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Dasycladacean alga *Palaeodasycladus* in the northern Tethys (West Carpathians, Poland) and its new palaeogeographic range during the Early Jurassic

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Abstract

The green alga *Palaeodasycladus* was recognized in Lower Jurassic shallow-marine high-energy calcarenites of the Choč Nappe (Hronicum Domain) in the Tatra Mts in Poland. This occurrence indicates the most Northern record of *Palaeodasycladus* as it is known mostly from the southern part of the Western Tethys. The stratigraphic range of *Palaeodasycladus* (Norian, Sinemurian–Pliensbachian) and the upper Pliensbachian age of the overlying calcarenites (previous data on the basis of brachiopods) suggest that the studied part of the section was deposited during the Sinemurian–early Pliensbachian. The previous and current reports on occurrences of *Palaeodasycladus* allowed determination of a new northern palaeogeographic range of the shallow-marine Mediterranean biota during the Early Jurassic time.

Keywords Calcareous algae · Carbonate microfacies · Palaeogeography · Biostratigraphy · Tatra Mts

1 Introduction

The green alga *Palaeodasycladus*, represented mostly by *Palaeodasycladus mediterraneus* (Pia), is typical of the Sinemurian–Pliensbachian shallow-marine carbonate sediments in the southern part of Tethys in the Mediterranean region (e.g., Bassoullet et al. 1978; Barattolo 1991; Barattolo and Bigozzi 1996; Sokač 2001; BouDagher-Fadel and Bosence 2007). However, its occurrence in the Choč Nappe in the Tatra Mountains (West Carpathians, Poland) presented in this paper challenges the picture of this alga as the exclusively southern genus. Presentation of the *Palaeodasycladus* in the new site, its meaning in the local stratigraphy and palaeoenvironmental interpretation based on microfacies analyses are the aims of this paper. Moreover, this is also an opportunity to complete a new data on the palaeogeographic range of the Mediterranean shallow–marine biota.

2 Geological setting

The Mesozoic succession of the Choč Nappe (Upper Sub-Tatric) belongs to the Hronicum domain of the Central Western Carpathians Basin. In the Tatra Mountains, its Jurassic part, about 300 m thick, occurs only in three small uprooted thrust sheets in the Kościeliska Valley region in the southern Poland (Fig. 1). They are represented by the Lower Jurassic peloidal-oolitic limestones, bioclastic limestones of the Hierlatz facies, crinoidal limestones, and the silicified crinoidal limestones with spiculites (Sokołowski 1924; Grabowski 1967; Uchman 1993), which belong to the Miętusia Limestone Formation (Lefeld 1985), and by the possible Middle Jurassic red micritic limestones (Uchman 1988). The crinoidal and bioclastic limestones are dated to the upper Sinemurian–Domerian on the basis of brachiopods (Uchman and Tchoumatchenco 1994). The Lower Jurassic limestones show rapid lateral changes referred to "horst-und-graben" basin topography caused by the early Jurassic rifting in the Western Tethys (Bernoulli and Jenkyns 1974) extending to the study area (Uchman 1993).

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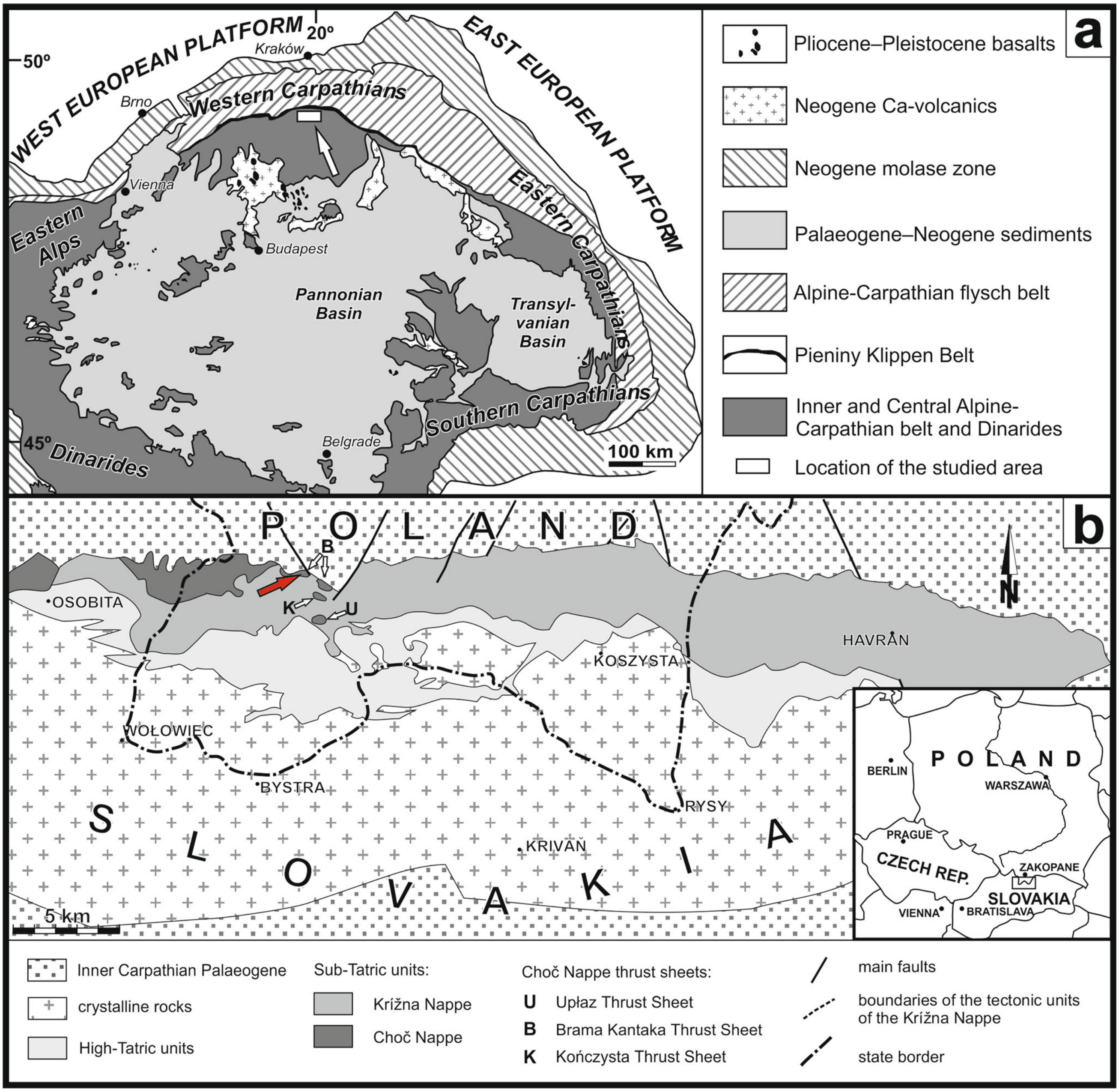

Fig. 1 Location of the study area. **a** Location of the Tatra Mts. against a background of the Alpine Carpathian units (after Jurewicz 2005, modified); **b** Tectonic sketch of the Tatra Mountains (based on Bac-Moszaszwili et al. 1979, red arrow points the location of the studied section)

The studied section (Fig. 1) belongs to the Brama Kantaka Thrust Sheet (Kotański 1965) and is located in the western side of the Brama Kantaka (Brama Kościeliska Niżna) rocky gate, on its northern tip, along the Kościeliski Stream, just below the Eocene conglomerates (Guzik et al. 1958) belonging the Paleogene infilling of Central Carpathian Basin, which erosionally truncates different tectonic units overthrusted during the Late Cretaceous. The limestone succession of the rocky gate (Fig. 2) is probably in an overturned position. Higher part of the succession, represented by crinoidal and bioclastic limestones with foraminifers, holothurians sclerites, sclerosponges, bivalves and brachiopods are dated to the Domerian, i.e. upper Pliensbachian (Uchman and Tchoumatchenco 1994) while the lower part, including the investigated section remains undated.

The investigated segment of the section begins with a metre of a crinoidal grainstone with irregular lenses of cherts, which is covered with the Eocene conglomerate. It is possible that this fragment is an ex situ block at the base of the conglomerate or a tectonically transported segment,

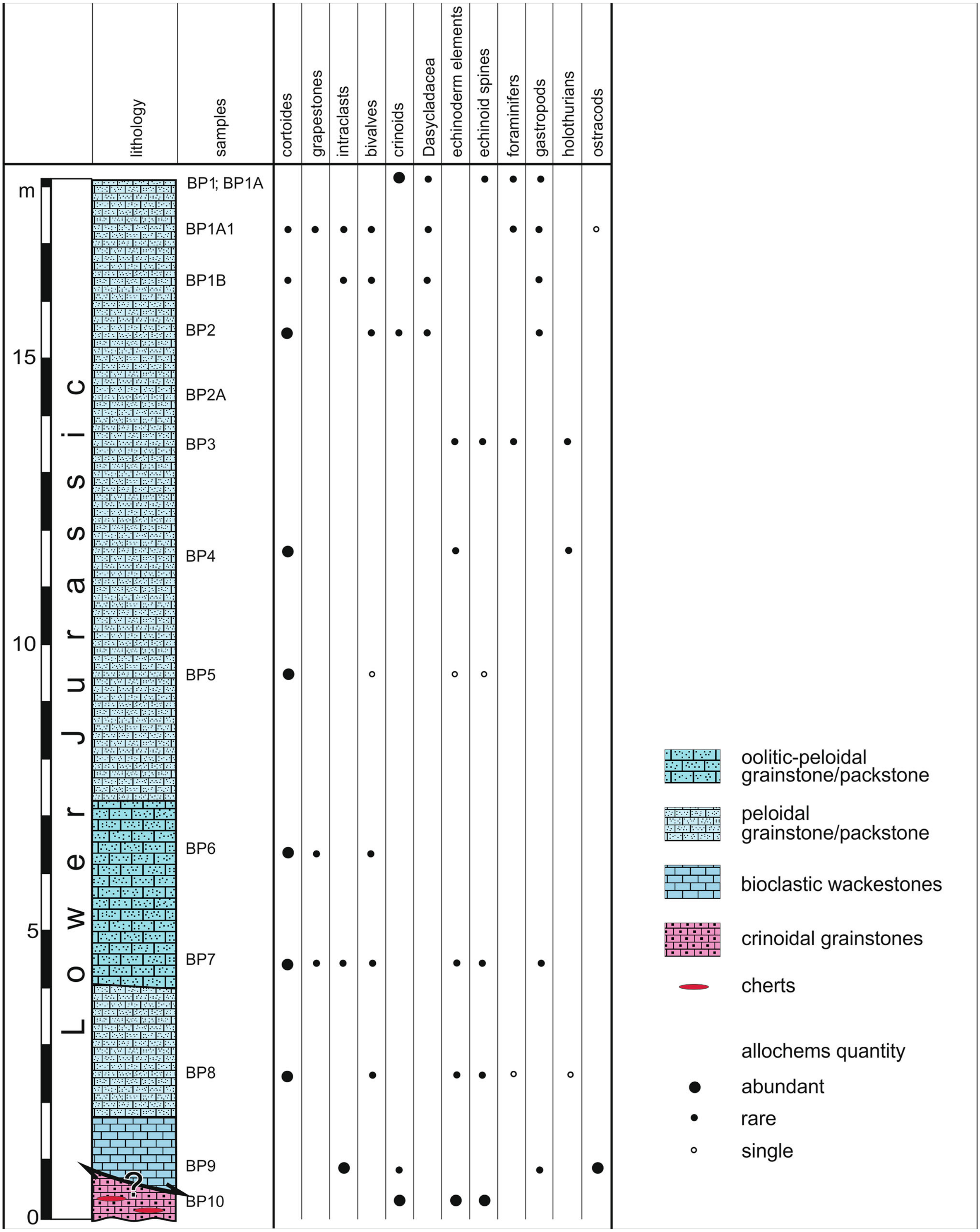

Fig. 2 Detailed lithological log of the studied section with marked samples location, lithological components and occurrences fossils with estimation of their abundance

but limitations of the outcrop does not permit to solve that problem.

3 Materials and methods

The section of Lower Jurassic carbonates was investigated bed-by-bed and sampled for microfacies investigations. Detailed lithological log of the mentioned sections is shown in Fig. 2. Samples, collected with average resolutions about 1 m were subject of microfacies analyses. There were prepared dozens of thin sections for detailed microfacies and micropalaeontological investigations with an optical microscope. Quantitative and qualitative analysis and relationship between the components as well as microfossils determinations were evaluated under the ×20, ×50 and ×100 magnifications. The textural classifications followed Dunham (1962) classification of carbonate rocks and its revised version (Wright 1992).

4 Microfacies description and palaeoenvironmental implications

A few major microfacies types have been recognized. Their detailed descriptions and environmental interpretations are given below.

Microfacies G-1. Oolitic-peloidal-bioclastic grainstone/packstone. This microfacies is represented by well sorted oolitic-peloidal grainstones with small admixture of other components. Allochems build about 70% of whole rocks. Ooids, 250–900 μm in diameter, and peloids, 60–200 μm in diameter, are predominant, while bioclasts (mostly echinoderm fragments and crushed, recrystallized bivalve shells and/or fragments of calcareous algae), micritic intraclasts and grapestones are subordinate. The shape of individual ooids depends on the shape of their nuclei. Nuclei of the ooids are mainly peloids and occasionally echinoderm fragments, crushed ooids or aggregate grains built of ooids. A large number of ooid cortices is micritized, while recrystallized cortices are subordinate. Peloids show diverse shapes. Some regular, rounded or oval peloids are probably micritized ooids (the so-called Bahamite peloids sensu Flügel 2010). Individual aggregate grains and lithoclasts of oolitic limestones were observed in some thin sections.

The carbonate grains are cemented with two types of cements: (1) even-rim cement, partly bladed, and with (2) blocky calcite spar filling the remaining pore space.

Microfacies P-1. Peloidal packstone/wackstone with bioclasts. This microfacies is characterized by a large amount of small (less than 250 μm), well sorted peloids and abraded bioclasts, mostly fragments of echinoderms, including echinoid spines and holothurian sclerites, moreover ostracods and rare foraminifers (*Earlandia* sp., Fig. 3e).

Microfacies P-2. Bioclastic-peloidal grainstone/packstone. The main components of the rock are represented by fragments of calcareous algae, fragments of echinoderms, echinoid spines, gastropod and bivalve shells, tests of foraminifers (*Neoendothyra* sp., Fig. 3a, b) and probable by cyanobacterium *Cayeuxia*. Some of them show micritized envelopes and form cortoids, while the others are fully micritized or recrystallized. Another components are small (up to 150 μm), well sorted peloids, while ooids are absent. This microfacies comprises a determinable fragments of *Palaeodasycladus* cf. *mediterraneus* (Pia) (see Fig. 4) described in details in the next chapter.

Microfacies P-3. Bioclastic packstone. This microfacies is similar to the microfacies P-1, but it is completely devoid of sparite. Fully or partially micritized allochems, mostly bioclasts (echinoderms, bivalves, foraminifer *Earlandia* sp.) predominate, while other components, i.e. ooids and grapestones are subordinate.

Microfacies R-1. Lithoclastic rudstone. The main components of this microfacies are intraclasts (up to 1 cm in diameter) of bioclastic wackestones, which are characterized by the presence of bioclasts, mostly ostracods and gastropods. The other components are microsparite intraclasts (up to 3 mm in diameter), detrital quartz, echinoderm fragments as well as some phosphate bioclasts, probably fish scales.

Microfacies W-1. Bioclastic packstone-wackestone. This microfacies is characterized by a great variety of bioclasts, which include fragments of gastropods, crinoids and other echinoderms, echinoid spines, green algae, bivalves and foraminifers (*Trocholina* sp., Fig. 3c, d). Intraclasts of microsparite limestone are subordinate. Most of the bioclasts are coated by even-rim cement, while the cement filling the remaining pore space is micritized.

The discussed section represents a carbonate platform environments changing from a high-energy oolitic-bioclastic shoals zone of the platform margin (microfacies G-1) through transitional environments between back-margin and the lagoon, settled by the alga *Palaeodasycladus* (microfacies P-1, P-2), to a low-energy inner platform lagoon (P-3, W-1). Microfacies R-1 represents synsedimentary reworked carbonates, which were influenced by storms. The evidence of the tropical storm action is present also in microfacies G-1 where the intraclasts of oolitic grainstones are present. The microfacies studied suggest that during their deposition the Hronicum basin was subjected to high energy regime characterized by open circulation, which is confirmed by relatively high-diverse biota.

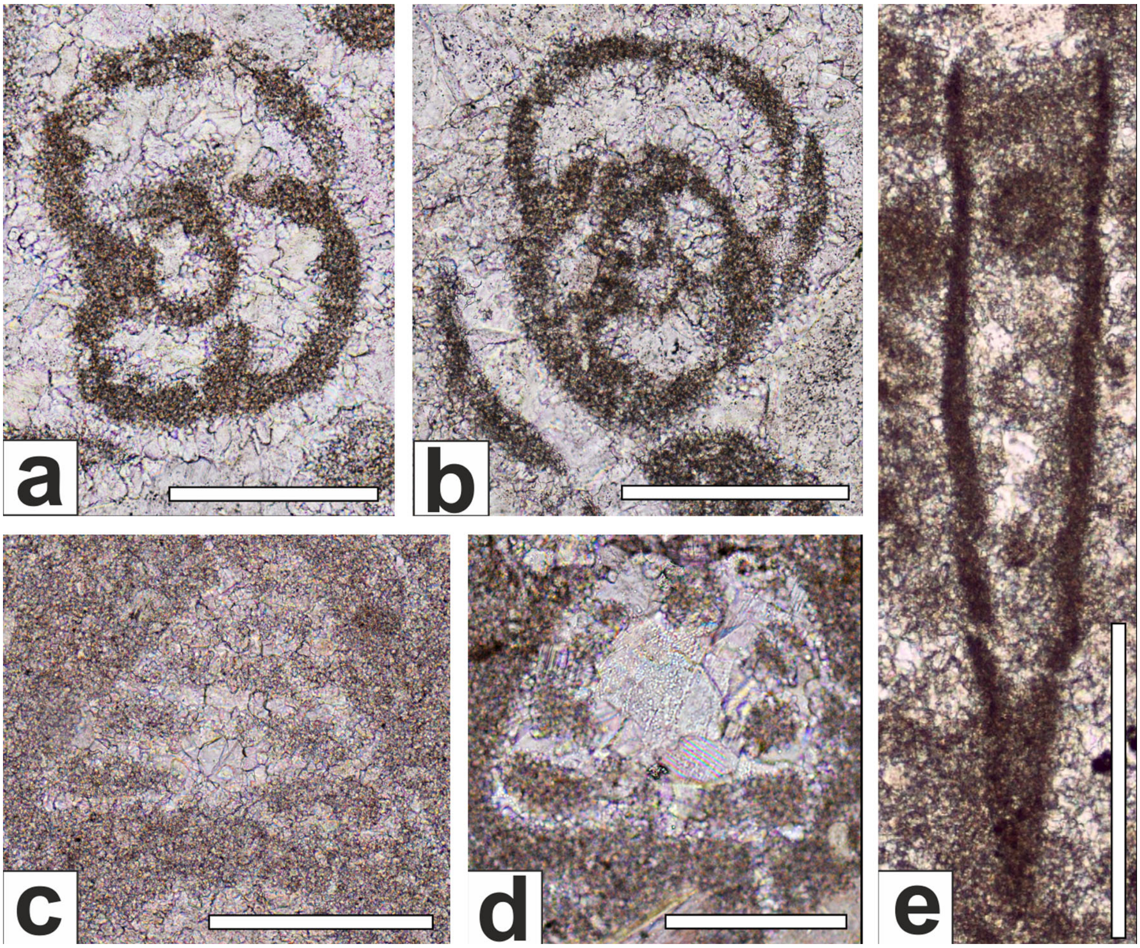

Fig. 3 Foraminifers from the studied section: **a**, **b** *Neoendothyra* sp. (sample BP1A1); **c, d** *Trocholina* sp. (sample BP 1); **e** *Earlandia* sp. (sample BP3). Scale bars are 200 µm

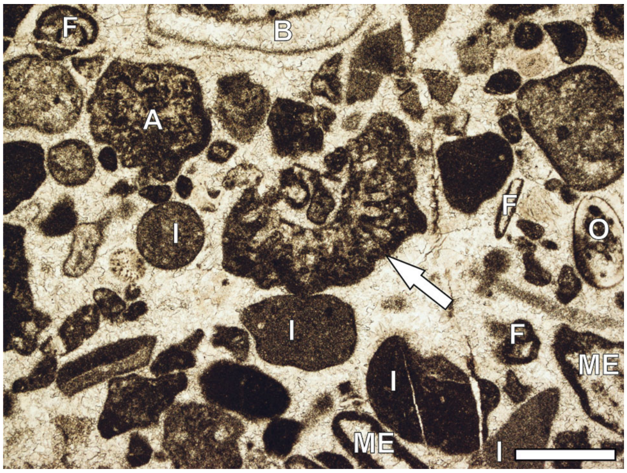

Fig. 4 General view of microfacies comprising *Palaeodasycladus* cf. *mediterraneus* (arrow): bioclastic-intraclastic grainstone comprising among others foraminifers (F), bivalves (B), ostracods (O), micrite intraclasts (I), unrecognizable remnants of green algae (A), and recrystallized bioclasts with micrite envelope (ME). Sample BP1A1. Scale bar is 500 µm

5 Systematic palaeontology

5.1 Dasycladacean alga

Order Dasycladales Pascher, 1931
Family Dasycladacea Kützing, 1843
Genus *Palaeodasycladus* (Pia, 1920) Pia, 1927

Genus *Palaeodasycladus* Pia, 1927

Type species: *Palaeocladus mediterraneus* (Pia, 1920) from the Lower Jurassic (Middle Liassic) of the southern Italy.

Palaeodasycladus cf. *mediterraneus* (Pia, 1920)
Text-Figs. 4, 5a–f

5.2 Selected synonyms of *Palaeodasycladus mediterraneus* (Pia, 1920)

*1920 *Palaeocladus mediterraneus* Pia – p. 118, text-fig. 22, pl. 6, figs. 1–5.

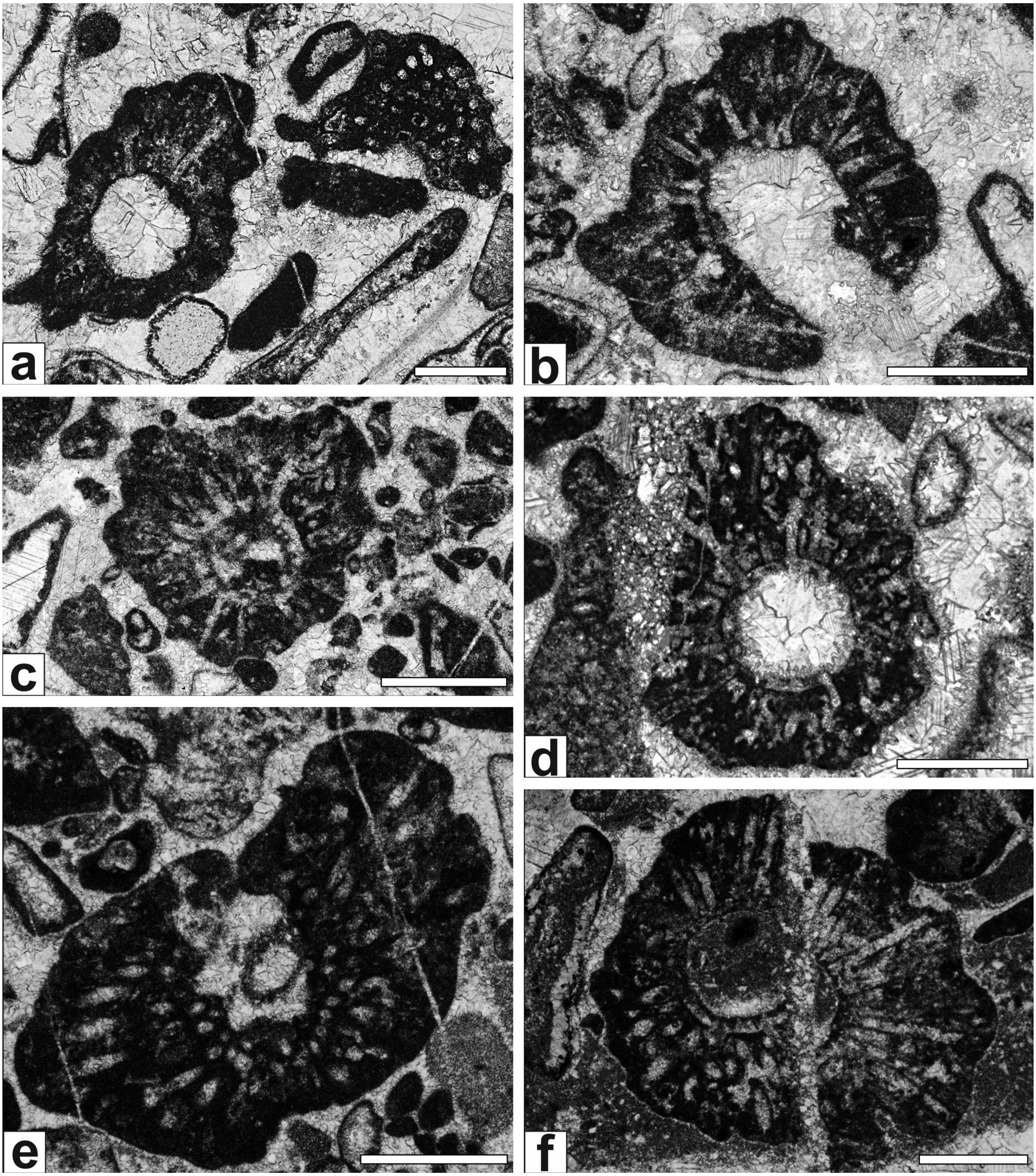

Fig. 5 Transverse sections of *Palaeodasycladus* cf. *mediterraneus* in bioclastic-peloidal grainstone/packstone. Samples BP1B (**a**) and BP1A1 (**b**–**f**). Scale bars are 500 µm

1927 *Palaeodasycladus mediterraneus* (Pia) – Pia, pp. 78–79, fig. 62.

1962 *Palaeodasycladus mediterraneus* (Pia) – Sartoni and Crescenti, p. 269, pl. 13, fig. 2; pl. 46, fig. 1.

1978 *Palaeodasycladus mediterraneus* (Pia) – Bassoullet et al., p. 192, pl. 22, figs. 8–9; pl. 23, figs. 1–2 [*cum syn*.].

1983 *Palaeodasycladus mediterraneus* (Pia) – Flügel, p. 271, pl. 46, figs. 5–9; pl. 47, figs. 1–6.

1988 *Palaeodasycladus mediterraneus* (Pia) – Sartorio & Venturini, p. 69, [plate in p. 69].

Material. Abraded fragments of the alga observed in thin sections from samples BP1, BP1A, BP1B, BP2 present in the uppermost part of the studied section (Fig. 2).

Remarks. *Palaeodasycladus* is a widely known Early Jurassic dasycladacean green alga. The studied material includes strongly disarticulated and abraded small fragments of alga thalli observable mostly in transverse and oblique-transverse sections, in which the characteristic primary branches (Fig. 5c–f) and rarely the secondary ones (Fig. 5d) are visible (see Sokač 2001). This way of preservation precludes correct estimation of the angle of inclination of primary branches towards the central steam, which is the diagnostic feature of *Palaeodasycladus mediterraneus* (see Bassoullet et al. 1978; Flügel 1983). Therefore, the alga is only tentatively identified as *P.* cf. *mediterraneus*, even though our material is very similar to specimens illustrated under that name by previous authors, especially by Sokač (2001) and Romano et al. (2005).

Distribution. *P. mediterraneus* is known from the Lower Jurassic of the southern part of the Western Tethys. It was reported from Italy, including the Umbria Marche platform (Fabbi and Santantonio 2012), Apennine Carbonate Platform (Barattolo and Bigozzi 1996), Trapani South Platform (Di Stefano et al. 2002), Trento platform (Romano et al. 2005), Calabria platform (Barattolo et al. 1994), Sicily (Marino and Santantonio 2010), from Turkey in the Eastern Taurus (Kalafatçioğlu 1973), Greece in the Korfu Island (Flügel 1983), Gavrovo—Tripolitza platform (Zambetakis-Lekkas 2006; Pomoni-Papaioannou and Kostopoulou 2008), Pelagonian Domain (Romano et al. 2008), from Slovenia in the Dinarides (Radoičić 1966; Dozet and Šribar 1998; Sokač 2001), from Spain in the Subbetic Zone (Rey et al. 1990), from Morocco in the High Atlas (Merino-Tomé et al. 2012) and the Middle Atlas (Deloffre and Laadila 1990), from Gibraltar (BouDagher-Fadel et al. 2001) and Albania (Schlagintweit et al. 2006). All the occurrences represent generally shallow-water platform carbonates of the Hettangian–Pliensbachian in age (Fig. 6).

6 Discussion

6.1 Palaeogeography

According to the palaeogeography of the Western Tethys during the Sinemurian (Thierry et al. 2000), the Hronicum Domain (represented in the Tatra Mts by the Choč Nappe) was located between 28° and 29° North on an isolated carbonate platform, separated from the other terranes and shallow water environments by deep-sea basins. Following this interpretation, at the area located southward (Licicum Domain), deeper-marine nodular limestones have been deposited. That isolation increased during the Toarcian, when the Bükkium oceanic furrows developed to the south (Thierry 2000). To the north, the area was occupied by the Fatricum Domain (Krížna Nappe in the Tatra Mts), which is characterized by clastic-carbonate sedimentation on the middle/outer shelf during the Hettangian and by hemipelagic and pelagic sedimentation of the spotted marls and limestones at the depth below shelf edge during the later stages of the Early Jurassic (Gaździcki et al. 1979b; Jach 2002, 2005). Thus, the occurrence of *Palaeodasycladus* cf. *mediterraneus* in the Sinemurian (?lower Pliensbachian) deposits of the Hronicum Domain appears as unique one. The other occurrences of *Palaeodasycladus mediterraneus* (see Fig. 6) are related to shallow water deposits of the Central Tethyan platforms, located generally in lower latitudes and separated from the northern units by deep-sea basins (Thierry et al. 2000). Further to the north, *Palaeodasycladus* up till now has not been recorded.

Based on the occurrences of *Palaeodasycladus* cf. *mediterraneus* in the Hronicum Domain of the Western Carpathians and in other sections of the Western Tethys (*see* previous chapter), the northern palaeogeographical range of the genus *Palaeodasycladus* in the Tethys ocean during the Early Jurassic is presented (Fig. 6). It is more or less correlated with the boundary between the Northwest European and Tethyan faunal domains, which during Carixian (i.e. early Pliensbachian) time was particularly sharp (Fig. 6; see also Dommergues and El Hariri 2002). Hence, it is not out of question that the northern range of the pan-tropical shallow-marine flora during late Sinemurian and maybe early Pliensbachian agrees with the range of *Palaeodasycladus* as the genus being the representative of the Mediterranean shallow–marine algae. The question remains: what was the way of migration of the species to the northward situated Hronicum Domain separated by deep water basin?

In the well dated and well outcropping section of the same age and similar facies in the Gran Sasso, Central Apennines, the first appearance of *Palaeodasycladus* sp. is noted 100–150 m above the Hauptdolomite/Calcare Massicio boundary which is determined there by the disappearance of the foraminifers *Aulotortus friedli* (Kristan-Tollmann), *Triasina hantkeni* Majzon and the algae *Griphoporella curvata* (Gümbel) (see Barattolo and Bigozzi 1996). In the Hronicum Domain, the Hauptdolomite facies (Carnian–Norian) are covered by limestones (bioclastic packstones/grainstones) of the Norovica Formation deposited in tidal and subtidal zone (Michalík and Gaździcki 1983). They comprise, among others, the same foraminifera species as mentioned above and

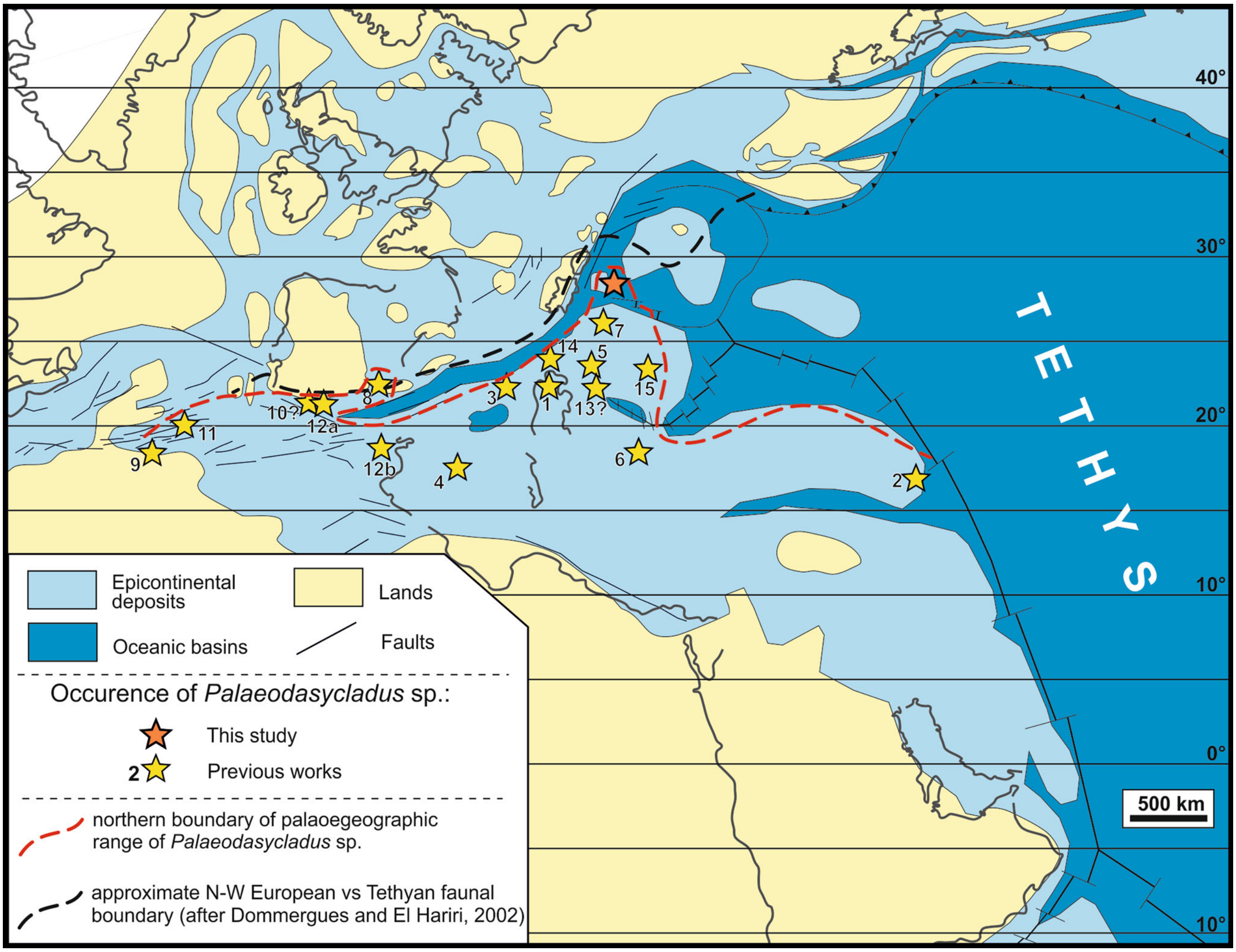

Fig. 6 Palaeogeographic map of the Tethys in the Mediterranean region in the early Sinemurian (after Thierry 2000) showing distribution of *Palaeodasycladus* based on this study and the literature data: *1*—Fabbi and Santantonio (2012); *2*—Kalafatçioğlu (1973); *3*—Barattolo and Bigozzi (1996); *4*—Di Stefano et al. (2002); *5*—Dozet and Šribar (1998), Sokač (2001); *6*—Pomoni-Papaioannou and Kostopoulou (2008); *7*—Barattolo and Romano (2005), Romano et al. (2005), Cocozza and Gandin (1990); *8*—Rey et al. 1990; *9*—Merino-Tomé et al. (2012); *10*—BouDagher-Fadel et al. (2001); *11*—Deloffre and Laadila (1990); *12*—BouDagher and Bosence (2007); *13*—Schlagintweit et al. (2006); *14*—Barattolo et al. (1994); *15*—Romano et al. 2008. Exact palaeogeographic location of 10 and 13 is uncertain

moreover the conodont *Misikella posthernsteini* Kozur & Mock, which correlates the formation to the Rhaetian (Gaździcki 1978; Gaździcki et al. 1979a; Gaździcki and Michalík 1980). Because of stratigraphic incompleteness and/or outcrop limitations, so far, the transition between the Rhaetian and the Lower Jurassic has not been described in the Hronicum Domain in the Tatra Mts. However, a gap ranging from the at least Ladinian to the middle Lower Jurassic is present in the Upłaz Thrust Sheet (Grabowski 1967). Nevertheless, the hypothesis assuming the existence of a connection between Hronicum Domain and the closest southward located shallow marine Trento Plateau, at least during the early Early Jurassic, is not groundless as is confirmed by similar facies development and fossils. However, the separation of these two basin during the Toarcian is rather unquestionable. In the Hronicum Domain, the youngest preserved sediments, probably representing early Aalenian, are developed as red, micritic pelagic limestones (Uchman et al. 1988, 2017). They overlie the Lower Jurassic limestones and filling the neptunian dykes, which cut the older deposits. The Lower Jurassic limestones of the Choč Nappe in the Tatra Mts. show rapid lateral facies changes referred to the “Horst-und-Graben” basin topography caused by the Early Jurassic rifting in the Western Tethys extending to the discussed Hronicum Domain (Uchman 1993). Deposition of the mentioned red limestones was connected with an episode of drowning of the Hronicum platform, which took place about the Early/Middle Jurassic transition. In the Bakony Mts of the Transdanubian Central Range, which during Sinemurian was adjacent to the Trento Platform (Thierry et al. 2000), the shallow water oolitic limestones were deposited only till the end of the Hettangian (Vörös and Galácz 1998). The Sinemurian and Pliensbachian sedimentation is characterized by deposition controlled by syndepositional blocky tectonics, with deposition of nodular limestones on the elevated blocks and allodapic limestones in the deeper, basinal parts of the basin. At the same time, in the area of the Trento Platform, located generally southward from the Hronicum and Bakony basins, calcareous deposition of the Calcari Grigi facies continued (e.g. Romano et al. 2005). Therefore, the unambiguous confirmation of the proposed hypothesis needs further research.

6.2 Stratigraphy of *Palaeodasycladus* and the section studied

The genus *Palaeodasycladus* is largely spread in lagoonal and shelf margin facies of the Late Triassic—Early Jurassic in the Tethys (Barattolo 1991; Barattolo et al. 2008). According to Herak et al. (1977), the genus *Palaeodasycladus* as a whole is confined to the Hettangian–Pliensbachian. However, Bassoullet et al. (1978) suggested also the Toarcian age as uncertain, while Baratollo (1991) widens their stratigraphic range to the whole Early Jurassic. The exception is the newly distinguished species *Palaeodasycladus lorigae* Barattolo, Cozzi & Romano (2008) from the Norian deposits of the Carnian Prealps (Barattolo et al. 2008). In the Central Apennines (Gran Sasso, Corno Grande region), deposits comprising the genus *Palaeodasycladus* covers the Hettangian and Sinemurian (Barattolo and Bigozzi 1996). Similarly, in the Dinarides, the subzone of the Cenozone *Palaeodasycladus mediterraneus* (Pia) with the *Orbitopsella praecursor* (Gümbel) was ascribed to the middle Early Jurassic (Dozet and Šribar 1998).

In the Hronicum Domain of the Tatra Mts, the lower boundary of the Jurassic System does not crop out or is absent due to the stratigraphic gap or tectonic or Cenozoic erosional truncation. In the studied sections, the latest two factors can be considered (*see* Fig. 2). The transition to the overlying crinoidal and bioclastic limestones is covered, but the higher part of the Early Jurassic succession comprising also foraminifers, holothurian sclerites, sclerosponges, bivalves and brachiopod shells is dated to the Domerian on the basis of brachiopods, such as *Spiriferina alpina alpina* (Oppel), *S.* cf. *alpina alpina* (Oppel), *Cuneirhynchia retusiformis* (Oppel) and *Zeilleria* aff. *subnumismalis* Davidson (Uchman and Tchoumatchenco 1994). Thus, the underlying deposits studied comprising *Palaeodasycladus ?mediterraneus* can be ascribed to the upper Sinemurian – lower Pliensbachian (Carixian) age span.

6.3 Conclusions

The green alga *Palaeodasycladus* is common in the southern part of the Western Tethys, but it (*P.* cf. *mediterraneus*) occurs also in the Hronicum Domain of the Western Carpathians (Choč Nappe, Tatra Mts). It is the most northern occurrence of this genus.

The northern range of the Early Jurassic shallow-marine flora depends on facies. Its occurrences are largely dependent on palaeolatitude and limited to shallow-marine lagoons and shelf edge environments located generally between 13° and 28° North. However, towards the higher latitudes shallow-water sedimentation is dominated by siliciclastics with minor contribution of carbonates, which indirectly depended on the climate.

The literature data along with the occurrence studied in the Hronicum Domain allow to outline the palaeobiogeographical range of the genus *Palaeodasycladus* as a representative of the pan-tropical shallow-marine flora during the Early Jurassic (Sinemurian–Pliensbachian).

The occurrence of *Palaeodasycladus* cf. *mediterraneus* on the isolated carbonate platform of the Hronicum Domain, separated from the southward located terrains by deep-sea basins, sheds a new light on the migration paths of the alga during the Early Jurassic and allows correction of the northern palaeogeographic range of *Palaeodasycladus* during Early Jurassic time.

The stratigraphic range of *Palaeodasycladus* (Norian; Hettangian–Pliensbachian) and the late Pliensbachian age of the overlying calcarenites suggest the Sinemurian–early Pliensbachian age of the lower part of the Jurassic succession of the Choč Nappe in the Tatra Mts.

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