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Early Jurassic radiolarians from the Weitenau area (Northern Calcareous Alps, Austria) and their implications for palaeogeography

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Abstract

The Lower Jurassic sedimentary sequence deposited on the outer shelf (Hallstat shelf) of the Neo-Tethys passive margin occurs mainly as blocks in different mélanges, or in rare cases, far-travelled nappes formed in the frame of the Middle–Late Jurassic mountain building process related to ophiolite obduction. Datable Lower Jurassic blocks are very rare in the Western Tethyan Realm, and are studied in detail for their age and sedimentological characteristics in order to reconstruct the Jurassic distal parts of the Neo-Tethyan passive continental margin. One of these exotic blocks, belonging to the marly siliceous limestones of the Dürrnberg Formation, was discovered in the Haselgebirge Mélange of the Weitenau Area (Northern Calcareous Alps, Austria). The block yielded a well-preserved radiolarian fauna, which is assigned here to the uppermost Lower Pliensbachian *Gigi fustis–Lantus sixi* Radiolarian Zone. The occurrence of this Lower Jurassic block beside other exotic blocks in the Upper Jurassic Haselgebirge Mélange proves the allochthony of the Haselgebirge Mélange in the Weitenau area.

Keywords: Jurassic, Pliensbachian, Radiolarian biostratigraphy, Eastern Alps, Palaeogeography, Tethys

1. INTRODUCTION

The Northern Calcareous Alps have a complex Mesozoic–Cenozoic tectono-stratigraphic history and experienced several mountain building processes. The first phase is the Middle–Late Jurassic ophiolite obduction in the frame of the formation of the Neotethyan Belt (MISSONI & GAWLICK, 2011a, b), which is followed by "Mid-Cretaceous" orogenesis (TOLLMANN, 1985; JANÁK et al., 2004; SCHMID et al., 2004). After that the true Alpine mountain building process occurred (HANDY et al., 2010 and references therein), with collision of the Austroalpine unit as the northern part of the wider Adria plate (GAWLICK & MISSONI, 2019) with Europe (FAUPL & WAGREICH, 2000), and the subsequent lateral tectonic extrusion since Miocene times (RATSCHBACHER et al., 1991). Therefore, the Northern Calcareous Alps presently consist of several nappes that were differentiated into, and in some cases rotated blocks, by Cenozoic faults and fault zones (LINZER et al., 1995; FRISCH & GAWLICK, 2003; PUEYO et al., 2007). During these polyphase mountain-building processes the original facies belts of the Triassic–Middle Jurassic passive continental margin configuration were completely destroyed in parts. The outer shelf area (Hallstatt shelf) can only be reconstructed by the analysis of reworked material in various mélanges (e.g., Hallstatt Mélange, defined by FRISCH & GAWLICK (2003); Haselgebirge Mélange defined by SPÖTL et al. (1998)), and by a comparison with other mountain chains in the Western Tethyan Realm (e.g., Western Carpathians, Southern Alps, Dinarides, Albanides, Hellenides and units in the Pannonian Realm; GAWLICK & MISSONI, 2019 and references therein). While the Triassic sedimentological history of the different Hallstatt facies belts is fairly well understood (LEIN, 1987; KRYSTYN, 2008) the Early–Middle Jurassic depositional history is, except for some details, mostly enigmatic (GAWLICK et al., 2009 and references therein), due to the lack of datable blocks in different mélanges around the Neotethyan belt. In fact, datable Lower Jurassic successions that derive from the outer (distal) shelf are at the moment only known from such mélanges in the Northern Calcareous Alps (Hallstat Mélange and Haselgebirge Mélange).

The Eastern Alps, including the Northern Calcareous Alps, were palaeogeographically situated in a relatively central position (GAWLICK & MISSONI, 2019) of the west-northwest striking passive continental margin spanning from the Hellenides to the Western Carpathians. To unravel the Early Jurassic outer (Hallstatt) shelf history of the Northern Calcareous Alps, it is important to study all the available blocks in these differentiated areas in terms of age, facies and depositional environment, to achieve a convincing Early Jurassic outer shelf reconstruction and depositional history for the whole Western Tethyan Realm. Radiolarians, besides the rare ammonoids, are usually the only available biostratigraphic tool to determine the age of these exotic blocks, and they have been widely applied in past tectono-stratigraphic studies and palaeogeographic reconstructions of the Northern Calcareous Alps (e.g., GAWLICK et al., 2007; AUER et al., 2009; GAWLICK et al., 2009).

Although well-preserved Early Jurassic radiolarian assemblages are rare, they are prerequisite for extensive and detailed taxonomic studies, which are the basis for precise age determinations. The best-preserved Early Jurassic assemblages in the Western Tethyan Realm, and globally, were studied from Pliensbachian limestones in Turkey (PESSAGNO & POISSON, 1981; DE WEVER, 1981a, b, 1982a, b) and from Sinemurian–Pliensbachian limestones in Austria (O'DOGHERTY & GAWLICK, 2008; CIFER et al., 2020, 2022; CIFER & GORIČAN, 2023a, b). Other studies from the Western Tethyan Realm are from Italy (BERTINELLI & MARCUCCI, 2011), Slovenia (GORIČAN et al., 2003), Austria (KOZUR & MOSTLER, 1990; GAWLICK et al., 2001), Greece (CHIARI et al., 2013), Cyprus (BRAGIN et al., 2022), and Turkey (TEKIN, 2002; TEKIN et al., 2020). Radiolarians generally radiate extremely fast and are globally abundant, but there are still major differences between the radiolarian assemblages of different provinces (the Western Tethyan Realm, Panthalassa, the Boreal and the Austral Realm). Many age-diagnostic species, important for the Lower Jurassic global radiolarian zonation (CARTER et al., 2010) are either not abundant or are completely missing in the Western Tethyan Realm (GORIČAN et al., 2013). Therefore, each well-preserved Early Jurassic radiolarian assemblage from the Western Tethyan Realm provides new important data on radiolarian taxonomy and biostratigraphy, further enhancing the use of radiolarians as an age diagnostic and palaeobiogeographical tool.

In this study we present the radiolarian inventory and a precise age assignment of a well-preserved radiolarian fauna collected from an exotic block in the Weitenau area in the central Northern Calcareous Alps (Austria), with the aim of providing new information on the age and distribution of Early Jurassic radiolarian species of the Western Tethyan Realm, and to define the palaeogeographic provenance and the tectono-stratigraphic evolution of the radiolarian bearing block, which was incorporated in the Haselgebirge Mélange.

2. GEOLOGICAL OVERVIEW

The Weitenau area lies in the central part of the Northern Calcareous Alps (Figs. 1A, B) and belongs the Tirolic mega-unit. It consists predominantly of uppermost Jurassic to Lower Cretaceous sedimentary rocks of the Oberalm, Schrambach and Rossfeld formations (PLÖCHINGER, 1987, 1990), with several windows made of the Upper Jurassic Haselgebirge Mélange, which is, according to SPÖTL et al. (1998), a mixture of Upper Permian–lowermost Triassic gypsum matrix (Haselgebirge Formation of Grubach Moosege; SCHORN & NEUBAUER, 2011; KRISCHE et al., 2013a) and various exotic components of Permian to Jurassic age (KIRCHNER, 1980; VON EYNATTEN & GAUPP, 1999; VON EYNATTEN et al., 1996; NEUBAUER et al., 2007; SCHORN et al., 2013). These components are limestone blocks and volcanics, occasionally with blue amphiboles indicating high-pressure/low temperature metamorphism (KIRCHNER, 1980). Limestone blocks from the Weitenau area have not been previously studied unlike the limestone blocks in the Berchtesgaden or Hallein-Bad Dürrnberg salt mines (GAWLICK et al., 2009; MISSONI & GAWLICK, 2011a). The Haselgebirge Mélange in the Weitenau area is part of the widespread occurring Haselgebirge Mélange in the central Northern Calcareous Alps (TOLLMANN, 1985), forming the important salt and gypsum deposits, which have been variously exploited for more than 3000 years.

The emplacement history of the Haselgebirge Mélange in the sense of SPÖTL et al. (1998) is rather complicated and polyphase. After formation of the different Hallstatt mélanges in Bathonian to Oxfordian times (see GAWLICK & MISSONI, 2019 and references therein), the Haselgebirge Mélange was emplaced above the Hallstatt mélanges and sealed by the latest Oxfordian to Kimmeridgian deep- to shallow-water limestones of the Plassen Carbonate Platform (GAWLICK & SCHLAGINTWEIT, 2006; GAWLICK et al., 2009, 2012; MISSONI & GAWLICK, 2011a, b). This is in line with the component spectrum in the various Hallstatt mélanges of the Northern Calcareous Alps, in which clasts of the latest Permian to earliest Triassic Haselgebirge Formation are missing. The first reworked clasts of the Haselgebirge Formation appear in the latest Oxfordian to Kimmeridgian Sillenkopf Formation (MISSONI et al., 2001). Later, during Tithonian times, the Haselgebirge Mélange was remobilized and transported further to the north to the Oberalm Formation (PLÖCHINGER, 1974, 1976, 1979; TOLLMANN, 1985; BUJTOR et al., 2013). At the contact between the gypsum (Haselgebirge Mélange) and the uppermost Jurassic to Lower Cretaceous sedimentary sequence (Oberalm, Schrambach and Rossfeld formations), Upper Kimmeridgian–Lower Tithonian *Saccocoma* Limestones are preserved. They limit the time of early emplacement of the Haselgebirge Mélange, before its reworking into the Oberalm Formation, to be above the Callovian–Oxfordian Hallstatt Mélange (Fig. 2; KRISCHE et al., 2013a). The *Saccocoma* Limestones were originally deposited above the Haselgebirge Mélange and seal its first emplacement around the Oxfordian–Kimmeridgian boundary. This early emplacement age of the Alpine Haselgebirge Mélange (SPÖTL et al., 1998) is in line with data obtained in the Salzkammergut (Rötelstein – STEIGER & WURM, 1980; Altausee – GAWLICK et al., 2012; Hallstatt – GAWLICK & SCHLAGINTWEIT, 2006; Krahstein – SCHLAGINTWEIT et al., 2003) or in the Salzburg-Berchtesgaden Calcareous Alps (Berchtesgaden and Bad Dürrnberg – MISSONI & GAWLICK, 2011b).

In the Late Triassic, the Weitenau area was part of the huge Hauptdolomite-Dachstein Carbonate Platform and situated in the transitional facies zone between the restricted area (Hauptdolomite) and the open lagoon (lagoonal Dachstein Limestone). In the Late Norian to Rhaetian, the Kössen Basin as a deepened lagoon was formed due to siliciclastic input with its maximal extent in the Late Norian. In the Early Rhaetian, reefs established at the southern rim of the Kössen Basin and prograded rapidly northwards during the Rhaetian. South of the Rhaetian reefs, the lagoonal Dachstein Limestones were formed. Only the relatively small Eiberg Basin (GOLEBIOWSKI, 1991) remained as a deeper area. The biotic crisis at the Triassic–Jurassic boundary (SEPKOSKI, 1996; PÁLFY, 2008), combined with a sea-level fall (HUBBARD & BOUTLER, 2000; GUEX et al., 2004), stopped the shallow-water carbonate production in the Northern Calcareous Alps and led to the demise of the Hauptdolomite-Dachstein Carbonate Platform

(GAWLICK et al., 1999; HILLEBRANDT & KRYSTYN, 2009). Deposition during Hettangian–Pliensbachian times followed the palaeotopography of the uppermost Triassic. On morphological highs, red nodular limestones of the Hettangian to Aalenian Adnet Group were deposited whereas in the basins, (i.e. the Eiberg Basin) grey siliceous limestones accumulated (BÖHM, 1992). The only exception is a small-scale basin at the northern edge of today's Tennengebirge-Hagengebirge Block (Fig. 1B), where locally condensed grey siliceous limestones (GAWLICK et al., 2009; GAWLICK & MISSONI, 2013) with a characteristic litho- and microfacies were deposited (GAWLICK et al., 2009). After a long-lasting

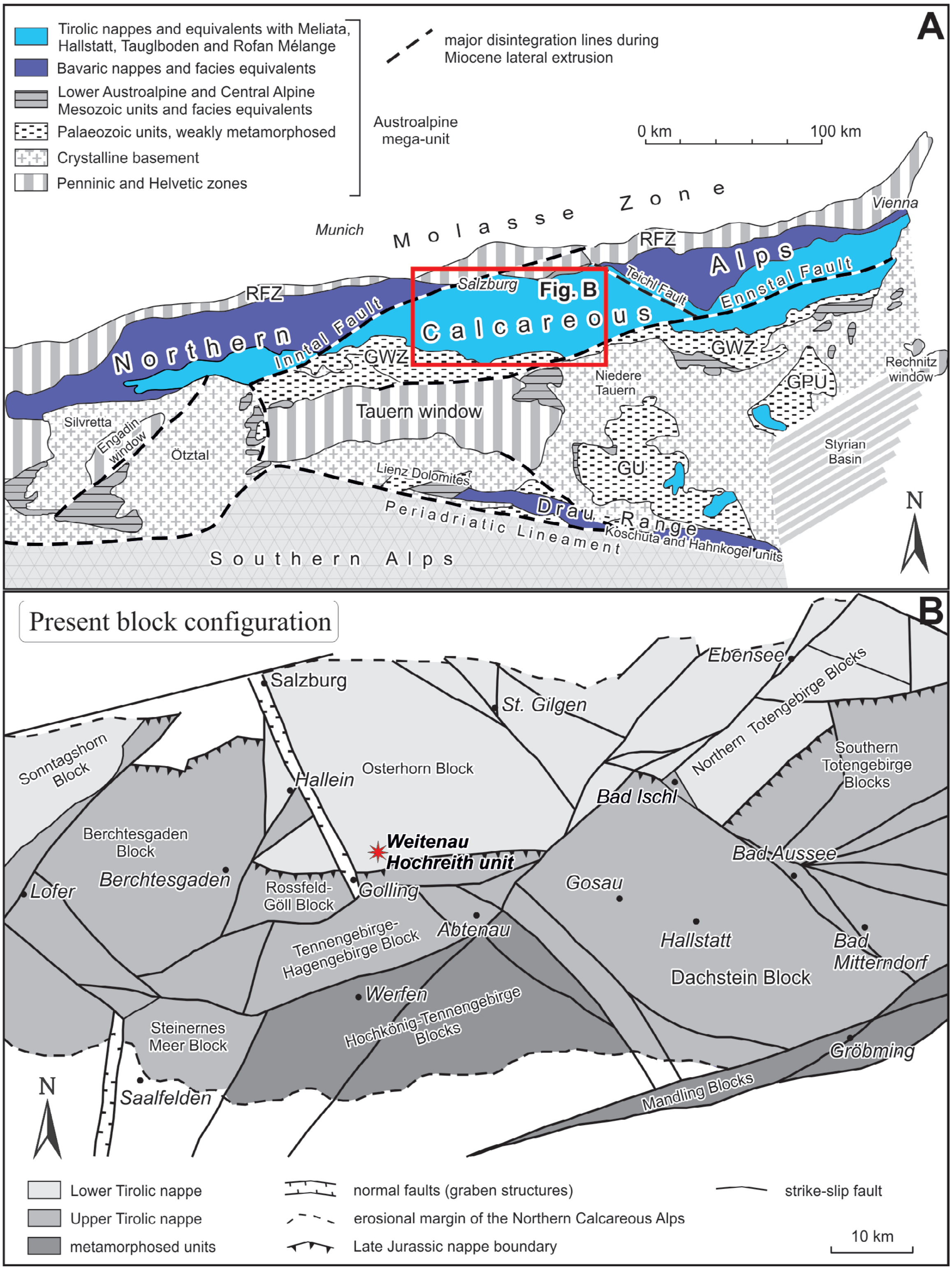

Figure 1. A) A tectonic sketch map of the Eastern Alps and study area (marked by the red box; Fig. 1B) in the central Northern Calcareous Alps (after TOLLMANN, 1977; FRISCH & GAWLICK, 2003, modified). GPU Graz Palaeozoic unit; GU Gurktal unit; GWZ Greywacke Zone; RFZ Rhenodanubian Flysch Zone. **B)** The recent block configuration of the Upper Jurassic Tirolic knappes in the central Northern Calcareous Alps with major faults during Miocene lateral tectonic extrusion (simplified and modified after FRISCH & GAWLICK, 2003). The studied locality of Weitenau (Hochreith unit according to KRISCHE et al., 2013a) northeast of Golling is marked by a red star.

gap in the Bajocian, deposition of the extremely condensed red nodular limestones of the Klaus Formation began (GAWLICK et al., 2009 for a summary and references) in the area of the southern Osterhorn Block and the Tennengebirge-Hagengebirge Block (Figs. 1B, 2). These *Bositra*- and *Protoglobigerina* limestones (Klaus Formation) are overlain by Callovian to Oxfordian radiolarites, which later also form the matrix in the newly formed trench-like basins in front of the propagating thrust belt (Hallstatt Mélanges; GAWLICK & MISSONI, 2019 for an overview and references) that were triggered by ophiolite obduction.

The Alpine Haselgebirge Formation, was deposited around the Permian–Triassic boundary in the area below the future Hallstatt shelf (TOLLMANN, 1985). Later, after the partial detachment of the siliciclastic Lower Triassic sequence and the uppermost Lower Triassic to Middle Jurassic open-shelf sequence, it acts as a basal thrust plane for the obducting ophiolites. During this process, blocks of the underlying sequence were scraped off and incorporated into the Haselgebirge Mélange, similar to other mélanges elsewhere (SCHMID et al., 2008; FESTA et al., 2016). These exotic blocks of the Haselgebirge Mélange also belong to the Lower Jurassic

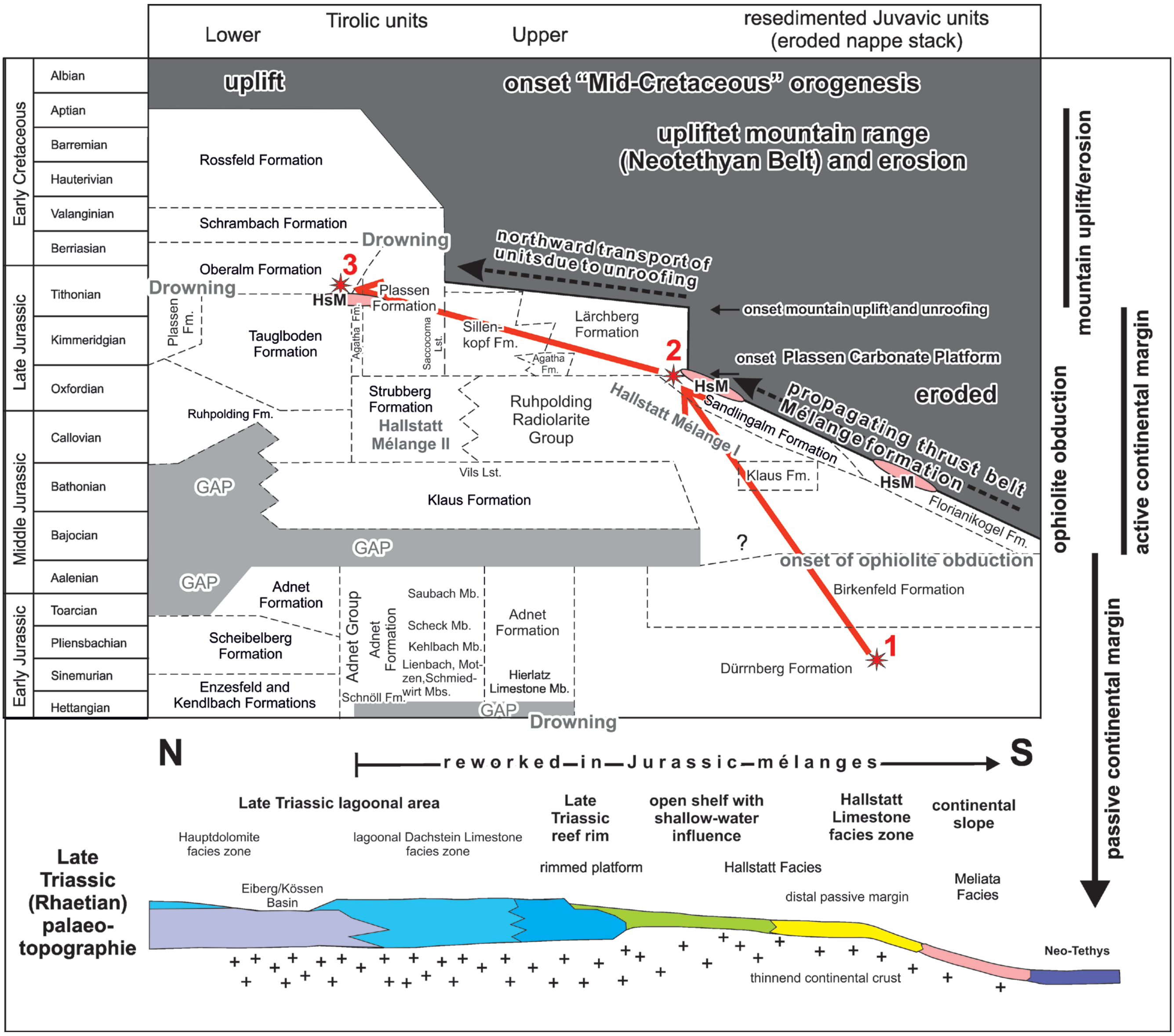

Figure 2. Jurassic to Early Cretaceous stratigraphic table of the Northern Calcareous Alps with the main tectonic Middle–Late Jurassic events and lithostratigraphic names of the Jurassic–Early Cretaceous of the Northern Calcareous Alps (modified after GAWLICK & MISSONI, 2019). The Early–Middle Jurassic depositional environment follows the Late Triassic topographic inventory of the Hauptdolomite-Dachstein Carbonate Platform formed of the passive continental margin of the Neo-Tethys Ocean to the south, according to the present-day position of the Northern Calcareous Alps. In the frame of obduction of Neo-Tethys derived ophiolites a northward propagating thrust belt formed since Middle Jurassic times. The obducting ophiolites were scraped off the Late Permian evaporites and blocks from the continental margin to the outer shelf (Position 1) and transported this Haselgebirge Mélange (SPÖTL et al., 1998) to the North until the Late Oxfordian (Position 2; for a detailed explanation see MISSONI & GAWLICK, 2011a, b). During the Tithonian, in the frame of mountain uplift and unroofing, the Haselgebirge Mélange was remobilized and transported further to the North (Position 3; PLÖCHINGER, 1976) and then sealed by the Lower Cretaceous Rossfeld Basin fill (KRISCHE et al., 2014; KRISCHE & GAWLICK, 2015). Tectonic motions, related to the lateral tectonic extrusion (RATSCHBACHER et al., 1991; LINZER et al., 1995; PUEYO et al., 2007), led to remobilization of the Alpine Haselgebirge Mélange and also formed the Hochreith unit, which contains the Alpine Haselgebirge Mélange in the Weitenau area (KRISCHE et al., 2013a). HsM – Haselgebirge Mélange.

marly-siliceous Dürrnberg Formation and to the Toarcian–Aalenian Birkenfeld Formation (GAWLICK et al., 2009; MISSONI & GAWLICK, 2011a, b). During this process, the Alpine Haselgebirge Mélange experienced a low-grade thermal overprint during Oxfordian and Early Kimmeridgian times (SPÖTL et al., 1998). Later, in the frame of the latest Jurassic mountain uplift and unroofing (Fig. 2), parts of the Alpine Haselgebirge Mélange glided northwards and were incorporated in the Tithonian Oberalm Formation (PLÖCHINGER 1974, 1976; KRISCHE et al., 2018) and sealed by the Lower Cretaceous sedimentary succession (Schrambach and Rossfeld formations; KRISCHE et al., 2013b, 2014). This tectonostratigraphic evolution is also documented in the area east–northeast of Golling (Fig. 1B; PLÖCHINGER, 1979). The Lower Jurassic marly siliceous limestone block, east of the Berggasthof Hochreith (Fig. 3) described here, is one of these exotic blocks transported to the actual position by the early emplacement of the Alpine Haselgebirge Mélange, similar to the known Lower Jurassic blocks from the outer shelf in the Berchtesgaden salt mine (GAWLICK et al., 2009). The block can be attributed to the Dürrnberg Formation, representing a deeper shelf facies (GAWLICK et al., 2009), which can only be reconstructed today from various blocks that are incorporated in different mélanges (i.e. Haselgebirge Mélange, Hallstatt Mélange).

3. RADIOLARIAN BIOSTRATIGRAPHY

The microfacies of this studied Lower Jurassic block is that of a slightly bioturbated marly siliceous radiolarian-spicule wacke- to packstone with some broken crinoids, similar to the Pliensbachian microfacies figured in O'DOGHERTY & GAWLICK (2008; Fig. 4). For radiolarian studies, three samples were processed in acetic acid (8–10 %) for five days. The residue was washed and sieved through a 63 µm mesh. Radiolarians were picked and observed under a stereomicroscope and photographed with a Leica scanning electron microscope. Of all the processed samples, only one (OK-W368), yielded a well-preserved radiolarian assemblage.

Altogether 53 species belonging to 30 genera were identified (Table 1), and are illustrated in Pls. 1–4. Of these, 14 species are in open nomenclature and six are described with either *affinis* or *confer*. We use the generic names revised by O'DOGHERTY et al. (2009). The species level taxonomy is according to GORIČAN et al. (2006) and more recent taxonomic studies (CIFER et al., 2020; TEKIN et al., 2020; CIFER & GORIČAN, 2023a, b). For age determination, the global radiolarian zonation by CARTER et al. (2010) was used. The studied radiolarian assemblage from sample OK-W368 is assigned to the uppermost Lower Pliensbachian *Gigi fustis–Lantus sixi* Radiolarian Zone (UA 12–18 of CARTER et al., 2010), based on the first appearance of *Archaeohagiastrum*

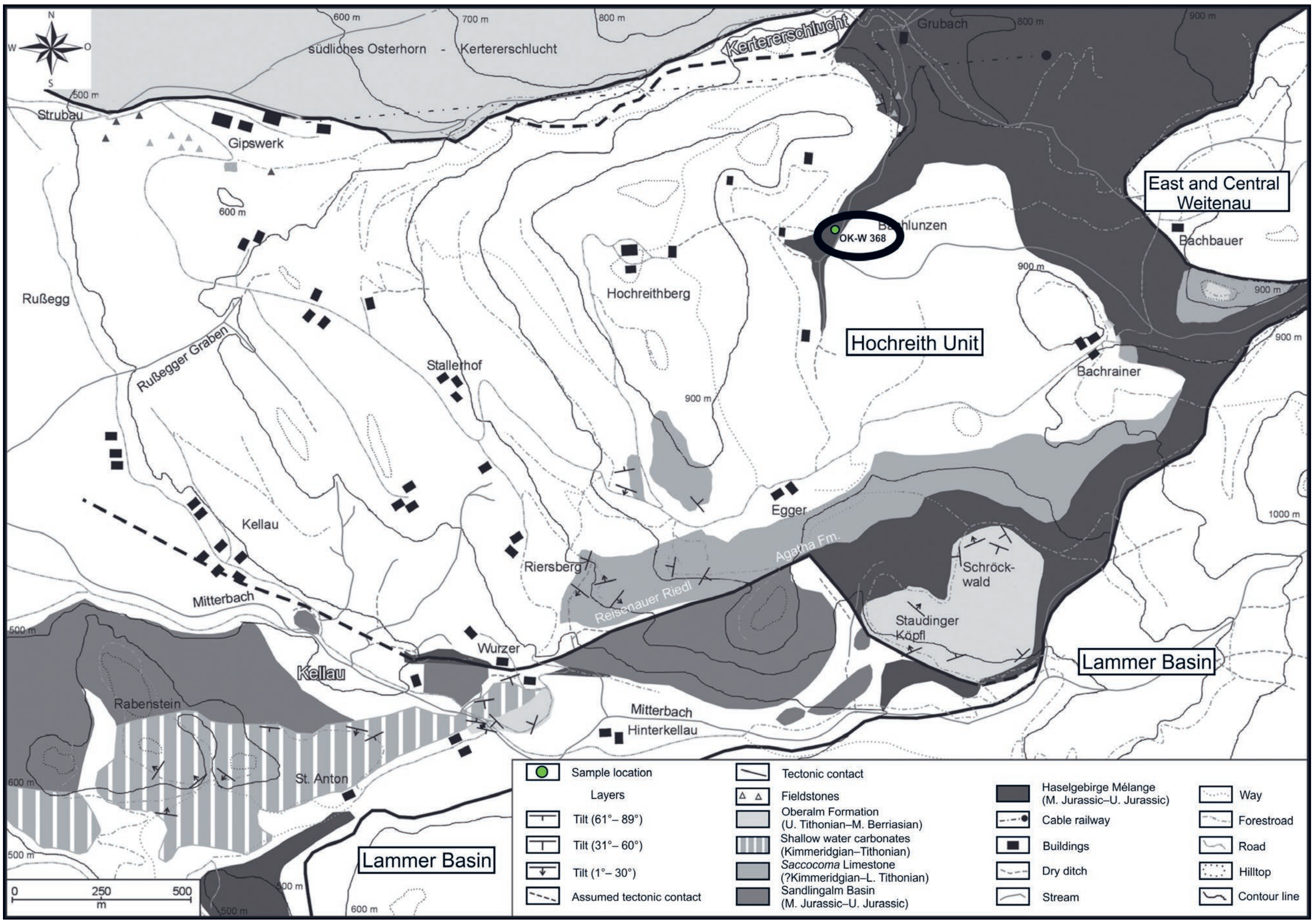

Figure 3. A simplified geological map of the Western Weitenau region, with the indicated sample locality of the Haselgebirge Mélange with the Lower Jurassic radiolarian-bearing block of the Dürrnberg Formation, after KRISCHE et al. (2013a). Lammer Basin: Middle to Upper Jurassic, indicated with white; Hochreith Unit and the East and Central Weitenau: Early Cretaceous to Quaternary, indicated with white.

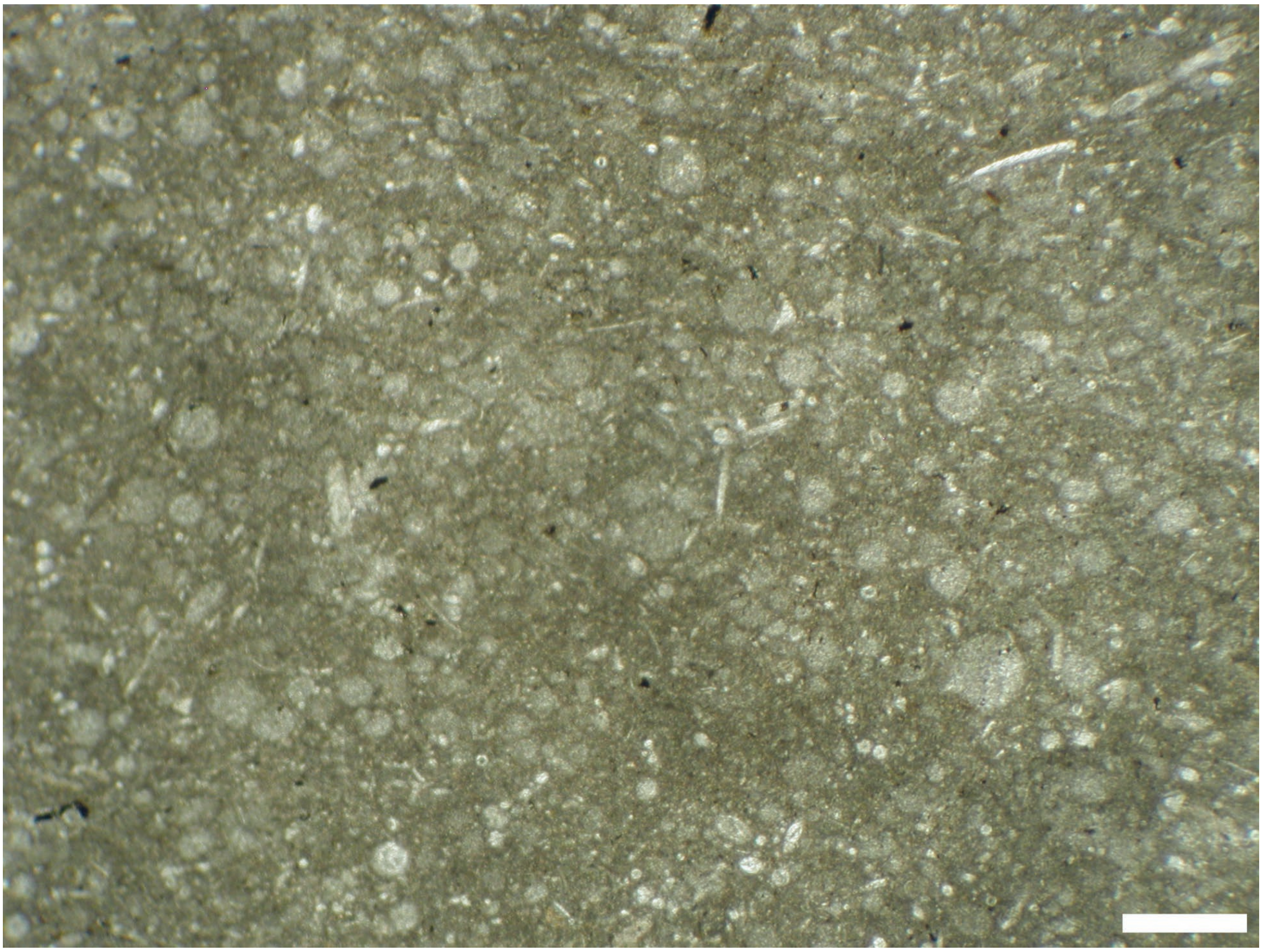

Figure 4. Microfacies of sample OK-W368 is a slightly bioturbated marly siliceous radiolarian-spicule wacke- to packstone, belonging to the Dürrnberg Formation. The scale bar is 200 µm.

longipes BAUMGARTNER and the last appearance of *Napora reiferensis* (PESSAGNO, WHALEN & YEH). Other important age diagnostic taxa that support a Pliensbachian age for the studied fauna are *Bagotum maudense* PESSAGNO & WHALEN (stratigraphic range from the Lower Pliensbachian *Canutus tipper–Katroma clara* Zone to the Lower Toarcian *Napora relica–Eucyrtidiellum disparile* Zone), *Helvetocapsa* cf. *plicata plicata* (MATSUOKA) (Lower Pliensbachian *Zartus mostleri–Pseudoristola megaglobosa* Zone to Lower Toarcian *Napora relica–Eucyrtidiellum disparile* Zone), *Lantus praeobesus* CARTER (Lower Pliensbachian *Canutus tipper–Katroma clara* Zone to Upper Pliensbachian *Eucyrtidiellum nagaiae–Praeparvicingula tlellensis* Zone); *Naropa vi* HORI, WHALEN & DUMITRICA (Lower Pliensbachian *Gigi fustits–Lantus sixi* Zone to Upper Pliensbachian *Eucyrtidiellum nagaiae–Praeparvicingula tlellensis* Zone); *Parahsuum mostleri* (YEH) (Lower Pliensbachian *Zartus mostleri–Pseudoristola megaglobosa* Zone to Lower Toarcian *Napora relica–Eucyrtidiellum disparile* Zone) and *Paronaella variabilis* CARTER (Lower Pliensbachian *Gigi-fustis–Lantus sixi* Zone to Aalenian *Higumastra transversa–Napora nipponica* Zone). The ranges of *Naropa vi* and *Parahsuum mostleri* were later extended downwards to the *Canutus tipper–Katroma clara* Radiolarian Zone (CIFER et al., 2022).

This fauna is similar in age to the well-known and extremely well-preserved radiolarian assemblage from sample 1662D from the Gümüşlü allochthonous unit in Turkey (e.g., DE WEVER, 1981a, b, 1982a, b; PESSAGNO & POISSON, 1981; GORIČAN et al., 2006) and the radiolarian fauna from sample BMW21 from the Teltschengraben in the Northern Calcareous Alps, Austria (O'DOGHERTY & GAWLICK, 2008). Several species were identified in the studied sample from Weitenau that were previously only identified from sample 1662D (Turkey) and BMW21 (Teltschengraben). These are *Paronaella tripla* DE WEVER, *Orbiculiformella radiata* DE WEVER and *Paronaella hirsuta* (DE WEVER). Two of these species, *Orbiculiformella radiata* DE WEVER and *Paronaella hirsuta* (DE WEVER), were identified exclusively at these three localities, only *Paronaella tripla* DE WEVER was identified at one additional locality, in Haida Gwaii, British Columbia (CARTER et al., 1988). Other age diagnostic species that are common but not exclusive to the studied sample from Weitenau and the afore mentioned samples from Teltschegraben and Turkey, are *Parahsuum mostleri* (YEH), *Zhamoidellum sutnal* (O'DOGHERTY & GAWLICK), *Homoeoparonaella lowryensis* WHALEN & CARTER, *Archaeohagiastrum longipes* BAUMGARTNER.

Table 1. Identified radiolarian taxa in sample OK-W368. The stratigraphic range is indicated for species with known ranges expressed in Unitary Associations (UA; after CARTER et al., 2010). ← indicates, which species have their stratigraphic ranges, published in CARTER et al. (2010), extended based on later studies (CIFER et al., 2020, 2022; CIFER & GORIČAN, 2023a, b). The studied assemblage is assigned to the *Gigi fustis – Lantus sixi* Radiolarian Zone (UA 12–18).

Radiolarian taxa	UA
Acaeniotylopsis? sp.	
Archaeocenosphaera ruesti PESSAGNO & YANG	
Archaeodictyomitra sp.	
Archaeohagiastrum longipes BAUMGARTNER	14–41
Bagotum erraticum PESSAGNO & WHALEN	
Bagotum maudense PESSAGNO & WHALEN	02–26
Beatricea? sp.	
Canoptum anulatum PESSAGNO & POISSON	06–28
Canoptum columbiaense WHALEN & CARTER	01–20
Charlottea sp.	
Crucella jadeae CARTER & DUMITRICA	
Crucella squama (KOZLOVA)	
Crucella sp.	
Doliocapsa sp. 1 sensu CIFER et al. (2020)	
Doliocapsa sp. C sensu CIFER & GORIČAN (2023a)	
Droltus hecatensis PESSAGNO & WHALEN	
Dumitricaella aff. *trispinosa* DUMITRICA	
Farcus cf. *asperoensis* PESSAGNO, WHALEN & YEH	
Farcus kozuri YEH	
Hagiastrum macrum gr. DE WEVER	
Hagiastrum sp.	
Helvetocapsa cf. *plicata plicata* (MATSUOKA)	08–27
Homoeoparonaella lowryensis WHALEN & CARTER	03–20
Katroma sp.	
Lantus praeobesus CARTER	←02–20
Loupanus pliensbachicus CIFER	
Loupanus cf. sp. A sensu CIFER & GORIČAN (2023b)	
Loupanus sp. C sensu CIFER & GORIČAN (2023b)	
Mendacastrum? sp. A sensu CIFER & GORIČAN (2023b)	
Napora reiferensis (PESSAGNO, WHALEN & YEH)	09–17
Naropa vi HORI, WHALEN & DUMITRICA	←12–19
Orbiculiformella radiata DE WEVER	
Orbiculiformella sp.	
Pantanellium carlense WHALEN & CARTER	
Pantanellium inornatum PESSAGNO & POISSON	03–22
Parahsuum mostleri (YEH)	←06–27
Parahsuum simplum YAO	01–36
Paronaella aff. *bona* (YEH)	
Paronaella grahamensis CARTER	←03–34
Paronaella hirsuta (DE WEVER)	
Paronaella notabilis WHALEN & CARTER	
Paronaella snowshoensis (YEH)	
Paronaella tripla DE WEVER	
Paronaella variabilis CARTER	17–34
Paronaella sp. A sensu CIFER & GORIČAN (2023b)	
Praeconocaryomma bajaensis WHALEN	←06–38
Praeconocaryomma pravimamma PESSAGNO & POISSON	
Praeconocaryomma whiteavesi CARTER	←08–23
Tozerium filzmoosense CIFER	
Tripocyclia? *tortuosa* DUMITRICA, GORIČAN & WHALEN	
Zhamoidellum sutnal (O'DOGHERTY & GAWLICK)	
Zhamoidellum yehae DUMITRICA	
Zhamoidellum sp.	

4. PALAEOGEOGRAPHIC PROVENANCE AND IMPORTANCE OF THE LOWER JURASSIC OUTER SHELF SEDIMENTARY SEQUENCE OF THE WEITENAU AREA

The wider area around the present position of the analysed exotic block incorporated into the Haselgebirge Mélange is characterized throughout the whole Early to early-Middle Jurassic by the deposition of red condensed nodular limestones (BÖHM, 1992; GAWLICK et al., 1999). In contrast, the provenance area of the studied block is characterized by predominantly grey siliceous limestones and in parts marly limestones and marls that were deposited on either the outer shelf (Fig. 2; Dürrnberg Formation – GAWLICK et al., 2001), or deep-water basins in the Tirolic unit (GOLEBIOWSKI, 1990, 1991), formed in the latest Triassic lagoonal areas in the former central shelf position (Fig. 2). The colouring is darker and the clay content is significantly higher in rocks of the outer (Hallstatt) shelf than in the brighter, spicula-rich siliceous limestones in the central to proximal shelf areas (Fig. 2; BÖHM, 1992; GAWLICK et al., 2009). In addition, the thickness of the Lower Jurassic sequence deposited in the outer shelf seems significantly higher in comparison with the age equivalent siliceous limestones in the proximal and central shelf areas of the Tirolic unit. This difference can be easily recognized by the sequences preserved in the various known rocks of the Dürrnberg and Birkenfeld Formation, with thicknesses of up to 30 m, deposited in a very short time interval (GAWLICK et al., 2001, 2009; O´DOGHERTY & GAWLICK, 2008; MISSONI & GAWLICK, 2011b). It can be estimated that the thickness of the Dürrnberg Formation reaches up to 200 m in some cases. Furthermore, the microfacies characteristics of the Dürrnberg Formation differ significantly from age equivalent grey siliceous limestones deposited in the former central shelf area (GAWLICK et al., 2009). Nevertheless, the clay content in the outer shelf sedimentary sequence decreased during the Rhaetian (Zlambach Formation; KRYSTYN, 2008) to the Sinemurian–Pliensbachian (Dürrnberg Formation; GAWLICK et al., 2001). This decrease in clay content can be easily explained by the ongoing extension in the area of the later Alpine Atlantic where, during the evolving graben structure from Middle to Late Hettangian times, a clay-rich sedimentary succession was deposited (Bündner schists; TOLLMANN, 1977 and references therein). In the Toarcian to Aalenian Birkenfeld Formation, the clay content increased again and led to the deposition of siliceous marls on the outer (Hallstatt; Fig. 2) shelf area. The increasing clay content on the outer shelf is interpreted as the result of the onset of ophiolite obduction (MISSONI & GAWLICK, 2011a, b).

A similar general sedimentological evolution is known from various blocks in the Hallstatt Mélange of Serbia (GAWLICK et al., 2017, 2018). Lithological differences between the outer shelf sedimentation from the Northern Calcareous Alps and Dinarides are the much lower clay content in the grey siliceous and spicula-rich limestones and the limited thickness in the latter, while the microfacies are similar in both. However, a comprehensive biostratigraphic proof, e.g., with ammonoids or radiolarians, has not yet been achieved, due to the lack of ammonoids and the generally predominant recrystallization of radiolarians. The age can only be estimated by the underlying conodont bearing latest Triassic limestones and the overlying Middle Jurassic radiolarites. In the Inner Western Carpathians similar successions are not known.

Although the deposition of open-marine sedimentary rocks in the outer shelf region of the western to north-western passive continental margin of the Neo-Tethys continued without a break from Late Triassic to early Middle Jurassic times, the detailed evolution is only poorly known due to the destruction of the whole outer shelf area during the Middle–Late Jurassic ophiolite obduction (GAWLICK et al., 2008; SCHMID et al., 2008; GAWLICK & MISSONI, 2019), with the formation of various ophiolitic and sedimentary mélanges throughout the whole of the Western Tethyan Realm. The analysis of the exotic block in the Haselgebirge Mélange of the Weitenau area fills therefore an important gap in the knowledge of the evolution of the outer (Hallstatt) shelf. The radiolarian bearing block is a missing part of the Lower Jurassic outer shelf sedimentary sequence and fits perfectly with the known blocks in the Hallstatt Mélange in the area of Hallein-Bad Dürrnberg (GAWLICK et al., 2001) or the Haselgebirge Mélange in the Berchtesgaden salt mine (MISSONI & GAWLICK, 2011b). Furthermore, the existence of this block in the Haselgebirge Mélange shows the allochthony of the Alpine Haselgebirge as a far-travelled mélange complex.

5. CONCLUSIONS

The studied fauna is assigned to the Lower Pliensbachian *Gigi fustis–Lantus sixi* Radiolarian Zone (UA 12–18) of CARTER et al. (2010). Altogether, the fauna comprises 53 species belonging to 30 genera. In terms of age and composition the studied assemblage is closest to the faunas from sample BMW21 (Teltschengraben, Austria) and sample 1662D (the Gümüşlü allochthonous unit, Turkey) as it contains several taxa that were previously only found in these two samples.

The well-preserved Early Jurassic radiolarian assemblage fills an important gap in the knowledge about the Early Jurassic depositional history of the outer shelf of the Neo-Tethys passive continental margin. The facies and age of the block, together with the rich and well-preserved radiolarian fauna, contrast significantly from the Lower Jurassic sedimentary sequence known from the wider area between the Tennengebirge Mts. to the south and the Osterhorn unit to the north. They prove the allochthonous nature of this block, transported in the Haselgebirge Mélange to its present-day position. The position of the block also indicates a polyphase transport of the Haselgebirge Mélange during Jurassic times from the outer shelf to the central shelf area; that is the former lagoon of the Upper Triassic Hauptdolomite-Dachstein Carbonate Platform.

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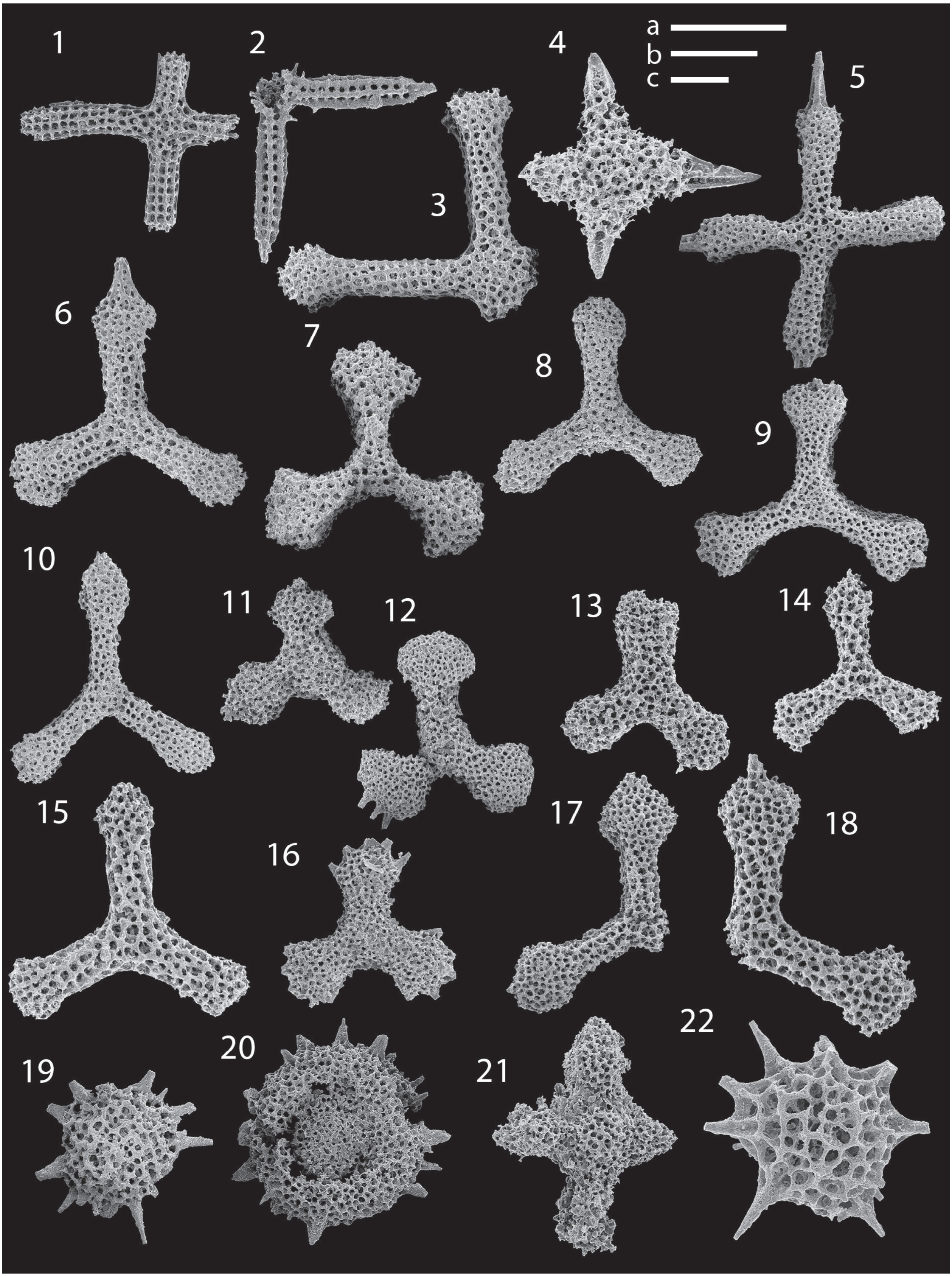

Plate 1. Sample OK-W368. Scale bar is 100 µm. a – 4, 21, 22; b – 1, 3, 7, 11, 13–16, 18–20; c – 2, 5, 6, 8–10, 12, 17. **1** – *Hagiastrum* sp., OK-W368-1.001; **2** – *Archaeohagiastrum longipes* BAUMGARTNER, OK-W368-1.002; **3** – *Hagiastrum macrum* gr. DE WEVER, OK-W368-1.003; **4** – *Crucella squama* (KOZLOVA), OK-W368-2.010; **5** – *Crucella jadeae* CARTER & DUMITRICA, OK-W368-1.014; **6** – *Homoeoparonaella lowryensis* WHALEN & CARTER, OK-W368-1.013; **7** – *Paronaella variabilis* CARTER, OK-W368-1.015; **8**, **10**, **15** – *Paronaella* sp. A sensu CIFER & GORIČAN (2023b), OK-W368-1.016, OK-W368-1.019, OK-W368-2.009; **9** – *Paronaella* aff. *bona* (YEH), OK-W368-1.017; **11** – *Paronaella notabilis* WHALEN & CARTER, OK-W368-1.006; **12** – *Paronaella tripla* DE WEVER, OK-W368-1.008; **13**, **14**, **18** – *Paronaella grahamensis* CARTER, OK-W368-2.002, OK-W368-2.008, OK-W368-2.103; **16** – *Paronaella hirsuta* (DE WEVER), OK-W368-1.004; **17** – *Paronaella snowshoensis* (YEH), OK-W368-2.101; **19** – *Orbiculliformella* sp., OK-W368-2.032; **20** – *Orbiculiformella radiata* DE WEVER, OK-W368-1.007; **21** – *Crucella* sp., OK-W368-2.104; **22** – *Mendacastrum*? sp. A sensu CIFER & GORIČAN (2023b), OK-W368-2.017.

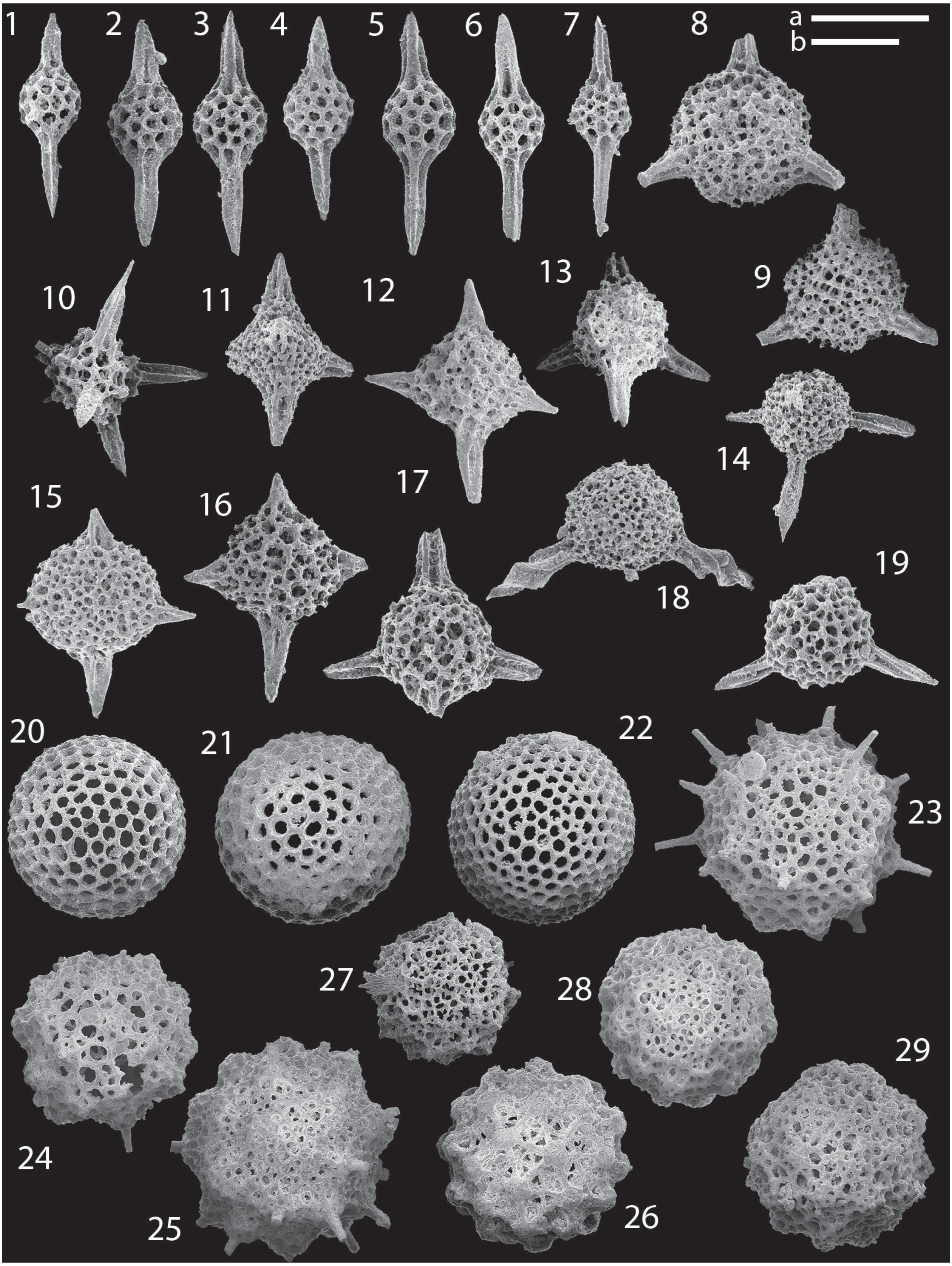

Plate 2. Sample OK-W368. Scale bar is 100 µm. a – 17, 18; b – 1–16, 19–29. **1-6** – *Pantanellium inornatum* PESSAGNO & POISSON, OK-W368-1.073, OK-W368-1.079, OK-W368-1.088, OK-W368-1.109, OK-W368-1.119, OK-W368-2.014; **7** – *Pantanellium carlense* WHALEN & CARTER, OK-W368-2.026; **8**, **9** – *Acaeniotylopsis*? sp., OK-W368-1.098, OK-W368-1.123; **10** – *Loupanus pliensbachicus* CIFER, OK-W368-1.084; **11** – *Loupanus* sp. C sensu CIFER & GORIČAN (2023b), OK-W368-2.018; **12**, **15**, **16** – *Beatricea*? sp., OK-W368-1.112, OK-W368-2.023, OK-W368-2.080; **13**, **14** – *Loupanus* cf. sp. A sensu CIFER & GORIČAN (2023b), OK-W368-1.128, OK-W368-2.015; **17** – *Tozerium filzmoosense* CIFER, OK-W368-2.086; **18** – *Tripocyclia*? *tortuosa* DUMITRICA, GORIČAN & WHALEN, OK-W368-2.089; **19** – *Charlottea* sp., OK-W368-2.097; **20-22** – *Archaeocenosphaera ruesti* PESSAGNO & YANG, OK-W368-1.053, OK-W368-1.103, OK-W368-1.115; **23**, **24**, **27**, **29** – *Praeconocaryomma whiteavesi* CARTER, OK-W368-1.062, OK-W368-1.063, OK-W368-1.111, OK-W368-2.061; **25**, **28** – *Praeconocaryomma bajaensis* WHALEN, OK-W368-1.064, OK-W368-2.049; **26** – *Praeconocaryomma parvimamma* PESSAGNO & POISSON, OK-W368-1.101.

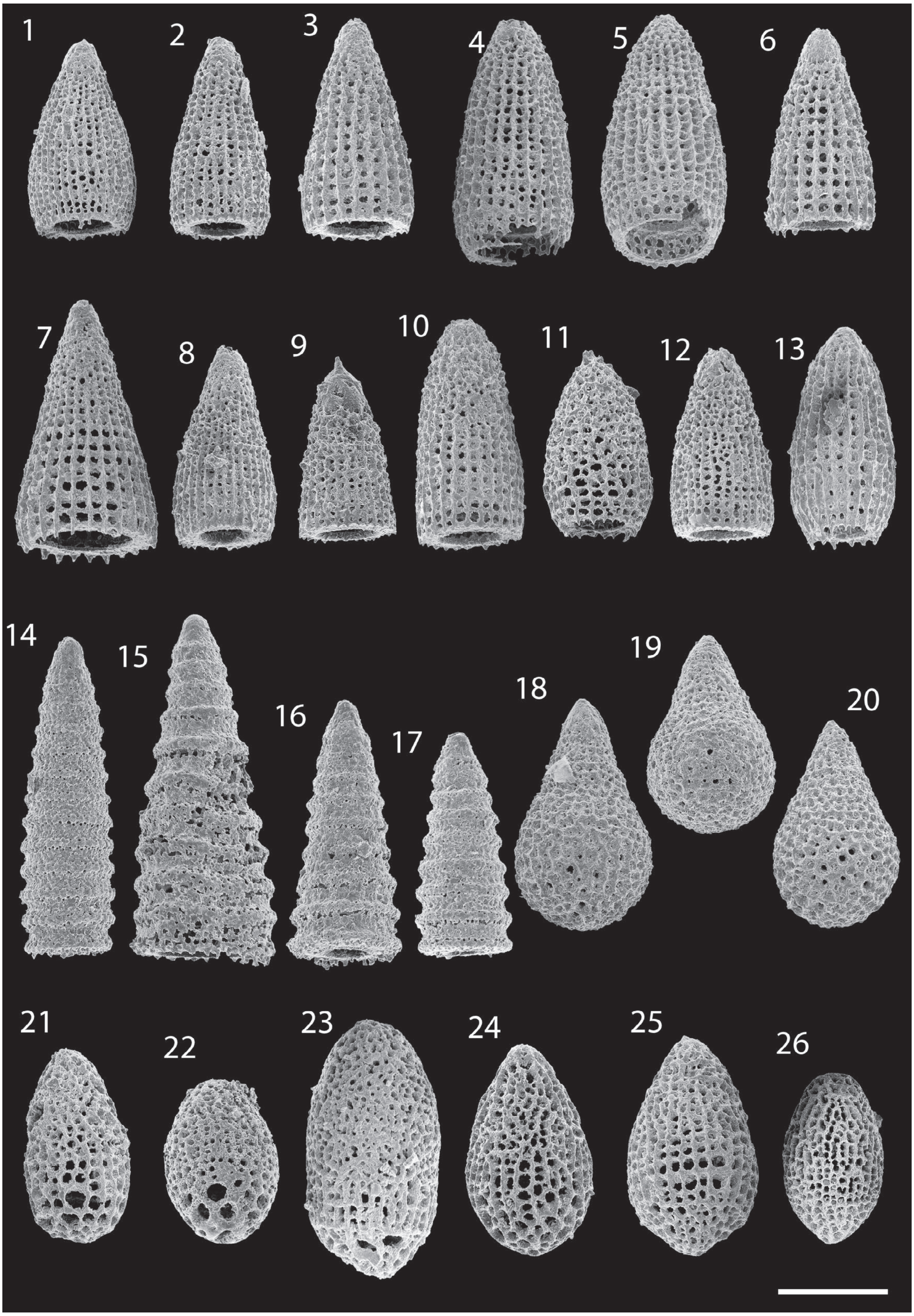

Plate 3. Sample OK-W368. Scale bar is 100 µm. **1-5**, **8** – *Parahsuum simplum* YAO, OK-W368-1.023, OK-W368-1.038, OK-W368-2.035, OK-W368-1.114, OK-W368-2.037, OK-W368-1.028; **6**, **7** – *Parahsuum mostleri* (YEH), OK-W368-2.044, OK-W368-1.124; **9-12** – *Droltus hecatensis* PESSAGNO & WHALEN, OK-W368-1.039, OK-W368-1.045, OK-W368-1.125, OK-W368-2.033; **13** – *Archaeodictyomitra* sp., OK-W368-1.107; **14** – *Canoptum anulatum* PESSAGNO & POISSON, OK-W368-1.026; **15-17** – *Canoptum columbiaense* WHALEN & CARTER, OK-W368-1.029, OK-W368-1.030, OK-W368-2.036; **18-20** – *Lantus praeobesus* CARTER, OK-W368-1.033, OK-W368-1.035, OK-W368-1.099; **21-23** – *Bagotum erraticum* PESSAGNO & WHALEN, OK-W368-1.126, OK-W368-2.069, OK-W368-2.075; **24-26** – B*agotum maudense* PESSAGNO & WHALEN, OK-W368-2.070, OK-W368-1.024, OK-W368-2.081.

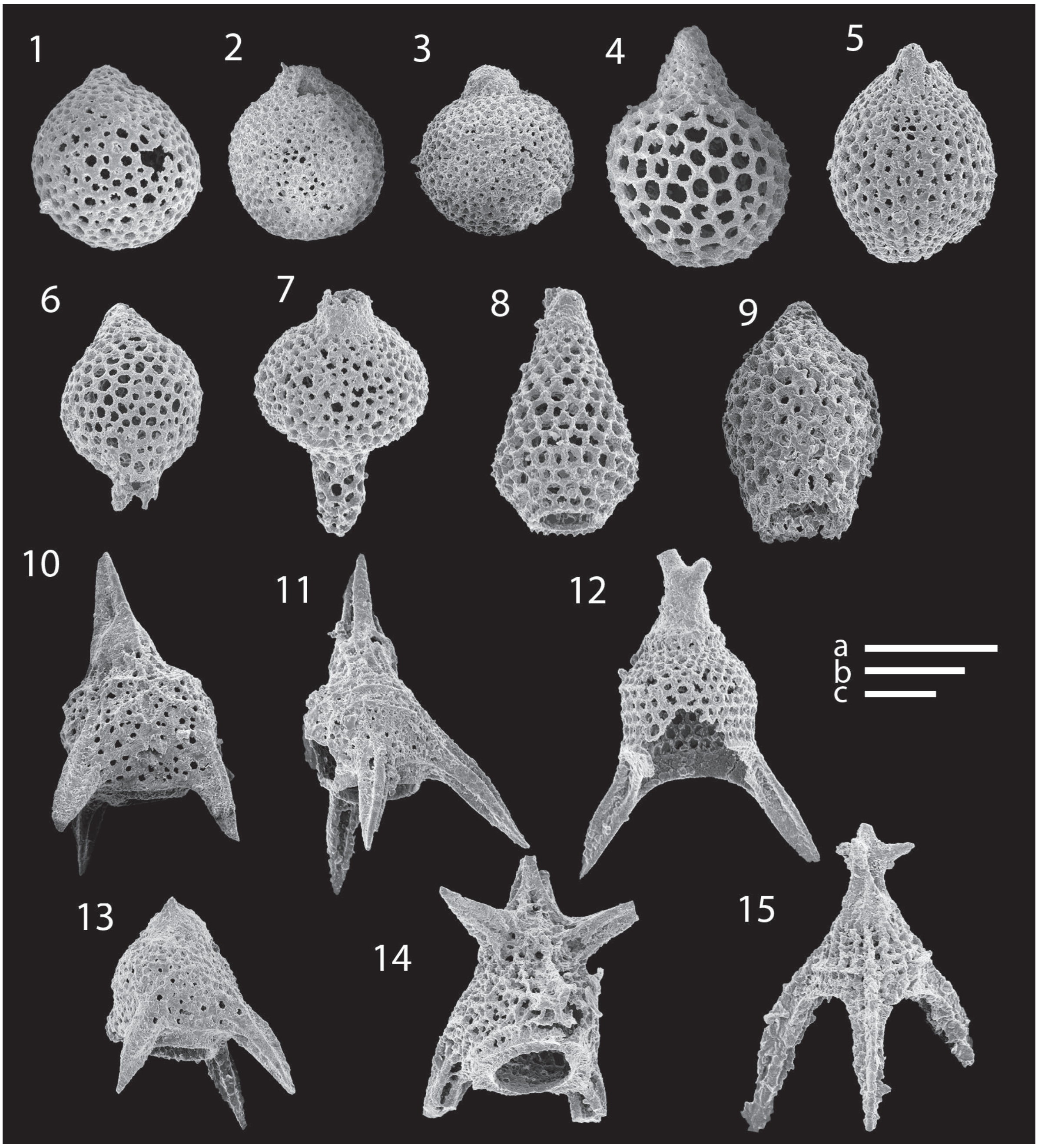

Plate 4. Sample OK-W368. Scale bar is 100 µm. a – 1, 3, 5–16; b – 4; c – 2. **1** – *Zhamoidellum* sp., OK-W368-1.066; **2**, **3** – *Zhamoidellum yehae* DUMITRICA, OK-W368-1.052, OK-W368-1.085; **4** – *Zhamoidellum sutnal* (O'DOGHERTY & GAWLICK), OK-W368-1.068; **5** – *Helvetocapsa* cf. *plicata plicata* (MATSUOKA), OK-W368-2.068; **6**, **7** – *Katroma* sp., OK-W368-1.108, OK-W368-2.038; **8** – *Doliocapsa* sp. 1 sensu CIFER et al. (2020), OK-W368-2.055; **9** – *Doliocapsa* sp. C sensu CIFER & GORIČAN (2023a), OK-W368-1.040; **10**, **11** – *Farcus kozuri* YEH, OK-W368-1.076, OK-W368-1.070; **12** – *Naropa vi* HORI, WHALEN & DUMITRICA, OK-W368-2.028; **13** – *Farcus* cf. *asperoensis* PESSAGNO, WHALEN & YEH, OK-W368-1.087; **14** – *Dumitricaella* aff. *trispinosa* DUMITRICA, OK-W368-2.030. This specimen has bigger V and l spines than the type material. These spines are equal in size to the apical horn; **15** – *Napora reiferensis* (PESSAGNO, WHALEN & YEH), OK-W368-2.108.