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TRACE FOSSIL *CURVOLITHUS* FROM THE MIDDLE JURASSIC CRINOIDAL LIMESTONES OF THE PIENINY KLIPPEN BELT (CARPATHIANS, POLAND)

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Abstract: The trace fossil *Curvolithus simplex* has been described for the first time in carbonate facies: the Bajocian crinoidal limestones of the Pieniny Klippen Belt. *Curvolithus* is typical of the *Cruziana* ichnofacies. This suggests deposition of the crinoidal limestones at shelf depths, below the fair-weather wave base. *Curvolithus* occurs exclusively in the lowermost part of the limestones, which are interpreted as having been deposited in the toes of migrating bars or banks of crinoidal sand. Such settings display increased preservational potential of trace fossils, and are preferred by the most probable *Curvolithus* tracemakers, that is, carnivorous or scavenging gastropods.

Key words: Jurassic, Poland, Carpathians, Pieniny Klippen Belt, trace fossils, *Curvolithus*.

Introduction

Trace fossils are useful tools for the reconstruction of benthic life and paleoenvironmental conditions (e.g., Frey 1975; Ekdale et al. 1984; Frey & Pemberton 1985; Pemberton 1992; Donovan 1994; Bromley 1996). Unfortunately, they are very rare in some facies, for example in massive calcarenites. Unexpectedly, the ichnogenus *Curvolithus* has been found in Middle Jurassic calcarenites of the Pieniny Klippen Belt, in two sections in similar stratigraphic position, but in different paleogeographical/tectonic units. This is the first occurrence of this trace fossil in carbonate facies. Its description and interpretation is the main aim of this paper.

The illustrated specimens are housed in Jagiellonian University in Kraków (acronym 169P).

Geological setting

The Pieniny Klippen Belt Basin is interpreted as a separate branch of the northern Tethys, in which several longitudinal facies zones can be distinguished. Each zone displays a distinctive vertical facies succession. One of them, the Czorsztyn Succession, corresponds to submarine ridges, others to troughs (Branisko and Pieniny Successions), while others occupy a transitional position (Niedzica and Czertezik Successions) (see Birkenmajer 1977, 1979, 1986) (Fig. 1).

Crinoidal limestones are a characteristic Middle Jurassic (Bajocian) Tethyan facies of the Pieniny Klippen Belt from Slovakia, Poland and Ukraine. They are usually massive, fine- to medium-grained, predominantly white, grey and red calcarenites, which only locally show indistinct bedding. The grains are dominated by crinoid ossicles, and other bioclasts are very rare. The thickness of these limestones depends on their primary paleogeographical position within sedimentary basin. The thickest limestones occur in the shallowest zone (Czorsztyn Succession — from 10 m up to 150 m thick), while the thinnest are associated with deeper zones (e.g., Niedzica Succession — only about 10 m) (Birkenmajer 1977) (Fig. 1).

Two localities — the Czorsztyn-Sobótka Klippe and Niedzica-Podmajerz Klippe — are examined here (Fig. 1). They belong to the Czorsztyn and Niedzica Successions, respectively, which accumulated generally in subtidal to neritic shelf environments of the submarine Czorsztyn Ridge (sensu Birkenmajer 1986; 1988 = swell — sensu Mišík 1994) and on its southern slope (Fig. 2). During the Aalenian, marlstones and claystones of the Fleckenmergel facies, represented by the Harcygrund Shale and Skrzypny Shale Formations, were formed (Birkenmajer 1977). Bajocian uplift of the Czorsztyn Ridge resulted in a marked change of sedimentary conditions (Birkenmajer 1963; Aubrecht et al. 1997; Wierzbowski et al. 1999) leading to deposition of white crinoidal limestone (Smolegowa Limestone Formation) followed by red crinoidal limestone (Krupianka Limestone Formation). In both successions, the crinoidal grainstones of the Smolegowa Limestone Formation were produced by crinoid communities, which developed on the southern shelf of the Czorsztyn Ridge. After gradual sea-level rise during the latest Bajocian and Bathonian, the red pelagic nodular ammonitico rosso-type limestones of the Czorsztyn and Niedzica Limestone Formations originated; these dominated in the time span from Callovian to Late Tithonian.

Locally, large scale cross-bedding (sets up to 50 cm thick) occurs in the Smolegowa and Krupianka limestones, for example in the Hatné-Hrádok (Aubrecht & Sýkora 1998) and the Czorsztyn Castle Klippe sections (Wierzbowski et al. 1999). The cross-bedding indicates strong bottom currents and depo-

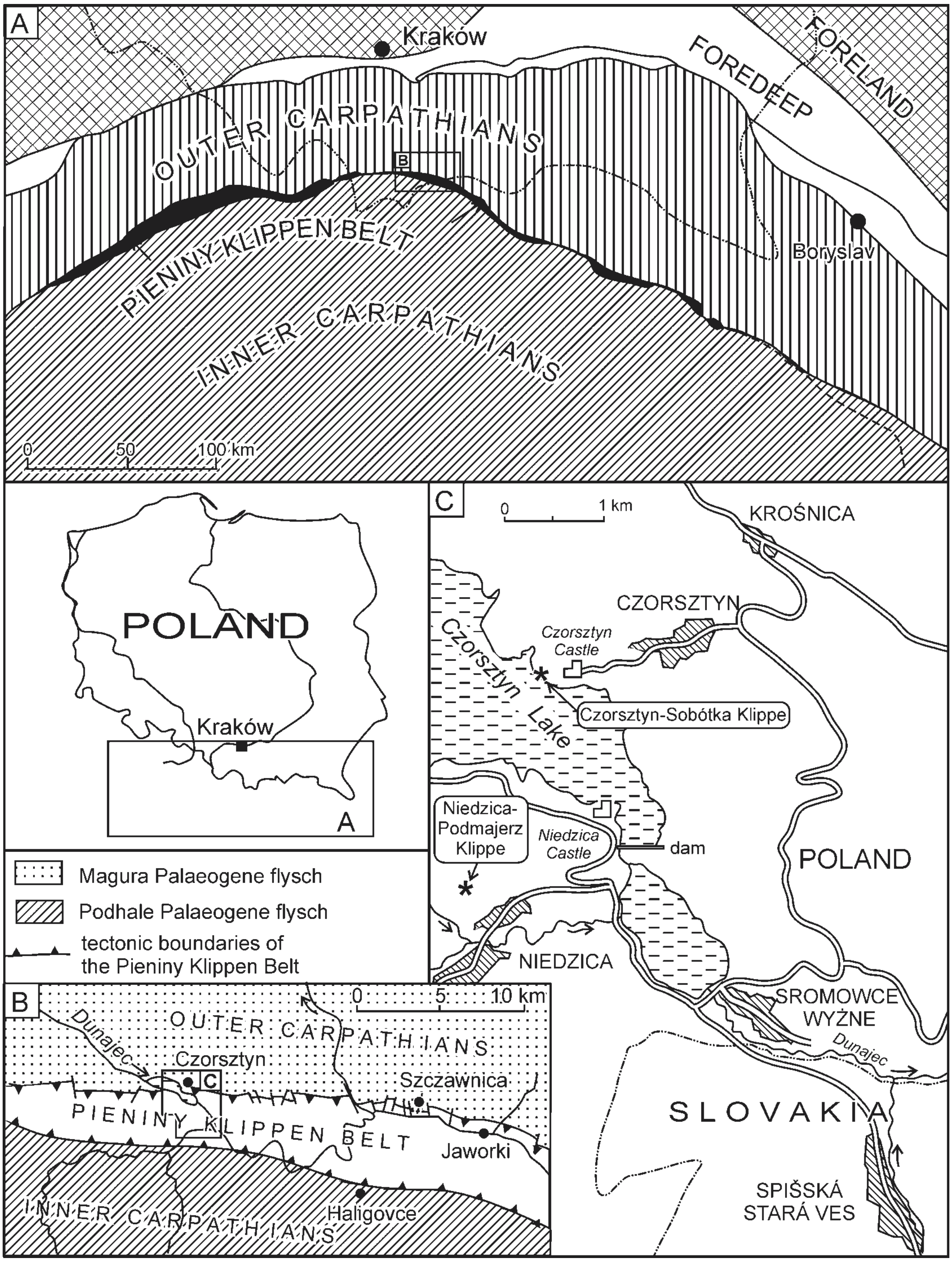

Fig. 1. Location map.

sition of large bedforms, probably bars. The crinoid calcarenites of the Smolegowa Limestone Formation may be interpreted as shallow-water crinoidal shoal complexes (Aubrecht & Sýkora 1998) that resulted from disintegration of "crinoid meadows" (with limited post-mortem transport of crinoid ossicles; Głuchowski 1987) and subsequent accumulation in submarine banks or bars.

The Middle Jurassic crinoidal limestones are widespread deposits within the entire western Tethys and they were probably deposited in similar paleotectonic and paleoenvironmental conditions (Jenkyns 1971; Bernoulli & Jenkyns 1974).

Studied sections

Niedzica-Podmajerz Klippe. This is a huge klippe located (Fig. 2) in the forest ~400 m north of the Niedzica village (Birkenmajer & Znosko 1955 — fig. 1; Birkenmajer 1958 — fig. 80; Birkenmajer 1977 — figs. 7K, 24A; Birkenmajer

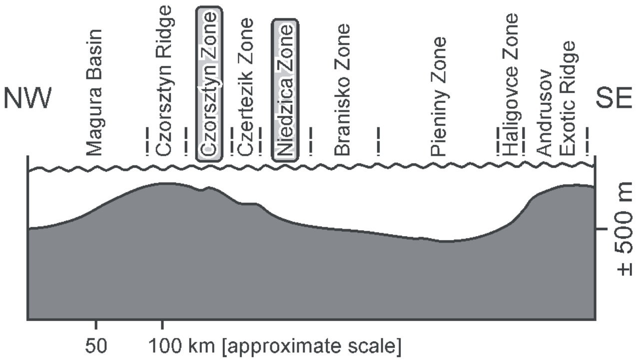

Fig. 2. Palinspastic cross-section of the Pieniny Klippen Belt Basin during the Middle Jurassic (after Birkenmajer 1977, 1986, simplified). Zones represented by the investigated sections are indicated in the shaded frames.

1979 — fig. 67). It displays a complete sequence of Jurassic deposits of the Niedzica Succession. The Jurassic limestones and radiolarites form tectonically overturned thrust blocks composed of two or three tectonic slices surrounded by Upper Cretaceous marls.

The section has been studied in an artificial trench dug in the northwestern part of the klippe, where soft, strongly weathered, grey and black marly shales (Fleckenmergel-type Alpine facies) with spherosiderite concretions of the Skrzypny Shale Formation dominate. The boundary between this formation and the lowermost beds of the light-greyish crinoidal limestones of the overlying Smolegowa Limestone Formation was exposed at the south-eastern end of the trench. The crinoidal limestones are about 3.70 m thick. They become red coloured and show an indistinct nodular character. These limestones, in turn, are overlain by 3.60 m thick, hard, dark red, thin-bedded crinoidal limestones with many marly intercalations, which are assigned to the Krupianka Limestone Formation. The overlying ammonitico rosso-type red nodular limestones with marked admixture of marls, about 11.0 m thick, belong to the Niedzica Limestone Formation (comp. Wierzbowski et al. 1999).

The lowermost part of the Smolegowa Limestone Formation consists of thin-bedded limestones with beds up to 25 cm thick, and with abundant fossils, mainly brachiopods and belemnite guards. The trace fossils described here were found in excavated blocks containing clasts of light-greenish micritic limestone, pyrite framboids, phosphate concretions, fragments of Middle Triassic dolomites and dedolomitized carbonates, and quartz grains transported from the emerged and eroded Czorsztyn Ridge (Birkenmajer 1958, 1963; Mišík & Aubrecht 1994).

Rare but well-preserved ammonites occur in a bed ~1 m above the base of the Smolegowa Limestone Formation. They belong to Stephanoceratidae family (A. Wierzbowski, pers. com. 2002), which is characteristic of the Lower Bajocian. The topmost part of the highest bed of the overlying Krupianka Limestone Formation yielded a single specimen of *Garantiana* (*Hlaviceras*) *tetragona* Wetzel, which is indicative of the Tetragona Subzone (uppermost part of the Garantiana Zone) of the Upper Bajocian (Wierzbowski et al. 1999).

Czorsztyn-Sobótka Klippe. This section is located in the northern part of the so-called Czorsztyn-Sobótka Klippe (Fig. 2) just above the water level of the artificial reservoir, about 200 m below Czorsztyn Castle (Birkenmajer 1963, 1977, 1979). During low-water, the lowermost part of the white crinoidal limestones of the Smolegowa Limestone Formation crop out at the contact with the spherosideritic black shales of the Skrzypny Shale Formation (lower Bajocian). The boundary between these two formations is very poorly seen due to weathering. The examined specimens of *Curvolithus* derive from a rubble containing blocks of light-yellowish, fine-grained crinoidal limestones with small clasts of greenish micritic limestones, weathered pyrite framboids, small phosphorite concretions and rare ammonite shell fragments. Still younger red crinoidal limestones of the Krupianka Limestone Formation are barren of index fossils, but the lowermost part of the overlying red nodular ammonitico rosso-type limestones of the Czorsztyn Limestone Formation contains ammonites (e.g., *Dimorphinites dimorphus* (d'Orbigny) and *Nannolytoceras tripartitum* (Raspail)) indicating the uppermost Bajocian (Parkinsoni Zone) (Wierzbowski et al. 1999). Therefore, both the Smolegowa Limestone Formation and the overlying Krupianka Limestone Formation belong to the Bajocian.

Trace fossils

Ichnogenus *Curvolithus* Fritsch, 1908

Diagnosis: Straight to curved, horizontal, subhorizontal to rarely oblique, ribbon-like or tongue-like, flattened, unbranched, essentially endostratal traces with three rounded lobes on upper surface and up to four lobes on concave or convex lower surface. Central lobe on upper surface wider that than outer lobes and separated from them by shallow, angular furrows. Faint, narrow central furrow dividing central lobe in upper surface may be present (after Buatois et al. 1998).

Ichnospecies *Curvolithus simplex* Buatois, Mangano, Mikuláš & Maples 1998
Fig. 3

Material: Five rock blocks with eight burrows.

Diagnosis: *Curvolithus* with a smooth, trilobate upper surface and a smooth, unilobate or trilobate, concave or convex lower surface (after Buatois et al. 1998).

Description: Straight to slightly winding, horizontal to inclined, trilobate ribbon-like trace fossils. From a hypichnial view, they are composed of a central, flat or slightly convex zone and two convex, rounded side lobes. All the parts are smooth. Width of the entire burrow ranges from 9 to 13 mm, while side lobes are 2–3 mm wide.

Remarks: According to the revision by Buatois et al. (1998), *Curvolithus* has only two ichnospecies: *C. multiplex* Fritsch, and *C. simplex* Buatois, Mangano, Mikuláš & Maples. *C. multiplex* is easily recognizable by his quadralobe lower surface.

Curvolithus is interpreted as a locomotion trace (repichnion), produced most probably by carnivorous gastropods (Heinberg

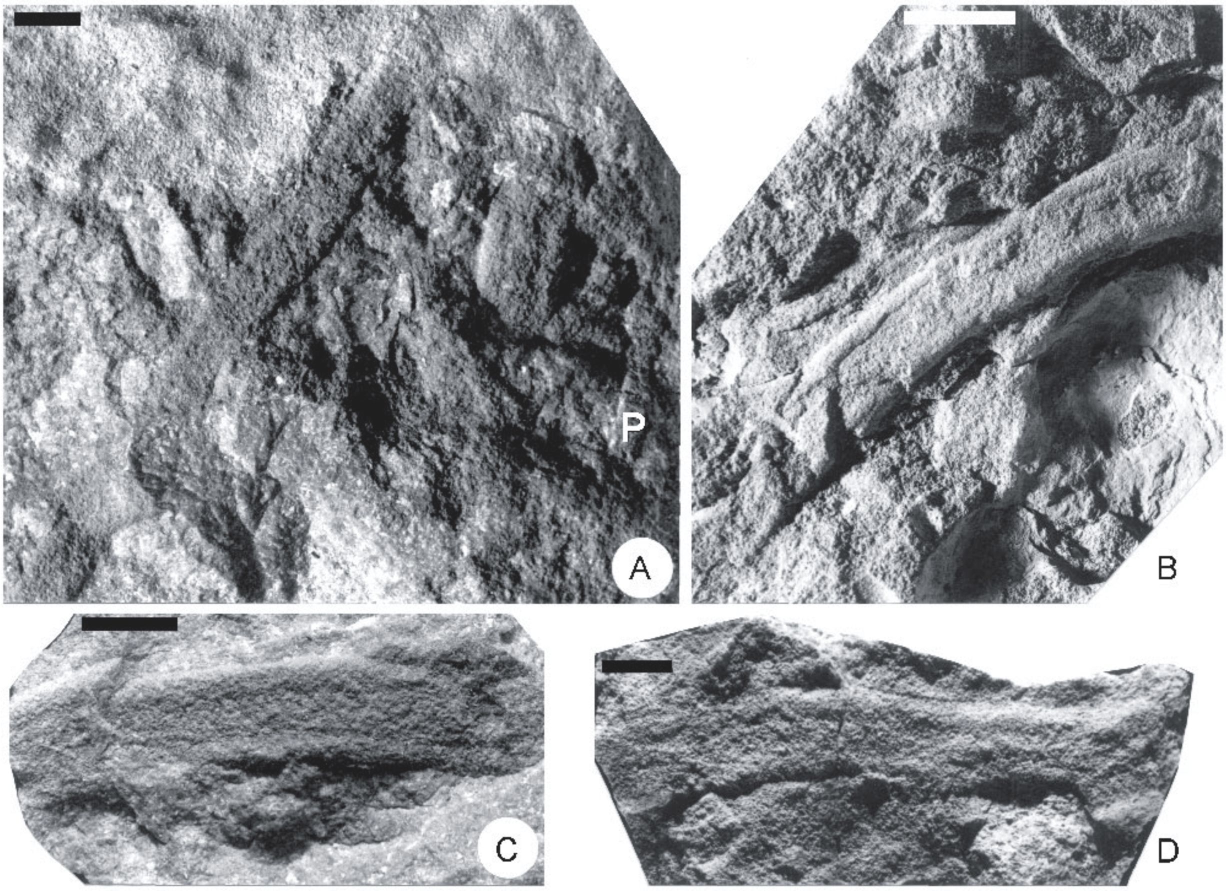

Fig. 3. *Curvolithus simplex* in the hypichnial view. Bajocian crinoidal limestones, Niedzica-Podmajerz Klippe. **A.** Specimen 169P1 (also *Planolites* isp. is visible — P). **B.** Specimen 169P2. **C.** Specimen 169P3. **D.** Specimen 169P4. Scale bars = 1 cm.

1973) similar to recent representatives of the Cephalaspidae family (Heinberg & Birkelund 1984). Buatois et al. (1998) added that scavenging gastropods as well as carnivorous forms may be the tracemakers, and that tubellarian or nemertean worms cannot be excluded. The flat worms (tubellarians) as tracemakers of *Curvolithus* were suggested earlier by Seilacher (1990).

Curvolithus occurs from the Proterozoic (Webby 1970) to the Miocene (Keij 1965) in various shallow marine or even brackish environments, including distal fan deltas, tidal flats and offshore settings (see Buatois et al. 1998, for review).

Discussion

Occurrences of *Curvolithus* in the Middle Jurassic crinoidal limestones of the Pieniny Klippen Belt are worthy of note for several reasons. Firstly, this is the first time this trace fossil has been documented in carbonate deposits. In general, trace fossils are very rare in crinoidal limestones, mostly because of taphonomic reasons. Crinoidal ossicles are very porous, with high buoyancy. They probably formed very shifting sediments with little cohesion, and thus with very low preservation potential for burrows. The massive character of some crinoidal limestones is most likely related to bioturbation, the effects of which are not preserved in recognizable ichnofabrics. Moreover, diagenetic processes, especially cementation, can change the primary small-scale fabric of sediments, including discrete bioturbation structures and small burrows.

Secondly, the occurrence of *Curvolithus* helps to confirm its paleoenvironmental interpretation. *Curvolithus* has never been found in deep-water facies, below shelf. It is a characteristic component of the *Cruziana* ichnofacies typical of the zone between fair-weather and storm wave basses (Seilacher 1967; Frey & Seilacher 1980). It is typical of the *Curvolithus* ichnofacies, which has been recognized as a subichnofacies (Lockley et al. 1987) within or as an "association" of the *Cruziana* ichnofacies (Bromley 1990). Heinberg & Birkelund (1984) concluded that *Curvolithus* tracemaker is very tolerant to grain-size changes, and that this confirms its production by carnivores. Therefore, *Curvolithus* occurs in a wide spectrum of shelf environments (Buatois et al. 1998). Lockley et al. (1987) noted that the *Curvolithus* ichnofacies is common in low-energy environments characterized by high rates of deposition and is typical in delta-influenced shelves. Buatois et al. (1998) distinguished two typical preservational situations for *Curvolithus*: low-diversity ichnoassociations in totally bioturbated sediments representing relatively low-energy environments; and high-diversity ichnoassociations in partly bioturbated sediments deposited in higher-energy environments.

In the investigated sections, *Curvolithus* is the only trace fossil, except for one example of *Planolites*. *Curvolithus* occurs exclusively in the lowermost part of the crinoidal limestones, just above calcilutitic marlstones of the Skrzypny Shale Formation, which are totally bioturbated (Tyszka 1993) and were deposited in offshore or even deeper settings. During the Bajocian shallowing, the deposition of crinoidal calcarenites most likely spread out from subtidal shoals in the form of bars or banks which encroached on deeper shoreface or offshore environments. Bars and banks are typical depositional forms for the Tethyan crinoidal limestones (Jenkyns 1971), and these from the Pieniny Klippen Belt are probably not an exception. This is confirmed by the local presence of large-scale cross-bedding. The lowermost part of the discussed crinoidal limestones, probably deposited on the edge of the shoals, can be related to toes of the bars or banks. Such places are preferred for accumulation of fresh biodetritus. At the transition between two facies types, very high animal diversity is expected. The toes can also be stabilized earlier than other parts of the bars or shoals owing to adherence to the fine-grained substrates, biological binding and more rapid cementation. Rapid burial by avalanching or rapid migration of the bars or banks is also possible. Thus, bedform toes are good places for the formation and preservation of burrows. At least some of these factors played a role in preservation of *Curvolithus* from situations known from the Lower Cretaceous where Heinberg & Birkelund (1984) noted an occurrence of abundant *Curvolithus* in upper offshore facies, close to distinct lithological changes (good hunting or scavenging areas). Dam (1990) described Lower Jurassic *Curvolithus*, among other trace fossils, from delta bottomsets, and Fürsich & Heinberg (1983) from ocean-side slopes of offshore bars of the Upper Jurassic (rapid bedform migration).

Conclusions

1. The trace fossil *Curvolithus simplex* has been found for the first time in carbonate deposits — in the Bajocian crinoidal limestones of the Pieniny Klippen Belt.

2. *Curvolithus*, a common trace fossil of the *Cruziana* ichnofacies, confirms deposition of the crinoidal limestones in shelf depths, below the fair-weather wave base.

3. Most probably, *Curvolithus* occurs in the toe of migrating bars or banks of crinoidal sand. Such a place is preferred by the most probable trace makers: carnivorous or scavenging gastropods, and it is a place of increased preservational potential. Therefore, *Curvolithus* is preserved only in the lowermost part of the crinoidal limestones.

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