly convex (abax.). Exsagittal length of the postocular genal field more than half length (exsag.) of the posterior border. *Lateral view:* Glabella sloping slightly obliquely and then dorsoventrally in its anterior part. Outline of L1 curved. L0 as high as glabella at its maximum convexity. Anterior border relatively short, ridge-like, projected slightly forward and sloping posteroventrally. Marginulation extending to genal angle. Posterior border furrow deep and narrow. Lateral border furrow moderately narrow and shallow at the front of the eye, becoming shallower towards back. Subocular librigenal field relatively narrow at the front of the eye, becoming larger and concave backwards with a slight subocular pad. Posterolateral border furrow shallow and posterolateral border widening at the genal angle. *Frontal view:* Glabellar outline sub-semicircular becoming barely oblique laterally (divergence of 37°). Palpebral area inflated and as high as the inflated palpebral lobe. *Ventral view:* Vincular furrow relatively deep and wide (sag.), broadly and evenly curved. Posterior band of the cephalic doublure long (sag.), with a hypostomal suture slightly convex backward medially. *Pygidium:* Rather long with a length/width ratio about 53% (excluding the half ring), and its maximum width (tr.) at about its midlength (sag.) in dorsal view. Posterior outline roughly broadly rounded. Pygidial axis very long (sag.) and

rather narrow (tr.), moderately tapered, with rather incomplete terminal closure. Eight distinct rings in the pygidial axis. Pygidial pleural field with five well-defined ribs delimited by deep pleural furrows. Interpleural furrows indistinct. Pseudo-articulating half rings very weakly suggested by expanded inter-rings furrows.

Sculpture: Cephalon covered with medium-sized to coarse tubercles of heterogeneous size, smaller on fixigenal cheek and palpebral lobe, dense to moderately dense on entire composite lobe. Numerous pits on the lateral border, at the basal part of the visual surface, on the coarser tubercles of the glabella and on the ridge-like anterior border. Posterior band of the cephalic doublure with short scaly ridges. Pygidium showing small granules on pleura and axis.

Fig4.jpg (from corel draw).

Size and dorsoventral file distributions: Bivariate plots have been constructed to establish size series and to follow the morphological evolution of the eye. Dimensions, especially the length and width of glabella (cephala often incomplete) and pygidia in dorsal view, were obtained using an optical image analyser (TPSdig v.2.17; Rohlf 2013). Length/width bivariate plots of glabella and pygidia show no distinct grouping, i.e. no distinct instars (Fig. 5b, 5c). The growth series is essentially represented by the holaspid period where no feature allows distinguishing instars. The relative proportions of this species represented by sufficient material remain constant (linear regression: $y = ax + b$; glabella: correlation coefficient $r = 0.964$, probability value $p < 0.001$ ***; significant at $p < 0.05$); pygidia: correlation coefficient $r = 0.976$, probability value $p < 0.001$ ***; significant at $p < 0.05$) whatever the degree of development of individuals as for others phacopids (Khaldi et al. 2016; Crônier et al. 2018a, 2018b). The scatter diagram of the number of lenses versus the glabellar length shows that during growth, there is no trend to increase the number of files (Fig. 5a). There are not enough specimens with a relatively important size range. Nevertheless, this species is characterized by a relatively higher number of lenses, greatly variable (from 54 to 64). For comparison, *Feistops mongoliensis* from the same time interval from a neighboring area (i.e., Mongolia) differs by a reduced number of lenses (only 50) for the same number of file (15), but this species is represented by the smallest size glabella (Fig. 5a). Another specimen 'Aomage' differs substantially by only 44 lenses (and only 14 files; Fig. 4c) represented by the largest size glabella (Fig. 5b).

Fig5.jpg (from corel draw).

Comparison: The holotype and paratypes are relatively well preserved but fragmented and eroded. However, the characters observed allow a complete description. *Clarksonops junggariensis* gen. nov. sp. nov. differs from all other known sighted genera of the same age worldwide.

By comparison with other taxa from the same time interval, *Clarksonops junggariensis* gen. nov. sp. nov. differs from *Feistops mongoliensis* Crônier in Crônier et al., 2021 from the *Palmatolepis glabra pectinata* conodont Biozone and possibly from the *Palmatolepis crepida* conodont Biozone according to Spalletta et al. (2017). *Feistops mongoliensis* is characterized by a lowered glabella bounded by moderately divergent axial furrows (66°), S2 and S3 indistinct, no marginulation, a cephalon covered with finer tubercles (about equal in diameter to lenses in eye), less dense on entire composite lobe, a more reniform palpebral lobe, and a narrower pygidial axis. In lateral view (Fig. 4), *Clarksonops junggariensis* gen. nov. sp. nov. is characterized by a very short (sag., exsag.), ridge-like anterior border, projecting slightly forwards as *Phacops sensu lato* (Crônier et al. 2011; Khaldi et al. 2016). *Feistops mongoliensis* differs by an anterior border relatively short, forming a border projected forward and sloping posteroventrally. However, *Clarksonops junggariensis* gen. nov. sp. nov. shares with *Feistops mongoliensis* a short postocular distance, kidney-shaped palpebral lobes and a similar visual surface in size: 15 dorso-ventral files, a maximum of five lenses in each file in both taxa, and total number of lenses 50 in *Feistops mongoliensis* against 54-64 in *Clarksonops junggariensis* gen. nov. sp. nov.

Clarksonops junggariensis gen. nov. sp. nov. differs from *Nephranops* Richter and Richter, 1926 from the middle *triangularis* to early *crepida*, i.e., *Palmatolepis crepida* conodont Biozone according to Spalletta et al. (2017), that is characterized by a low kidney-shaped palpebral lobes with a visual surface generally without lenses or only with residual lenses.

Clarksonops junggariensis gen. nov. sp. nov. differs from *Pulvinocephalus* Feist, 2019 from early *triangularis* to early *marginifera*, i.e., *Palmatolepis marginifera marginifera* conodont Biozone according to Spalletta et al. (2017), that is characterized by a reduced-eyed visual surface or blind and with an anterior cephalic border forwardly extending beyond the anterior outline of glabella.

Clarksonops junggariensis gen. nov. sp. nov. differs from *Cryphops* Richter and Richter, 1926 from middle to late *crepida*, i.e., *Palmatolepis glabra prima* conodont Biozone according to Spalletta et al. (2017), that is characterized by an elliptical visual surface with 7-11 lenses, a very broad (sag.) and slightly vaulted pre-vincular doublure inclined posteroventrally, a deep and long (sag.) vincular furrow bordered by sharp edges and without post-vincular doublure.

Clarksonops junggariensis gen. nov. sp. nov. differs from *Babinops* Feist and Becker, 1997 from late *crepida* to *rhomboidea* zones that is characterized by genal spine or reducing to pointed genal angle, and a cephalic doublure without vincular furrow. This obsolescence of the vincular furrow is also observed in the contemporaneous phacopidelline taxa *Ductina* Richter and Richter, 1931 and *Dienstina* Richter and Richter, 1931. However, *Clarksonops junggariensis* gen. nov. sp. nov. shares with *Babinops minor* Feist et al., 2009 a short postocular distance, kidney-shaped palpebral lobes and a similar visual surface in size: 16 dorsoventral lens files in *Babinops minor* against 15 in *Clarksonops junggariensis* gen. nov. sp. nov., a maximum of five lenses in each file in both taxa, and maximum total number of lenses 61 in *Babinops minor* against 64 in *Clarksonops junggariensis* gen. nov. sp. nov.

Clarksonops junggariensis gen. nov. sp. nov. differs from *Houseops* Feist et al., 2009 from late *triangularis* to late *crepida*, i.e., *Palmatolepis glabra prima* conodont Biozone according to Spalletta et al. (2017), that is characterized by a relatively subdued transverse cephalic profile, a relatively flat glabella, smaller eyes distant from the posterior margin, flat palpebral lobes, a flat and short post-vincular area, and an ornamentation consisting of thin and sparse tubercles.

?*Houseops nalivkini* (Maksimova, 1955) from the early Famennian (possibly *triangularis* to *marginifera*) of the Southern Urals has been tentatively assigned to *Houseops* by Feist et al., 2009 mainly on account of the retracted anterior outline of its low glabella. *Clarksonops junggariensis* gen. nov. sp. nov. differs ?*H. nalivkini* because of these characters and by its more reduced abaxially postocular area, its coarser tuberculation, and a pygidial pleural field with at least 6 well-defined ribs.

The new species resembles *Phacops granulatus* (Münster, 1840) from the Famennian of Europe (Germany, Silesia, Poland, Moravia, Austria, England, Spain, Portugal) and North Africa (Algeria, Morocco), but also encountered in Urals, Kazakhstan, China, and Iran on account of its narrow cephalon, a visual surface with 15 vertical files and both palpebral area and palpebral lobe about same level in height. However, *Phacops granulatus* differs in having a broader (tr.) and inflated glabella pointed anteriorly, a palpebral furrow less convex (abax.), a longer exsagittal length of the postocular genal field, a lower edge of eye in the lateral border furrow and dense homogeneous tubercles on glabella.

The new species also resembles *Rabienops wedekindi* (Richter and Richter, 1926) from the late Famennian because of its narrow cephalon. However, *Rabienops wedekindi* differs in having a broader (tr.) glabella and a shorter visual surface with only 13 vertical lens files with four maximum lenses per file.

By comparison with other taxa from the same area but in the upper part of the Hongguleleng Formation where the genus *Omegops* [Struve, 1976](#) has been encountered in the late Famennian ([Xiang 1981](#); [Yuan and Xiang 1998](#)), *Clarksonops junggariensis* gen. nov. sp. nov. differs from *Omegops mobilis* ([Xiang, 1981](#)) or *O. cornelius* ([Richter and Richter, 1933](#)) that are characterized by a reduced intercalating ring as a narrow flat band, a distinct postocular pad, and coarser tubercles on glabella. *Clarksonops junggariensis* gen. nov. sp. nov. shares with *Omegops* a visual surface with 15 dorso-ventral files.

By comparison with other taxa from [neighboring areas](#) such as western Mongolia, *Clarksonops junggariensis* gen. nov. sp. nov. differs from *Feistops khovdensis* [Crônier in Crônier et al., 2021](#) from the *Palmatolepis rhomboidea* conodont Biozone according to [Spalletta et al. \(2017\)](#) that is characterized by a very wide cephalon, a visual surface with maximum six lenses per file and subdued and dense fine-sized tubercles on cephalon.

Clarksonops junggariensis gen. nov. sp. nov. differs from the poorly preserved *?Houseops olonbulagensis* [Crônier in Crônier et al., 2021](#) from the *Palmatolepis glabra pectinata* conodont Biozone according to [Spalletta et al. \(2017\)](#) that is characterized by a wide cephalon, a rather wide occipital ring, a thin inter-lensar sclera, no subocular pad, a rather wide pygidium, and a [shorter](#) pygidial axis.

Clarksonops junggariensis gen. nov. sp. nov. differs from the undetermined Mongolian specimens from the *Palmatolepis rhomboidea* conodont Biozone according to [Spalletta et al. \(2017\)](#) that are represented by pygidia showing no evidence of sculpture, rather wide with a length/width ratio about 49% (53% for *Clarksonops junggariensis* gen. nov. sp. nov.), a pygidial axis long (sag.) and rather narrow (tr.), and showing a slight constriction from the fourth axial ring.

? Houseops cf. olonbulagensis [Crônier in Crônier et al., 2021](#)

[Fig. 6a-c](#)

Material: One fragmented cephalon [NIGP/180510](#) from the lower limestones and marly beds of the lower part of the Hongguleleng Formation ([Fig. 1](#)): Aomage locality (Latitude 46°37.59'N, Longitude 86°00.25'E in the vicinity of Aomage), Hongguleleng Formation, lower part of the lower member, [lower](#) Famennian, *Palmatolepis crepida* conodont Biozone, Late Devonian.

[Fig6.jpg \(from corel draw\)](#)

Remarks: The fragmented cephalon can be assigned with doubt to ? *Houseops cf. olonbulagensis* from the latest *crepida* conodont Biozone of western Mongolia on account of a wide cephalon (about 56%), a narrow glabellar base (48%), L1 with subquadrate lateral lobes not strongly inflated, a visual complex with a maximum of 5 lenses per file (Fig. 4c), an exsagittal length of the postocular genal field almost equal length (exsag.) of the posterior border, and moderately dense medium-sized/coarse tubercles of rather homogeneous size on glabella. Incompleteness and bad preservation of the exoskeleton prevents us to get a complete description and a right assignation. We are not confident with this assignation.

Undetermined phacopid

Fig. 6d

Material: One mostly exfoliated pygidium (plus few thoracic segments) NIGP/180511 from the lower limestones and marly beds of the lower part of the Hongguleleng Formation (Fig. 1): Aomage locality (Latitude 46°37.59'N, Longitude 86°00.25'E in the vicinity of Aomage), Hongguleleng Formation, lower part of the lower member, lower Famennian, *Palmatolepis crepida* conodont Biozone, Late Devonian.

Remarks: The mostly exfoliated pygidium is rather wide with a length/width ratio about 42% (excluding the half ring), and its maximum width (tr.) at about of its midlength (sag.) in dorsal view. Posterior outline broadly rounded. Pygidial axis long (sag.), rather narrow (tr.) and tapered. Pygidial pleural field with probably five distinct ribs delimited by deep pleural furrows. Interpleural furrows indistinct. Last thoracic segments and pygidium showing no evidence of sculpture.

4. Discussion and conclusions

The studied material from the Hongguleleng Formation originates from 3 km west of Bulongguoer Reservoir in northwestern Xinjiang that ranges stratigraphically from the *Palmatolepis crepida* to at least the late *rhomboidea* Biozone, i.e., the *Palmatolepis gracilis gracilis* Biozone (Spalletta et al. 2017). Trilobites were sampled from an interval of very thin-bedded limestone with shale and volcanoclastic rocks within the *crepida* Biozone, which also yielded other fauna such as diverse macrofossils including small crinoids, brachiopods, corals and bryozoans. Within this interval, Fan and Gong (2016) showed that the Lower Member of the Hongguleleng in the Bulongguoer section is dominated by interbedded bioclastic calcarenites and calcareous mudstones with common parallel- or cross-stratification and local hummocky cross stratification and benthic fossils.

The studied material is most often incomplete, often poorly preserved as internal mold. Due to insufficient preservation of well-preserved cephalons, additional material is required. However, the relatively well-preserved phacopid trilobites are assigned to *Clarksonops junggariensis* gen. nov. sp. nov., a so-far endemic taxon, and *?Houseops cf. olonbulagensis*, a taxon with doubt encountered in western Mongolia, from the *crepida* conodont Biozone. The biometric analysis is complementary to the descriptive systematic study because it enables us to characterize the intra-specific variability quantitatively. More particularly, *Clarksonops junggariensis* gen. nov. sp. nov. is characterized by a relatively higher number of lenses, greatly variable. If the common morphological characteristics of the Silurian-Middle Devonian phacopids is the development of large kidney-shaped eyes with a great number of lenses, the common morphological characteristics of the Upper Devonian phacopids is the development of the reduced eyes or blind taxa. The so-far ancestral configuration of a large-eye was reported by van Vierssen and Vanherle (2018) in the Frasnian in shallow neritic environments in the Ardennes. Newly, Feist and Klapper (2022) documented a genus, i.e. *Cronierella* Feist and Klapper, 2022 from the topmost Givetian and lower Frasnian in Montagne Noire (France). With several features of the cephalon, i.e. the outline and vault of the glabella and the configuration of the intercalating ring *Cronierella* is very close to late representatives of *Eldredgeops* Struve, 1990 recognized with confidence in the late Givetian. Nevertheless, their pygidia are quite dissimilar (general shape, short axis distant from the posterior edge). The question of phyletic relationships remains open. Moreover, the faunal endemicity from the Bulonguoer section is also underlined by an endemic shallow-water conodont (Zhang et al. 2021) or ostracod (Song et al. 2016) faunas indicating isolation of the Junggar Basin during the early Famennian. Nevertheless, the observed endemism could be only the expression of a hitherto unexploited shallow-water domain.

Interestingly, a comparison of the studied trilobites from the reference section in the CAOBS with those from neighboring areas, i.e. western Mongolia including the western Mongolia Hushoot Shiveetiin gol section (Crônier et al. 2021) has been made to get a better understanding of the palaeogeographical and palaeoecological distribution of Late Devonian faunas. Indeed, the Samnuuruul Formation is also Famennian in age as the Hongguleleng Formation. The eastern part of the Hushoot Shiveetiin gol section that ranges stratigraphically from the *Palmatolepis minuta minuta* conodont Biozone to at least the *Palmatolepis rugosa trachytera* conodont Biozone with hiatuses of several conodont biozones (Munkhjargal et al. 2021). Trilobites were sampled in several levels, which also yielded other fauna such as diverse conodonts and macrofossils including brachiopods,

solitary rugose corals, branching tabulate corals (Suttner et al. 2019; Munkhjargal et al. 2021; Nazik et al. 2021; Waters et al. 2021). According to conodont biofacies and microfacies analyses (Suttner et al. 2019; Munkhjargal et al. 2021), a slight change in bathymetric conditions seems to occur from a slight shallowing during the late *Palmatolepis crepida* conodont Biozone followed by a deepening during the *Palmatolepis rhomboidea* conodont Biozone in the Hushoot Shiveetiin gol section. In the Bulongguoer section, from the base of the Hongguleleng Formation onward a transgressive regime prevails (Kido et al. 2013). Fan and Gong (2016) documented an offshore transition with calcareous storms and background deposits with local volcanic influences as sedimentary environment according to trace-fossil biofacies and sedimentary facies analyses. They recognized a colonization window in the arc-related setting that is closely related to sedimentation rates and frequency of events, determining completeness of burrow system structure and maturity of benthic communities. The water energy could also be an environmental factor controlling the composition of communities as recognized by Song et al. (2018) for the ostracod assemblages from the Lower Member of the Hongguleleng Formation. Different patterns of sedimentation have been recognized between the Hongguleleng Formation in western Junggar region and the Samnuuruul Formation in western Mongolia leading to a geographic isolation to support ecological refugia, mainly in the aftermath of the Frasnian/Famennian event (Kido et al. 2013).

At a global scale Famennian phacopids are characterized by a worldwide distribution (Chlupáč 1975; Crônier and François 2014). However, if the majority of genera is apparently limited to a single cratonic margin, the other few genera are cosmopolitan (Crônier and François 2014). New discoveries such as the recently studied western Mongolia or West Junggar (present study) in NW China once again reveals the endemic nature of many genera.

In the early Famennian, the post-Kellwasser event recovery marked a new step especially for phacopid trilobites (Lerosey-Aubril and Feist 2012; Crônier et al. 2013). The evolutionary pattern in phacopids shows a major increase in the specific origination during the late early Famennian (Crônier et al. 2013). A first turnover occurred during the early Famennian with few new genera reported, i.e., *Nephranops* Richter and Richter, 1926 in European deep offshore cephalopod environments and *Pulvinocephalus* Feist, 2019 from the *Palmatolepis triangularis* Biozone. Nevertheless, the significant post-Kellwasser recovery occurred during the late early Famennian leading to a second turnover with new blind phacopid genera from deep offshore habitats and eyed-phacopid genera from shallower habitats in the photic zone (Crônier et al. 2013; Feist 2019). This study provides

an update for species and subspecies currently known with regard to their age distribution according to conodont zonation.

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Figure 1. (a) Location of the Central Asian Orogenic Belt (CAOB) on a palinspastic map (<http://www.palaeos.com>) (modified from [Blakey \(2016\)](#), with continent positions and shapes modified from the tectonic data of [Hara et al. \(2010\)](#), [Metcalf \(2011\)](#), and [Xiao et al. \(2010\)](#); trilobite assemblages modified from [Crônier and François \(2014\)](#)). (b) Geographical location of Xinjiang, northwestern part of China and location of studied sections in the Western Junggar exhibiting Paleozoic deposits. Geological map of the investigated area: modified from [Safonova et al. 2019](#)).

Figure 2. Lithological log, stratigraphical range, and trilobite level of the Hongguleleng Formation from the western Junggar, Late Devonian NW China. Modified from [Carmichael et al. 2016](#).

Figure 3. *Clarksonops junggariensis* gen. nov. sp. nov., phacopid trilobites from 3 km west of Bulongguoer Reservoir, western Junggar, Hongguleleng Formation, lower part of the lower member, lower Famennian, *Palmatolepis crepida* conodont Biozone, Late Devonian NW China. (a-c) Cephalon, NIGP/180500, respectively in dorsal, ventral and lateral views. (d-f) Cephalon, NIGP/180501, respectively in dorsal, frontal and lateral views. (g-h) Cephalon, NIGP/180504, respectively in frontal and ventral views. (i-j) Cephalon, NIGP/180502, respectively in dorsal and frontal views. (k-m) Cephalon, NIGP/180506, respectively in dorsal, lateral and frontal views. (n) Displaced enrolled exoskeleton, NIGP/180509. (o) Cephalon, NIGP/180505, in lateral view. (p) Cephalon, NIGP/180503, in lateral view. (q) Fragmented pygidium, NIGP/180508, in dorsal view. (r-s) Pygidium plus few thoracic segments, NIGP/180507, respectively in dorsal and lateral views. Scale: 3 mm.

Figure 4. (a) Sagittal profiles of anterior part of cephalon in *Feistops* illustrated in [Crônier et al. 2021](#), *Houseops* illustrated in [Feist 2019](#), and *Clarksonops junggariensis* gen. nov. sp. nov. (this study). (b-c) Schematic representations of (b) eight visual surfaces in *Clarksonops junggariensis* gen. nov. sp. nov., Bulongguoer Reservoir and (c) one available visual surface in ? *Houseops cf. olonbulagensis* [Crônier in Crônier et al. 2021](#), Aomage locality, western Junggar, Hongguleleng Formation, Late Devonian NW China. I–VII: horizontal rows; 1–15 (from the front): vertical files. Grey boxes indicate number of lens present

Figure 5. Bivariate plot using (a) the glabellar length (in mm) as a function of the number of lenses; (b) the glabellar length (in mm) as a function of the glabellar width (in mm); (c) the pygidial length (in mm) as a function of the pygidial width (in mm).

Figure 6. Phacopid trilobites from the western Junnger, Hongguleleng Formation, lower part of the lower member, lower Famennian, *Palmatolepis crepida* conodont Biozone, Late Devonian NW China. (a-c) ? *Houseops cf. olonbulagensis* Crônier in Crônier et al. 2021, Aomage, NIGP/180510, fragmented cephalon respectively in dorsal, frontal and lateral views. (d) Undetermined phacopid, Aomage, NIGP/180511, fragmented thoracopygon in dorsal view. Scale: 3 mm.