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First record of malformed trilobites from the Silurian of Ukraine

Presented by Academician of the NAS of Ukraine S.B. Shekhunova

This article presents the first documented case of malformed trilobite exoskeletons from the Silurian of Ukraine. Fossils of animals with injuries and pathologies are of significant palaeobiological value, as they provide essential insights into the evolution of predator-prey interactions, trophic networks, animal behavior, and genetic anomalies. The material under study consists of two pygidia of Bumastus restevensis from the Rykhta Formation (Ludlow, Upper Silurian) in Khmelnytskyi Oblast (western Ukraine, the Volyn-Podillia Monocline). A comparative analysis of these malformed exoskeletons with similar specimens from other global localities reveals that they are unique, with no direct analogues. The injuries observed are interpreted as "predation scars," indicative of unsuccessful predatory attacks. The distinctive morphology of these malformations suggests that they were most likely inflicted by cephalopods, arthropods, such as phyllocarid crustaceans and/or aquatic chelicerates, or fishes.

Key words: *exoskeleton malformation, Trilobita, Ludlow, Volyn-Podillia Monocline, "predation scars".*

Introduction. The fossilized remains of extinct animals exhibiting injuries and pathologies are essential for understanding the evolution of predator-prey interactions, trophic networks, animal behavior, congenital anomalies, growth defects, and related phenomena [1, 2]. Trilobites, due to their biomineralised exoskeletons, possess a high preservation potential and therefore serve as a significant source of data on abnormalities in fossil arthropods [3—7 and references therein].

In Ukraine, trilobites have been reported from the Cambrian to Devonian strata of the Volyn-Podillia Monocline [8, 9], the Carboniferous deposits of the Lviv Palaeozoic Trough [10], the Donets Basin, and the Dnipro-Donets Depression [11, 12], as well as Permian strata of the Crimean Geosyncline [13, 14]. To date, only a single case of a malformed trilobite has been documented from Ukraine [10: Fig. 4J]. Typically, abnormal trilobites comprise around 0.05 % of a given population; however, their frequency can locally reach up to 2 %, or even 5 % in exceptional cases [15].

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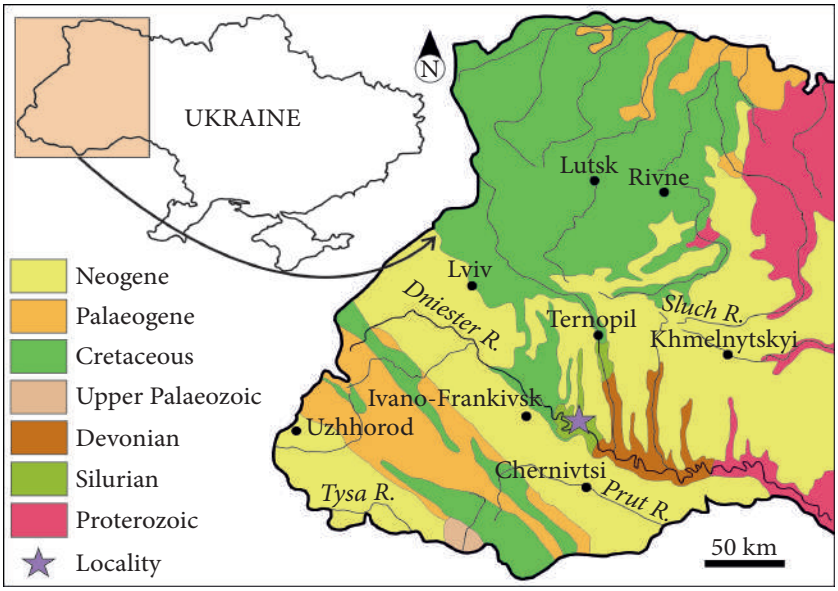

Fig. 1. Schematic geological map of western Ukraine showing the geographical location of the fossil site with malformed trilobites

The **aim** of this article is to investigate the palaeoecological significance of the first documented occurrence of malformed trilobite exoskeletons from the Silurian of Ukraine.

Material and methods. The material under investigation consists of two moderately preserved pygidia of *Bumastus restevensis* Balashova, 1975 (specimens NMNHU-G 9763/02 and NMNHU-G 9763/09). These specimens were collected by the late Dr. Leonid Konstantynenko (1943–2014) from the Rykhta Formation (Ludlow, Late Silurian) at outcrop No. 21 (outcrop numbering as per [16: Fig. 2]), located near the village of Hrynchuk in Khmelnytskyi Oblast. This locality lies within the Volyn-Podillia Monocline on the southwestern margin of the East European Craton (Fig. 1).

Specimens NMNH-G 9763/02 and NMNH-G 9763/09 are housed in the Department of Geology of the National Museum of Natural History, National Academy of Sciences of Ukraine (Kyiv; acronym: NMNHU). Prior to photography, the fossils were coated with ammonium chloride (NH_4Cl). The terminology used in this article follows the traditional classification of trilobite exoskeleton malformations [3–7].

Geological setting. The trilobite specimens examined in this study originate from the Late Silurian Rykhta Formation (Fig. 2). This formation extends across the Volyn-Podillia Monocline and the western part of the eastern slope of the Lviv Palaeozoic Trough. It comprises a 22—48 m thick sequence of argillaceous limestones interbedded with marlstone layers and thin-bedded dolomites. In the Dniester River region, the upper part of the formation consists of a succession of domerites and dolomites, up to 7.0 m thick. North of the reference section near the village of Rykhta (Khmelnytskyi Oblast), the formation is laterally replaced by dolomites of the Toky Formation and domerites of the Velytsi Formation. Based on lithological characteristics, the formation is subdivided into the Hrynchuk Subformation (argillaceous limestones and marlstones) and the Isakovytsi Subformation (thin-bedded dolomites) [16, 17]. The Rykhta formation contains a diverse and abundant marine biota, including calcareous algae, chitinozoans, corals, stromatoporoids, brachiopods, bivalves, tentaculitids, and ostracods [16, 17 and references therein].

	Series	Stage	Group	Formation
SILURIAN	Pridoli		Skala	Dzvenyhorod
				Trubchyn
				Varnytsya
				Pryhorodok
	Ludlow	Ludfordian	Malynivtsi	Rykhta
				Tsviklivtsi
				Konivka
		Gorstian	Bagovytsya	Bagovytsya
	Wenlock	Homerian	Kytayhorod	Ternava
		Sheinwoodian		
	Liandovery	Telychian		Furmanivka

Fig. 2. Silurian stratigraphy of Podillia in western Ukraine and the position of the Rykhta Formation. Stratigraphic scheme modified after [17]

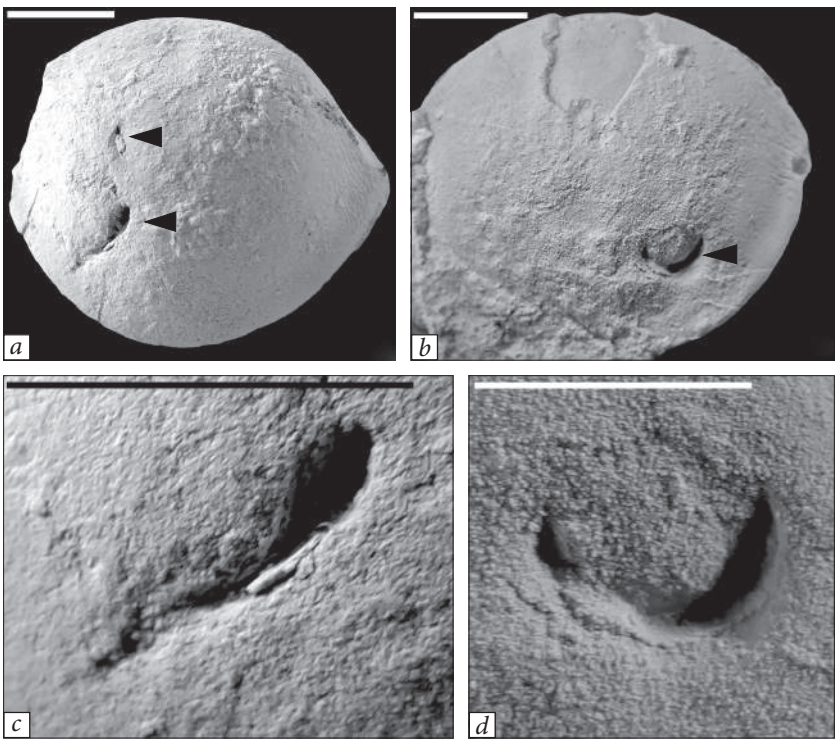

Fig. 3. Malformed pygidia of *Bumastus restevensis* Balashova, 1975 from the Late Silurian Rykhta Formation of western Ukraine. *a*, *c* — specimen NMNHU-G 9763/02 (*a* — dorsal view of the pygidium, *c* — enlarged malformation); *b*, *d* — specimen NMNHU-G 9763/09 (*b* — dorsal view of the pygidium, *d* — enlarged malformation). Scale bars — 5 mm

Description of the malformed *Bumastus restevensis*. Specimen NMNHU-G 9763/02 (Fig. 3, *a*, *c*) is an almost completely preserved pygidium, measuring 24 mm in width and 19 mm in length. It displays two elongated pits located on the left side of the pygidium: one near the posterior margin (the larger pit), and one near the mid-length of the pygidium (the smaller pit). The larger pit is wedge-shaped, slightly curved towards the lateral margin of the pygidium, and measures 5 mm in

length and 0.15—0.70 mm in width. Its depth and width gradually decrease from anterior (near the anterior margin of the pygidium) to posterior, reaching a maximum depth of approximately 0.5 mm

The smaller pit is ellipsoidal or teardrop-shaped, located approximately 4 mm from the larger pit. It measures 2 mm in length and 1 mm in width at its widest point and is partially filled with matrix.

Specimen NMNHU-G 9763/09 (see Fig. 3, *b*, *d*) is a nearly complete, though poorly preserved, pygidium measuring 17 mm in length and approximately 20 mm in width. The malformation consists of a crescent-shaped pit in the posterior part of the pygidium, near the sagittal line. The pit's width along the anterior-posterior axis is 2 mm, with a length of approximately 2 mm and a depth of about 1 mm. The greatest depth is at the posterior end of the pit (near the posterior margin of the pygidium), with the depth gradually decreasing towards the edges. The transverse profile of the pit is V-shaped, with steep walls and a narrow, sharply concave bottom with angular margins.

Discussion and concluding remarks. The Palaeozoic deposits of Podillia have experienced minimal tectonic deformation or metamorphism, supporting the interpretation that the trilobite exoskeleton injuries described here occurred during the animals' lifetime.

The malformations observed in the studied specimens are interpreted as the result of unsuccessful predatory attacks ("predation scars" as described in [2—4]), likely by cephalopods, arthropods or fishes. This interpretation is supported by the characteristic morphology of the injuries, which is distinct from those typically caused by other factors [cf. 2—7].

The elongated pits on pygidium NMNHU-G 9763/02 are nearly symmetrically placed. However, the force responsible for these damages was insufficient to produce a smaller pit that fully corresponded morphologically to the larger one. This discrepancy could be due to the direction of the predator's attack on the trilobite and the considerable bulging of the pygidium, which may have prevented the formation of perfectly symmetrical damage. Additionally, uneven regeneration of the injury across the pygidium may have further contributed to the asymmetry.

The malformation in specimen NMNHU-G 9763/02 bears a strong resemblance to a similar injury observed on the pygidium of the Ordovician trilobite *Parabarrandia bohemica* (Novák, 1884) from the Czech Republic [18]. This injury was interpreted as a partially healed wound from a failed predatory attack by a cephalopod or arthropod during the trilobite's life [18].

The injury in specimen NMNHU-G 9763/02 is also similar to injury types 4 and 5 observed on the shells of the brachiopod *Ivdelinia pulchra* Franchi, Schemm-Gregory et Klug, 2013 from the Givetian (Middle Devonian) of Morocco [19]. Cephalopods are likely the agents responsible for these injuries, as they are known to produce paired fractures with their beaks [20—24]. Therefore, the paired injuries in the *Bumastus* specimen can reasonably be attributed to cephalopods, albeit with some caution [19].

Silurian cephalopods of Podillia are relatively well-studied (see review in [25]). Fossils of *Aptychopsis*, calcite structures interpreted as the aperture operculum of orthocerid nautiloids [26], parts of the jaw apparatus of orthocerids [27], or protective shields used by orthocerids for defense [28], have been found in Silurian deposits of Podillia [29: pl. 2, fig. 4]. However, there is no evidence to suggest that *Aptychopsis* was part of the jaw apparatus of nautiloids. Moreover, the morphology of the malformation on specimen NMNHU-G 9763/09 indicates that the predator's tool was slightly pointed and semi-circular in plan, whereas *Aptychopsis* are typically flat or only slightly convex.

Arthropods capable of causing injuries, as observed in the trilobite specimens, include phyllocarids, eurypterids, and other aquatic chelicerates [1, 30]. Although phyllocarids — known as scavengers and predators [31] — have not yet been recorded from the Silurian of Ukraine, eurypterids have.

Baltoeurypterus tetragonophthalmus (Fischer de Waldheim, 1839) [32, 33] and *Pterygotus* sp. [34], as well as the synziphosurine *Pasternakevia podolica* Selden et Drygant, 1987 [32, 33], are known from the Ludlow deposits in Podillia. However, since these chelicerates are found in lagoonal facies that lack trilobites [32, 35], the likelihood that they caused the injuries observed in the trilobites is considered negligible.

The Silurian Period marked the emergence of the first jawed fishes, including placoderms and acanthodians [36]. Rare and poorly preserved fish remains occur in the Ludlow strata of Ukraine [37]. The shape of the malformation on the pygidia of *Bumastus restevensis* resembles the shape of the upper jaw morphology of some placoderms, suggesting that these early fishes might also have been responsible for the damage investigated in this study.

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ПЕРША ЗНАХІДКА ПРИЖИТТЄВО ПОШКОДЖЕНИХ ТРИЛОБІТІВ
У СИЛУРІЙСЬКИХ ВІДКЛАДАХ УКРАЇНИ

Досліджено перший задокументований випадок прижиттєво пошкоджених екзоскелетів трилобітів із силурійських відкладів України. Скам'янілості тварин з пошкодженнями та патологіями мають значну палеобіологічну цінність, оскільки дають змогу зрозуміти еволюцію взаємодій хижака і жертви, трофічних мереж, поведінки тварин та генетичних аномалій. Досліджений матеріал складається з двох пігідіїв *Bumastus restevensis* з рихтівської світи (лудлов, верхній силур) Хмельницької області (Волино-Подільська монокліналь). Порівняльний аналіз цих екзоскелетів з аналогічними зразками з інших місцезнаходжень світу показує, що вони є унікальними і не мають прямих аналогів. Виявлені пошкодження інтерпретуються як «шрами хижацтва», що свідчать про невдалі напади хижаків. Характерна морфологія цих ушкоджень дає підставу припустити, що вони, найімовірніше, були завдані головоногими молюсками, членистоногими, такими як філокариди та/або водні хеліцерові, або рибами.

Ключові слова: *прижиттєві пошкодження екзоскелета, Trilobita, лудлов, Волино-Подільська монокліналь, "шрами хижацтва".*