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EXCURSION 2

Characteristic features of the Lofer cyclicity on the Dachstein Plateau (Austria)

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Introduction

The Upper Triassic Dachstein Limestone plays an outstanding role in the building up of the Northern Calcareous Alps. It was formed by a tropical shallow marine carbonate factory of an extremely large carbonate platform system. Moreover, the extension of the Dachstein-type platform carbonates far exceeds the region of the Eastern Alps; they are known all along the margin of the Late Triassic Tethys Ocean.

SIMONY (1847) named the thick bedded, *Megalodus*-bearing limestone formation as Dachsteinkalk after the Dachstein Range. SUESS (1888) described red marl interlayers in the Dachstein Limestone and interpreted them as results of periodical subaerial exposure.
SANDER (1936) first recognised metre-scale sedimentary cycles in the Dachstein Limestone, terming this cyclic facies as Lofer facies because of its excellent exposure in the Loferer Steinberge and attributed the cyclicity to sea level changes. SCHWARZACHER (1947, 1954) carried out further studies of these cycles. Based on studies in the Loferer Steinberge, Steinernes Meer and Dachstein, FISCHER (1964) provided a detailed description of the facies characteristics of the members of the cycles ("Lofer cyclothems") defining an upward-deepening facies trend and proposed orbital control of the cyclicity. He characterised and interpreted the typical Lofer cycle as follows: a disconformity at the base; member A – a basal argillaceous member (red or green) representing reworked residue of weathered material; member B – intertidal member of loferites with algal mats and abundant desiccation features; member C – subtidal megalodont limestone. HAAS (1982, 1991, 1994) modified the basic pattern of the Lofer cycles, proposing a symmetrical ideal cycle. GOLDHAMMER et al. (1990) and SATTERLEY (1996a) reinterpreted the ideal Lofer cycle as shallowing upward. SATTERLEY (1996a,b) and ENOS & SAMANKASSOU (1998) stressed the lack of evidence for subaerial exposure at the cycle boundaries and assumed allocyclicity as the predominant control. In contrast studies of HAAS et al (2007) in the Krippenstein area provided a number of evidences for subaerial exposure and related karstification and peculiar sediment deposition. However the evaluation of the characteristic features and accordingly main control for Lofer cyclicity is still open. Main aim of the excursion is to observe the basic characteristics of well exposed sequences in the type locality of the Dachstein Limestone.

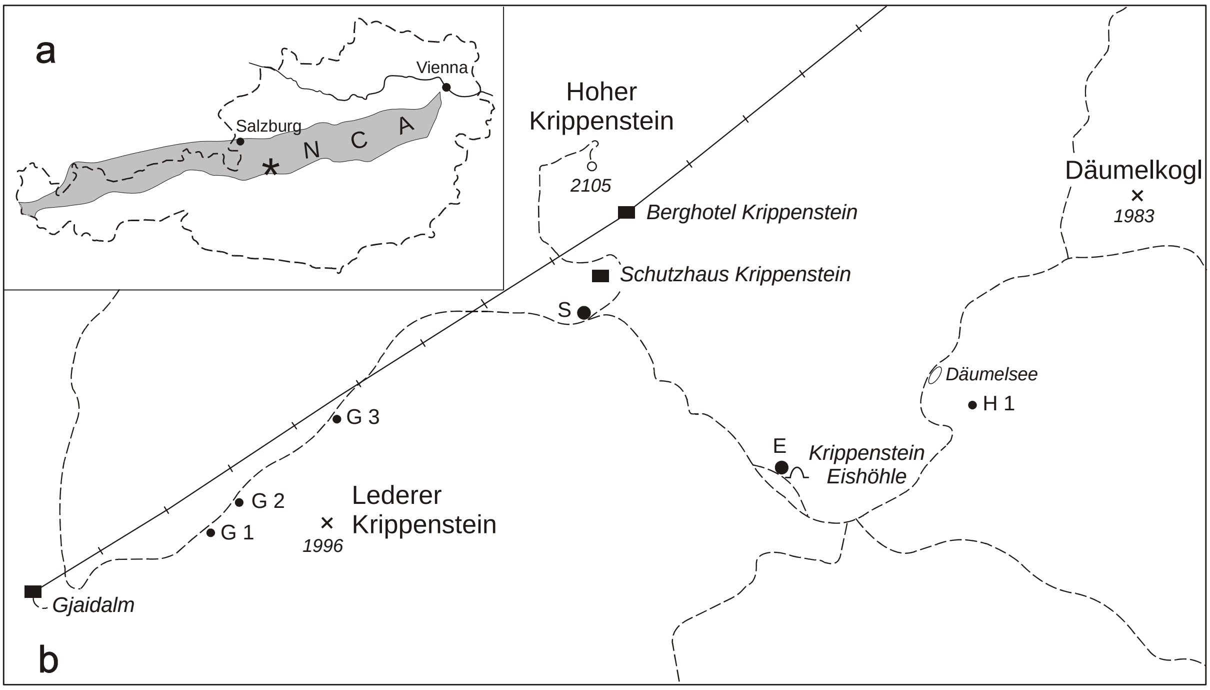

Fig. 1: a) Geographic setting of the study area. b) Location of the studied sections on the Dachstein Plateau. G 1–3 sampling points near to Gjaidalm, S section at Krippenstein Schutzhaus, E section at Krippenstein Eishöhle.

Toward the south to the Hoher Dachstein and in the area of Mt. Hierlatz, the Dachstein Plateau excellently exposes a significant part of the approximately 1000 m-thick succession of the Lofer cyclic Dachstein Limestone. However, the natural rock surfaces are usually not suitable to study the details of the facies succession and especially the subtle unconformity surfaces and peritidal layers due to erosion by Pleistocene glaciers, the subsequent karstification and the crustose lichens that cover the rock surfaces as a rule. Recently, near the Krippenstein Schutzhaus (Lodge) and between the Krippenstein and Gjaidalm cable car stops, new ski trails have been constructed and the previous ones broadened, resulting in new excellent exposures (Fig. 1). These fresh cuts make possible the observations of the details of the cycles a special regard to the unconformity surfaces and basal parts of the cycles which are of critical importance for evaluation of the cause of the cyclicity.

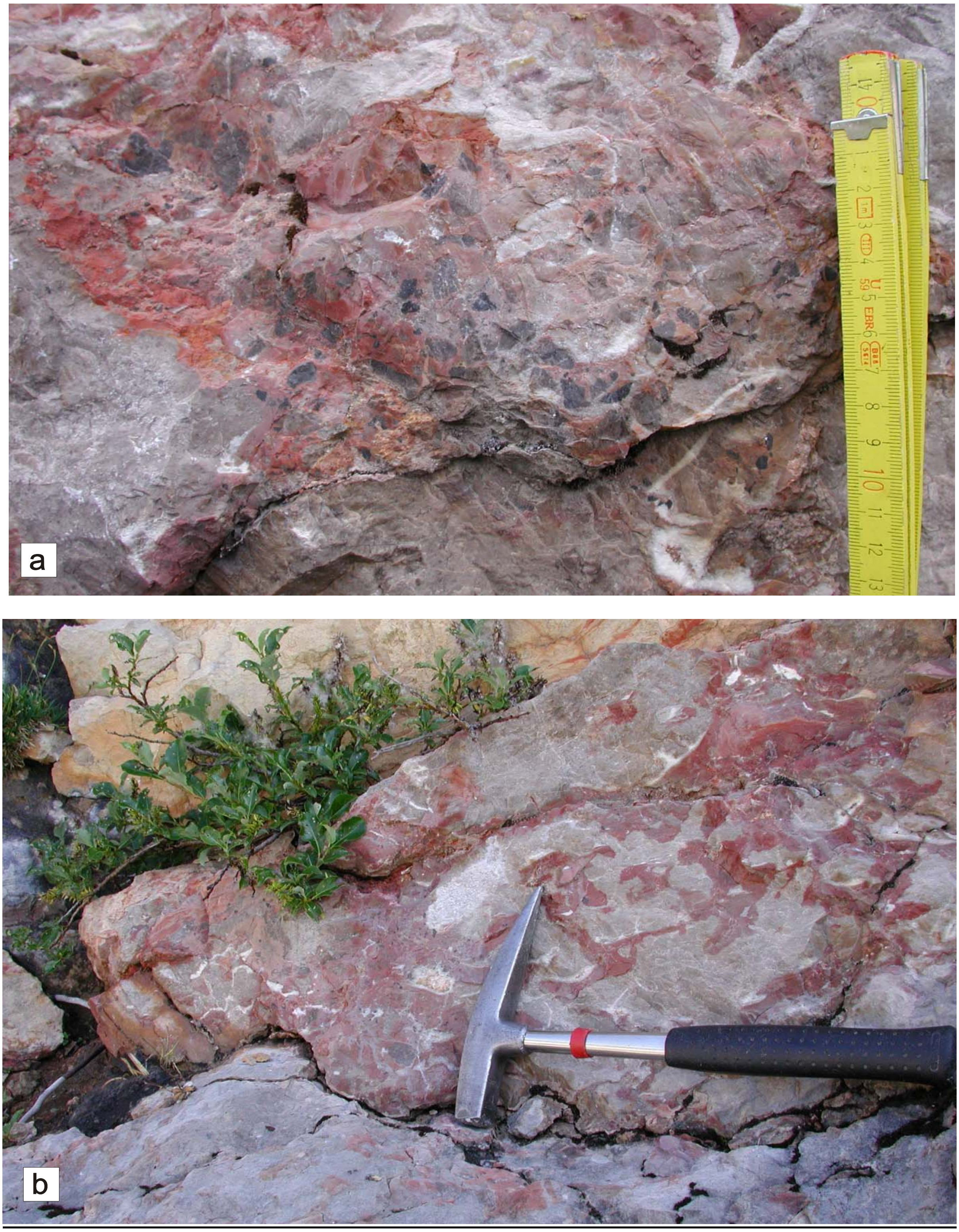

Fig. 2: a) Uneven disconformity surface overlain by red limestone with black pebbles. Ski trail between Gjaldalm and Krippenstein (G2 on Fig 1/b); b) Network of solution pipes and cavities filled by red mudstone–wackestone. Ski trail between Gjaldalm and Krippenstein (G2 on Fig1/b).

1. Outcrops along the ski trail between Gjaidalm and Krippenstein

Between Gjaidalm and Krippenstein a newly made ski trail exposed a significant interval of the cyclic Dachstein Limestone (Fig. 1b). Although a continuous section is not visible, the exposures permit the detailed observation of the boundary interval (top and base) of many cycles.

Very pronounced disconformity surfaces and definite microkarstic features were observed in the majority of cases at the base of the cycles (Fig. 2a). Below the disconformity surface at a depth of 0.5 to 1 m, a network of solution pipes and cavities filled by red mudstone is visible (Fig. 2b). Above the disconformity, a 5 to 10 cm red mudstone layer occurs that commonly contains blackened and non-blackened lithoclasts (A facies) (Fig. 2a). The same material or locally calcite cement fills the solution pipes, pockets and cavities.

2. Krippenstein Schutzhaus

The section is located south of the Krippenstein Lodge, about 50 m below the level of the building (Fig. 1b). It is an artificial exposure, a cut of the new ski trail that excellently exposed even the smallest details of a 12 m-thick continuous succession (Fig. 3). The Lofer cycles are clearly visible and there is no significant tectonic disturbance. Fissures and cavities filled by red argillaceous mudstone locally occur but they do not hamper the recognition of the cycles, since the fissure and cavity fill even if they are sub-parallel with the bedding can usually be distinguished from the normal sediments.

Fig. 3: Measured section south of the Krippenstein Schutzhaus. Scale bar is one metre.

The exposed section (Fig. 4) begins with a thick light grey limestone bed containing plenty of calcite speckles (biomoulds), small bivalve fragments and calcite moulds of megalodonts. The upper bedding plain is an uneven disconformity surface Cracks, pockets and cavities filled by red and grey mudstone occur in the uppermost 30 cm of the bed that shows a pinkish colour. According to the thin-section studies, foraminifera wackestone was the original texture of the limestone just below the disconformity surface. Along with the abundant and diverse foraminifera fauna, fragments of bivalves and ostracodes also occur. Due to intense solution moldic pores were formed that were subsequently filled by sparry calcite. Larger (1-3 mm) pores or networks of amalgamated pores are also common. They may have formed by solution leading to enlargement of moldic pores. These larger pores are filled totally or partially by carbonate silt--microsparite, geopetal structures occur in the latter case. Ostracodes are rarely present in the lower part of the geopetal pore fills.

The disconformity is covered by 1-2 cm-thick red argillaceous mudstone (facies A). The basal red mudstone is succeeded by white, dolomitised mudstone with fenestral pores and mm-wide desiccation cracks (loferite – facies B) in a thickness of 17 cm. This layer is separated from the overlying crinkle stromatolite layer by a 1-2 cm red argillaceous mudstone horizon. The 20 cm-thick stromatolite layer is followed by light grey limestone (facies C) with rip-up clasts of loferite at the basal part of the 60 cm-thick bed that is succeeded by 5 to 10 cm of white, laminated dolomitised mudstone with desiccation cracks (facies B). An uneven disconformity surface ends the cycle that is covered by 2-5 cm red, argillaceous mudstone (facies A – Fig. 4b). It is followed by an approx. 1 m-thick stromatolitic – loferitic interval (facies B) with a light grey wackestone interlayer, rich in small gastropods. There is a sharp boundary between the upper loferitic bed and the overlying 2.5 m-thick light grey wackestone bed (facies C) showing vague lamination in the topmost 10 cm. It is bound by an uneven disconformity surface that is covered by 2-10 cm of red or greenish grey mudstone (facies A), which is the basal layer of the next cycle (Fig. 4c). The mudstone contains a number of thin-shelled and a few thick-shelled ostracodes (Fig. 5) and a few poorly preserved foraminifera. It has a mottled texture, i.e. micritic patches occur in microsparite–carbonate silt, probably due to bioturbation. Mm-sized lithoclasts showing microbial texture were also found.

The basal layer is overlain by light grey mudstone that grades upward into dark grey mudstone with vague lamination. Pinkish staining of the upper part of the mudstone might indicate short-term subaerial exposure, i.e. the end of a thin cycle. It is overlain by grey mudstone rich in small gastropods and yellowish-white dolomitic mudstone with shrinkage cracks. A slightly uneven disconformity surface closes the cycle.

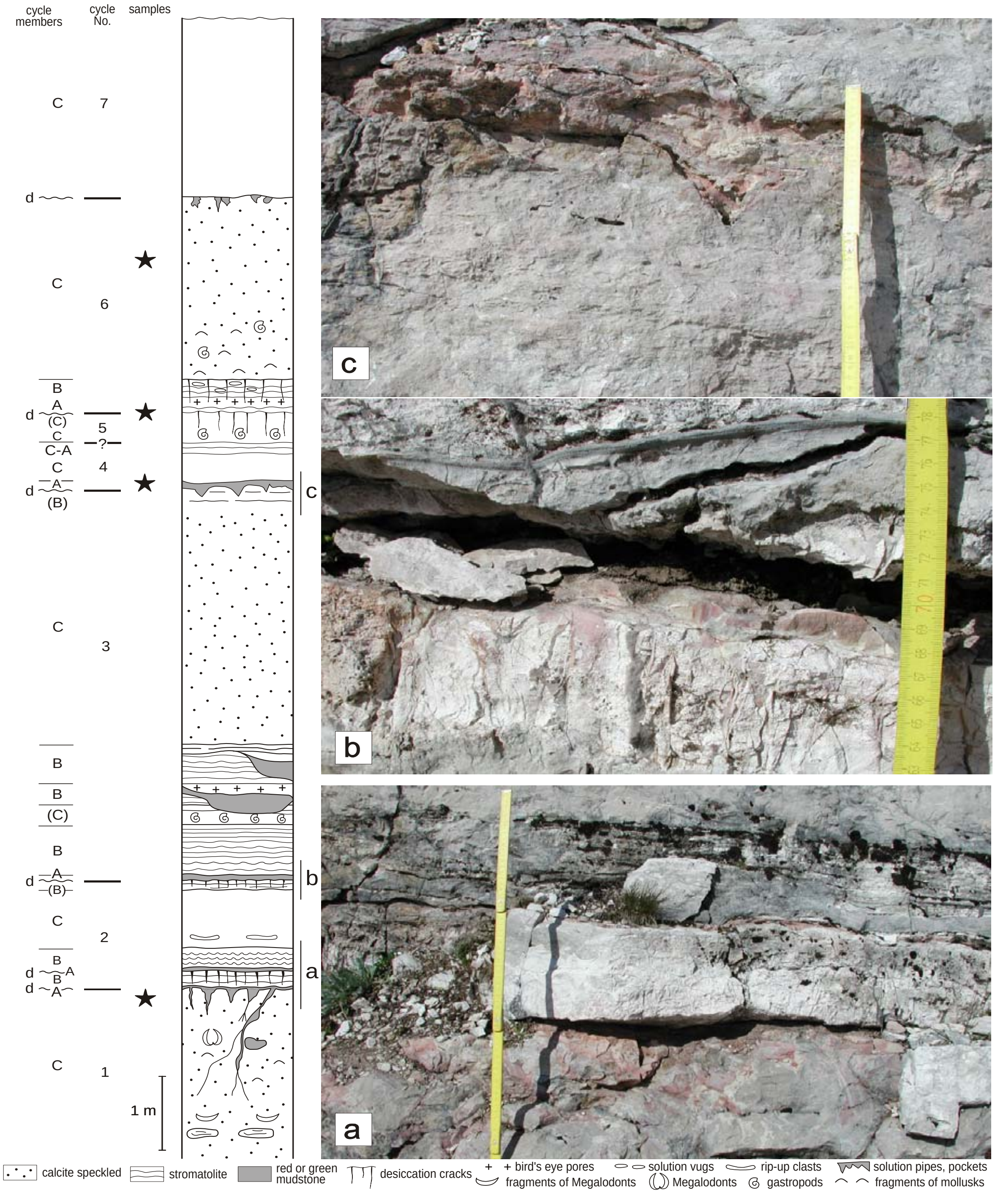

Fig. 4: Section south of the Krippenstein Schutzhaus. Lithologic log, cycles and facies types; location of the samples referred in the text is marked by asterisk; a) karstified disconformity surface of the lowermost exposed cycle and the overlaying peritidal beds; b) the upper boundary interval of the second cycle; c) the upper boundary interval of the third cycle.

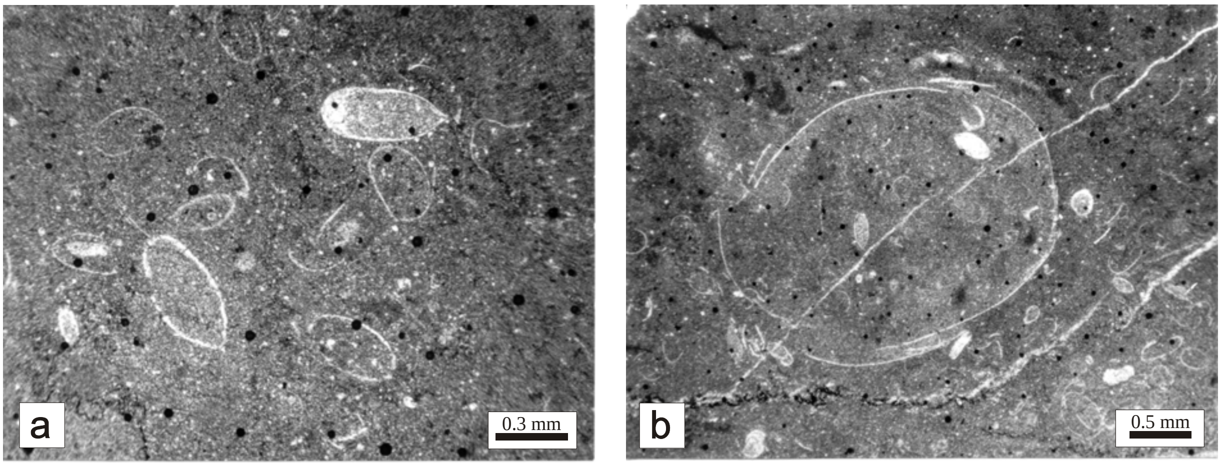

Fig. 5: Typical microfacies of facies A. a) ostracodal wackestone ; b) ostracodal wackestone. The large fragmented shell in the central part of the photomicrograph is probably also an ostracode carapace.

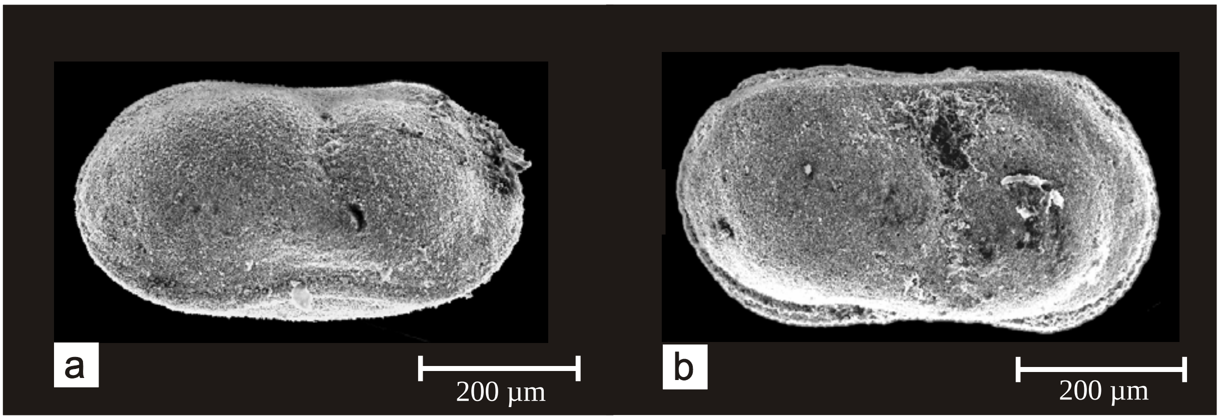

Fig. 6: *Lutkevichinella* aff. *grammi* Kozur, 1972. Carapaces (right valves)

It is covered by greenish grey argillaceous mudstone 1–4 cm in thickness. Its texture is of clotted micrite with dolosparite patches. Solution of a sample taken from this layer yielded well-preserved ostracodes in relatively large number (Fig 6). These fossils are very similar to those described by H. KOZUR as *Lutkevichinella* aff. *grammi* Kozur, 1972 n. sp. from the Rhaetian Dachstein Limestone in the Transdanubian Range, Hungary (HAAS et al, 2006).

The ostracode-bearing greenish mudstone grades upward into yellow mudstone with scattered fenestral pores and small gastropods. It is succeeded by stromatolite with shrinkage cracks and cm-sized cavities which probably formed via solution of evaporites. The next 1.8 m-thick bed is made up of bioclastic, peloidal grainstone. The bioclasts are well sorted, abraded, and usually coated by a micrite envelope. Foraminifera, usually strongly recrystallised are abundant; fragments of molluscs, ostracodes, echinoderms, and calcareous sponges are common. *Favreina*-type fecal pellets also occur. This bed that shows the characteristics of the subtidal facies C is truncated. It is bounded by an uneven disconformity surface showing microkarstic features. The solution pockets are filled by red mudstone. A bed showing similar facies characteristics and thickness as the underlying one (facies C) directly overlies this surface.

Along the measured section the following patterns of facies succession were encountered: ABCB'; BCB'; ABC; C.

3. Krippenstein Eishöhle

A continuous succession in a thickness of about 15 m is visible on the eastern side of the large entrance of the cave (Fig 1b) where the succession was excellently exposed in a width of 5 to 10 m that also allowed the observation of the small-scale lateral facies changes (Fig.7). Thin subvertical fissures with sparry calcite or pinkish micrite fill and thicker fissures subparallel to the bedding that are filled by pinkish micrite or alternating stripes of grey micrite and sparite (zebra-type fissure fill) locally occur. However, no significant tectonic disturbances were found.

Fig. 7: Section at Krippenstein Eishöhle. Scale bar (lower left) is one metre.

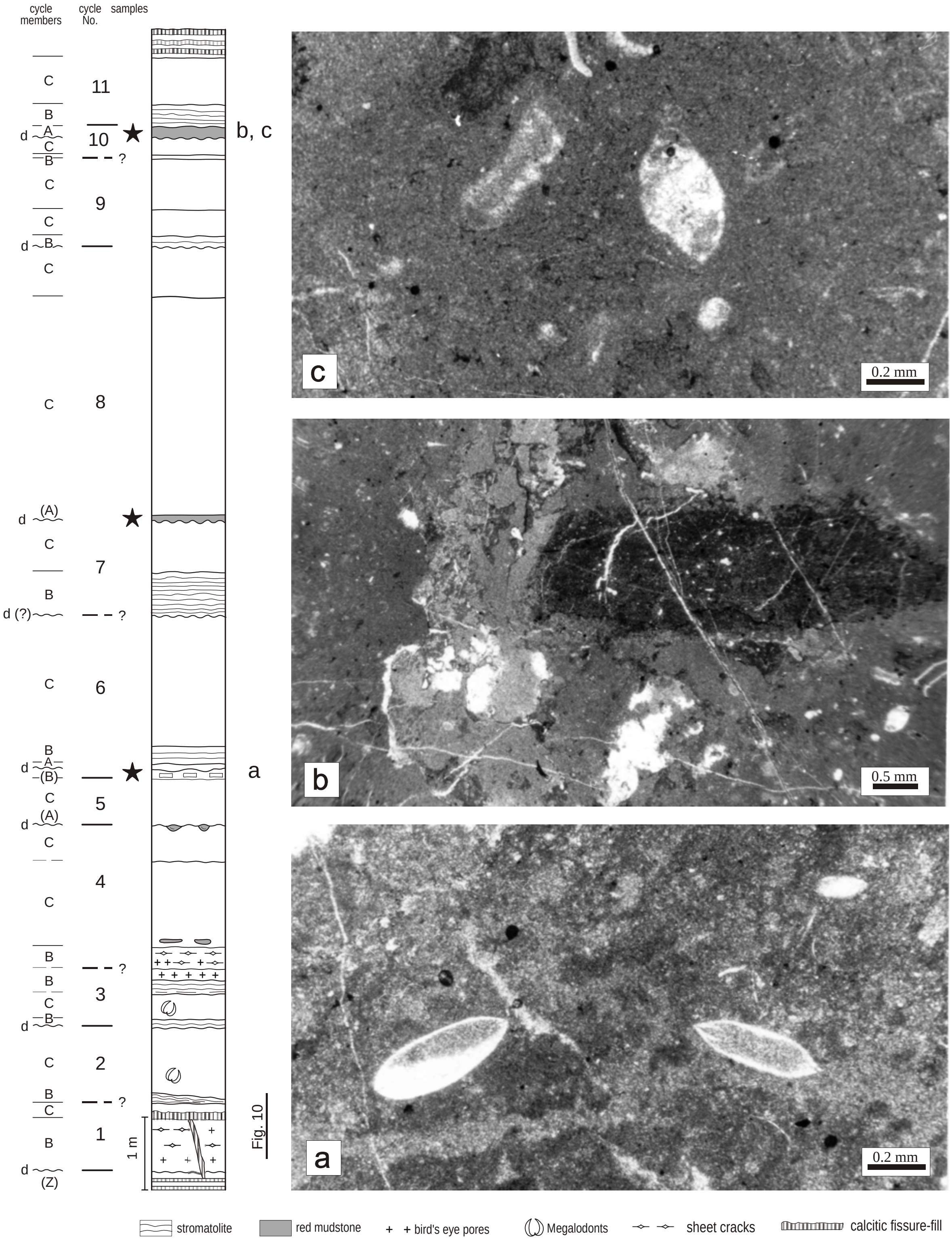

Fig. 8: Section at Krippenstein Eishöhle. Lithologic log of the section, cycles and facies types. Typical microfacies of facies A: a) Ostracodal wackestone; b) Intraclast in ostracodal wackestone c) Redeposited marine foraminifera in ostracodal wackestone.

Eleven cycles that are made up of typical members of FISCHER's (1964) Lofer cycles could be recognised. Usually there is an uneven disconformity surface at the base of the cycles. If it is missing, an exact determination of the boundary between the neighbouring cycles is ambiguous. Usually it can be drawn within the stromatolitic or loferitic facies (member B).

A few mm to 10 cm-thick greenish, yellowish, red or variegated, mottled, commonly argillaceous mudstone was generally found at the base of the cycles directly above the disconformity surfaces (member A). In a few cases this material was encountered only in minor depressions of the disconformity surfaces. According to microscopic observations this facies is characterised by clotted mudstone–wackestone texture that is relatively rich in thin, double or single-shelled ostracodes. In the sample taken from the basal member A of cycle 6 (see Fig. 8) shrinkage cracks and pores filled completely or partly by microsparitic cement occur (Fig. 8a). In the sample taken from the basal A member of cycle 8 (see Fig. 8) small lumps and larger intraclasts were found. Ostracodes and foraminifera are common both in the matrix and the intraclasts (Fig. 8b, c).

The basal mudstone (or if it is missing, the disconformity surface) is overlain by white to light yellow or rarely darker grey stromatolite or mudstone with fenestral pores and sheet cracks (member B) in a thickness of 10–75 cm. The stromatolites are usually slightly crinkled, microtepee structure also occurs, but rarely.

The B or rarely the A facies is overlain by light brown, greyish brown finely crystalline limestone that rarely contains megalodonts (member C). Their thickness varies between 0.7–3 m.
In the studied section the composition of the Lofer cycles is rather variable. The following patterns were found: ABC; ACB; BCB; BC; AC. This means that the cycles are incomplete and/or truncated as a rule.

4. Outcrops along the karst study trail between Krippenstein and Heilbronner Kreuz

The karst study trail also provided several suitable exposures for studying the composition of the Lofer cycles and especially the mode of their superposition. It is clearly visible that the cycles are bound by well-developed, uneven disconformity surfaces. In several cases beneath the disconformity a network of solution pipes and cavities filled by red mudstone was found. A typical example of the microkarstic phenomena is shown in Fig. 9 (for location see Fig. 1b).

The disconformity surfaces are usually overlain by 5–20 cm thick red micrite (facies A). In the neighbourhood of the Krippenstein Ice Cave decimetre-thick loferitic layers (facies B) usually also occur either directly on the disconformity or on facies A. In many cases both facies A and B are missing. The thickness of facies C is 1–2 m. *Megalodon*-bearing beds are common; the size of the molluscs may reach 20–30 cm.

Fig. 9: Well-developed karstic solution pipes and cavities beneath a cycle-bounding discon-formity surface. Karst study trail between Krippenstein and Heilbronner Kreuz.

Summary of the observations and conclusions

1. In the visited sections on the Dachstein Plateau the boundaries of the Lofer cycles are usually erosional disconformities showing features of karstification. Penetration of the karstic solution was not more than a few decimetres (microkarst) since during the recurrent sea-level drops the platform was only slightly emerged above the sea-level.
2. The reddish or greenish argillaceous carbonate member that is facies A cannot be interpreted as palaeosol although it may contain reworked palaeosol-derived material. Facies A represents tidal flat deposit consisting predominantly of subtidal carbonate mud redeposited by storms. The subtidal mud was mixed with airborne fines and/or reworked lateritic soil that were accumulated and subjected to further weathering and alteration on the subaerially-exposed platform. Rip-ups from consolidated sediment, blackened intraclasts and carbonate mud formed in the tidal flat ponds, and skeletons of tidal flat biota may have also contributed to the material of facies A. The ostracodes (*Lutkevichinella*) found in facies A suggest very low salinity to freshwater conditions.

3. In the studied sections an ABC facies succession was found at the base of many cycles, suggesting a transgressive trend. In contrast the regressive part of the cycles is frequently missing due to the post-depositional truncation. Consequently the present-day thickness of the cycles may significantly differ from their original thickness. This point must be kept in mind when using series of thickness data for analysing the periodicity of cyclic successions in the Dachstein Limestone.

4. Erosional boundaries of most of the investigated cycles, and definite features of the karstic solution beneath the disconformities, suggest periodical sea-level drop followed by renewed transgression. This appears to confirm the allocyclic model for the explanation of the origin of the Lofer cycles, although other factors may have influenced the characteristics and preservation conditions of the cycles.

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