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Facies changes of the Upper Triassic–Lower Cretaceous Hödl-Kritsch quarry (Lunz Nappe, Northern Calcareous Alps, Austria)

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2 Text-Figures, 6 Plates

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Facies change
Carbonate sedimentology
Upper Triassic to Lower Cretaceous
Rhaetian to Berriasian
Lunz Nappe
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Contents

Abstract

Detailed palaeontological, lithological and facies studies of a Mesozoic succession within the Lunz Nappe (Hödl-Kritsch section, Northern Calcareous Alps, Lower Austria) uncovered new details on the facies of the Upper Triassic to Lower Cretaceous. The outcrop is situated in an abandoned quarry within the easternmost Flössel Syncline (northern part of the Lunz Nappe, High Bajuvaric Unit), which is formed of Upper Triassic dolomites, the Kössen Formation and Rhaetian limestone, followed by a reduced Jurassic sequence with Klaus Formation, Tegernsee limestone, and Ammergau Formation. The core of the Flössel Syncline consists of the Lower Cretaceous Schrambach Formation. The outcrop provides Upper Triassic (Rhaetian) to Lower Cretaceous (Berriasian) formations and lithologies. The detailed investigation of

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microfacies and fossil content is new for the Hödl-Kritsch quarry and for the first time allows precise biostratigraphy of the Triassic to Cretaceous succession. Two main hiati can be recognized in the succession: one marked by a stromatolitic layer at the top of the reefal Upper Triassic limestones (uppermost Rhaetian to Bajocian), and a second one in the upper Lower Tithonian (between the *Parastomiosphaera malmica* and the *Chitinoidella* Zone) marked by intense reworking at the erosive base of the red limestones in the Lower Tithonian.

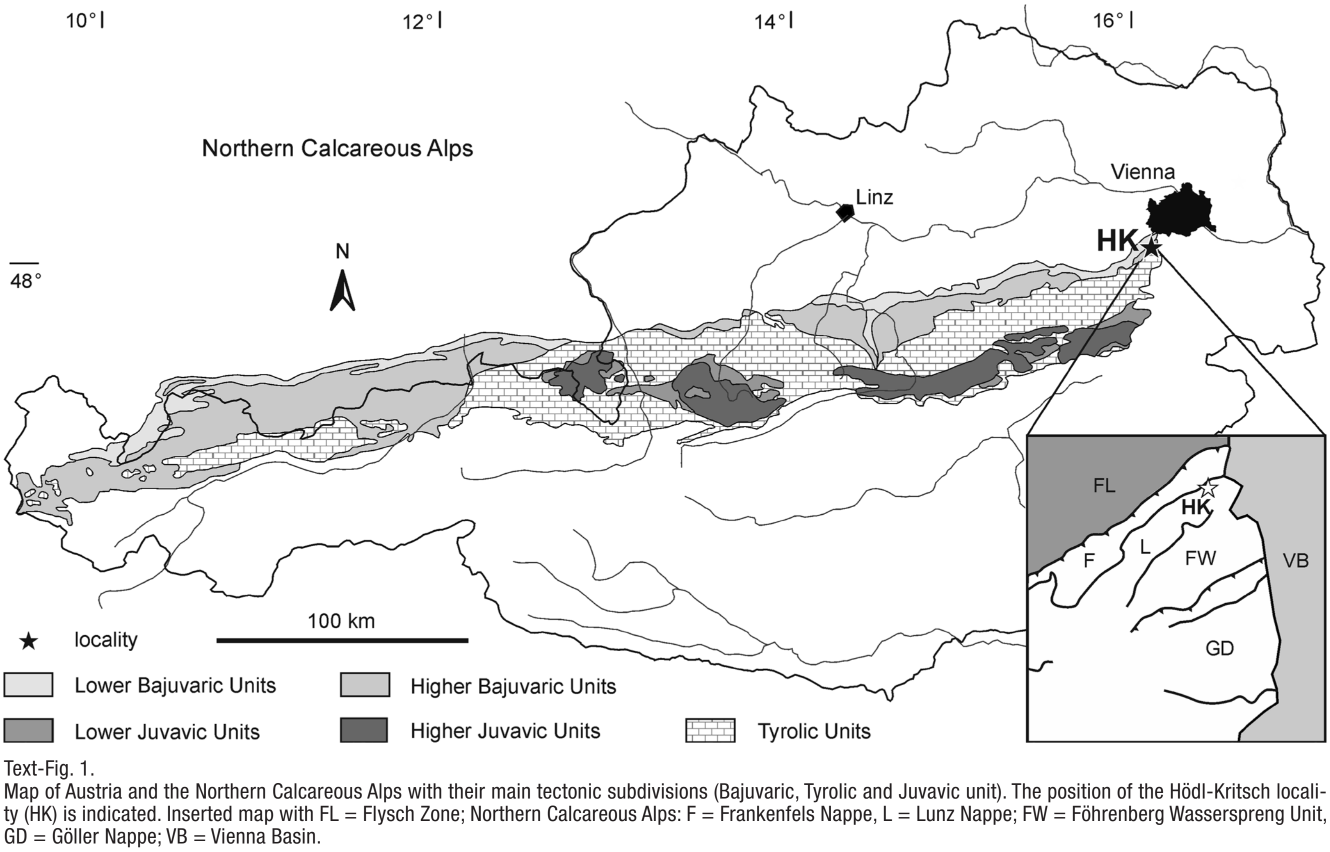
Fazieswechsel in der Obertrias- bis Unterkreide-Schichtfolge des Hödl-Kritsch Steinbruchs (Lunz-Decke, Nördliche Kalkalpen, Österreich)

Zusammenfassung

Detaillierte paläontologische, lithologische and fazielle Untersuchungen einer Mesozoischen Abfolge aus der Lunz-Decke (Lokalität Hödl-Kritsch, Nördliche Kalkalpen, Niederösterreich) enthüllten neue Details zur Fazies der späten Trias bis zur jüngeren Kreide. Der Aufschluss liegt in einem aufgelassenen Steinbruch innerhalb der östlichsten Flössel Mulde (nördlicher Teil der Lunz-Decke, Hochbajuvarikum). Die Mulde wird aus Dolomiten, der Kössen-Formation und rhätischen Kalken der späten Trias aufgebaut, gefolgt von einer reduzierten jurassischen Abfolge der Klaus-Formation, der Tegernseer Kalke und der Ammergau-Formation. Der Kern der Flössel Mulde besteht aus der unterkretazischen Schrambach-Formation. Der Aufschluss bietet Formationen und Lithologien der Obertrias (Rhätium) bis Unterkreide (Berriasium). Die detaillierte Untersuchung der Mikrofazies und des Fossilinhalts ist neu für den Steinbruch Hödl-Kritsch und erlaubt erstmals eine exakte biostratigrafische Einstufung der Trias- bis Kreideabfolge. Zwei große biostratigrafische Lücken können dabei beobachtet werden: eine wird dabei durch eine markante Stromatolithenlage am Top der triassischen Riffkalke gekennzeichnet (spätes Rhätium bis Bajocium), eine zweite Lücke markiert den Kontakt zwischen dem grauen Top der Klaus-Formation im frühen Tithonium und der erosiven Basis der roten Tegernsee Kalke im späten Tithonium (zwischen *Parastomiosphaera malmica*- und der *Chitinoidella*-Zone).

Introduction

Upper Triassic, Jurassic, and Lower Cretaceous shallow-water limestones and pelagic to hemipelagic sediments are known to form a significant element of the northernmost tectonic units of the Northern Calcareous Alps (e.g., Ternberg-, Reichraming-, Frankenfels-, and Lunz nappes; TOLLMANN, 1976, 1985; EGGER, 1988; EGGER & FAUPL, 1999; VAŠÍČEK & FAUPL, 1999; see also PILLER et al., 2004). However, sections with well-preserved and documented transitions from the Upper Triassic to the Jurassic and to the Lower Cretaceous sequences are rare in the Northern Calcareous Alps. The Hödl-Kritsch locality (northern Lunz Nappe, Lower Austria; Text-Fig. 1) comprises Hauptdolomit (Norian), "Plattenkalk" (Norian), Kössen Formation (Rhaetian), Rhaetian limestones (Rhaetian), Klaus Formation (Bajocian–lower Oxfordian), Ruhpolding Radiolarite Group (Oxfordian), Tegernsee limestones (Late Tithonian), Ammergau Formation (Tithonian–Berriasian), and the Schrambach Formation (Berriasian–Valanginian). Lithologies and formations of the area and distinct parts of the Hödl-Kritsch quarry (Neumühle quarry) were previously described by TOULA (1871, 1879), SPITZ (1910), ROSENBERG (1965), KRYSTYN (1970, 1971, 1972), PLÖCHINGER &



Text-Fig. 1.
Map of Austria and the Northern Calcareous Alps with their main tectonic subdivisions (Bajuvaric, Tyrolic and Juvavic unit). The position of the Hödl-Kritsch locality (HK) is indicated. Inserted map with FL = Flysch Zone; Northern Calcareous Alps: F = Frankenfels Nappe, L = Lunz Nappe; FW = Föhrenberg Wasserspreng Unit, GD = Göller Nappe; VB = Vienna Basin.

Prey (1993), Plöchinger & Karanitsch (2002), Wessely (2006) and Egger & Wessely (2014). Comparable occurrences of similar sequences and sections were described from various regions in Austria (Tollmann, 1976; Wessely, 2006). No microfacies and foraminifera transitions were described in detail or figured until now from the classic Hödl-Kritsch quarry of the Lunz Nappe.

In this paper, we present a detailed study of the Hödl-Kritsch quarry succession comprising marly limestones and limestones of the Kössen Formation, the Rhaetian Limestone Unit, Klaus-, Tegernsee-, and Ammergau formations (Text-Fig. 2). Micro- and macrofossils are determined herein to provide biostratigraphic framework. Three main stratigraphical and lithological units can be subsequently observed: A, the transition from Triassic (Rhaetian) shallow-water limestones into, after a gap, the condensed limestones of the Klaus Formation (Bajocian–lower Oxfordian); B, the transition from the Klaus Formation into deep water radiolaria-rich limestones of the Tegernsee limestone (Kimmeridgian–Tithonian); C, the transition from the red condensed limestones into hemipelagic to pelagic red to grey limestones of the Ammergau Formation (Tithonian–Berriasian). The latter in turn passes to Schrambach Formation (Berriasian–Valanginian), which, however, was not logged in this study. The new faunal record increases the knowledge on the Triassic/Jurassic and Jurassic/Cretaceous transitions from the Northern Calcareous Alps, especially aiding in better understanding of the Mesozoic environments and facies zonation in the Bajuvaric units. The Hödl-Kritsch section may be a standard reference for the Upper Triassic to Jurassic drowning of Alpine carbonate platforms.

Geographic setting

The outcrop Hödl-Kritsch (340 m above sea level) is located in the municipality Perchtoldsdorf (postcode A 2380) 3 km northwest of Kaltenleutgeben within the Lunz Nappe in Lower Austria, at the border to Vienna, south of the Dürre Liesing creek (Schnabel et al., 1997: 1:50,000, sheet 58 Baden; Austromap Online, 2019; Text-Fig. 1). The steep walls of the abandoned quarry are exposed on the northern flank of Mount Bierhäuslberg (488 m). The exact position of the ammonite locality (Klaus Formation) was determined by GPS (global positioning system): N 48°7'44.50" and E 16°14'29.10". The site can only be accessed with the permission of the owner, the Ökotechna – Entsorgungs- und Umwelt GmbH in Perchtoldsdorf (manager Bernd Hajek).

Geological situation

Classically, the Northern Calcareous Alps (NCA) are subdivided from north to south into the Lower and Upper Bajuvaric units, the Tyrolic Unit, and the Lower and Upper Juvavic units (Text-Fig. 1; Wagreich et al., 2008). The northernmost tectonic elements of the NCA are the Ternberg and Frankenfels nappes, followed subsequently to the south by the Reichraming and Lunz nappes. The Weyrer arcs ("Weyerer Bögen") at the Upper Austrian/Lower Austrian boundary separate the Ternberg and Reichraming nappes to the west from the eastern tectonic equivalents with the Frankenfels and Lunz nappes (Tollmann, 1964, 1976; Steiner, 1968; Oberhauser, 1980; Ehrendorfer, 1988; Decker et al., 1994; Egger & Faupl, 1999; Janda, 2000; Faupl et al., 2003). Upper Triassic to Lower Cretaceous pelagic sediments are known to form a significant element of the Ternberg, Reichraming, Frankenfels, and Lunz nappes (Lukeneder, 2003, 2005).

The Upper Triassic to Lower Cretaceous Hödl-Kritsch section is located in the westernmost part of the Flössel Syncline (Höllenstein Unit, Geological map 1:50,000, sheet 58 Baden, Schnabel et al., 1997; Text-Fig. 1). The Flössel Syncline is the northernmost Jurassic/Cretaceous Syncline of the Lunz Nappe followed by the Höllenstein Anticline in the north and the Teufels Anticline to the south. The Lunz Nappe (High-Bajuvaric Unit of the Northern Calcareous Alps) is bordered to the north by the Frankenfels Nappe, and to the south by the Upper Cretaceous Giesshübel Syncline and the Tyrolic units of the Göller Nappe (Schnabel et al., 1997). The complete succession within the Flössel Syncline (see Schnabel et al., 1997; Lukeneder, 2003, 2005; Lukeneder & Schlagintweit, 2005; Lukeneder & Smrecková, 2006; Wessely, 2006) includes a Mesozoic succession from the Norian up to the Barremian.

Previous biostratigraphic research

The investigated succession was previously researched only for ammonites. Biostratigraphic ammonite data from the area around the Hödl-Kritsch quarry ("Öder Saugraben") were already given by Štúr (1860), and more detailed reported by Toula (1871, 1879), later reproduced by Spitz (1910). The most prominent outcrop with abundant ammonites was the "Öder Saugraben" quarry. Toula (1871) noted that the locality was described as the "Klauslokalität bei Kaltenleutgeben" or erroneously from the wrong local description as "Öder Saugraben". In this outcrop Upper Triassic (Rhaetian), Middle Jurassic ("Dogger") and Upper Jurassic ("Malm") formations occur. There is no doubt that the ammonite layer from this outcrop, described as "Doggerian" ammonite bed with abundant ammonite specimens, coated by limonitic crusts, is identical with the ammonite layers described by Krystyn (1971, 1972) from the nearby Hödl-Kritsch quarry. Indeed, the expansion of the quarry from Hödl-Kritsch in the 1960s "absorbed" the classic "Öder Saugraben" locality which since then does not exist. The fauna from the "Öder Saugraben" quarry was assumed to be of Bathonian in age (Toula, 1871). All described specimens from Krystyn (1971, 1972) derive from the boundary zone (30 cm thick interval with layers H1–H4) at the base of the Klaus Formation, immediately overlying the Rhaetian coraline limestone (= limestone with *Rhetiophyllia*, former "Thecosmilien Kalk"). Reinvestigation of the collection, housed in the Natural History Museum Vienna (NHMW) shows, that most ammonites are in contact with the stromatolitic bed (Hkrstromatolite) described herein. Krystyn (1971) reported very dense packings of approximately 30 ammonite specimens per square metre. The condensed layers show uppermost Bajocian (H1 and H2, *Parkinsonia parkinsoni* Zone) to uppermost Bathonian (H2 and H3, *Zigzagiceras zigzag* Zone; H4, middle to upper Bathonian). According to KRYSTYN (1972), the upper Bathonian *Oxycerites aspidoides* and the *Prohecticoceras retrocostatum* zones could be detected. The filamentous Klaus Formation (layer b in KRYSTYN, 1970; renamed as layer c in KRYSTYN, 1972), following the ammonite and stromatolite layer, appears to be lower Callovian, while the top of the Klaus Formation with the grey *Protoglobigerina* limestones (layer c in KRYSTYN, 1970; renamed as layer d and "Reitmauerkalk" in KRYSTYN, 1972) is already of Oxfordian age (KRYSTYN, 1971, 1972).

Material and methods

The now abandoned Hödl-Kritsch quarry was sampled in two sections, and a combined section of almost 50 m thickness was reconstructed (Text-Fig. 2). Sedimentologic and lithologic features were described and specimens were collected bed-by-bed, prepared and photographed. Thin section sampling has been obtained from significant beds in metre distant intervals. Sampling was denser near lithological boundaries, with samples taken in intervals of 20 cm, or even in cm-intervals. Three thin sections were additionally made from an ammonite cast with the surrounding sediment, extracted from the top stromatolite layer (NHMW collection).

Digital high-quality photomicrographs of the thin sections were performed on a Discovery.V20 Stereo Zeiss microscope. Specific magnifications were x 4.7, x 10.5 and x 40 in transmitted light mode. Data from the AxioCam MRc5 Zeiss were processed and documented by using the AxioVision SE64 Rel. 4.9 imaging system. Additional photomicrographs were made from surfaces of the samples cut for the thin sections. The images of the microfossils from the samples HKr-7-R to HKr-7 Base were made with the Nikon Eclipse 800 microscope and AxioCam 3.1 camera of the Palaeontological Department, Eötvös Loránd University and Hantken Foundation, Budapest. Classification of DUNHAM (1962), EMBRY & KLOVAN (1972), BÖHM (1992) and TOMAŠOVÝCH (2004) was used for description of standard microfacies types (SMF types, WILSON, 1975; FLÜGEL, 2004).

For the determination of calpionellids and calcareous dinoflagellates, sampling in the Steinmühl and Ammergau formations was realized in every one-and-a-half and later every one-meter interval. Beds have been numbered by prefixes of HKr. In total 45 samples were selected for thin sections. Thin sections were studied under the LEICA DM 2500 polarizing microscope. The Axiocam ERc 5s camera was used for documentation of microfacies and biomarkers. Calpionellid zonal scheme sensu REHÁKOVÁ & MICHALÍK (1997), combined with the cyst zonation of REHÁKOVÁ (2000) were adopted. The material is stored at the Natural History Museum in Vienna (NHMW 2019/0162/0001–0110). Ammonite material has been studied within collections of the NHMW from the same locality.

The Hödl-Kritsch section – lithology and lithostratigraphy

The Hödl-Kritsch section (HKr) is located in the steep walls on the mountain side in the abandoned quarry. The section is separated in the lower part A (sample numbers HKr7A to HKr7St450; Text-Fig. 2, Pl. 1), and the upper part B (samples from HKr2 to HKr6), approximately 100 m to the west. Beds are in normal position, dipping to the south (azimuth 190°) at 40° angle. The lower part (N 48°7'44.50" and E 16°14'29.10") ranges from the basal Rhaetian Kössen Formation to the Middle to Upper Jurassic Klaus Formation to the Tithonian Tegernsee limestones. The Rhaetian Kössen Formation comprises fossiliferous (bivalves, brachiopods, corals) grey to black marls and limestones (6.5 m). The Kössen Formation is overlain by the Rhaetian limestone formed by grey coral limestones (4 m) with orange interbeddings of residual layers. After a sedimentological gap, marked by stromatolite occurrences and manganese crusts, the Klaus Formation appears with grey and red filamentous *Bositra*-like limestones (2 m), followed by protoglobigerinid limestones and micritic ooids on top. These are overlain by red saccocomid/radiolaria limestones of the Tegernsee limestones, that contain reworked nodules in dark red limestones at the bottom (4.5 m). As recorded in the second section (N 48°7'43.3" and E 16°14'24.6"), the red saccocomid/radiolaria limestones of the Tegernsee limestones are followed by pink limestones (2 m), light grey limestones (5 m) and whitish limestones (5 m) of the Tithonian to Berriasian Ammergau Formation (Text-Fig. 2).

Microfacies analyses

A brief description of samples, taken along the logged succession, is given below. For the position of samples, see Text-Figure 2. A detailed biostratigraphy with microfossil ranges and figures is in preparation (LUKENEDER et al., in prep.), hence the given biostratigraphic data are preliminary. Facies zones and standard microfacies types (FZ types and SMF types, WILSON, 1975; FLÜGEL, 2004).

Kössen Formation – Hochalm Member

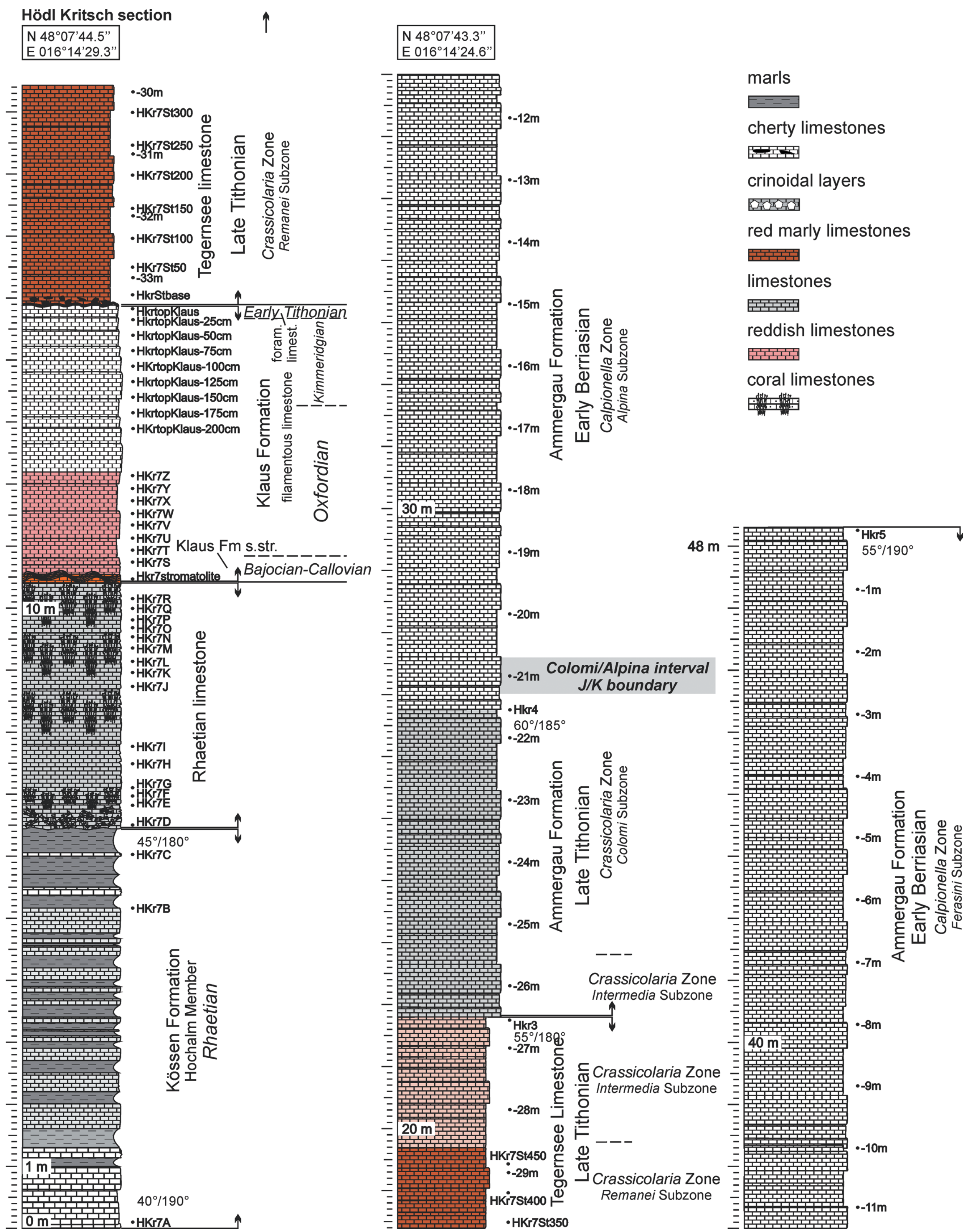
from HKr7A–HKr7D (SMF 15 of FZ 7–8; Text-Fig. 2, Pl. 2)

HKr7A bivalve-brachiopod grainstone, with oosparitic layers, most shells preserved with micritisation seams (micrite envelopes), numerous gastropods, rare foraminifera.

HKr7B bivalve-brachiopod grainstone, most shells preserved with micritisation seams, numerous gastropods, frequent foraminifera.

HKr7C crinoidal grainstone, well laminated, crinoids and echinoids, graded bedding.

HKr7D coral boundstone, corals with preserved septa, frequent brachiopod shells, most shells preserved with micritisation seams, crinoids and echinoids.



Text-Fig. 2.
Composite vertical section of the Hödl-Kritsch outcrop with the stratigraphic position of the corresponding formations and sample numbers.

Rhaetian limestone member

HKr7E–HKr7R (SMF 7, 11, 12, 13 of FZ 5–6; Text-Fig. 2, Pl. 3)

HKr7E crinoid-brachiopod packstone, encrusting foraminifera, residual layers with “algae”, dissolution seams, crinoids and echinoids, rare foraminifera.

HKr7F brachiopod-coral packstone, encrusting foraminifera, brachiopods, corals.

HKr7G crinoidal-brachiopod wacke- to packstone, residual layer.

HKr7H coral boundstone, corals recrystallized, interspace filled by brachiopod coral packstone, rare crinoids, rare foraminifera.

HKr7I coral brachiopod packstone, rare corals with partly recrystallized septa, frequent crinoids and echinoids, rare foraminifera.

HKr7J crinoidal-brachiopod wacke- to packstone, rare echinoids, residual layer.

HKr7K crinoidal-brachiopod packstone, most shells preserved with micritisation seam, encrusting foraminifera, crinoids and echinoids, rare foraminifera.

HKr7L brachiopod packstone to grainstone, most shells preserved with micritisation seam, encrusting foraminifera, crinoids and echinoids, rare foraminifera.

HKr7M packstone, most shells preserved with micritisation seam, encrusting foraminifera, crinoids and echinoids, frequent ostracods, frequent foraminifera.

HKr7N *Bacinella* packstone, with graded filled cracks, most shells preserved with micritisation seam, encrusting foraminifera, *Bacinella irregularis*, brachiopods, corals fragments, gastropods, crinoids and echinoids, frequent ostracods, frequent foraminifera.

HKr7O to HKr7Q coral-*Bacinella* packstone, most shells preserved with micritisation seam, encrusting foraminifera, *B. irregularis*, brachiopods, coral fragments, gastropods, rare crinoids, frequent ostracods, frequent foraminifera.

HKr7R brachiopod-gastropod packstone, most shells preserved with micritisation seam, encrusting foraminifera, *B. irregularis*, brachiopods, coral fragments, gastropods, rare crinoids and echinoids, frequent ostracods, frequent foraminifera.

Stromatolite boundary

HKr7stromatolite (SMF 20 of FZ 7–9; Text-Fig. 2, Pl. 4)

HKr7stromatolite boundstone, *Frutexites*, reworked base with lithoclasts, well laminated, oncoids and cortoids, frequent foraminifera, residual crusts, condensed, with crinoid layers. Stromatolite layer can be up to 40 cm thick. As reported in the 1970s (Krystyn, 1971, 1972) the thick stromatolites grow on the abundant ammonite shells, which cannot be observed at the present state of the outcrop situation. Ammonites are mostly orientated parallel to bedding plane. In most specimens, the upper part of the shell is dissolved and eroded. Bioerosional traces occur frequently, reflecting a transgressive, shallow subtidal depositional environment (Flügel, 2004). The fabric is dominantly a packstone exhibiting rounded wackestone intraclasts. The microfossil content of the rock mainly consists of *Bositra*-like shell-fragments. Additionally, echinoids, planktic and benthic foraminifera, *Globochaete alpina*, radiolaria, ostracods, gastropods brachiopods and calcareous dinoflagellate cysts occur. Foraminifera are often limonitized (especially agglutinated groups), and filled with limonitic or glauconitic sediments.

Klaus Formation

HKr7S–HKrtopKlaus (SMF 3–5 of FZ 3, 4 Text-Fig. 2, Pl. 5)

HKr7S to HKr7Z filamentous packstone, mass occurrences of the *Bositra*-like shell-fragments, bioturbation, frequent peloids, rare crinoids, rare foraminifera.

HKrtopKlaus-200cm to HKrtopKlaus-25cm filamentous grainstone, mass occurrences of the *Bositra*-like shell-fragments, bioturbation, frequent peloids, rare radiolaria, rare crinoids, rare foraminifera.

HKrtopKlaus foraminiferal packstone, *Protoglobigerina* mass occurrences, bioturbation, rare benthic foraminifera.

Tegernsee limestone

HKr7baseSt–HKrSt450–HKr3; base Steinmühl, -33 m to -27 m; two separate sections are correlated in that formations, samples St50 to St450 with the part -33 m to -29 m (SMF 3 of FZ 2, 3; Text-Fig. 2, Pl. 6).

HKr7baseSt radiolaria-*Saccocoma* packstone, with clayey residual lamination, with radiolarians and protoglobigerinid lithoclasts from reworked older formations (i.e. top Klaus Formation and Ruhpolding Formation). Clasts of type A: *Protoglobigerina*-radiolarian wackestone – calcified radiolarians and planktonic foraminifera are accompanied by less frequent crinoids, ostracods, aptychi, *Saccoccoma* sp., bivalves and spores of *Globochaete alpina*, cyst of *Colomisphaera fibrata*. Fragments of type B: radiolarian wackestone. Slightly recrystallized matrix with calcified or partially silicified radiolarians and less common sponge spicule. Clasts of type C: *Saccoccoma* wackestone – with *Saccoccoma* sp. fragments dominated.

HKr7St50 to HKr7St400 radiolarian-*Saccocoma* packstone, frequent radiolaria and *Saccocoma* sp., *Laevaptychus* sp., bivalves, ostracods, nodular fabric.

HKr7-33 m to -27 m radiolarian packstone, nodular, frequent *Saccocoma*, bivalves, ostracods, *Laevaptychus* sp. calpionellids start at 32 m.

Ammergau Formation

HKr3+5cm–HKr5; -26 m to -0 m = HKr5 (SMF 3 of FZ 2, 3; Text.-Fig. 2, Pl. 6), -26 m to -0 m = HKr5 radiolaria-calpionellid wackestone, foraminifera, laevaptychi.

HKr5-26m *Saccocoma*-*Globochaeta*-*Calpionella* wackestone.

HKr5-25m *Globochaeta*-*Calpionella* wackestone.

HKr5-24m *Calpionella*-radiolarian wackestone.

HKr5-23m *Saccocoma*-*Globochaeta*-*Calpionella* wackestone.

HKr5-22m up to HKr5 *Calpionella*-radiolarian wackestone.

Preliminary biostratigraphy of the Hödl-Kritsch section

The Triassic Kössen Formation and Rhaetian limestones

Foraminiferal assemblages from the Hödl-Kritsch section were investigated in the upper 10 m of the Kössen Formation. Special attention was given to the stromatolite level representing the unconformity at top of the Rhaetian limestone (Text-Fig. 2). The assemblages are not particularly rich in species but nevertheless, display notably different characters. The number of specimens in sampled beds of the Kössen Formation is low. The erosional discordance between the Upper Triassic light coloured limestone and the Jurassic red marly limestone could be studied in the sample HKr7R. The Triassic limestone of the sample is a packstone with calcite veins (microcracks with offsets) and cortoids, small-sized (up to 5 mm) gastropods, fragments of echinoderms, brachiopods, algae and foraminifers. The microfacies and the fossils indicate a shallow marine environment, with constantly agitated water, at or above the wave base.

The Jurassic Klaus Formation

Two types of fabric could be observed in the Jurassic limestone. The first is a partially dolomitized wackestone. The recrystallisation fabric is nearly equigranular porphyrotropic, the floating rhombs are idiotropic. The dolomitization of the sediment probably took place at shallow burial setting. Molluscs, echinoderms and the epilithic *Lithocodium aggregatum* are the usually present fossils. Following the interpretation of Schlagintweit et al. (2009), a shallow, but transgressive, normal marine palaeoenvironment is the most plausible, which is in accordance coincides with the erosional surface and the fabrics. The second type of the fabric is also partly dolomitized limestone (mudstone to wackestone), but dolomite crystals are in porphyritic contact fabric and the shape of the crystals is planar-e (euhedral). This could indicate a near surface, early meteoric dedolomitization (Flügel, 2004). In this microfacies, few ostracod shells and foraminifera could be recognised.

From the thick basal stromatolite layer, an ammonite cast with the surrounding sediment was studied in detail. In a chamber of the phragmocone, a bed-parallel geopetal structure could be observed. The fabric, microfacies and microfossil content are nearly the same outside and inside of the ammonite shell. The main difference can be found in the grain sizes.

The living chamber of the ammonite is filled with packstone with rounded wackestone intraclasts, oncoids and various bioclasts. Oncoids are of centimetre-size. The cores of the oncoids are aggregates with stromatolites and/or cortoidal surface, or micritic intraclasts. The microfossil content of the rock in the order of the frequency, shell-fragments of *Bositra*-like bivalves, echinoids, planktonic foraminifera, benthic ones, *Globochaete alpina*, radiolarians, ostracods, gastropods, brachiopods and calcareous dinoflagellate cysts. The infill of the second and third chambers of the ammonite shell is almost identical to the first chamber. The largest bioclast, a gastropod shell about 800 μm in size, is visible in the second chamber, while in the innermost visible chamber, the lengths of the *Bositra*-like fragments are only about 300 μm.

The determined protoglobigerinid fauna is very similar to the one from the Callovian of Hungary (Görög et al., 2012). The most common forms are the middle-sized (150–200 μm) tests with low spire and four chambers on the last whorls, the group of *Globuligerina oxfordiana.* The foraminiferal fauna is characteristic for the outer platform-slope environment. Based on the ranges of the benthic forms, the most probable age is Bathonian to lowermost Callovian, which coincidences well with the ammonite age determination (Krystyn, 1970, 1972).

Above the stromatolite layer, in the 4.5 m thick succession (the samples HKr7S–Z and HKr7topKlaus-200cm to -25cm), the rocks have relatively similar fabrics: packstone (sensu Dunham, 1962) or poorly washed biosparite (sensu Folk, 1962) with microcracks and sometimes irregular stylolites. The majority (up to 98 %) of the fossil content are fragments of thin-shelled *Bositra*-like bivalves (filaments). These are arranged randomly, except at the margins of common bioturbations. Based on the ratio of bioclasts, two types of the microfacies (MF 1 and MF 2) can be distinguished.

In the MF 1, in the samples HKr7S-U, X and Z, and HKr7topKlaus-75cm to -25cm, the filaments account for ~95 % of the rock volume. The shells are partly recrystallized. Fibrous cement can regularly be observed between the valves. In this microfacies, the second most common bioclasts after the bivalve shells are the foraminifers. Besides them are a few echinoid fragments, calcareous dinoflagellate cysts, *Globochaete* specimens, ostracods, juvenile gastropods (HKr7topKlaus-75cm), sponge spicules (HKr7topKlaus-75cm), and a few calcified radiolaria (only in samples HKr7X and HKr7topKlaus-25cm). Among the benthic foraminifera, the most common group are the lagenids, namely large sized (up to 800 μm), bioeroded *Lenticulina*, *Nodosaria*, *Dentalina* and *Lingulina*. Few specimens of spirillinids also occur in most samples, while agglutinated *Glomospira* sp., *Verneuilina* sp. and porcellanous ophthalmids are very rare. Protoglobigerinids are rare and occur only in the samples HKr7S and HKr7topKlaus-75cm. They could be classified into the morphogroup of *Globuligerina oxfordiana* and *Favusella hoterivica*. These species differ only in the ornamentation of the surface of the shell, which only can be studied in isolated specimens.

In two samples (HKr7X and HKr7Z) small-sized (up to 250 μm), limonitic grain aggregates built up oncoids in relatively large quantities. There is no fibrous cement between the bivalve shells. Dark layers could be observed on both sides of the shells, sometimes showing fibrous structure, perpendicular to the surface of the shells.

In the second microfacies type (MF 2, samples HKr7sV, HKr7sW, HKr7sY, HKr7topKlaus-200cm, -175cm, 150cm, -125cm, -100cm) the amount of fragments of thin bivalve shells drops to only about 40 % of the rock volume. At the same time, the volume of the micritic matrix increases. Moreover, these samples are characterized by the existence of spherical (up to 150 μm) peloids – with micrite content – up to 5 % of the rock volume, calcified spumellarian radiolaria, and the globochaets also occur in each sample of MF 2. Similarly to the MF 1, foraminifers are rare. Other fossils, described in MF 1, are present in this microfacies as well, except for a few sclerites of holothuroids and a brachiopod shell. All foraminiferal taxa of the MF 1 appear sporadically in the MF 2, e.g., protoglobigerinids (*Globuligerina oxfordiana-Favusella hoterivica* group) only in the samples HKr7V and HKr7topKlaus-100cm. Besides them, there are one or two specimens of agglutinated genera, *Textularia* sp., *Valvulina* sp. and *Trochammina* sp., and encrusting, porcellanous forms, tentatively classified to cf. *Nubecularia mazoviensis*. This latter foraminifer appears on the surface of some intraclasts. It was originally described from the residue of the upper Kimmeridgian to lower Tithonian. Gradziński et al. (2004) documented similar forms from the same palaeoenvironment, from the succession built up *Bositra*-like bivalve shells of the Toarcian–Aalenian part of the Krízńa Unit in the Western Tatra Mountains.

At the top of this succession, in the sample HKr7topKlaus, the microfacies significantly changes. The fabric of MF 3 is packstone with intraclasts and bioclasts. More than 90 % of the latter are protoglobigerinid shells, forming nearly 70 % of the rock volume. The other microfossils, in order to their frequency, are fragments of *Bositra*-like bivalves, benthic foraminifers, ostracods (with articulated or disarticulated valves), *Globochaete alpina,* calcareous dinoflagellate cysts and radiolarians. The protoglobigerinid assemblage is relatively homogenous, seems to be oligospecific, consisting of medium-sized (largest diameter 200 µm), dominantly low-trochospiral and a few high trochospiral groups. Usually, the tests are filled with micrite, but sometimes the older part of the shell is filled with sparry calcite. The low trochospiral foraminifers with a lobated outline and four chambers on the final whorls can be assigned to the *Globuligerina oxfordiana-Favusella hoterivica* group, while the high-trochospiral ones belong to cf. *Globuligerina bathoniana*. Within the benthic foraminifers, the most common group are the porcellanous miliolinids, followed by the lagenids and spirillinids. *Ophthalmidium strumosum* is the most common species within the miliolinids. Additionally, a few strongly keeled specimens of *Ophthalmidium* mg. *marginatum* occur. Large, even giant-sized (up to 1.6 mm), lenticulinids, different nodosarids, *Spirillina* sp. and *Radiospirillina* sp. could be identified in this sample.

The most important diagnostic fossils for the detailed biostratigraphy of this succession (HKr7S – HKr7topKlaus-25cm and HKr7topKlaus) are the calcareous dinoflagellate cysts. In the *Bositra*-like shells packstone facies (MF 1 and MF 2) the range of the occurring dinoflagellate cysts are the following: *Cadosina semiradiata fusca*: Oxfordian–Berriasian; *Colomisphaera carpathica*: Oxfordian–upper Berriasian; *Stomiosphaera moluccana* lower part of the upper Kimmeridgian–Valanginian (e.g., Reháková, 2000; Olszewska et al., 2012; Ivanova & Kietzmann, 2017). Based on these data, the Oxfordian starts with the sample HKr7T. Since the lowest occurrence of *S. moluccana* firstly is in the sample HKr7topKlaus-175cm, from this level on the age of the unit is upper Kimmeridgian or younger. The age of the uppermost sample (HKr7topKlaus) is most probably lower Tithonian (based on the relatively frequent *S. moluccana,* the upper Oxfordian–lower Valanginian *Col. lapidosa* and the lower Tithonian *Committosphaera pulla*; Ivanova & Kietzmann, 2017). It coincides with the protoglobigerinids, as the monospecific *Globuligerina* gr. *oxfordiana* fauna characterises the lower Tithonian (Görög & Wernli, 2004; Görög et al., 2010). This, however, seems to contradict the age given by the miliolid foraminifers of this sample. Namely, according to the literature (e.g., Clerc, 2005; Ivanova et al., 2008; Olszewska et al., 2012), the range of the *Ophthalmidium strumosum* is late Oxfordian–lower Kimmeridgian, and *O.* gr. *marginatum* is upper Bajocian–Kimmeridgian. Thus, most probably the range of the *O. strumosum* was longer, extending into the upper Kimmeridgian.

According to the microfacies study, MF 1 represents an unfavourable environment on the sea floor where almost exclusively the benthic, opportunistic and r-strategist *Bositra*-like bivalves could live. The disarticulated, broken, tiny and thin shells, the calcitic cement between them and the bioturbations indicate oxic and moderately agitated bottom water (e.g., Jach, 2007; Molina et al., 2018). This microfacies was characteristic for the lower and the upper part of this interval. In the middle part of the succession (approx. HKr7topKlaus-200cm–100cm), the appearance of the peloids and the radiolarians signifies a higher nutrient availability. During the time when the sediment of the uppermost sample deposited, the environment has changed drastically. Since aragonitic shells of the protoglobigerinids are preserved, the water depth was probably lower, above the aragonitic lysocline.

Jurassic–Cretaceous Tegernsee limestone and Ammergau Formation

Late Tithonian *Crassicollaria* Zone, *Tintinnopsella remanei* Subzone (Remane et al., 1986); samples HKr7–base, HKr7–St200cm, HKr7–St250cm, HKr–St300cm, HKr7–St350cm, HKr7–St400cm, HKr7–St450cm

In the red *Saccocoma*-bearing wackestone different clasts of reworked older rocks a few mm to 1.2 cm in size were recognised (Pl. 6). Several types of clasts can be recognised. Type 1 is protoglobuligerinid-radiolarian wackestone. Calcified radiolarians and planktonic foraminifera are accompanied by less frequent crinoids, ostracods, aptychi, *Saccocoma* sp., bivalves and spores of *Globochaete alpina*. Cysts of *Colomisphaera fibrata* were determined. Type 2 is radiolarian wackestone. Slightly recrystallized matrix contains calcified or partially silicified radiolarians and less common sponge spicule. Clasts of Type 3 are *Sacoccoma* wackestone. Clasts of Type 4 are small (1–2 mm) fragments of micritic limestone appear with calpionellids and spumellarian radiolarians. Planktonic crinoids *Saccocoma* sp. dominate over less frequent filaments, spores of *Globochaete alpina*, calcified radiolarians, crinoid collumnalia, aptychi, bivalves, cysts of *Colomisphaera*, *Stomiosphaera* and *Cadosina*, and rare calpionellids. The microfossils and the microfacies indicate an open marine environment.

The overlying beds – samples HKr7–St50cm, HKr7–St-100cm belong to biomicritic, slightly bioturbated limestones of *Saccocoma* microfacies (wackestone to packstone; SMF 2) and radiolarian-*Saccocoma* microfacies (wackestone; SMF 2). *Saccocoma* sp. dominate with calcified radiolarians and sponge spicules , being accompanied by less frequent filaments. Additional spores of *Globochaete alpina,* bivalves, aptychi, and cysts of *Parastomiospahera* and *Colomisphaera* occur. Saccocomid skeletal elements of the saccocomid zone Sc 5 prevail. This zone coincides with the *Fallauxi* ammonite zone as proposed by Benzaggagh et al. (2015). Dinoflagellate cysts indicate this interval belongs to lower Tithonian *Malmica* Zone (sensu Nowak, 1968; Reháková, 2000). The latest lower Tithonian *Chitinoidella* Zone, *Dobeni* Subzone was identified in the next sample (HKr7–St-150cm). Here, biomicritic limestone of the radiolarian-*Saccocoma* microfacies (wackestone to packstone; SMF 2) contains *Saccocoma* sp., calcified radiolarians, sponge spicules, ostracods, bivalves, aptychi, calpionellids with *Borziella*, *Carpathella,* spores of *Globochaete*, and cysts of *Colomisphaera* and *Colomisphaera.* Saccocomid skeletal elements of the Sc 6 zone (Benzaggagh et al., 2015) are present. Dissolution seams and stylolites are commonly present.

If the base of the Tegernsee limestones belongs to the *Remanei* Subzone, deposits of the lower Tithonian *Malmica* and the *Chitinoidella* zones, mentioned in HKr7–St50cm, HKr7–St100cm and HKr7–St150cm, represent reworked and resedimented beds incorporated into the sediments of upper Tithonian *Remanei* Subzone of the *Crassicollaria* Zone.

In the HKr7–St200cm and higher, marly limestone (mudstone to wackestone, SMF 3) with rare bioclasts (calcified radiolarians, sponge spicules, spores of *Globochaete alpina, Saccocoma* sp., bivalves), bioturbated radiolarian-*Saccocoma* wackestone to packstone), and radiolarian wackestone predominate. *Saccocoma* sp., calcified radiolarians, and sponge spicules are the most common bioclasts. There are less frequent and rare ostracods, bivalves, aptychi and crinoid fragments, spores of *Globochaete,* and poorly preserved rare hyaline calpionellids with *Tintinnopsella*, and cysts of *Committosphaera, Colomisphaera*, and *Cadosina.* Saccocomid skeletal elements of the higher part of the Sc 6 zone are present. According to Benzaggagh et al. (2015), this zone coincides with the *Microcantum* ammonite zone. Bioclasts are locally chaotically arranged, or concentrated into clusters. The matrix of the sample HKr7–400cm is slightly bioturbated and exhibits some differently orientated geopetal structures. This indicates resedimentation of the lithified sediment. Limestone contains fine silty admixture, mainly clays, less frequent to rare silty quartz grains. Dissolution seams and stylolites are common.

Late Tithonian *Crassicollaria* Zone, *Crassicollaria intermedia* Subzone (Remane et al., 1986); samples 28 m, 27 m, 26 m

The biomicrite is locally slightly laminated and bioturbated limestone of *Saccocoma-Calpionella, Globochaete-Calpionella* and *Calpionella*-radiolarian microfacies (wackestones; SMF 3) occur. Calpionellids occur with *Calpionella*, *Crassicollaria* and *Tintinnopsella,* cysts of *Colomisphaera* and *Stomiosphaerina* forms an assemblage with calcified radiolarians, sponge spicules, rare fragments of bivalves and aptychi. The rock is highly fractured, criss-crossed by calcitic veins. Stylolites locally highlight lamination. Fine silty admixture – mainly clays – is concentrated in dissolution seams. Sample 26 m contains the marks of tectonic breccia.

Late Tithonian *Crassicollaria* Zone, *Crassicollaria colomi* Subzone (Pop, 1994); samples 25 m, 24 m, 23 m, 22 m

Locally slightly bioturbated limestone of *Calpionella*-radiolarian and *Globochaete-Calpionella* microfacies (wackestones, SMF 3). Limestone contains calcified radiolarians, sponge spicules, rare fragments foraminifera (*Spirillina* sp.), bivalves, calpionellids occur with *Calpionella, Crassicollaria* and *Tintinnopsella,* cysts appear with *Colomisphaera* and *Stomiosphaerina*. Limestones show locally signs of resedimentation. Redeposited sediments concentrated in laminae contain microfossils of the older *Intermedia* Subzone with *Crassicollaria*, *Calpionella*; also the angular extraclasts (biomicrite limestone of *Calpionella* microfacies (wackestone) and slightly recrystallized radiolarian wackestone were observed) were observed. Sample 23 m – limestone of *Saccocoma-Globochaete* microfacies (wackestone) with filaments, rare bivalves, aptychi and cysts of *Parastomiosphaera, Stomiosphaera,* and *Colomisphaera* belong probably to the extraclast derived from the lower Tithonian *Malmica* Zone. Matrix of limestones is penetrated by thin fractures and veins filled by calcite. Fine silty admixture, mainly clays, is concentrated in dissolution seams.

Early Berriasian *Calpionella* Zone, *Calpionella alpina* Subzone (sensu Pop, 1974; Remane et al., 1986); samples 21 m, 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m

The *Colomi-Alpina* passing interval or J/K boundary limit was fixed to the sample 21 m. Biomicritic limestones of *Calpionella*-radiolarian microfacies (wackestones; SMF 3) prevails in this interval. Limestones contain calcified radiolarians, sponge spicules, and calpionellid assemblage dominated by small forms of *Calpionella alpina*, rare *Crassicollaria parvula* and *Tintinnopsella carpathica*. There are also rare foraminifer fragments (*Spirillina* sp.), bivalves, crinoids, aptychi, cysts of *Cadosina* and *Colomisphaera*. The rock is fractured. Different infillings of veins – blocky and radiaxial calcite – was observed. Matrix contains also fine silty admixture. Clays are concentrated in dissolution seams. Some of calpionellid loricae appear deformed.

Early Berriasian *Calpionella* Zone, *Remaniella ferasini* Subzone (Pop, 1994); samples 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m, HKr5

Biomicrite limestones of *Calpionella*-radiolarian microfacies (wackestones; SMF 3) contain calcified radiolarians, sponge spicules, fragments of aptychi, ostracods, bivalves and foraminifera (*Spirillina* sp., *Patellina* sp.). Calpionellid assemblage consist of *Calpionella, Remaniella, Tintinnopsella*, *Lorenziella* and *Crassicollaria*. Numerous of the loricae are deformed. Cysts are represented by *Colomisphaera*, *Stomiosphaerina*, and *Cadosina*. Calpionellid loricae (and a single fragment of *Sacoccoma* sp.) are concentrated in thin laminae, suggesting redeposition. The matrix is locally penetrated by fractures and veins of different orientation, filled by calcite. Locally (sample 13 m) *Frutextites*, typical for deeper and less oxic environments, were observed in the matrix.

Discussion

The age and biostratigraphy of the limestones, siliceous limestones and marly limestones from the Hödl-Kritsch quarry near Kaltenleutgeben at the western border of Vienna were not known in detail until now. On the geological map of Baden (Geological map 1:50,000, sheet 58; Schnabel et al., 1997) the area is characterized only by the occurrence of the Upper Triassic Kössen Formation, Middle to lower Upper Jurassic Klaus Formation and Lower Cretaceous Schrambach Formation.

For a correlation of Upper Triassic (Rhaetian), Jurassic (Bajocian–Tithonian) to Lower Cretaceous (Berriasian) lithologies and formations observed in the Flössel Syncline with other comparable sections from Upper and Lower Austria see LUKENEDER et al. (in prep). It has to be stated, however, that numerous formation names and lithological terms need clarification or still lack formalisation (see also FLÜGEL, 1967; TOLLMANN, 1976; PILLER et al., 2004; MOSER et al., 2017). Especially the Upper Jurassic formations are under intense debate and numerous terms are used in literature without any facts and microfacies data.

Klaus Formation

The term Klaus Formation with its type section at the Klausalm in Upper Austria (SUESS, 1852; SPENGLER, 1919; KRYSTYN, 1971; GAWLICK et al., 2009) is in the lower part also used as a synonym of Bathonian Filament limestones. MOSER et al. (2017) described this part as Callovian „*Bositra*-Kalk“ (= “*Bositra buchi* Lumachelle“), hence part of the upper Klaus Formation („unterer Reitmauerkalk“; see TRAUTH, 1922, 1948, 1954; KUNZ, 1967; TOLLMANN, 1976; JANDA, 2000). FLÜGEL (1967) used for the lower red to grey part of the Arrach quarry (near Waidhofen an der Ybbs, Lower Austria) the term „Filament Kalke“, equivalent to the Bajocian part of the Klaus Formation. FLÜGEL (1967) introduced four limestone members in that quarry with the basal filamentous red limestone (Filament limestone, ?Callovian). KRYSTYN (1972) described the red „Mikrolumachellenkalk“ (approx. 1 m) formed of *Bositra buchi* shells from the Hödl-Kritsch quarry (= Neumühle quarry, Abb. 2 in KRYSTYN, 1972, bed c, Callovian). For the possible mechanisms of the formation of such *Bositra*-like bivalve mass occurrences see JACH (2007).

The term Klaus Formation (upper part) is also used as a synonym of Callovian *Globigerina* limestones. WESSELY (2006) used for this lithology of Callovian to Oxfordian limestones in Bajuvaric units the terms „Globigerinen Oolith“ and „Mikro-oolith“, and only for the filamentous limestones („Filament Kalk“ = „*Bositra* Kalk“) in the Middle Jurassic the term „Klauskalk“. MOSER et al. (2017) described this part already as lowermost Oxfordian „*Protoglobigerina*-Mikrit“, hence part of the lower part of the Reitbauernmauer Formation (sensu MOSER et al., 2017). This recently introduced formation is equivalent to the „Miktitooidkalk“ (= micritic ooid limestone, „Oberer Reitmauerkalk“; see TRAUTH, 1922; KUNZ, 1967; EHRENDORFER, 1988; JANDA, 2000). KRYSTYN (1971) assumed and Oxfordian age for the light grey limestones of the Klaus Formation (e.g „Oberer Reitmauer Kalk“). TRAUTH (1948) established the term „Obere weisse Reitmauerkalke“ which seems to be equivalent to the Oxfordian micritic ooid limestones (KRYSTYN, 1971; see also KRYSTYN, 1972; MOSER et al., 2017). The well-defined members of the Middle Jurassic Klaus Formation are well documented for numerous other localities of the Frankenfels Nappe in the Reitbauernmauer section (Lower Austria; TRAUTH, 1922, 1948; MOSER et al., 2017), the Arrach quarry section (TRAUTH, 1922, 1948, 1954; FLÜGEL, 1967; TOLLMANN, 1976), and the Lunz Nappe with the Oisberg localities (Oi 1, 2 and 3, Lower Austria; KRYSTYN, 1971; LUKENEDER et al., in prep). The lower filamentous member (with mass occurrence of *Bositra*) and the upper foraminiferal part (with mass occurrence of protoglobigerinid foraminifera) of the Klaus Formation were observed in each of the documented sections. The Klaus Formation clearly needs revision (LUKENEDER et al., in prep.), in its present state it is not valid.

Tegernsee limestone

In the near future the Steinmühl Formation („Malm Cephalopodenkalk“ in TOLLMANN, 1976) should be formalized for all micritic Lower to Upper Jurassic red limestones, with wide occurrences in the Bajuvaric Units. This would result in a range from Kimmeridgian to Berriasian. The Oxfordian red Rotensteiner Kalk is equivalent to the Lower Steinmühl Formation (TRAUTH, 1948; TOLLMANN, 1976; see LUKENEDER, 2000; LUKENEDER & REHÁKOVÁ, 2004).

Today, numerous terms exist for red limestones in the Kimmeridgian with the Tegernsee limestone in the Bavarian Bajuvaric Units (Allgäu Nappe and Lechtal Nappe). WESSELY (2006) integrated both, the Kimmeridgian Agatha limestones and the basal part of the Tithonian limestones, in the term „Tegernseer Kalk“. The term „Tegernseer Kalk“ was used by TOLLMANN (1976) for Kimmeridgian to Lower Tithonian red *Saccocoma* limestones. The term Agatha limestone (= *Acanthicus* beds) derives from the Tyrolic Unit of the Salzkammergut (after St. Agatha near Bad Goisern, Upper Austria), consequently *Aspidoceras acanthicus* after a Kimmeridgian ammonite species, found in Gießhübl (“Tirolerhof”) in the historic “Acanthicus Steinbruch” situated in the Bajuvaric Unit (see OBERHAUSER, 1980). WESSELY (2006) used the term „Agatha Kalk“ and „Saccocomakalk“ for the same Kimmeridgian *Saccocoma* dominated red limestones (e.g. in the Hödl-Kritsch quarry, Lunz Nappe, Lower Austria).

Red Tithonian limestones are often termed as Haselberg limestone (after the Haselberg near Ruhpolding in Bavaria, Germany, see TOLLMANN, 1976; JANDA, 2000), also in the Bajuvaric Unit. After OBERHAUSER (1980) the “Haselbergkalk” is a variegated Tithonian clayey fibered limestone. In the literature concerning Upper Jurassic lithologies of Lower Austria, the term Tithonflaser limestone is used as a synonym for the Diphyakalk named after the brachiopod *Pygope diphya* in the Bajuvaric units (e.g. Reichraming Nappe, Upper Austria). OBERHAUSER (1980) separated the Tithonian–Berriasian Ammergau Formation or „Aptychenschichten“ from the variegated „Tithonflaser Kalk“ or coloured Ammergau Formation (see TOLLMANN, 1976). OBERHAUSER (1980) used the term “Steinmühlkalk” for the entire ammonite rich Upper Jurassic red facies formed on deepwater swells and submarine highs. At the type locality Arrach quarry, he distinguished the middle Oxfordian Lower Steinmühl limestone, named as the “Rotensteinkalk”, from the Kimmeridgian to Tithonian Upper Steinmühl limestone, named the “Tegernseer Kalk”.

All these terms could/should be linked with different members of the Steinmühl Formation (Kimmeridgian–Berriasian), maybe on the basis of the main fossil groups, as once introduced by FLÜGEL (1967; Steinmühl Limestone Group) for the sequence in the type section Arrach Steinbruch (Lower Austria). FLÜGEL (1967) introduced four members: the basal red Limestone (Filament Limestone, ?Callovian), for the Oxfordian “Radiolaria Siliceous”, the Kimmeridgian *Saccocoma* Limestone, and the Tithonian (“Portlandian”) *Calpionella* Limestone (see TRAUTH, 1948).

In the Hödl-Kritsch section, the *Saccocoma* limestones contained also the lower Tithonian cysts of calcareous dinoflagellates, and a relatively rich *Saccocoma* microfacies persists into the upper Tithonian part of the succession, bearing calpionellids of the *T. remanei* Subzone of the *Crassicollaria* Zone (Text-Fig. 2). The drop of their abundance began in the *Cr. intermedia* Subzone and prior to the J/K boundary saccocomids practically disappeared. The same was documented in other well documented sections of the Tethyan area (Michalík et al., 2016; Svobodová et al., 2019; Grabowski et al., 2019). The last upper Tithonian *Cr. colomi* Subzone of the *Crassicollaria* Zone was documented in the higher part of the Tegernsee limestone. It is worth to mention that the *Chitinoidella* and *Praetintinnopsella* calpionellid zones were not documented. On the basis of the presence of rare chitinoidellid and ?*Praetintinnopsella* species, which were observed in the *T. remanei* Subzone of the *Crassicollaria* Zone, we suggest redeposition from older strata. The same was documented by Svobodová et al. (2019). The Tegernsee limestone unit needs formalisation (Lukeneder et al., in prep.).

Ammergau Formation

The Ammergau Formation is equivalent to the "Aptychenschichten", representing fine, light grey, well-bedded limestones of Tithonian to Berriasian age (see Tollmann, 1976). Tollmann (1976) used for the type section the exposure in the Arrach quarry (see also Trauth, 1948) the term "Ammergau Schichten" ("Ober Tithon Aptychenkalk") and the term "Schrambach Schichten" ("Neokom Aptychenschichten"). Wessely (2006) used the term Ammergau Formation and "Calpionellenkalk" for upper Tithonian calpionellid-dominated grey limestones in the Bajuvaric units. The term "Aptychenschichten" was also used for the Ammergau Formation of the Hödl-Kritsch quarry. Compared with data, given by Krystyn (1972), the results from the Hödl-Kritsch section show a more detailed stratigraphy of the Ammergau Formation, starting in the higher part of the upper Tithionian *Crassicollaria* Zone (*Cr. intermedia* Subzone) and ending in the lower Berriasian *Calpionella* Zone (*R. ferasini* Subzone, Text-Fig. 2).

By increasing the clay content and the multitude of marly interbeds, the Schrambach Formation develops, ranging from Valanginian to Aptian. The term Ammergau Formation is also used as a synonym for Tithonian *Calpionella* limestones and the term Schrambach Formation unit B is used a synonym for Berriasian limestones, whereas the term Schrambach Formation unit A is also used as a synonym of Valanginian–Aptian limestones and marls.

Conclusions

The so far not precisely described Mesozoic sequence of the Hödl-Kritsch (Lunz Nappe, Northern Calcareous Alps) is presented in detail of microfacies and fossil content. Altogether 100 rock samples for thin sections were collected and analysed for their specific lithological changes and microfacies evolution. The corresponding formations or lithological members are the Rhaetian Kössen Formation, the Rhaetian reefal limestone member, the Middle to Upper Jurassic *Bositra* and protoglobigerinid bearing Klaus Formation (Bajocian to Kimmeridgian filamentous and protoglobigerinid members, topmost bed lower Tithonian), the red Upper Jurassic *Saccocoma* limestones of the Tegernsee limestone (upper Tithonian) and the calpionellid limestones of the red to grey Tithonian to Berriasian Ammergau Formation.

The stromatolite level on top of the Kössen Formation represents the unconformity between the Upper Triassic Kössen Formation and the Middle to Upper Jurassic Klaus Formation. The numerous planktonic foraminifera (protoglobigerina), in addition to thin-shelled bivalve "*Bositra*" and less numerous radiolarians, suggest that the Klaus Formation deposited in a deeper and open marine basin, in contrast to the Kössen Formation, which contains numerous coral boundstone and cortoids, suggestive of deposition within the photic zone. The stromatolite level thus represents a drowning unconformity and a significant time gap. The gap spans at least from the upper Rhaetian to the Bajocian, exhibiting a depositional gap of approximately 30 million years.

The sequence is characterized by the drowning of the platform environment in the Upper Triassic to Middle Jurassic, followed by a continuous deepening in the Upper Jurassic to Lower Cretaceous. The standard microfacies types SMF 2, 3, 4, 5, 7, 11, 12, 13, and 15 were detected. They characterize basin and slope environment of deposition (facies zones FZ 2–8). The deepening is documented by the following shift of microfacies types, subsequently by a change of environmental facies zones. The Kössen Formation is characterized by the SMF 15 type of FZ 7–8 zones restricted to open marine platform interior environments. Rhaetian limestones appear with diversified SMF 7, 11, 12, 13 of FZ 5–6 attributed to platform margin reefal structures and adjacent platform margins. The stromatolite boundary layer represents SMF 20 of FZ 7–9 of the open marine or restricted areas of the platform interior. Klaus Formation shows SMF 3–5 of FZ 3, 4of the middle to deeper slope. The Tegernsee limestone appears with SMF 2 and 3 of FZ 2, 3 of deeper slope and shelf areas. The Ammergau Formation occurs with SMF 3 of FZ 2, 3 characterizing the deeper slope and shelf.

Detail chronostratigraphic calibration of the lower Tithonian to lower Berriasian deposits of the Tegernsee limestone and the Ammergau Formation in the Hödl-Kritsch section was performed using calpionellids and calcareous dinocysts. The top of the Klaus Formation covers one calcareous dinocyst zone of lower Tithonian age (*P. malmica* Zone). It will need to be verified in the future if the top of the formation reaches even younger zones (or deposition lasted longer and the formation top is younger). No complete succession of calpionellid zones and subzones was documented. The *Chitinoidella* and *Praetintinnopsella* zones were not documented. Rare species typical for the *Ch. dobeni* Subzone, as well as few species of *Praetintinnopsella*, were observed in the *T. remanei* Subzone of the *Crassicollaria* Zone. There is a short gap between the *P. malmica* and the *Chitinoidella* Zone. The last known lower Tithonian dinocyst *C. semiradiata* Zone was not confirmed. Further calpionellid succession proved the standard *Crassicollaria* Zone with the *T. remanei*, *Cr. intermedia* and *Cr. colomi* subzones as well as the standard *Calpionella* Zone and its *C. alpina* and *R. ferasini* subzones.

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Plates

Plate 1

Images from the Upper Triassic to Lower Cretaceous outcrop recorded at the Hödl-Kritsch section.

Fig. A: Rhaetian limestones of the Kössen Formation, HKr7A, metre 0.

Fig. B: Top of the Rhaetian limestones of the Kössen Formation, HKr7D, metre 6.5.

Fig. C: Rhaetian reefal limestones, HKr7H, metre 7.5.

Fig. D: Transition from the Rhaetian reefal limestone to the red condensed limestones of the Middle Jurassic (Bajocian/Bathonian) Klaus Formation, separated by a few cm-thick stromatolitic crust, HKr7Q-S, metre 10.5.

Fig. E: Facies change from the topmost grey protoglobigerinid Klaus Formation to the red *Saccocoma* limestones (Kimmeridgian), HKrtop-Klaus and HKrStbase, metre 13.5.

Fig. F: Red, well bedded flaser like to nodular *Saccocoma* limestones, HKrSt100-350, metre 15–18.

Fig. G: Transition from the light red Tithonian limestone of the Ammergau Formation into the grey to whitish Ammergau Formation, metre 25.5.

Fig. H: Top of the light grey Berriasian Ammergau Formation, HKr5, metre 30.5.

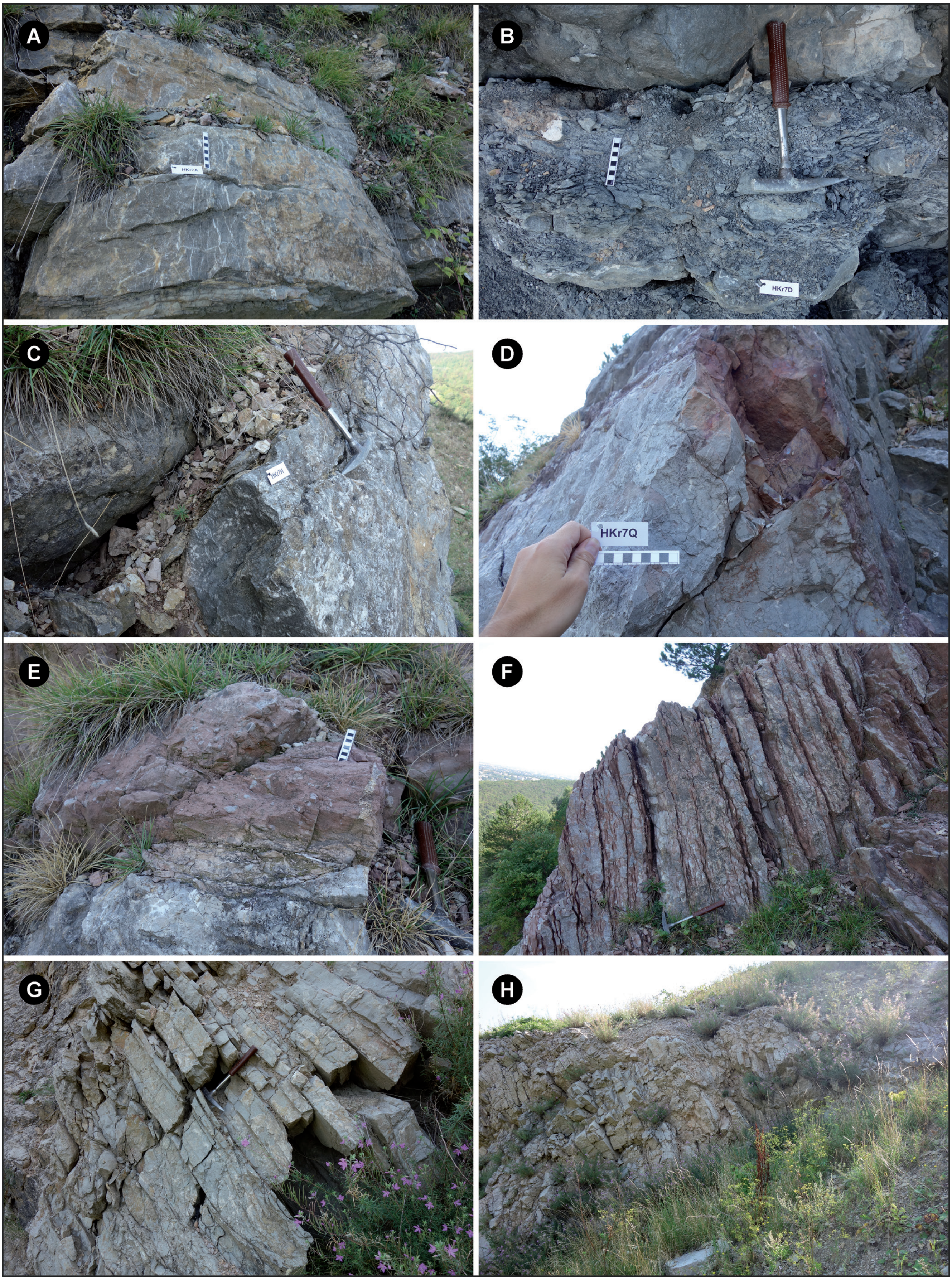
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Plate 2

Thin sections from the Rhaetian Kössen Formation recorded at the Hödl-Kritsch section.

Fig. A: Bivalve-brachiopod grainstone, with oosparitic layers, most shells preserved with micritisation seams (micrite envelopes), numerous gastropods, rare foraminifera, HKr7A.

Fig. B: Magnification of A with oosparitic layers.

Fig. C: Bivalve-brachiopod grainstone, most shells preserved with micritisation seam, numerous gastropods, frequent foraminifera, HKr7B.

Fig. D: Magnification of C with abundant foraminifera.

Fig. E: Crinoidal grainstone, well laminated, crinoids occurred with echinids, graded bedding, HKr7C.

Fig. F: Magnification of E with crinoids and echinoid spines.

Fig. G: Coral boundstone, corals with preserved septa, frequent brachiopod shells, most shells preserved with micritisation seam, crinoids occurred with echinoids, HKr7D.

Fig. H: Magnification of G with corals and punctated brachiopod shell.

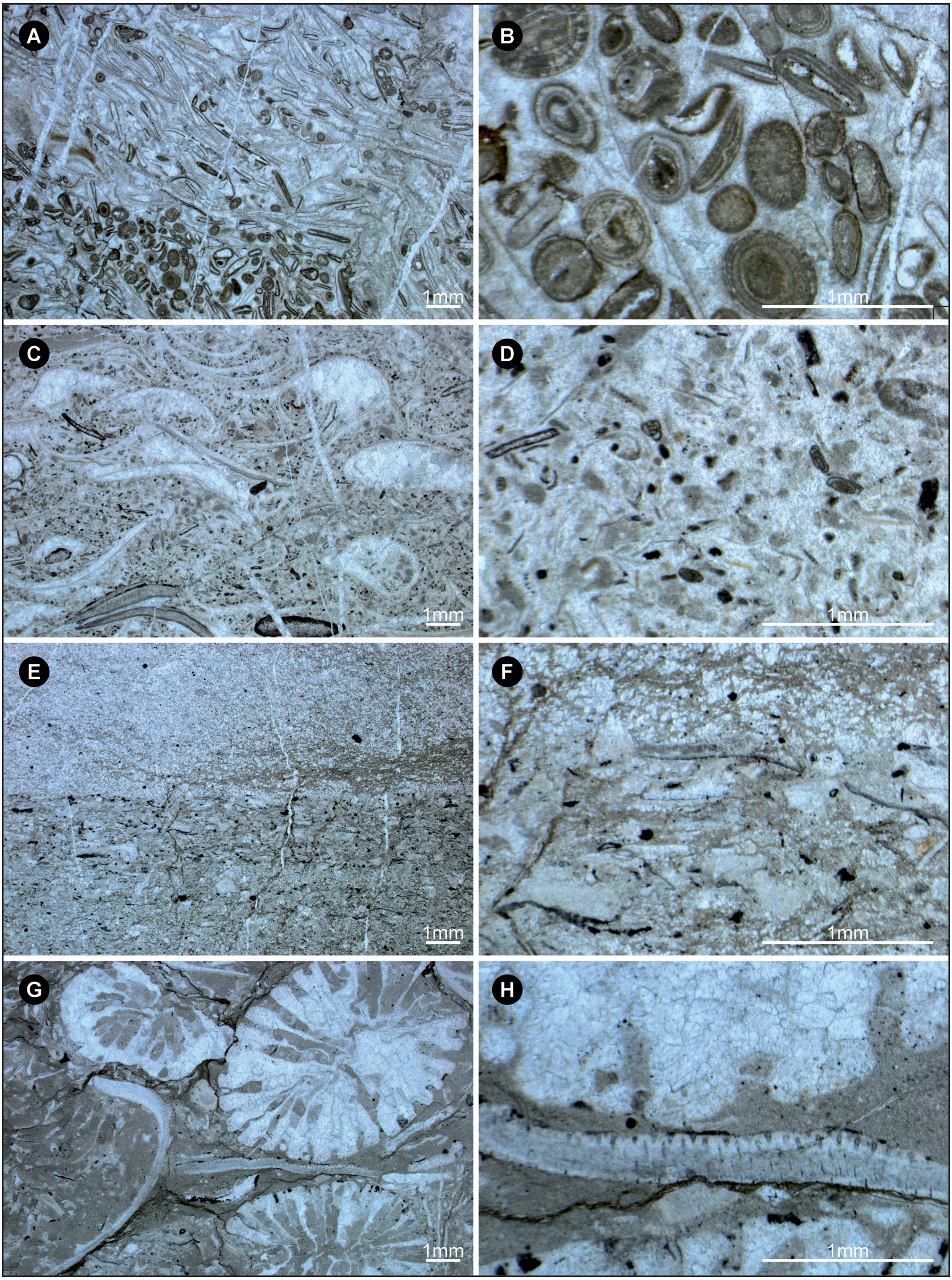
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Plate 3

Thin sections from the Rhaetian limestone member recorded at the Hödl-Kritsch section.

Fig. A: Crinoid-brachiopod packstone, encrusting foraminifera, residual layers with “algae”, dissolution seams, crinoids occurred with echinoids, rare foraminifera, HKr7E.

Fig. B: Magnification of A with crinoids and echinoid spine.

Fig. C: Crinoidal-brachiopod wacke- to packstone, rare echinoids, residual layer, HKr7J.

Fig. D: Magnification of C with crinoids in the residual matrix.

Fig. E: Coral-*Bacinella* packstone, most shells preserved with micritisation seam, encrusting foraminifera, *Bacinella irregularis*, brachiopods, corals fragments, gastropods, crinoids occurred with echinoids, frequent ostracods, frequent foraminifera, HKr7O.

Fig. F: Magnification of E with coral septa encrusted by *B. irregularis*.

Fig. G: Brachiopod-gastropod packstone, most shells preserved with micritisation seam, encrusting foraminifera, *B. irregularis*, brachiopods, corals fragments, gastropods, rare crinoids and echinids, frequent ostracods, frequent foraminifera, HKr7R.

Fig. H: Magnification of G with gastropod and brachiopod shells.

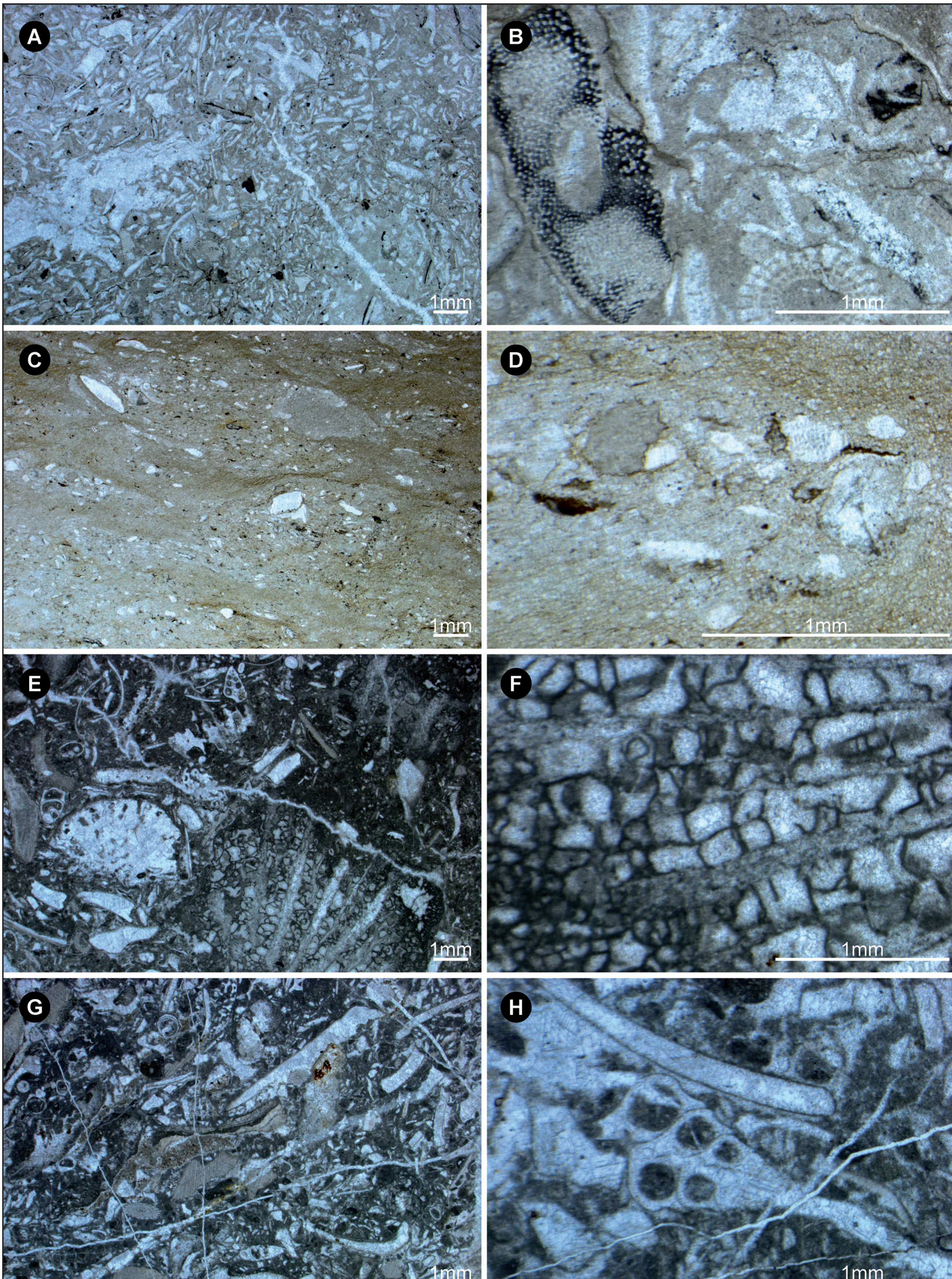
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Plate 4

Thin sections from the middle Jurassic stromatolite layer recorded at the Hödl-Kritsch section.

Fig. A: Stromatolite boundstone, *Frutexites*, reworked base with lithoclasts, well laminated, oncoids and cortoids, frequent foraminifera, residual crusts, condensed, with crinoid layers, HKr7stromatolite-10cm.

Fig. B: Magnification of A with crinoids, echinids and filaments.

Fig. C: Multi-layered redeposited fine crinoidal limestone with limonitic crusts impregnation by limonite, note erosive base and top, HKr7stromatolite-5cm.

Fig. D: Magnification of C with the erosive base.

Fig. E: Stromatolite with redeposited and encrusted lithoclasts, filamentous matrix at the top with foraminifera, HKr7stromatolite.

Fig. F: Magnification of E, interspace filled by matrix with foraminifera, bivalves, gastropods and isolated filaments.

Fig. G: Layers of the stromatolite with columnar growth, HKr7stromatolite.

Fig. H: Magnification of G with filled interspaces, note filaments and redeposited foraminifera.

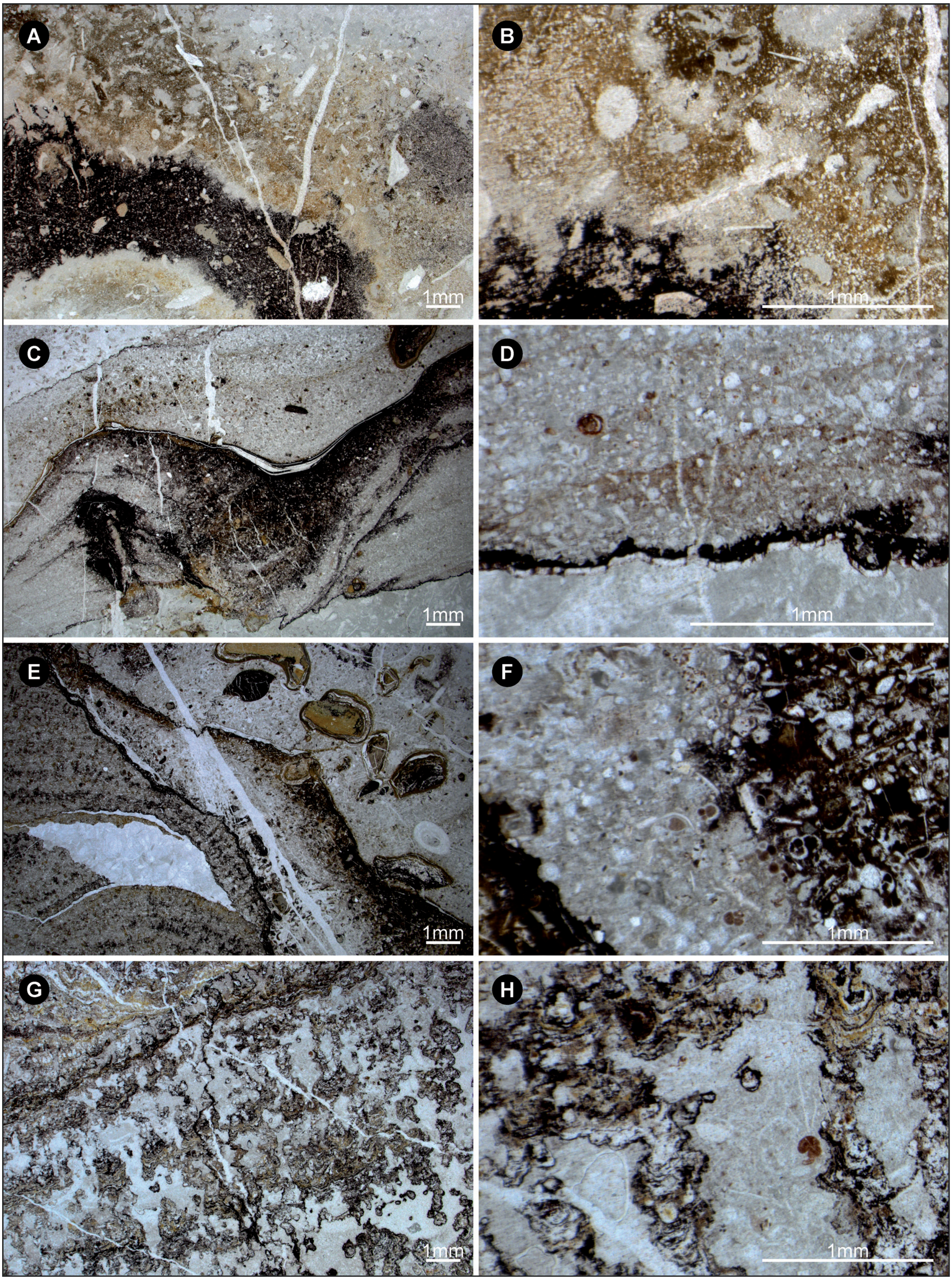
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Plate 5

Thin sections from the Bajocian/Bathonian lower Klaus Formation and the Tithonian top of the Klaus Formation recorded at the Hödl-Kritsch section.

Fig. A: Filamentous limestone, mass occurrences of the *Bositra*-like shell-fragments, shells show micritisation seams, HKr7S.

Fig. B: Magnification of A with stacking *Bositra*-like *fragments and* rare peloids.

Fig. C: Filamentous limestone with mass occurrences of the *Bositra*-like shell-fragments, note micritisation seams and bioturbation, HKr7.

Fig. D: Magnification of C with cortoidal mass occurrences of the *Bositra*-like shell-fragments.

Fig. E: Start of foraminiferal limestones with frequent *Bositra*-like shell-fragments, HKr7topKlaus-125cm.

Fig. F: Magnification of E with mass occurrence of filaments.

Fig. G: Foraminiferal limestone with filaments, crinoids and radiolaria, mass occurrence of protoglobigerinids, start of “micritic ooids”, HKr top Klaus.

Fig. H: Magnification of G with mass occurrence of protoglobigerinids and rare filaments.

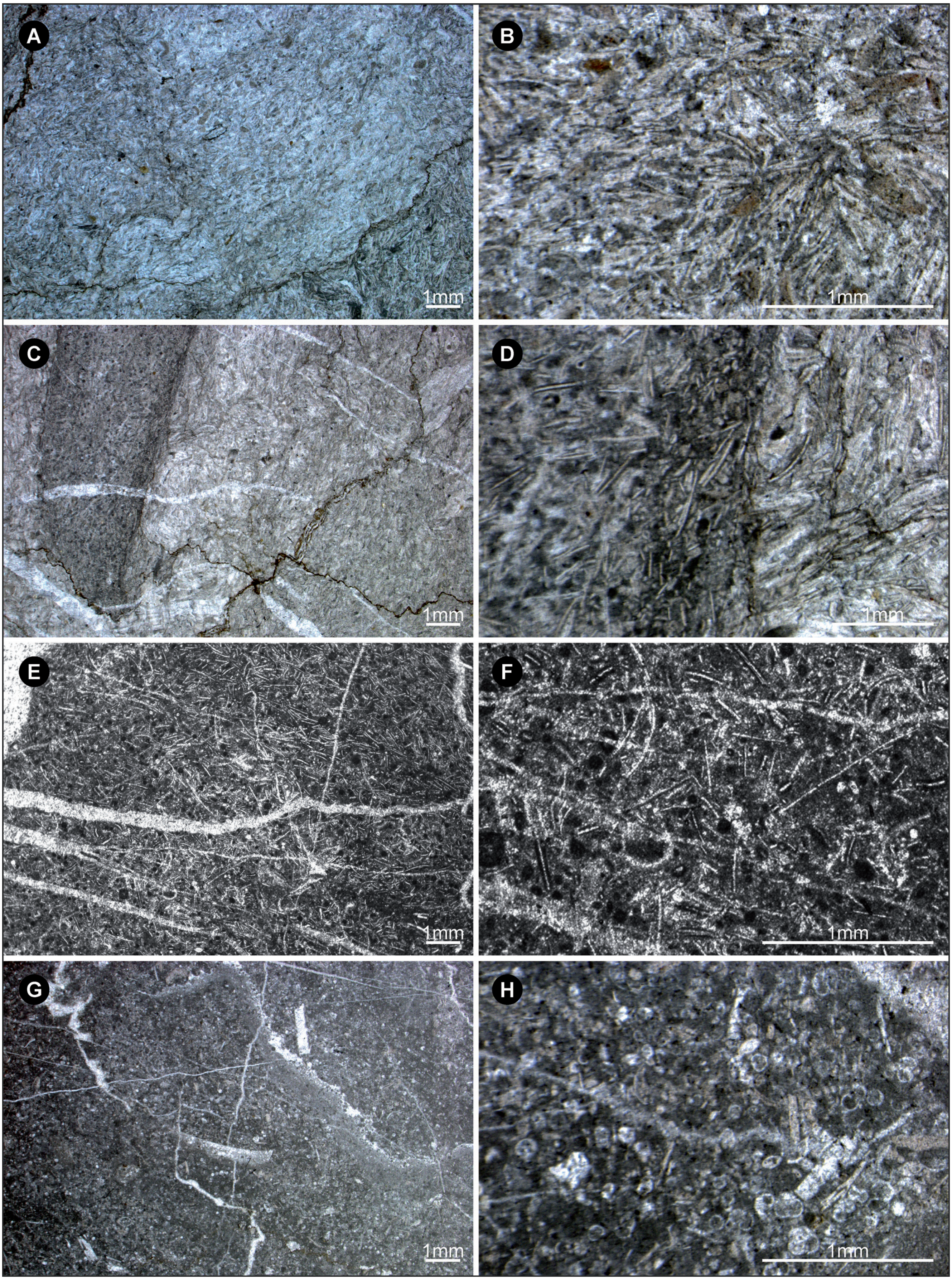
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Plate 6

Thin sections from the late Tithonian *Saccocoma* limestones (Tergernsee limestone) and the Tithonian/Berriasian Ammergau Formation recorded at the Hödl-Kritsch section.

Fig. A: Biogenous red limestone with lithoclasts, abundant radiolaria and the start of the crinoidal *Saccocoma* specimens, HKrbaseSt.

Fig. B: Biogenous red limestone with abundant *Saccocoma*, HKr7St50.

Fig. C: Red nodular biogenous limestone bivalves, ostracods and crinoidal fragments, HKr7St450.

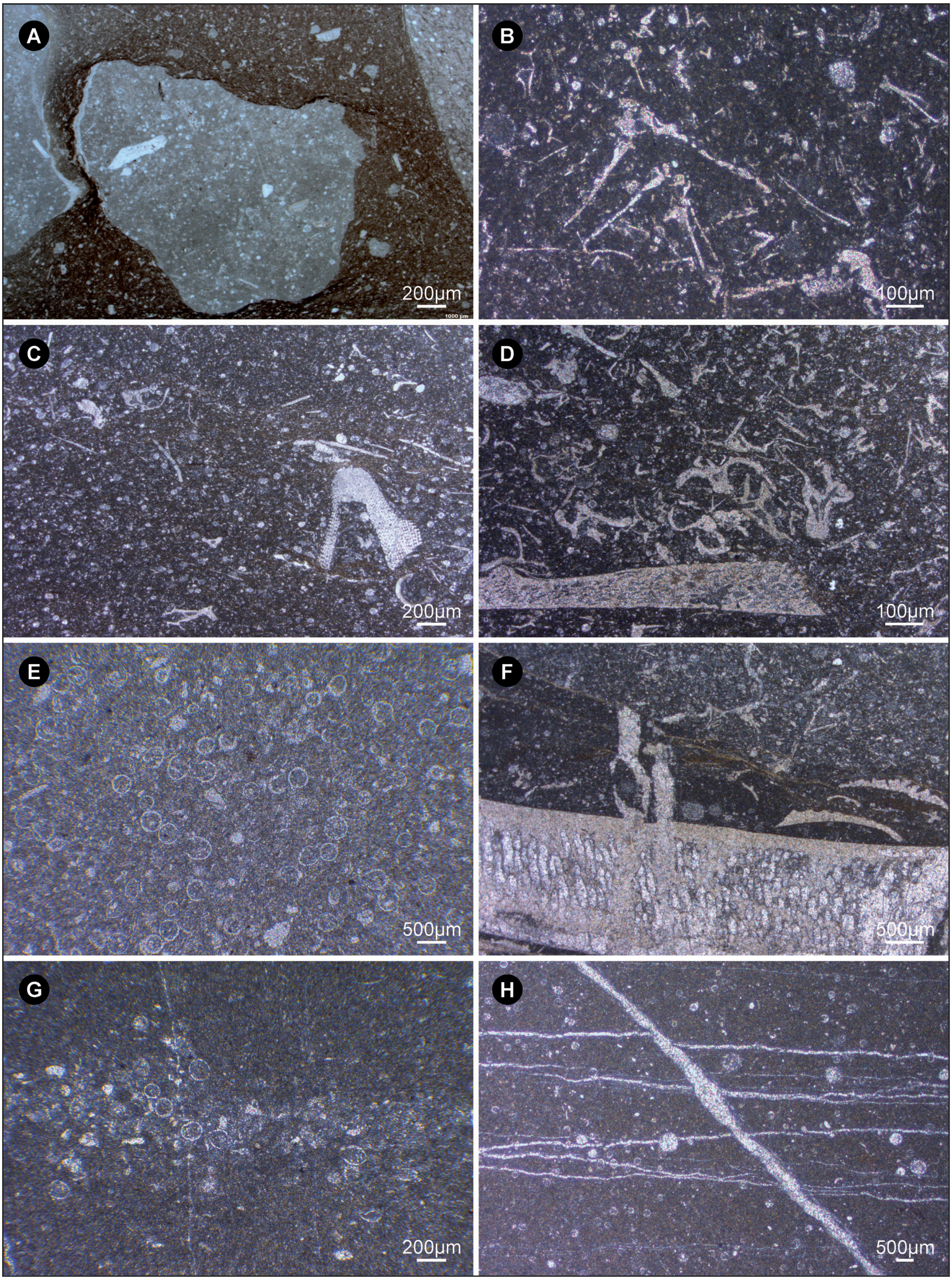
Fig. D: Red nodular, radiolarian-*Saccocoma* packstone with frequent *Saccocoma*, bivalves, ostracods and *Laevatychi*, HKr7St350.

Fig. E: Radiolaria-calpionellid wackestone with abundant calpionellids, HKr5-25m.

Fig. F: Grey biogenous limestone, with radiolaria, saccocomids and calpionellids, note resedimentation structures and meshed internal structure of *Laevaptychus*, HKr5-22m.

Fig. G: Grey mudstone with calpionellid laminae and nesting, HKr5-16m.

Fig. H: Top of the radiolaria-calpionellid wackestone with numerous calcite veins, HKr5.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