



Lower Permian (Artinskian) chondrichthyan tooth remains (Petalodontidae) from Dovje (Karavanke Mts., NW Slovenia)

Spodnjepermski (artinskijski) ostanki zob morskih psov (Petalodontidae) iz Dovjega (Karavanke, SZ Slovenija)

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Ključne besede: Petalodontiformes, *Petalodus ohioensis*, zgornji paleozoik, artinskijski, Karavanke, Slovenija

Abstract

Fossil remains of chondrichthyan tooth bases (roots) were found in Lower Permian beds exposed along the forest road between Dovje and Plavški Rovt. These layers are part of the clastic development of the Trogkofel Group beds. They are composed of an alternation of dark to light-grey shales, siltstone, and sandstone with rare beds of the conglomerate. Within the clastic succession, layers or lenses of dark-grey to black limestones (biosparitic, biomicritic and oolitic) and limestone breccias occur. The limestone consists remains of algae, fusulinids, brachiopods, and mostly crinoids (*Palermocrinus* and *Entrochus*). Detail study has shown that two remains of tooth bases belong to the genus *Petalodus*, one of them to the species *Petalodus ohioensis*. The bases are tongue-shaped and come to a rounded point in the distal (base end) edge. On the surface of the base, the typical oval-shaped foramina are visible. In addition, the osteodentine is visible on the cross-section of one specimen. Teeth of *Petalodus* are often the most common chondrichthyan fossil vertebrate remains reported from the Carboniferous and Permian rocks of the USA, Europe, and Russia. In Slovenia, *Petalodus ohioensis* has been recorded only from Upper Carboniferous beds. The new record of Lower Permian remains contributes to the knowledge of this cosmopolitan but still common genus of Late Paleozoic chondrichthyans.

Izvleček

Iz spodnjepermskih plasti med Dovjim in Plavškim Rovtom so bili odkriti fosilni ostanki korenin zob hrustančnic. Najdbe izhajajo iz klastičnih plasti Trogkofelske grupe, kjer se menjavajo temni do svetlo sivi glinavci in peščenjaki ter redke leče konglomeratov. Med plastmi se pojavljajo tudi zaporedja temno sivih in črnih apnencev in apnenčevih breč, ki vsebujejo fosilne ostanke alg, fuzulin, ramenonožcev in večji delež ploščic morskih lilij (rodov *Palermocrinus* in *Entrochus*). Novo odkrita ostanka zob sta dobro ohranjeni korenini, značilni za rod *Petalodus* in smo ju vsaj v enem primeru taksonomsko pripisali vrsti *Petalodus ohioensis*. Oba ostanka korenin imata jeziku podobno obliko, ki se proti koncu zaokroži. Na površini so opazne manjše odprtine (foramni), medtem ko je na enem primerku opazna tudi kostna struktura (osteodentin). Zobje rodu *Petalodus* se pojavljajo v karbonskih in permskih plasteh skoraj povsod po svetu, predvsem v ZDA, Evropi in Rusiji. V Sloveniji so bili dobro ohranjeni zobje vrste *Petalodus ohioensis* najdeni le v zgornjekarbonskih plasteh, medtem ko so novi ostanki iz spodnjega perma prvič predstavljeni tukaj. Nove najdbe iz Slovenije dopolnjujejo paleontološko sliko tega kozmopolitskega rodu poznopaleozojskih hrustančnic.

Table 1. Compiled list of Late Paleozoic chondrichthyan teeth from the South Karavanke (NW Slovenia). Note: All listed specimens were figured in cited publications. *Preliminary identification of the specimen.

Tabela 1. Pregledni seznam poznopaleozojskih ostankov zob hrustančnic iz južnih Karavank (SZ Slovenija). Opomba: vsi primerki so ilustrirani v citirani literaturi. *Preliminarno določeni primerki.

Age (Stage) Starost (obdobje)	Species (number of the specimen) / Vrsta (število primerkov)	Fossil site - locality / Najdišče fosila	Reference (Publication) / Referenca
Lower Permian (Asselian-Artinskian)	<i>Glikmanius</i> cf. <i>occidentalis</i> (1)	Hrušica (north), forest road near Na Visokih	Križnar, 2015 Križnar, 2016
	Petalodontidae gen et. sp. indet. (1)*	Dovžanova soteska	Novak, 2006 Novak, 2019
Upper Carboniferous (Gzhelian)	<i>Petalodus ohioensis</i> (2)	Javorniški Rovt, Spodnja Počivala	Ramovš & Bedič, 1993 Ramovš, 1997 Ramovš, 1998 Peternel, 1995
	<i>Petalodus ohioensis</i> (1)	Forest road Planina pod Golico - Črni vrh	Ramovš, 1997 Ramovš, 1998
	Petalodontidae gen et. sp. indet. (1)	Planina pod Golico, brook southeast of the village	Ramovš, 1998
	Petalodontidae gen et. sp. indet. (1)	Črni vrh	Peternel, 1995

Introduction

The Petalodontiformes are a small intriguing group of late Paleozoic chondrichthyans, ranging from the Carboniferous (Mississippian) to the Permian. Up to now, there are about 17 genera referred to Petalodontiformes, but most are known principally from isolated teeth (Ginter et al. 2010; Lund et al., 2014). *Petalodus* is the longest-known petalodont cosmopolitan genus. The late Paleozoic chondrichthyans »shark« record from Slovenia consists of complete or partial remains of petalodont teeth (*Petalodontidae* gen et. sp. ident. and *Petalodus ohioensis*) and one tooth of *Glikmanius* cf. *occidentalis* (for the references and the list of localities see Table 1).

Geological and Stratigraphical settings

In the Southern Karavanke Mts. the outcrops of Upper Paleozoic (Upper Carboniferous and Lower Permian) fossiliferous shallow marine deposits are scattered between Solčava and Dovje (Fig. 1). The broadest and best exposed Lower Permian beds are present north of Tržič, in the vicinity of famous fossil sites Dovžanova soteska and Jelendol (Novak, 2007; Novak & Skaberne, 2009). In the western part of Southern Karavanke Mts. Lower Permian beds are mainly exposed

in Javorniški Rovt and Pristava, and between Planina pod Golico and Dovje village (Novak & Skaberne, 2009).

The lithostratigraphic subdivision of Lower Permian rocks in the Southern Karavanke mountains is composed of the Grenzland Fm., Zweikofel Fm. and on top the Trogkofel Group (Novak & Skaberne, 2009, 199). In the youngest beds of the Trogkofel Group, carbonate and clastic developments are distinguished. The carbonate part is represented by light-grey, dark-red, and rose-red reef fossiliferous limestones and fore-reef limestone breccias in some parts. The Trogkofel limestone is massive (as reef bioherm) or thick-bedded and rich in fossils. The clastic development of the Trogkofel Group beds is composed of the alternation of dark to light-grey shales, siltstone, and sandstone with rare beds of conglomerate (Novak & Skaberne, 2009). Within the clastic succession, layers or lenses of dark-grey to black limestones (biosparitic, biomicritic and oolitic) and limestone breccias occur, containing rock-forming remains of algae, fusulinids, brachiopods, rare corals, and crinoids (Novak & Skaberne, 2009). The age of the Trogkofel Group (with Trogkofel limestone) in the Southern Karavanke is middle to late Artinskian, with a thickness of a maximum of 400 meters (Novak & Skaberne, 2009).

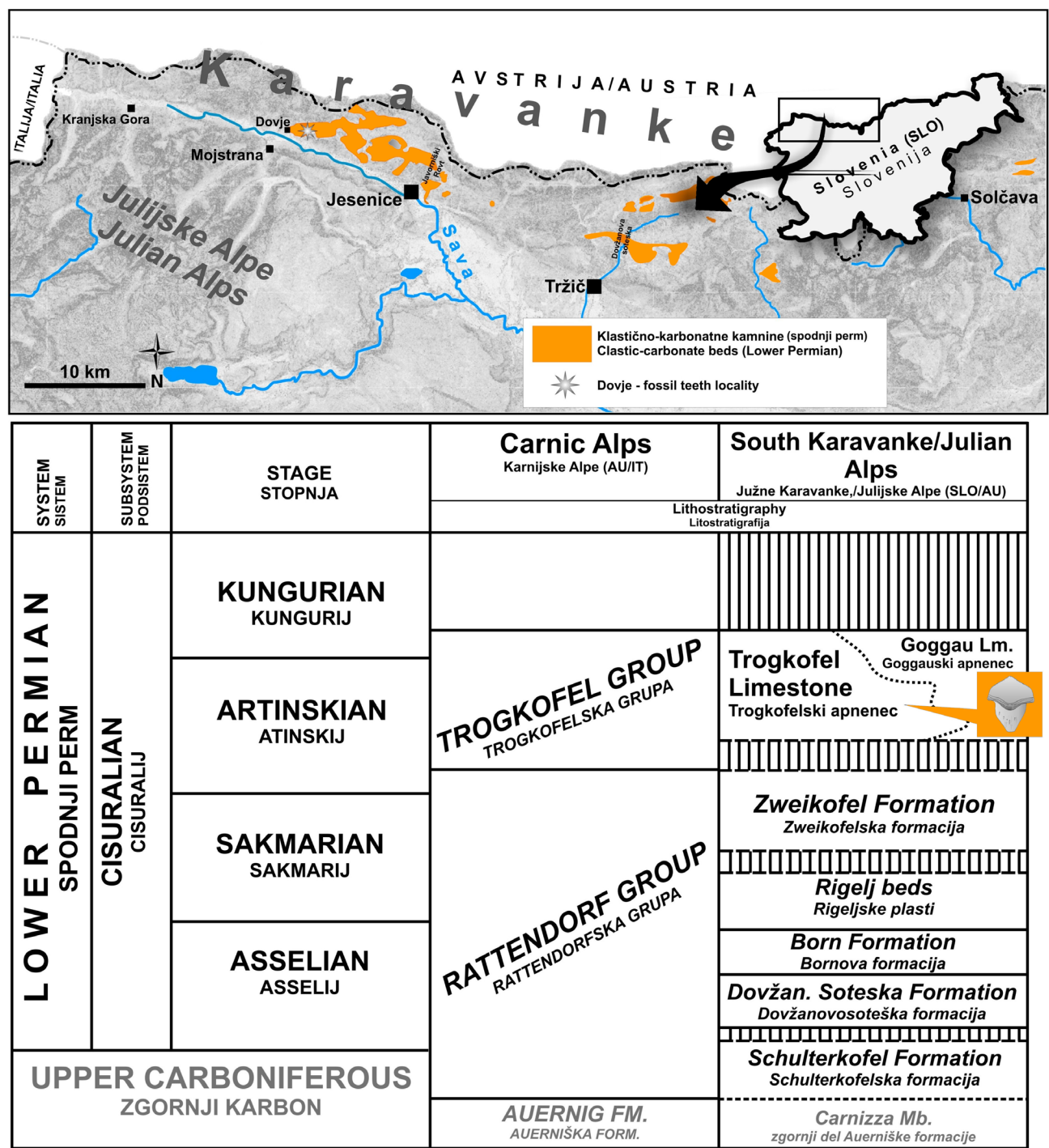


Fig. 1. Index map (top) showing the outcrops of Lower Permian clastic-carbonate beds in the Karavanke (Slovenian part) with the fossil location near Dovje. Summary of the Permian stratigraphy and biostratigraphy (bottom) of the Karavanke Mountains, with the position of fossil chondrichthyan teeth in the Trogkofel Group (adapted from Novak & Skaberne, 2009).

Sl. 1. Zemljevid razprostranjenosti klastično-karbonatnih spodnjepermjskih plasti v Karavankah (slovenski del) in pozicija najdišča fosilov pri Dovjem (zgoraj). Poenostavljen stratigrafski stolpec spodnjepermjskih plasti v Karavankah (prirejeno po Novak & Skaberne, 2009).

The outcrop of the newly discovered chondrichthyan tooth fragments is located along the forest road between Dovje and Plavški Rovt (Fig. 2). Layers of dark-grey limestones and an alternation of light-grey shales and siltstone are exposed. All beds are extremely fossiliferous

with numerous disarticulated crinoid remains. The remains of crinoids are mostly fully disarticulated parts (ossicles) of stems (columnals), arms, pinnules, and rarely crinoid crowns (Lach et al. 2013). Crinoid remains were not yet the subject of a thorough paleontological investigation, but

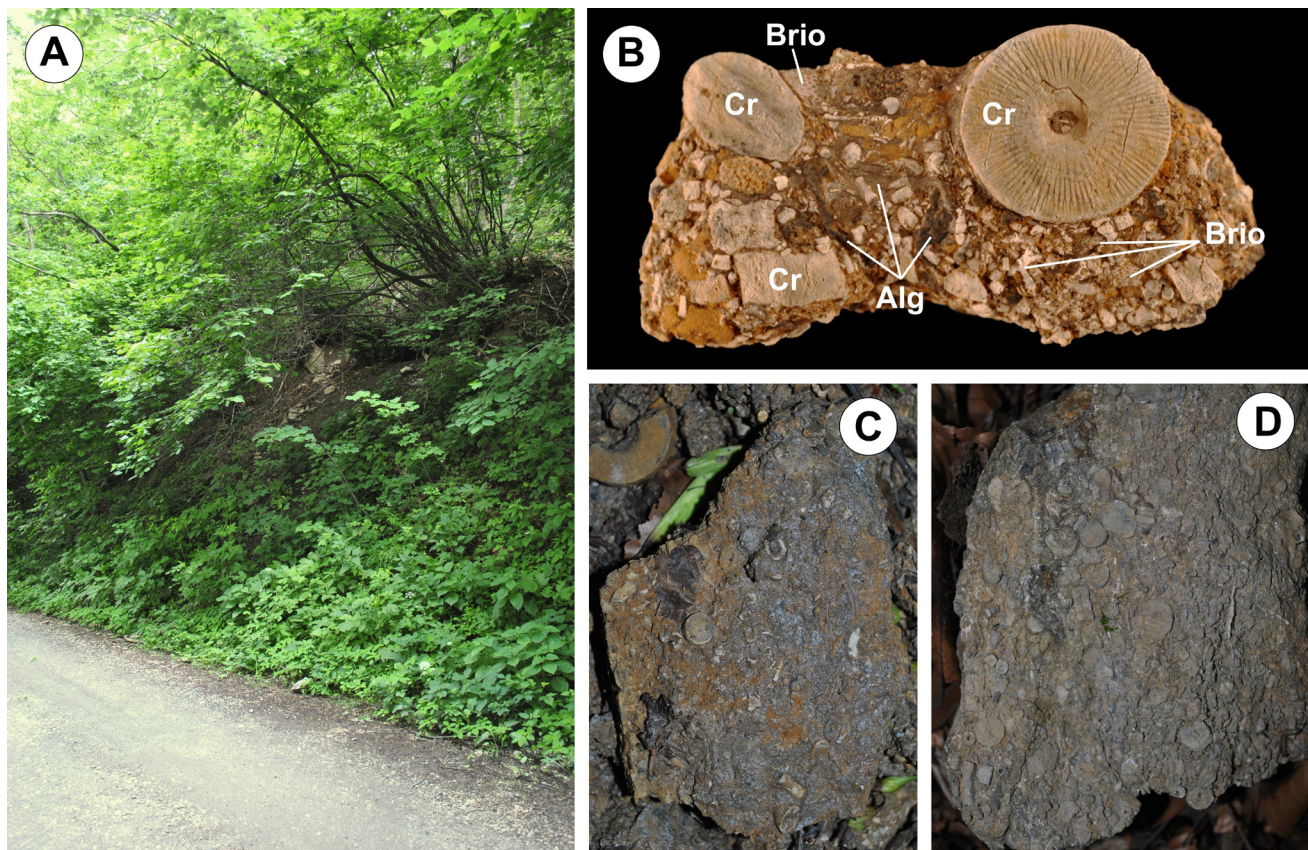


Fig. 2. A: The location of petalodontid teeth remains on a forest road in the vicinity of Dovje (13°58'14", 46°28'1"). B-D: Various remains from crinoid-bryozoan-algae assemblage (biofacies) from the Dovje locality. Not to scale. Abbreviations: Cr - crinoid remains (mostly crinoid columnals); Brio - bryozoans; Alg - algae.

Sl. 2. A: Najdišče petalodontidnih ostankov zob ob gozdni cesti v okolici Dovjega (13°58'14", 46°28'1"). B-D: Različni fosilni ostanki iz krinoidno-briozojско-algnih združb iz najdišča pri Dovjem. Ni v merilu. Okrajšave: Cr - krinoidni ostanki (prevladujejo ploščice morskih lilij); Brio - brizoji (mahovnjaki); Alg - alge.

preliminary research shows the presence of the crinoid genera *Palermocrinus* and *Entrochus*, with probably some members of Codiocrinidae (Lach et al., 2013; Ramovš & Sieverts-Doreck 1968). The associated fauna is composed of brachiopods (productids and spiriferids), bivalves, gastropods, foraminifers (fusulinids), algae (*Shamovella-Archaeolithoporella*), and fenestellid bryozoans which are with the crinoids, form the main biotic component in some parts. Similar crinoidal limestone with *Palermocrinus togatus*, with higher carbonate content, is known at Pristava in Javorniški Rovt. The age of the outcrop with new fossil tooth remains is Artinskian (Novak & Skaberne, 2009; Novak M., personal comm.).

Materials and methods

Specimens were discovered by Jure Zupanc around the year 2000 and are stored in his private geological collection. For the specimens described here, we use working identification numbers JZC 001 (Fig. 4) and JZC 002 (Fig. 5). Both specimens were prepared only with minor mechanical tools (needles) and measured with a

metal hand vernier caliper. The specimens were photographed using a Nikon D7200 camera coupled with an AF-S Micro NIKKOR 60mm f/2.8G ED lens. Photos of specimens were additionally edited with the advanced photo editing program Adobe Photoshop Lightroom which enhanced the visibility of some features.

Our description of the tooth base (Fig. 3) follows combined terminology suggested by Dalla Vecchia, (1988), Robb (2003), Harper (2018, 7), and Gai et al. (2021, see their Fig. 2, a1-a3).

Systematic Paleontology

Systematics follows the taxonomic views of Ginter et al. (2010) and Carpenter & Itano (2019).

Class Chondrichthyes Huxley 1880

Subclass Euchondrocephali Lund & Grogan 1997

Order Petalodontiformes Patterson 1965

Family Petalodontidae Newberry & Worthen 1866

Genus *Petalodus* Owen 1840

Petalodus ohioensis Safford 1853

Figure 4

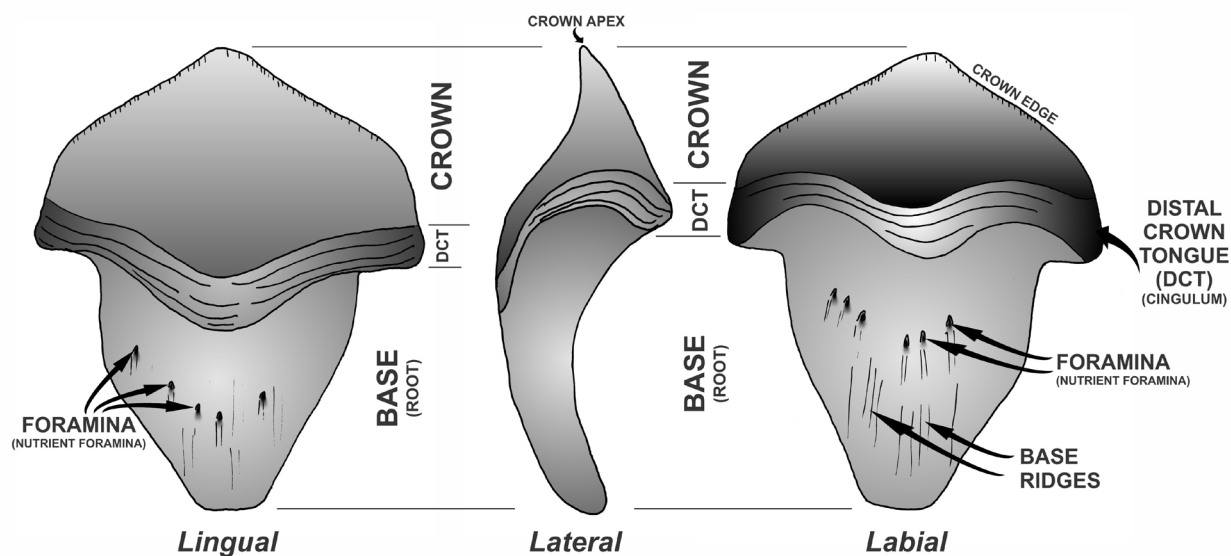


Fig. 3. Anatomical terminology of petalodontid tooth (*Petalodus*). Adapted from Dalla Vecchia, (1988), Robb (2003), and Gai et al. (2021).

Sl. 3. Anatomska terminologija petalodontidnega zoba (*Petalodus*). Prirejeno po Dalla Vecchia, (1988), Robb (2003) in Gai et al. (2021).

Material: One specimen of base of petalodontid tooth (Fig. 4). Specimen (JZC 001) was discovered by Jure Zupanc and is stored in his private geological collection. The specimen represents the complete tooth base (Fig. 4A-C) of a typical petalodont tooth. The tooth crown is missing.

Description: The base is triangular in tongue shape and comes to a rounded point in the distal edge (base end). Transversely the base is oval.

The mesiodistal width is 30 mm, and the total length is 36 mm. The maximal lingual-labial thickness of the tooth base is 6.4 mm. The lingual side of the base is bent to the labial side. On the surface of the lingual side, a few oval-shaped foramina are visible, on faint traces of ridges. On top of the base, the distal crown tongue is poorly preserved and overhangs the base. The labial side of the base has four elongated ridges, with no visible foramina, partially covered with a matrix.

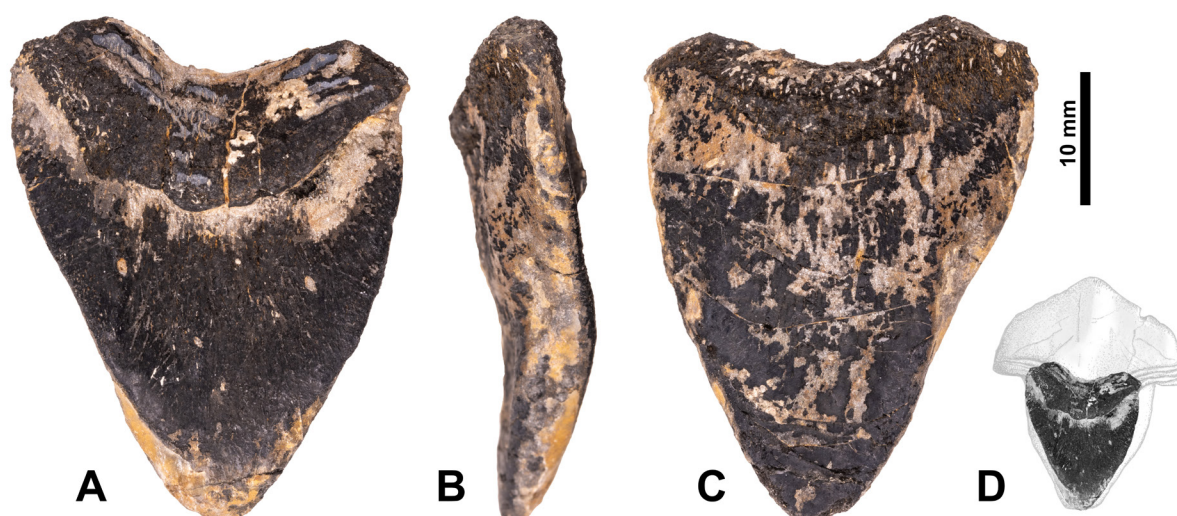


Fig. 4. *Petalodus ohioensis* from Dovje locality. Specimen JZC 001: A - lingual, B - profile, C - labial views. The scale bar equals 10 mm. D - reconstructed position of the base in a tooth.

Sl. 4. *Petalodus ohioensis* iz najdišča pri Dovjem. Primerek JZC 001: A - lingvalni, B - stranski, C - labialni pogledi, merilo je 10 mm. D - rekonstrukcija položaja korenine na zobu.

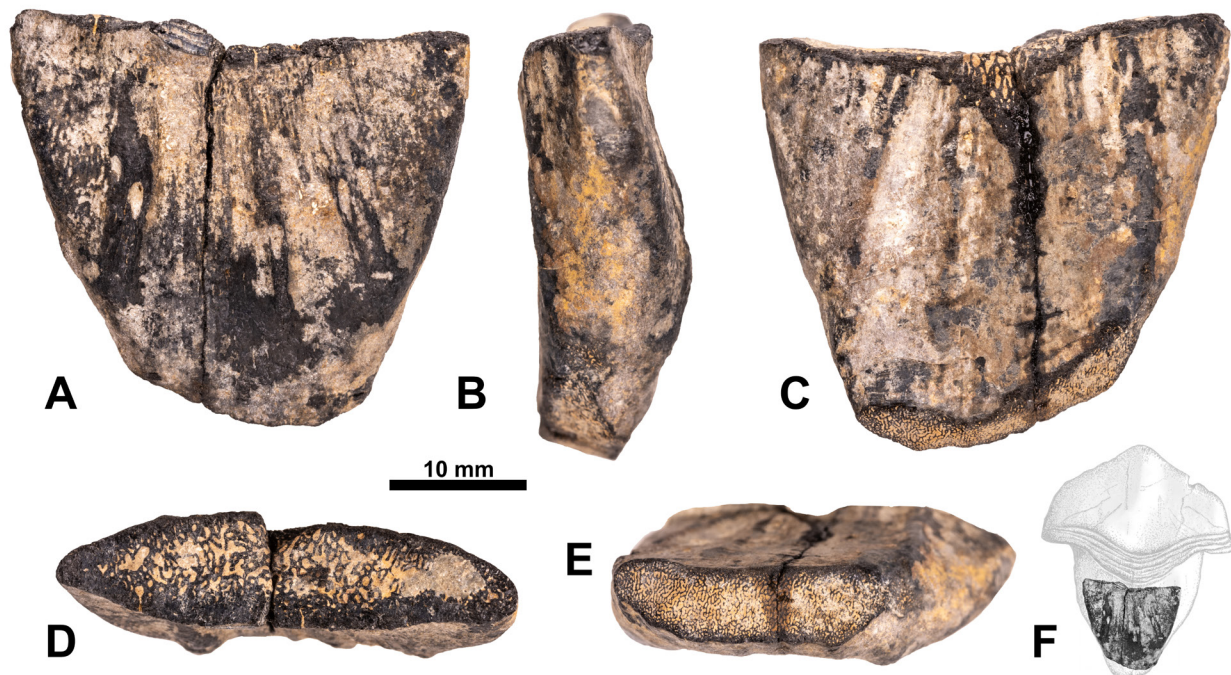


Fig. 5. *Petalodus cf. ohioensis* from Dovje locality. Specimen JZC 002: A - lingual, B - profile, C - labial views, D, E - distal surfaces with visible spongy tissue (osteodentine). The scale bar equals 10 mm. F - reconstructed position of the base in a tooth.

Sl. 5. *Petalodus cf. ohioensis* iz najdišča pri Dovjem. Primerek JZC 002: A - lingvalni, B - stranski, C - labialni pogled, D, E - distalna površina primerka z vidno kostno strukturo (osteodentin), merilo je 10 mm. F - rekonstrukcija položaja korenine na zobu.

Petalodus cf. ohioensis SAFFORD 1853

Figure 5

Material: One specimen of base of petalodontid tooth (Specimen JZC 002) (Fig. 5). The remains represent a fragmentary but typical petalodont tooth base (Fig. 5A-E). The tooth crown is missing.

Description: The base is triangular in shape and it is transversely oval. The mesiodistal width of the preserved base is 33 mm. The maximal lingual-labial thickness of the preserved tooth base is 9.5 mm. Labially the base is more concave and lingually convex. On both sides (lingual and labial) three elongated (vertical) ridges are present. On the lingual side, the oval-shaped foramina are visible on all ridges. On the bordered part (top of the base), a small part of the distal crown tongue is present, with two rows of ridges. On both distal surfaces of the specimen, the spongy tissue is visible. According to Zangerl et al. (1993), this tissue is circumpulpar trabeculine (cavities) and trabecular dentine, or osteodentine by Dalla Vecchia, 1988 and Gai et al., 2021 (Fig. 5D-E).

Discussion and Conclusion

Teeth of *Petalodus* are often the most common chondrichthyan fossil remains reported from the Carboniferous and Permian rocks of the USA, Europe, Russia, and China (Ginter et al. 2010, 141; Dalla Vecchia, 2008; Gai et al. 2021). The remains are mainly isolated teeth. *Petalodus ohioensis* is well known from Upper Carboniferous and Lower Permian beds and it is widespread (Hansen, 1985; Elliott et al, 2004, 277-278; Ginter et al. 2010, 141). The specimen presented here (JZC 001) (Fig. 4), preserved as a tooth base, is typical of *Petalodus ohioensis*. The shape of the tooth base is very similar in shape and dimensions to specimens presented by Brusatte (2007, 3, fig. 2), Harper (2018, 4, fig. 1), Ramovš & Bedič (1993, 149, fig. 1) and Ramovš (1997, 110, fig. 1). All these specimens come from Upper Carboniferous strata and are probably from the anterior part of *Petalodus ohioensis* jaw, based on shape and size of teeth base (Elliott et al, 2004, 277, fig. 5A-B). Even though our second specimen (JZC 002) (Fig. 5) is broken, we attribute it to the genus *Petalodus*. Its shape and dimensions and comparison with other specimens (see Brusatte, 2007; Harper, 2018; Ramovš & Bedič 1993) allow us to classify it as *Petalodus cf. ohioensis*.

The new finding increases the petalodont diversity in the Southern Alps, and also sheds new light on the distribution and stratigraphic range of petalodonts in Slovenia and this part of Europe.

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