Middle Triassic platform/basin transition along the Alpine passive continental margin facing the Tethys Ocean – the Gamsstein: the rise and fall of a Wetterstein Limestone Platform (Styria, Austria)

By

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With 13 Figures and 6 Plates

Field Trip Guide

29th IAS Meeting of Sedimentology
Schladming, Austria

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Journal of Alpine Geology	54	S. 471-498	Wien 2012

Content

Abstract

The Triassic sedimentary succession of the northwestern Tethyan realm is characterized by a complex carbonate platform - basin pattern, especially in Middle Triassic to early Late Triassic times. Theme of this field trip is the onset and demise of carbonate platforms and their platform/ basin transitions: To see two superimposed shallow-water carbonate complexes of Middle Triassic age (Steinalm ramp and Wetterstein platform of the classical north-alpine Mesozoic) together with their basin-ward transition to resedimented (Raming-Formation) and deep basinal carbonates (Reifling-Formation). To see and discuss:

- Growth and internal architecture of the Steinalm ramp and the Wetterstein platform.
- Ramp vs. platform margin sedimentation and carbonate platform progradational sequences.
- Breakdown of the carbonate production and carstification of the Wetterstein platform in the wake of the Carnian Crisis.
- Sedimentary evolution and palaeodepth reconstruction of the coevally subsiding attached basin (Reifling Formation).
- Middle Triassic platform-basin palaeogeographic reconstruction of tectonically isolated platform fragments.

Object of the excursion is Mount Gamsstein in the eastern Northern Calcareous Alps (Styria), situated 10 km east of the classical Middle Triassic basinal sequence of Grossreifling.

1. Introduction

Middle Triassic carbonate platforms are quite thick and widely developed within the Northern Calcareous Alps. They exhibit two major growth phases, the first during Anisian, the second and longer-lasting from Ladinian to Early Carnian time. Geographically these platforms form two elongated belts to the north and south of the Northern Calcareous Alps with an intermediate and considerably deep basin called the Reifling (limestone) Basin after its principal lithological component. The earlier or Steinalm (platform) shallow-water carbonate complex rests on lagoonal respectively restricted mudstone carbonates of the Early Anisian Gutenstein Formation with which it later interfingers. Its relatively homogeneous subtidal facies with only minor lateral variations points to a flat-ramp depositional setting. During Middle Anisian time the Steinalm (platform) carbonate complex underwent either uplift in the interior or drowning in marginal areas, becoming

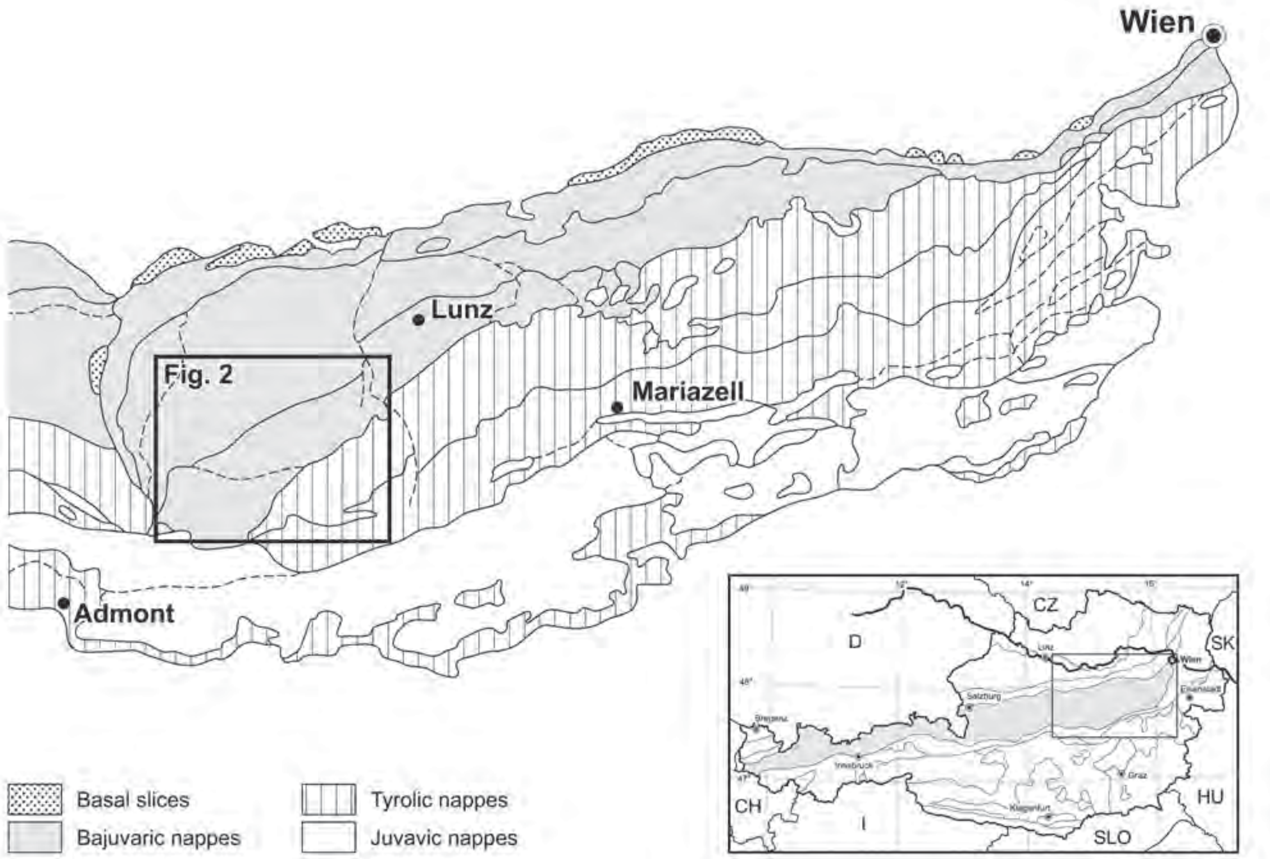


Fig. 1: Tectonic map of the eastern part of the Northern Calcareous Alps with the Gamsstein Unit (inserted).

initially buried by encrinitic and subsequently by deeper water cherty limestone of the Reifling Formation. This widely developed flooding event has been called the "Reiflinger Wende" (now Reifling Event) by Schlager & Schöllnberger (1975). Platform growth rebounded during the uppermost Anisian with widespread onset of Wetterstein limestone deposition, which due to enforced subsidence was initially aggradational during the Early Ladinian and becoming two-phase progradational in the Late Ladinian (first phase) and especially in the late Early Carnian (second phase). At that time platforms developed large and diverse barrier reefs in front of the lagoon and reached their maximum extent, thereby covering nearly half of the original area of the Reifling Basin (Hornung & Brandner 2005, Fig. 2b). Platform growth, however, ended in the late Early Carnian due to exposure related to the end of subsidence and subsequent karstification. When subsidence resumed soon thereafter the platforms failed to recover because of the distinct change to terrigenous and siliciclastic sedimentation of the Lunz Group. This probably Tethys-wide recorded event has been called the "Reingrabener Wende" (now Reingraben Event) by Schlager & Schöllnberger (1975) and more recently renamed as Carnian Pluvial Event (Simms & Ruffell 1989). Wetterstein-type carbonate platforms with still intact transition to the attached basin are quite rare in the Northern Calcareous Alps. Some more recently studied ones are located in the Nordkette Range near Innsbruck, Tyrol, described by Brandner & Resch (1981), and at the Hochstauffen, a mountain west of Salzburg, documented in Henrich (1982, 1983). Neither example, however, shows a direct transition but rather the platform progradation above the basin. The true transition is - as in nearly all cases - tectonically truncated since this zone acted as a structurally weak area preferred for south to north-directed detachment and thrusting during Alpidic nappe (de)formation. The Gamsstein Unit presumably maintained the facies transition intact through a specific tectonic deformation event that led to an unusual 90-degree rotation of a small part of the Northern Calcareous Alps known as the Weyrer "Bogen" structure (arc in English) during initial deformation. In this way the platform - basin interfingering took a west-east orientation and was no longer subjected to the more common dismembering during the subsequent main south to north-directed thrusting and shortening phases of the Northern Calcareous Alps. The result of this deformation event is now a peculiar arrangement of tectonically-isolated blocks at the southeastern side of the Weyrer structure, with the Gamsstein sliver as one of them (Fig. 2A). The problems concerning a restoration of the former position of these isolated units are as yet unsolved and the discussions attached to these questions (Tollmann 1964, Steiner 1965) not closed but beyond the scope of the excursion. Only in the case of the former position of the Gamsstein sliver does it appear necessary to point out its allochthonous position in respect to its neighborhood. A facies overview of the Triassic series of the northern Tirolikum and of the

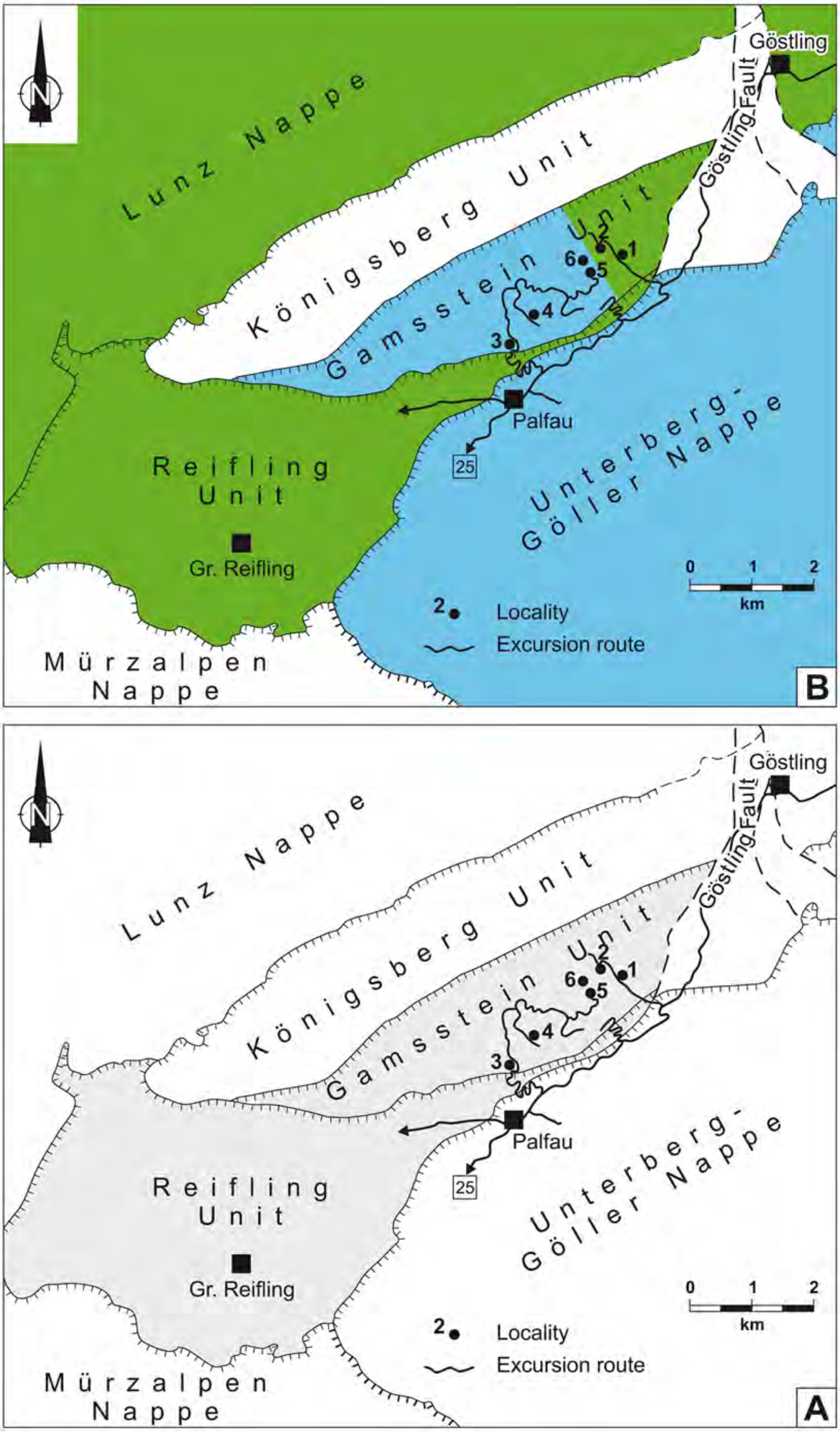


Fig. 2a: Tectonic map of the Gamsstein Unit with the Excursion sites (1-6). 2b: Facies distribution in the late Middle Triassic (green: basinal facies - Reifling Fm., blue: shallow-water platforms - Wetterstein Fm.).

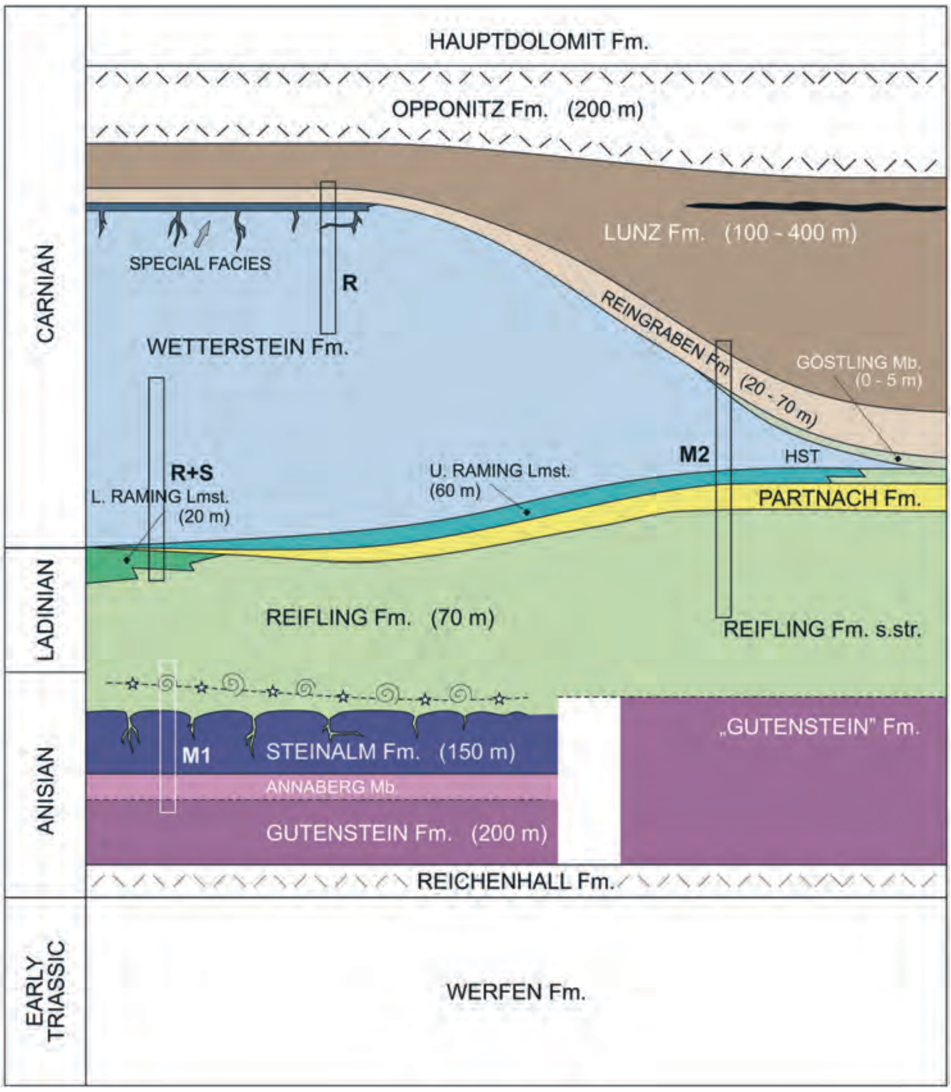


Fig. 3: Lithostratigraphic sequence of the Gamsstein Unit, elaborated in the inserted sections (R+S Raffelgraben- and Scheibenberg Section, R Ruhkogel Section, M1 Mendlingbauer forest road Section, M2 Mendlingbach Section.

Gamsstein Range can be seen in Fig. 2B.

2. Field Trip

2.1. Route

Coming from Schladming we follow Federal Roads 320, 146 and 25 eastward to the small village of Lassing, from where we continue along the Mendlingbach Valley on Rural Road L 6179 for less than 1 km to the north. This road was widened some time ago, exposing excellent and continuous outcrops through most of the Anisian to Carnian sediments developed there.

2.2. Locality 1: Anisian Ramp, Mendlingbach section

The section starts at coordinates 47°45’01,4" N/ 14°52’40,5" E and exposes steeply eastward-dipping, thick-bedded limestone of variously shallow, quiet to turbulent water conditions. Later the inclination of this sequence turns to WNW.

The thick-bedded rocks of these two series, which are developed throughout the entire area of the Gamsstein-Scheibenberg Unit at its base in the same facies and thickness as in the Mendlingbach section, act together as a mechanically stiff plate, which considerably limited the possible effects of internal deformation of this unit.

2.2.1 Gutenstein Fm.

The outcrop of Gutenstein Fm. on the southern side of the Gamsstein Unit, its oldest component and the one closest to the valley, forms over a large distance the boundary to the Reifling Unit, the tectonic unit located immediately to the south. The geometry of this tectonic lineament, which separates two units of considerable facies difference (Fig 2b), is an indicator for its nature as a steeply-dipping fault with signs (?) of lateral movement.

The proximity to this fault also appears to be the reason for considerable deformation of the bounding limestone of the Gutenstein Fm., including partial absence of strata. The original thickness of this sedimentary unit cannot be determined at this locality. The best outcrops are along the road crossing the Mendlingbach stream, where the hanging wall section of the series is especially well exposed. The lithology of the rocks encountered there, however, does not represent the ideal type of this series on account of its lighter color and thicker bedding.

2.2.2. Annaberg Mb.

(70 m)

The onset of the Annaberg Mb. over the thin-bedded, dark limestone of the Gutenstein Fm. is not a sharp one, but instead includes a transitional zone varying in thickness between a few meters to tens of meters. Along with the macroscopic markers identified by Tollmann (1966) (thick bedding and color), the following microfacies details must be noted: Embedded in the largely sterile micrite and pelsparite of the Gutenstein Limestone resulting from the compaction of pellet mud, one now notes an increase of allochthonous detrital layers, the components of which originated in the higher-energy shallow-water (Plate 1, Fig. 3). The absence of bioturbation in this level, thanks to which the mentioned stratification was not destroyed, could be the result either of increased sedimentation rates or of very early lithification. A further characteristic is the sudden mass appearance of echinoderm detritus in the bedded limestone of the Annaberg Mb. Fragments of (usually indeterminate) dasycladaceans also appear for the first time in this part of the section. On the other hand the typical pellet mud facies so typical for the Gutenstein Fm. can occur in bedded fashion in the higher parts of the Annaberg Mb., as can beds, which were often noted and named “Wurstelkalk“, or “calcaires vermiculés“ (Baud 1976) because of their strange appearance due to the accumulation of trace fossils.

These facially aberrational intercalations are often accompanied by ochre-colored siltstones. In summary the Annaberg Mb. presents a picture of a beginning change of the depositional environment to one where highs and lows are beginning to be shaped. Fossils are rare; only some foraminifers of minor stratigraphic value are present (such as *Meandrospira dinarica*; Plate 2, Fig. 7). Due to the absence of time-diagnostic fossils correlations to other sections are problematic.

See also: Excursus concerning the lithostratigraphic nomenclature of the Anisian.

2.2.3. Steinalm Fm.

(110 m)

The overlying Steinalm Limestone is largely developed as a foraminiferal-dasycladacean grainstone (SMF-Type 18) (Plate 2, Fig. 2-5). In contrast to the underlying Annaberg Limestone there is a notably higher diversity of faunal and floral communities. This is considered to be the result of improved water circulation linked to a deepening of the depositional environment.

At road km 1.8 the Steinalm Limestone is overlain by Reifling Limestone. The often discussed question concerning the cause of the termination of the Steinalm Limestone Platform, or whether the drowning was preceded by an interruption caused by emersion, cannot be answered with certainty here. In any case there are no indications of karsting and subaerial diagenesis in the uppermost meters of the Steinalm Limestone. In its uppermost decimeters (Plate 2, Fig. 7) there is a noticeable step-wise decrease in water current energy indicated by a corresponding decrease in grain size. The overlying Reifling Limestone follows with a sharp boundary at an omission surface, which is perforated by numerous glauconite-filled microborings. In addition there occurred an early geopetal filling of the partially still open pore space of the Steinalm Limestone with calcareous mud of the Reifling sediments. The dasycladaceans located in the uppermost centimeters were silicified as a result of the effects of silica-rich pore fluids. The emplacement of the Steinalm Limestone in the Pelsonian is based upon a characteristic algal flora with *Physoporella pauciforata*, *Macroporella sp.* and *Oligoporella pilosa* as well as the occurrence of *Paragondolella bifurcata* in the basal Reifling Limestone. The sharp boundary, without any transition, between the dark dolomite of the Annaberg Mb. below and the light-colored limestone of the overlying Steinalm Fm. is undoubtedly caused by a stratigraphic hiatus. We suspect a sequence boundary at this point (Fig. 13). In the time period represented in the first meters of the section, doubtlessly the most optimal living conditions were present, and a strong seafloor current led to good grain-size sorting, so that the rocks of this part of the section initially consist largely of well-washed algal limestone (Plate 2, Figs. 3, 4, 6). Thereafter a smoothing of the depositional environment followed. In the Raffelgraben section, 4 km away, oncoidal limestone follows. The further development appears to have been cyclically-driven.

Excursus concerning the lithostratigraphic nomenclature of the Anisian

Despite the early establishment of the Gutenstein Limestone as an independent lithostratigraphic unit (Hauer 1853), different, lithologically quite distinct rocks of Middle Triassic age were often lumped together under the collective term of “Alpine Muschelkalk“ (Krauss 1913), presumably to simplify field mapping work. Even in relatively recent maps this unacceptable term can be found (Spengler 1931, Cerny 1983). Pia (1923, 1930) was the first to deliberately break with this practice and to extract from this heretofore usual collective term this light-colored Middle Triassic algal limestone as an independent sedimentary unit (Steinalm Limestone). The term finally introduced by Tollmann (1966) of “Annaberg Limestone“, which was meant to be a transitional unit between the Gutenstein and the Steinalm Limestone, was not accepted for a long time, which may have been due to its largely macroscopic definition. Due to the lateral continuity of this unit, as well as to its definite microfacial differentiation from the limestone of the Gutenstein and the Steinalm Fms. and its mappable thickness, its recognition as an independent lithostratigraphic unit has proved to be justified, either as a member of the Gutenstein Fm. or as a

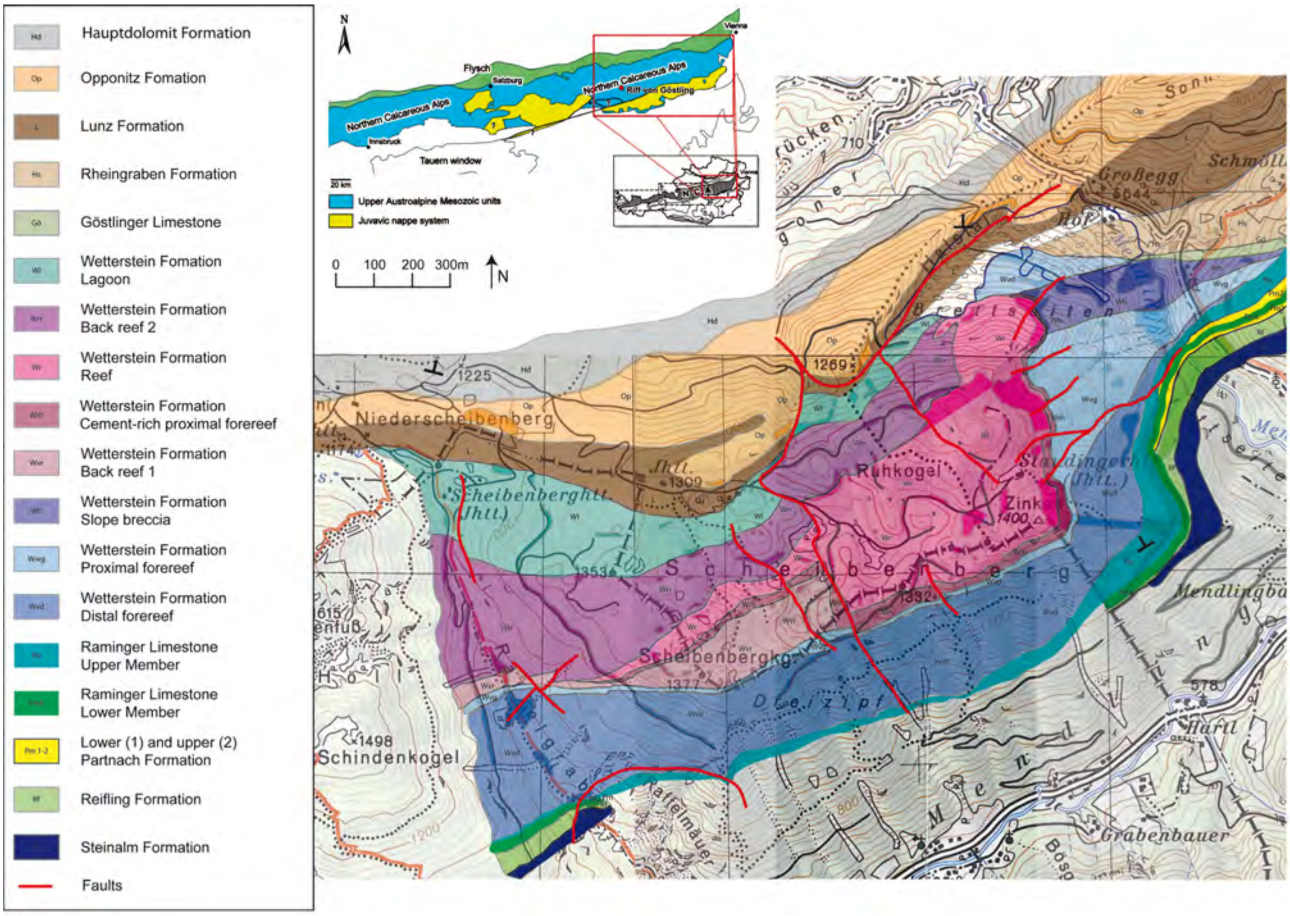


Fig. 4: Geologic map of the eastern part of the Gamsstein/Scheibenberg Unit (between Mendlingbach and Raffelgraben), mapped by Richoz (2009).

formation in its own right (Lein et al. 2010). The temporal span of the Annaberg Limestone is defined by sudden improvement of water circulation over the shelf, which until then had been characterized by stagnating conditions. This change of the sedimentological framework conditions in the shelf is linked to a continuing thinning of the underlying continental crust (Lein 1987), where differential subsidence led to the formation of submarine relief, the boundaries of which were to remain determining throughout the entire Middle Triassic.

2.3. Locality 1: Reifling Basin, Mendlingbach section

This part of the section continues at coordinates 47°45'12,1" N/ 14°52'25,6" E with identically steep dipping; its beginning is easily visible thanks to the thinner bedding of the rocks.

2.3.1. Reifling Fm., Partnach Fm. and Raming Limestone/Upper Mb.

Stop 2 is at the top of the previously described section and begins, as mentioned, immediately above a hardground at the top of the Steinalm Limestone with chert-bearing deposits of deeper water (Lower Reifling Limestone). Knobby-wavy, brown-grey, one decimeter-thick, bedded, chert-bearing nodular limestone alternates with thin, brown, partially silty marl layers. From a microfacies viewpoint we are dealing with bioclastic wackestone, at the base of which brachiopods (*Tetractinella* ?) and echinoderms are noted.
Thickness of the lower Reifling Limestone: 19 m.
Emplacement: Upper Pelsonian based on the occurrence of *Nicorella kockeli* und *Paragondolella bifurcata*.

This is followed by a 4 m-thick **transitional horizon** with thick-bedded clay and chert-free, slightly wavy-bedded limestone with some brachiopods, and an increase in crinoids and ammonites at the top.
Emplacement: Illyrian (*Neogondolella cornuta*, *N. szaboi*, *N. liebermani*). The heavy bioclastic component is an indicator of increased water current energy and possibly of redeposition from shallow marine (sea-level drop ?).

Upper Reifling Limestone: 27 m
Light grey, thin-bedded, partially extremely chert-rich nodular limestone with three, up to 10 cm-thick fine-grained tuffite beds (T1: Base, T2: 12 m above the base, T3: 20 m above the base) and thin, light-green marl layers. The above-mentioned three tuffitic levels are found throughout the entire area of the Calcareous Alps (cf. Gallet et al. 1998, Brühweiler et al. 2007).
Thickness: 27 m (Lower Ladinian: 11 m, Upper Ladinian: 16 m)

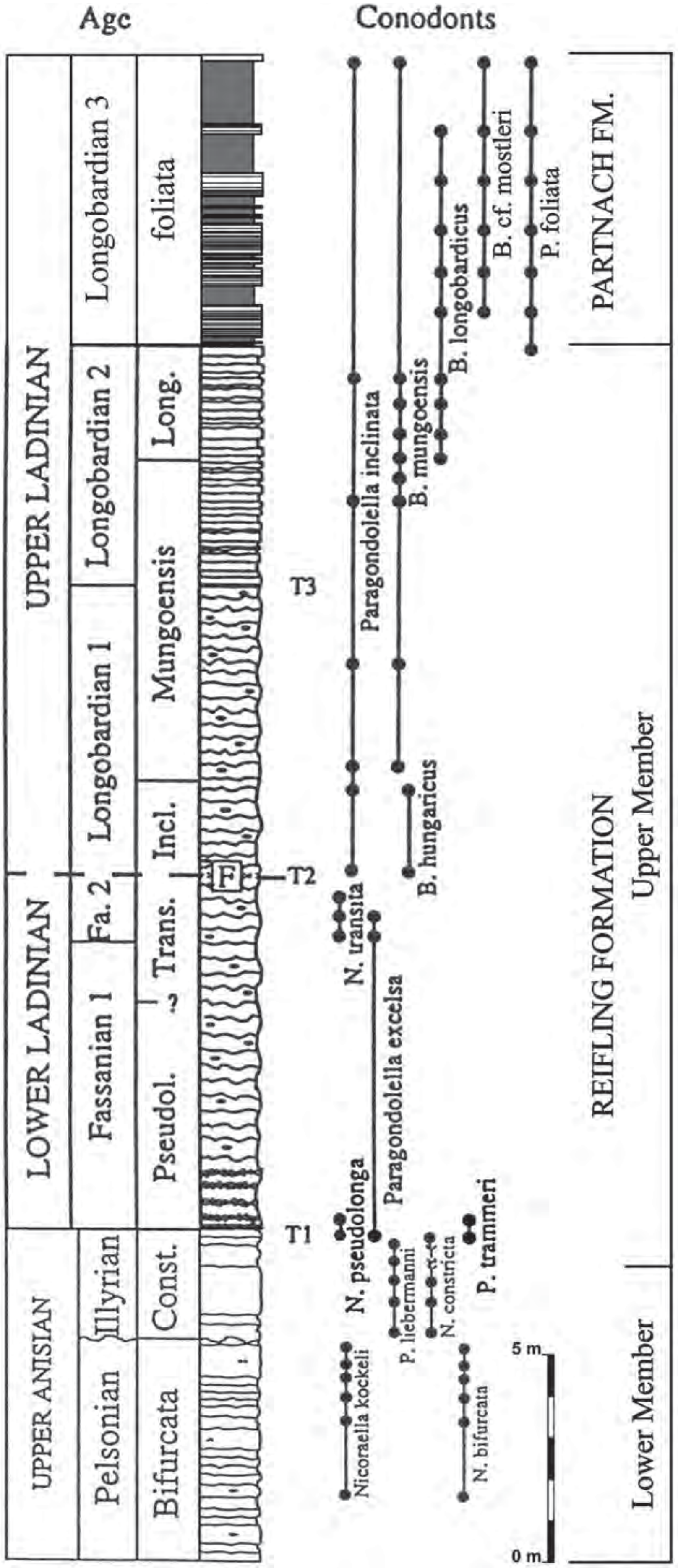


Fig. 5: Lihostratigrohic sequence of the Mendlingbach Section.

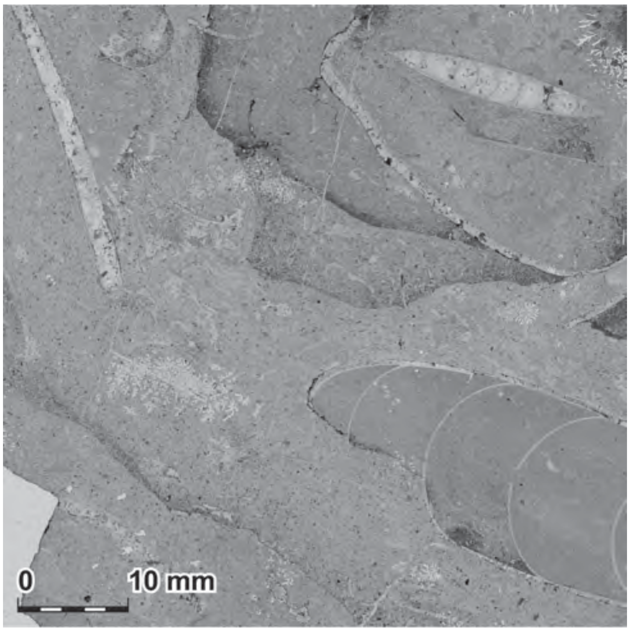


Fig. 6: Condensed section with a rich Ammonite-fauna in the Upper Anisian part of the Reifling Fm.

Emplacement: Lower Ladinian portion with *Paragondolella excelsa*, *P. trammeri* and *Neogondolella transita*.
Upper Ladinian confirmed by *Budurovignathus hungaricus*, *B. mungoensis*, *Paragondolella trammeri*, *Neogondolella praehungarica*.

Platy limestone (= Reifling Limestone / Partnach Beds transition): 8 m
Light grey, evenly bedded, dm-thick limestone layers alternate with grey-brown clay-marl.
Emplacement: higher Upper Ladinian (*Paragondolella inclinata*, *Budurovignathus mungoensis*, *B. longobardicus*, *Metapolygnathus tadpole*).

Partnach Beds: 42 m
They are subdivided into a lower argillitic complex (9 m), a middle (tectonically disturbed) platy limestone (? 20 m), and an upper argillitic complex (at least 10 m). The middle platy limestone is thinly and evenly bedded; microfacies definition: sterile mudstone.
Emplacement: The Ladinian / Carnian boundary, indicated by the beginning occurrence of *Metapolygnathus polygnathiformis* lies in the middle of this part of the section.

Raming Limestone: 60 m
Evenly and thinly-bedded, basal (m 0-6) limestone, locally cherty. It is overlain by thickly-bedded to apparently massive coarse-grained limestone, which contain increasing amounts of shallow-water detritus upsection.

2.3.2 Locality 2: Göstling Mb.
coordinates 47°45’25,5" N/ 14°52’18,5" E.

On the orographically right side of the Mendlingbach a small isolated outcrop with dark grey-colored limy marl is the only indication for the local occurrence of this stratigraphic unit.

2.3.3. Locality 3: Reingraben Fm.
coordinates 47°45’33,2" N/ 14°52’19,5" E

3.1. Route

We return to Federal Road 25 and continue westward to Palfau from where we take a forest road along the Raffelgraben up to the Gamsstein-Scheibenberg Plateau.

3.2. Locality 3: Basin-Platform transition, Raffelgraben section

The Raffelgraben section provided excellent outcrops about 20 years ago when the forest road was constructed. Today only very little is visible of the once perfectly exposed Reifling Fm., which was studied for magnetostratigraphy by Gallet et al. (1992). Better exposures are still provided by the more resistant carbonates of the overlying basin to platform transition at coordinates 47°43’62,3" N/ 14°49’44.8" E, where the lower member of the Raming Limestone and the base of the Wetterstein Fm. are exposed. They are separated by an approx. 10 m-thick covered interval, which forms the westward thinning and finally wedging tongue of the Partnach Fm.

3.2.1. Raming Limestone

The Raming Limestone interfingers with and progrades over the wavy to nodular, thin-bedded wackestone of the Reifling Fm., reaching a thickness of about 20 m. It consists of 2-4 dm of evenly bedded, light-colored limestone grouped into meter-thick packages of upward-thickening cycles. Bioturbated packstone and skeletal grainstone (Plate 4: Fig. 8) are common, the later containing fragments of thin shelled bivalves and lithoclasts and interpreted as proximal turbidites.

3.2.2. Wetterstein Fm.

The basal part of the Wetterstein Fm. is massive and lacks coarse reefal debris. It represents foreslope deposits of a rapidly prograding platform and is characterized by a uniform grainstone texture of platform-derived material.

4.1. Route

We continue along the forest road to the north and after crossing the Raffelgraben turn back southward along the eastern margin of the depression to the end of the road.

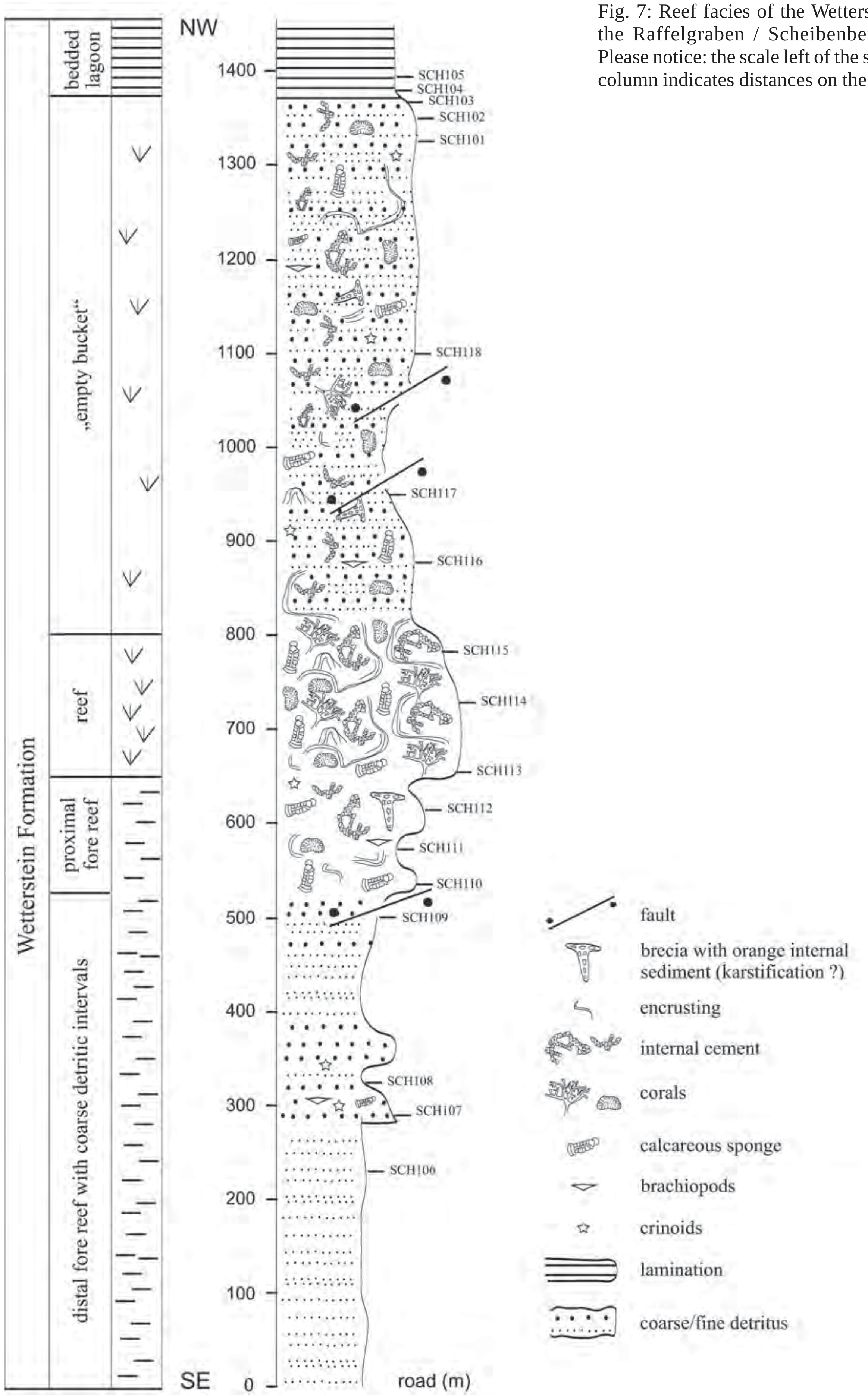


Fig. 7: Reef facies of the Wetterstein Fm. in the Raffelgraben / Scheibenberg Section. Please notice: the scale left of the stratigraphic column indicates distances on the forest road.

Fig. 8: The thick bedded calciturbidites of the Upper Raming Mb.

4.2. Locality 4: Wetterstein Fm., Scheibenberg section

At the end of the road (47°44’03,3" N/ 14°49,88,7" E) begins a nearly 800 m-thick massive Wetterstein sequence with foreslope facies and a thin reef rim followed by a rather thick, finer-grained, unusual lagoonal (?) facies with local isolated patch reefs or reefal debris accumulations (Fig. 7).

4.2.1. Lagoonal reef (“empty bucket“)

The absence of bedding and sedimentary structures indicating shallow-water deposition as well as the presence of reefal associations in growth position point to a comparatively deep and quiet depositional environment. The great thickness of 400 m with constant facies further indicates stable sedimentary conditions in the Gamsstein through early Carnian time. The area could not keep up with the high subsidence rate (approx. 5 cm/Kyr) and was thus unable to approach sea-level or rise above it, despite being located behind the main reef front in a classical lagoonal platform position. Instead, the early Wetterstein lagoon at Scheibenberg always remained in the subtidal zone and in an aggrading system that mirrors well the “empty bucket“ process as described by Schlager (2005).

5.1. Route

From Scheibenberg we continue on a forest road eastward along the plateau toward the Ruhkogel.

5.2. Locality 5: Wetterstein Fm, Ruhkogel area

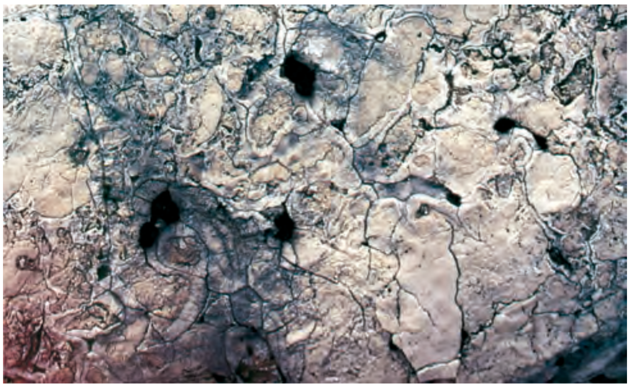
Around the Ruhkogel there are numerous outcrops rich in reefal organisms overlain to the north by a well-bedded lagoonal facies.

5.2.1. Central reef
(coordinates 47°44’80,3" N/ 14°51’50,9" E)

Central reef with great amounts of pore-space cement and highly diverse framework-builder fauna (calcareous sponges predominate, along with large coral assemblages). Of note among others are pore-spaces filled with brown crystalline siltite. It is overlain in a northwesterly direction by the lagoon, primarily made up of well-bedded dasycladacean grainstone. Intercalations of levels in grapestone facies indicate periods of change in terms of water circulation and current energy.

5.2.2. “Special Facies“
coordinates 47°44’80,3" N/ 14°51’50,9" E

Outcrops in the upper course of the Schottgraben, near the Gamsstein Hut (= 2 km SW Niederscheibenberg). The



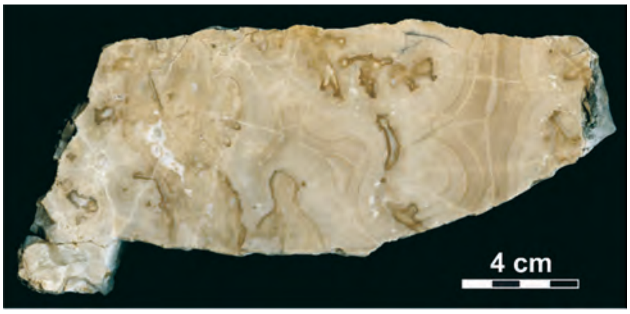


Fig. 9, Fig. 10: Great parts of the central reef area of the Wetterstein Platfom are mainly built up by calcite cements, whereas reef building organisms are rare.

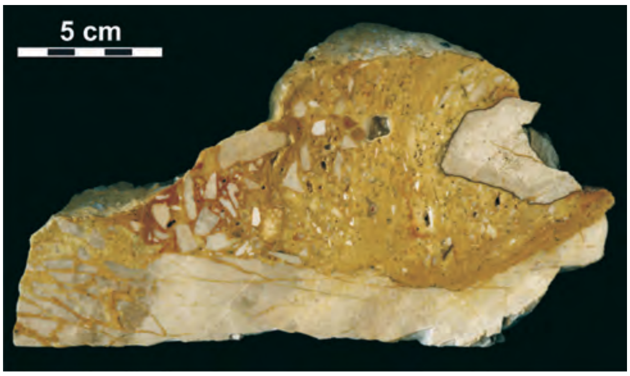


Fig. 11: Fissures in the uppermost part of the Wetterstein Fm. filled with bad sorted stained rubble of ochre color.

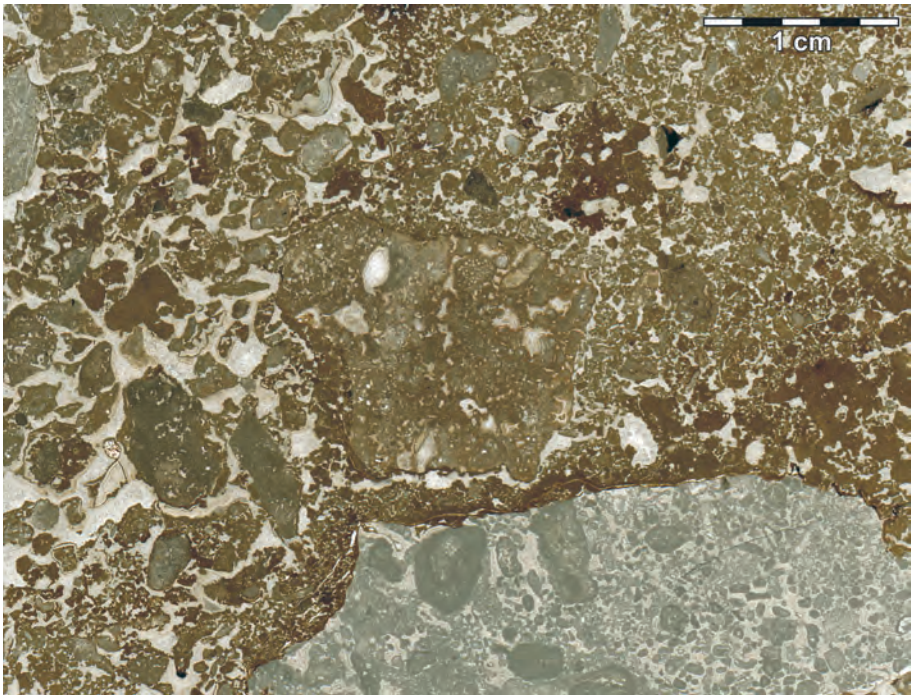


Fig. 12: Sedimentary breccia of the "Special Facies". This sedimentary unit, which partly covers the surface of the atroph Wetterstein Platform, is composed of mostly brownish clasts which were derived from weathering and karstification processes.

contact between the uppermost beds of the Wetterstein Fm. and the overlying Reingraben Fm. is only directly observable in a few locations. Generally this part of the sequence appears to have been erosionally removed at an early date. The first thing to notice is that in the uppermost beds of the Wetterstein Fm., resedimented material is present, in the form of black pebbles (Plate 3/Figs. 2-4).

Notes concerning the term "Special Development of the Uppermost Wetterstein Limestone"

In 1954 several authors (SCHNEIDER, TAUPITZ, MAUCHER) described a series only tens of meters thick at most from the Bavarian Calcareous Alps, below the North Alpine Raibl Beds, the synsedimentary mineralizations of which had in the past been several times the object of short-lived attempts at exploitation.

The erroneous classification of this sequence within the Wetterstein Fm., despite obvious lithological differences, was based exclusively on its position beneath the first terrigenous horizons of the North Alpine Raibl Beds. In reality this series, separated from the underlying Wetterstein Fm. by a sequence boundary, should be considered as an independent unit. The Fe mineralizations of the series are often tied to breccia horizons, the components of which are cemented together with limonite. The target of earlier mining activities were primarily crude ore crusts, which originated as layers on hardgrounds on the back of the Wetterstein Fm., as well as limonitic fill of karstified cavities within it. WEBER et al. (1998) have classified these ore occurrences, initially only known from the western part of the Northern Calcareous Alps, as belonging to the Ausserfern (Reutte) district. The genetically identical formation of limonitic ores along the edge of the Lunz Nappe in the area of the Dirn Anticline may be considered to be the eastward extension of this ore district; these ores were exploited for a long time at the Arzberg near Reichraming and in the Wendbach Graben (FREH 1949).

6. Evolution of the two platforms

6.1. Steinalm ramp

The rapid environmental change on a restricted circulation shelf (= Standard Microfacies Zone 8) during early Anisian times (Gutenstein Fm.) from anaerobic or dysaerobic conditions to a better oxygen supply due to an improvement of the circulation pattern on the shelf is well documented by a rapid increase of carbonate production and faunal diversity at the begin of deposition of the Annaberg Member (leading to the naming of the "Annaberg Event"; LEIN et al. 2010). From that time onward progressive crustal thinning of the continental crust below the shelf, together with differential subsidence, were responsible for the forming process of an accentuated submarine relief and therefore the major control on deposition.

6.2. Wetterstein Platform

6.2.1. Depositional history and architecture of the Wetterstein Platform

The westerly tectonic truncation of the Gamsstein unit (see Fig. 1B) does not allow studying the initiation and early sedimentary history of the Wetterstein platform. Compared to other areas of the Northern Calcareous Alps (f.i. the Zugspitze), Western Carpathians (Aggtelek; VELLDITS et al. 2011) or Southern Alps (f.i. Rosengarten - MAURER 2000), the growth of the Gamsstein Platform may have begun in the latest Anisian over the widespread, low-relief Middle Anisian Steinalm ramp, after a considerable depositional break. Following a supposedly initial aggrading platform phase - again in comparison with the Rosengarten - the first and still indirect proof for the platform, recorded in the deposition of the lower Raming Limestone, is mirrored in a rapid progradation phase over several kilometers in Gamsstein during the middle Late Ladinian. Afterward the platform retreated or, more probably, this first platform growth cycle was terminated and interrupted for 1-2 Myr during deposition of the terrigenous Partnach Formation, because 1) Partnach marl and Wetterstein limestone do not interfinger and 2) no reefal or platform debris was shed onto the slope and basin during that time interval. Interestingly, no indication of a break and/or subaerial exposure or erosion has been found in the platform interior, though it might be expected from the margin to basin record and the interpreted sequence boundary. The record of the Gamsstein Platform s.s. already begins above the Partnach interval, first with a short but rapid progradation phase of the upper Raming Limestone, followed by a rapidly upward-growing aggradational platform with a stationary, wide and boundstone-rich reefal rim. The extraordinarily rapid sea-level rise outpaced carbonate accumulation in the attached lagoon, leading to continuous subtidal "empty-bucket" conditions there of relatively fine-grained, unbedded sediment with local but widespread patch reefs. When subsidence began to cease, vertical platform growth changed to lateral and the reef prograded to the east. Later on, outstepping and/or oversteepening parts of the margin collapsed to produce a thick downslope-transported megabreccia sheet. The contemporaneously shallowing lagoon began a cyclic stacking pattern with common emersion, punctuated by thin subaerial exposure layers ("special facies"). Finally the combined subsidence halt and sea-level drop led to a complete exposure of the platform and a deep-reaching karstification of the reef rim, as well as pervasive vadose cementation and dolomitization of the platform top interior. Carbonate sedimentation retreated to the toe-of-slope, where a thin pavement of reworked micro-debris carrying turbiditic limestone (Göstling Mb.) was deposited as a lowstand wedge.

6.2.2. Drowning

An interpretation of what occurred between the termination of carbonate production of the Wetterstein Platform and the beginning of siliciclastic sedimentation of the Lunz Fm., must take the following facts into consideration:
Already in the uppermost meters of section of lagoonal Wetterstein Limestone, temporary desiccation, vadose cementation of pore space and the formation of pisolitic crusts occurred (Plate 3, Figs. 4, 5).
The termination of carbonate production along with unchanged subsidence rates led to sinking and flooding of formerly tidal zones. Crusts were formed on hardgrounds, which stored Fe and Mn minerals.
The formation and expansion of (?submarine) fissures, as well as their filling with eroded detritus from the platform. The composition of this fill includes (unaltered) lagoonal Wetterstein Limestone as well as material which has been slightly colored by iron-bearing solutions (with different microfacies, Fig. 12).
Finally, in the subtidal zone, just beneath the wave base, dark limestone rich in bioclasts was deposited (this bathymetric assumption is underpinned by an increased presence of crinoid stem material). However, shortly thereafter the limestone, which has been exposed again, is subjected to soil formation and infiltration of organic material via a root system which has forced its way into the not yet lithified carbonate sediment (Plate 6, Figs. 1-7). This could also have occurred in an intertidal zone covered with mangroves.
The deposition of the terrigenous sediments of the Reingraben Fm. occurred in a zone already entirely in the marine environment, as documented by the presence of ammonites and halobiid bivalves.
Only thereafter emersion of large portions of the shelf occurred again, together with the input of fluviatile sediments.
The sequence of events presented above indicates high-frequency sea-level changes, with amplitudes in excess of 30 m.

7. Anisian to Carnian Sequence Stratigraphy at the Gamsstein

Unlike the well-studied Southern Alps, sequence stratigraphic interpretations of the North Alpine Triassic are rare and still of a preliminary character. Rüffer & Bechstädt (1998, Fig. 2) distinguished for the Anisian - within the time interval of the Steinalm Ramp - five depositional sequences, the last of which is already Ladinian in age. Of the other four sequences, only the fourth one is sedimentologically and stratigraphically clearly defined, whereas the A1 to A3 sequences are tagged by the authors with question marks or - in the case of A5 - "have been interpolated" (Rüffer & Bechstädt (1998: 754). Overall their division strikingly mirrors the South Alpine Anisian sequence chart of De Zanche et al. (1993; 1998) and may be considered a copy of it. For Ladinian through Carnian time (in which the Wetterstein platform was formed) two highly differing 3rd order divisions have been proposed: of these the five 3rd-order sequences ((L1-L4, C1 - respectively 6 if including A5) of Rüffer & Bechstädt (1998) contrast sharply with only two discriminated by Hornung et al. (2007). Proof of this high number of cycles is obviously meager and based more on assumptions than on real observations (Rüffer & Bechstädt 1998: 754). Rüffer & Bechstädt 's (1998) Ladinian subdivision may again have been influenced by the South Alpine situation, where specific phenomena such as local transpression and massive volcanism created an abnormally high sequence amplitude (De Zanche et al. 1993, Gianolla et al. 1998). At the Gamsstein we distinguish, from Anisian to Carnian, a total of eight depositional sequences (3 Anisian, 2 Ladinian and 3 Carnian), close to half of those identified by Rüffer & Bechstädt (1998).
An exact understanding and correlation of sequences in surface exposures is only possible if undisturbed platform

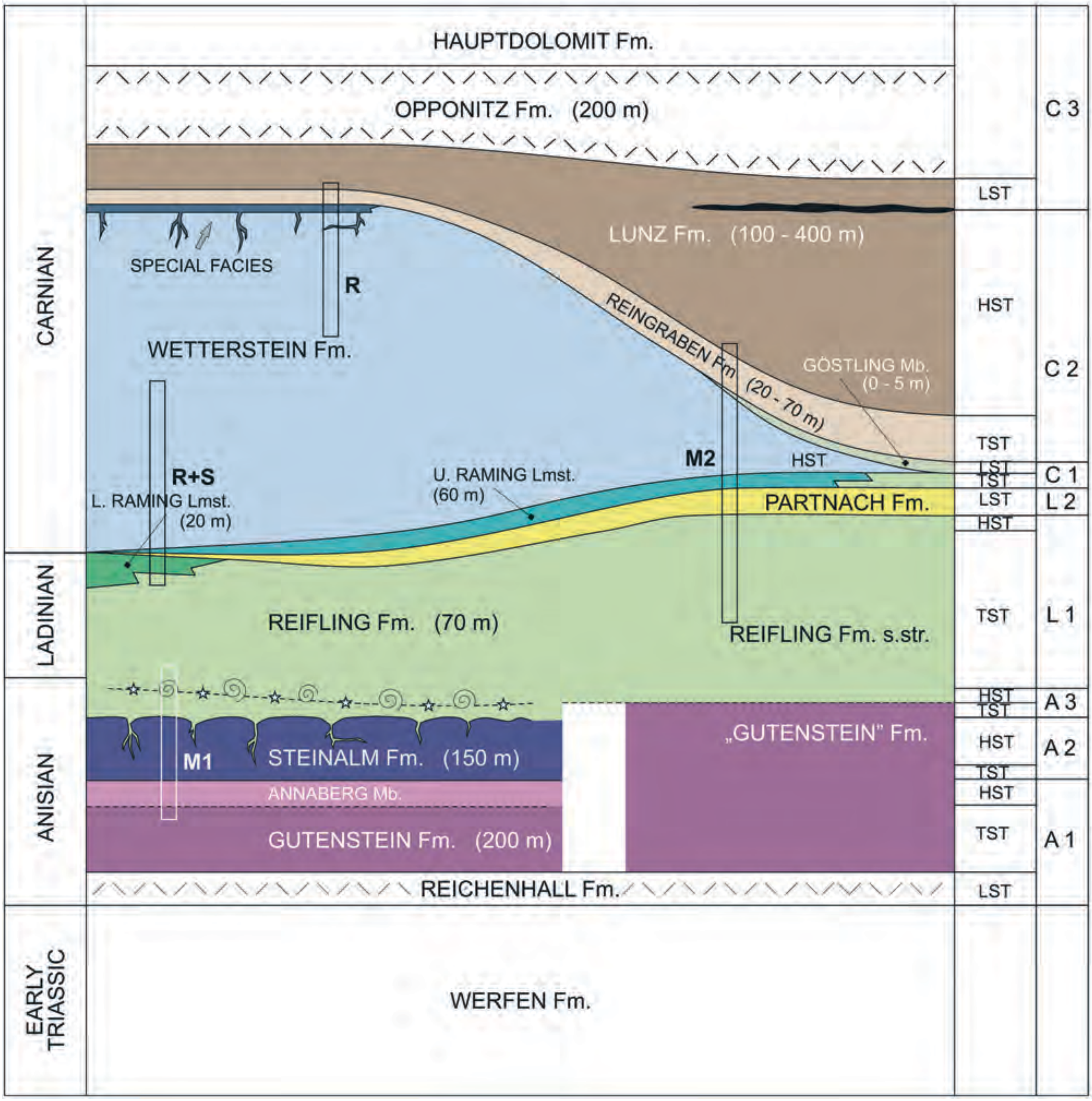


Fig. 13: Sequence stratigaphic interpretation of the sedimentary succession of the Gamsstein Unit.

to basin transitions can be studied. In the Northern Calcareous Alps this is almost never the case because of the intensive N-S directed narrowing and nappe formation, the early initiation of which often occurred at facies boundaries. The Gamsstein unit is an exception because here, due to an early, paleomagnetically-documented rotation (GALLET et al. 1998), the interfingering between the Wetterstein Limestone Platform and the Reifling Basin swung to a W-E direction. That is the reason why the platform-basin transition escaped disintegration during subsequent N-S narrowing and is intact till today. Of equal advantage is the steep northward dip of the sequence, thanks to which the original relief of the platform and its edge were exposed but without a complete erosion of the terrigenous cover (Reingraben and Lunz Fms.). Thus interfingering between basin and platform sediments can be directly observed, especially the geometries of sedimentary bodies within the transition zone from slope or toe-of-slope to the basin. This allows a much clearer identification of low-stand wedges and their respective system tracts and sequence boundaries. Above all time levels can be correlated between the basin and the platform, permitting the more detailed temporal determination of sedimentation and subsidence rates.

The A1 sequence begins with a mixed siliciclastic-evaporitic carbonate environment (Reichenhall Fm.) with local accumulations of gypsum up to tens of meters thick. This interval is interpreted as a lowstand tract and is possibly of latest Spathian (Olenekian) age but tectonically absent from the Gamsstein unit. The thin-bedded, micritic and detritus-free Gutenstein Fm. constitutes the transgressive system tract and the thick-bedded, bioclastic to lithoclastic Annaberg Mb. makes up the highstand system tract. A Type 1 sequence boundary leads to the A2 sequence made up of the Steinalm Fm., the lowest part of which contains biogenic wackestone with crinoids and thin-shelled bivalves of an open ramp facies, representing a short transgressive system tract. Upward thickening and coarsening of the beds containing layered debris of shallow-water skeletal grains mixed with lagoonal material (oncoids) characterizes the highstand system tract of the Steinalm Fm., the top of which is bounded by a regional unconformity. The top Steinalm unconformity can be traced throughout the Gamsstein and beyond in many areas of the Northern Calcareous Alps. At Gamsstein it marks the sudden onset of the basinal facies of the Reifling Formation, whereas other and probably more outboard-located Steinalm ramp areas show a supplemental crinoidal limestone interval, rich in brachiopods, of a more complete drowning succession. This significant and widespread sea-level change has been recognized by SCHLAGER & SCHÖLLNBERGER (1974) and is called the "Reiflinger Wende" (or Reifling Event in English). An indication of subaerial exposure of the Steinalm top is the thin net-like silicification reaching 10-20 cm downward from the corroded hardground. Sequence A3 corresponds to the lower member of the Reifling Formation. Its transgressive system tract consists of biogenic wackestone with a large amount of siliceous sponge spicules, which changes to a massive, thick-bedded and fossiliferous interval made of echinoderm-rich bioclastic packstone, which despite the slight thickness is thought to represent a highstand phase. This shallowing phase is well known from many sections in the Reifling Basin and easily detectable by the mass occurrence of glauconite-filled microfossils in thin section.

Ladinian to Early Carnian depositional sequences correspond to the growth phase of the Wetterstein platform and its coeval basinal sediments of the Reifling and Partnach Formations. Chert-rich filament packstone to wackestone characterize the transgressive system tract of the L1 sequence, which ends with a distinct maximum flooding surface developed in a thin red, condensed, limy lithofacies ("Schusterberg Limestone" auct.). Though the coeval platform is tectonically truncated and not preserved in the Gamsstein unit we assume platform aggradation during that time interval, as is described in the Southern Alps (MAURER 2000). With the onset of allodapic dumping (Raming Limestone, lower member) in the middle Upper Ladinian (Fig. 13) the first progradation phase and the highstand system tract of the L1 sequence begin. The interpretation of the predominantly terrigenous Partnach sediments as a lowstand system tract is somewhat ambiguous. Obviously the Partnach Fm. cannot interfinger with the Wetterstein Platform at Gamsstein since it thins out toward the platform margin and has already disappeared well before the platform top. Observation of the stratal and thereby genetic independence and the absence of coarser platform or reefal debris within the Partnach Fm. are good reasons to support a lowstand interpretation. One problem with our lowstand interpretation may be seen in its duration, which should lead to at least local subaerial emersion and a Type 1 sequence boundary in the platform. However, this remarkable Late Ladinian and earliest Carnian (Cordevolian) sedimentary break has until now not been detected in any of the widespread Wetterstein lagoons of the western Northern Calcareous Alps. RÜFFER & BECHSTÄDT (1998, Fig. 5) propose an alternative concept for the Partnach interval by including it in their L4 highstand and C1 lowstand to transgressive system tract, without, however, a convincing explanation.

The transgressive system tract of the C1 sequence begins in the platform in an immediately near-basin position with Wetterstein Limestone that integrates with the basin, with a short interval of filament-dominated wackestone to packstone; it is overlain by detritus-rich packstone to grainstone of the upper member of the Raming Limestone. A sudden progradation phase of the Wetterstein Fm. marks the onset of the highstand system tract of the C1 sequence. An extraordinary subsidence rate (~50 m per 100 kyr) leads to an aggradational system with a wide and vertically fast-growing, stable reefal rim, whereas the attached lagoon becomes buried due to reduced productivity by deep subtidal fine-grained sediment and dispersed small patch reefs - exemplifying the empty bucket concept (e.g. SCHLAGER 2005). The slowing sea-level rise during the late highstand phase leads to a final platform progradation and is paralleled by the development of a cyclically-bedded lagoon with common emersion phases ("special facies") immediately behind the reefal rim, accompanied by a cyclically-bedded lagoon with local emersion phases directly behind the back reef area. The end of the Wetterstein Limestone Platform is indicated by a development of a shelf margin wedge (LST, C1 sequence) on the lower slope and in the basin close to the reef in the form of the Göstling Beds. The sea-level drop finally led to the emersion and deeply effective karstification of the platform edge at Gamsstein (sequence boundary Type 1). This sea level drop is also known from numerous other locations of the Northern Calcareous Alps and correlates with the uplift phase of LEUCHS & MOSEBACH (1936), erroneously interpreted as "Late Ladinian". Renewed sea-level rise, within, however, humid conditions (Carnian Pluvial phase), led to the burial of both platform and basin floor by terrigenous sediments of the Reingraben Fm. during the transgressive system tract of the C2 sequence, followed by more proximal coarse clastic sediments of the Lunz Fm., delineating the highstand system tract of the C2 sequence. The onset of the probably Tethys-wide recorded Carnian Pluvial phase has been called the "Reingrabener Wende" (now Reingraben Event) by SCHLAGER & SCHÖLLNBERGER (1974).

Concluding remarks

In contrast to all other platform/basin transitions Mt. Gamsstein provides an exact stratigraphic dataset forming the base for all further interpretations.

The Wetterstein Carbonate Platform consists in fact of two independent platforms separated in the stratigraphic niveau of the Parnach Formation.

Typical reef builders are scarce, huge parts of the platform are made of “cement crust reefs“. The reason for that bloom of cement crusts is unexplored.

The reasons for the demise/drowning of this platform stage in the northwestern Tethyan realm are relatively unexplored. The complex pattern of the “Reingraben event“ are not fully understtod untill today.

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Plate 1: Steinalm Fm. (Fig. 1-2, 4-8) and Annaberg Mb.

Page 488, (Fig. 3)

Mendlingbach section

Fig. 1, 2: Steinalm Fm. (base) (sample A 4821), bioclastic wackestone with fragments of dasycladaceans, bivalves, ostracods and bryozoans.

Fig. 3: Annaberg Mb. (sample A 4813A/2), cyclic layering of pelsparitic grainstone to packstone (autochthonous) with lithoclastic layers. The sharp boundary between both lithologies is due to early lithification.

Fig. 4: Steinalm Fm. (sample A 4823), lithoclastic grainstone with large reworked clasts.

Fig. 5: Steinalm Fm. (sample A 4825), bioclastic grainstone to wackestone with ostracods, dasycladaceans and ecrystallized frame-building organisms.

Fig. 6, 8: Steinalm Fm. (20 cm below the top) (sample A 4716), bioclastic and lithoclastic grainstone with foraminifera, crinoids and bivalves, and resedimentated lithoclasts (black pebbles).

Fig. 7: Steinalm Fm. (2 m below top) (sample A 4715/1, at road km 1.8), bioclastic and lithoclastic grainstone.

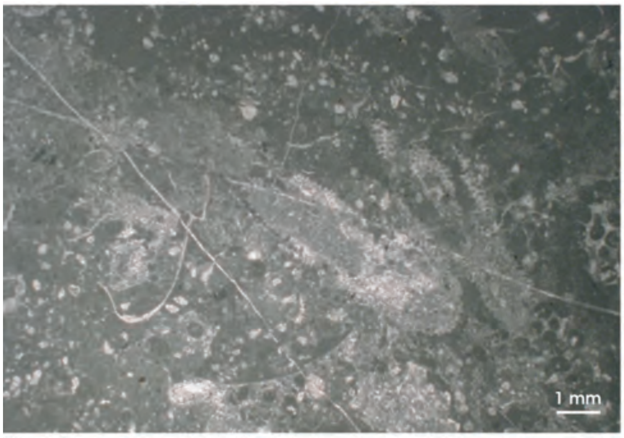


Fig. 1

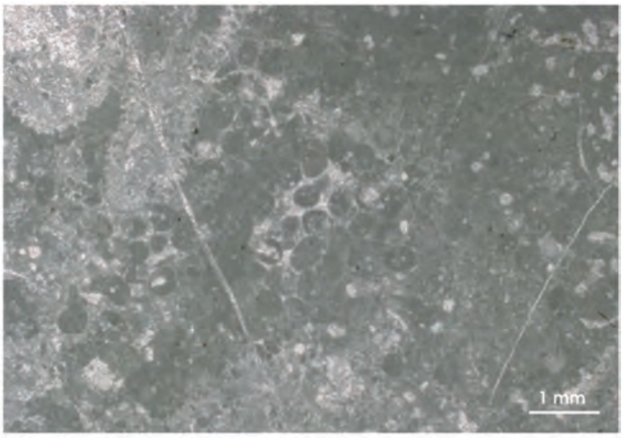
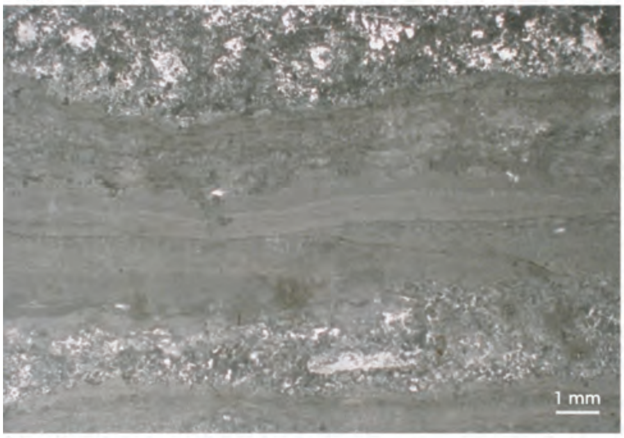


Fig. 2



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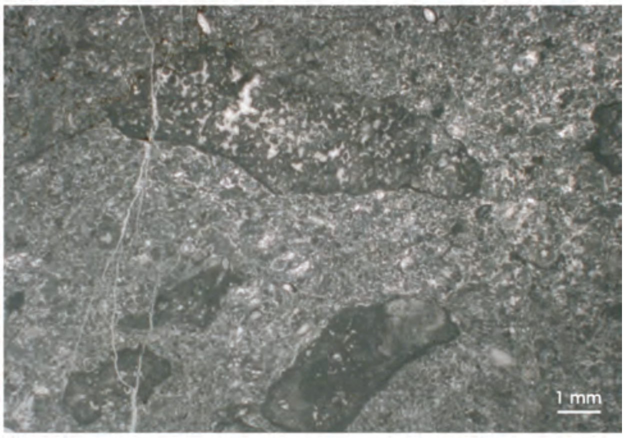

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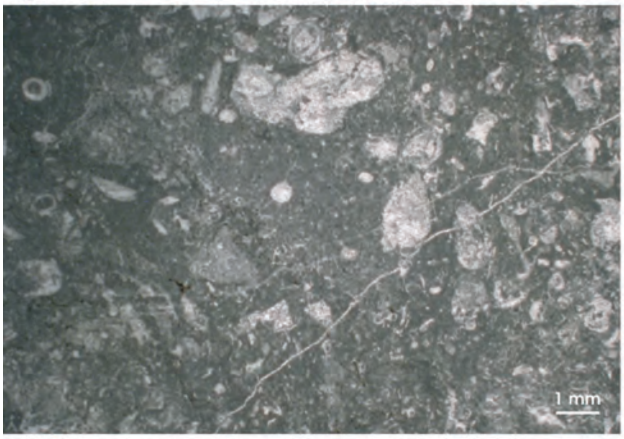

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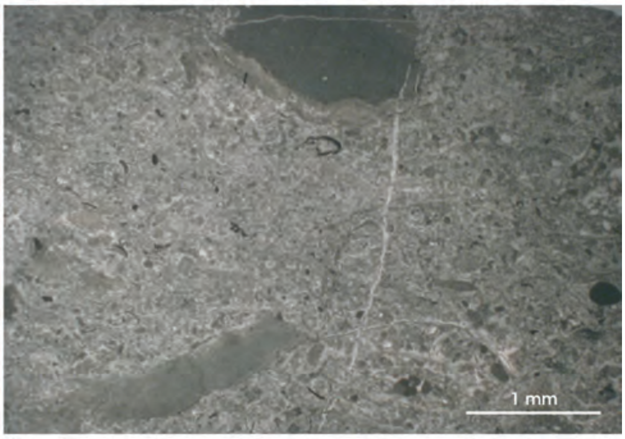

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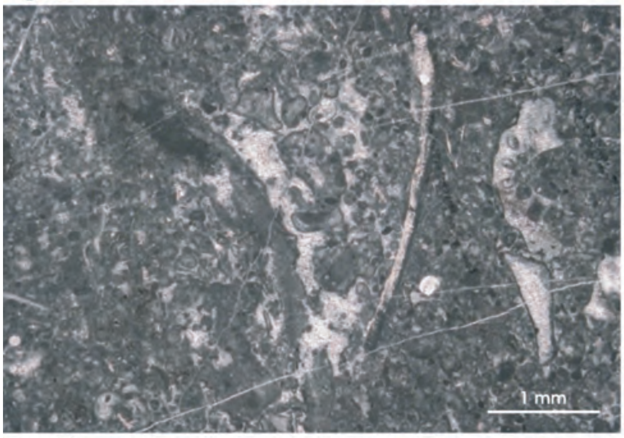


Fig. 7

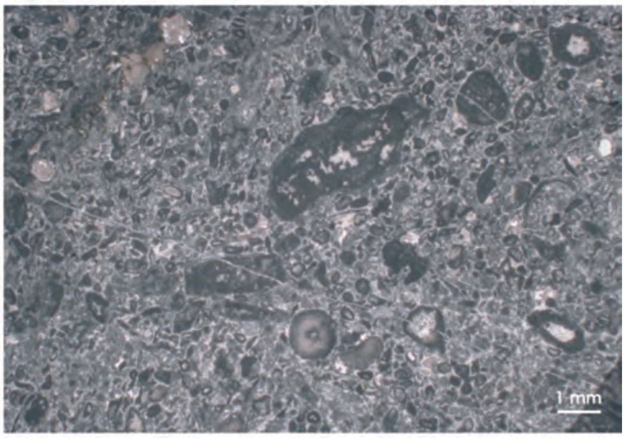


Fig. 8

Plate 2: Annaberg Mb. (Fig. 1, 2, 6) and Steinalm Fm.

Pge 490, (Fig. 3-5, 7-8)

Annaberg Mb. (Fig 1, 2, 6), Mendligbach section
Fig. 1: Reworked spongiostromata crusts embedded in a micritic matrix, sample A 4813.
Fig. 2: Pelletoidal packstone, sample A 4816.
Fig. 3: Bioclastic grainstone with Meandrospira dinarica, sample A 4824.

Steinalm Fm. (Fig. 3-5, 7), Mendlingbach section
Fig. 3, 4: Bioclastic grainstone with foraminifera (*Earlaninita* sp., „*Trochammina*“ sp.), gastropods and rounded lithoclasts (black grains), sample A 4824.

Fig. 5: Bioclastic grainstone with *Glomospirella* sp.and ostracods, sample A 4823

Fig. 7: Sedimentary contact between the top of the Steinalm Fm. and the Reifling Fm. above it. The sharp boundary between both sedimentary units indicates a long-lasting sedimentary break, sample A 4715.

Wetterstein Fm. (Lagoon)
Fig.8 : Brecciated pale-colored oncoidal grainstone, derived from the topmost part of the Wetterstein Fm., bound together by a dark-colored limestone of similar lithology and microfacies.

Further thin sections from the same locality see Plate 3, Figs. 1-5.

Fig. 1

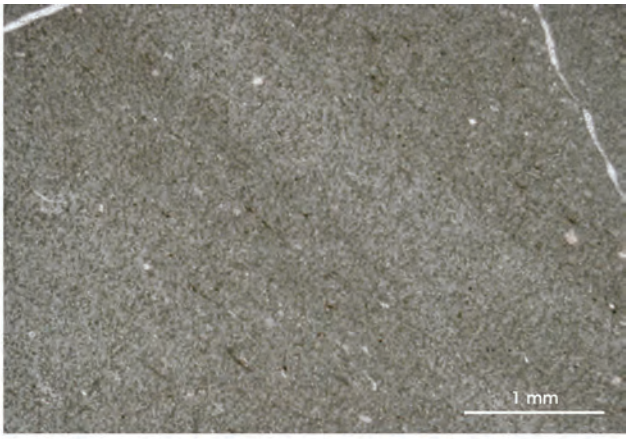
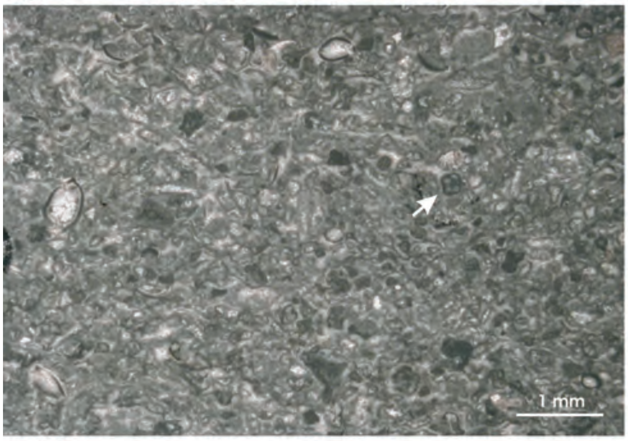


Fig. 2



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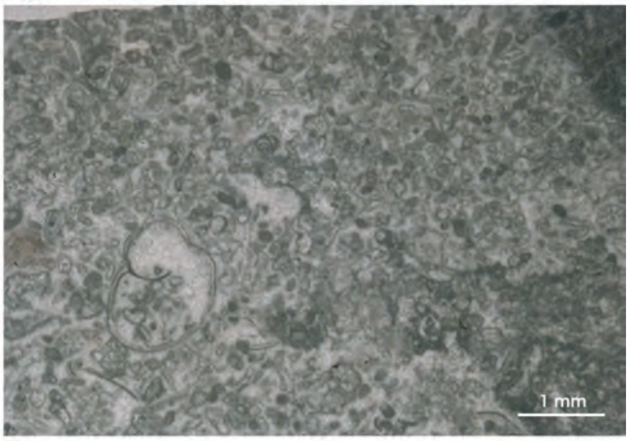

Fig. 4

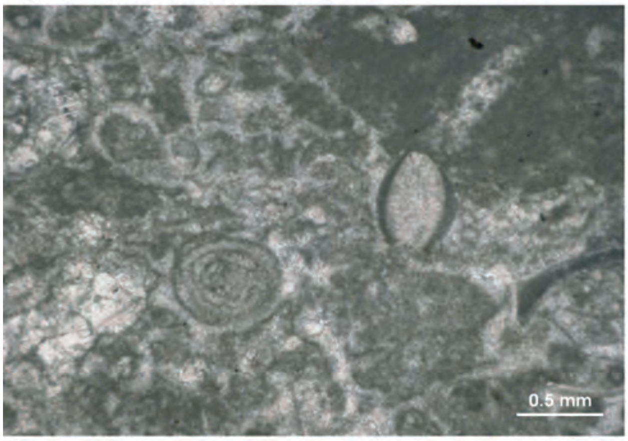

Fig. 5

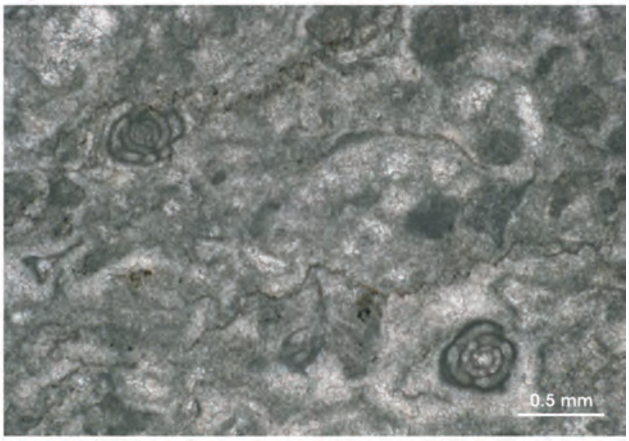

Fig. 6

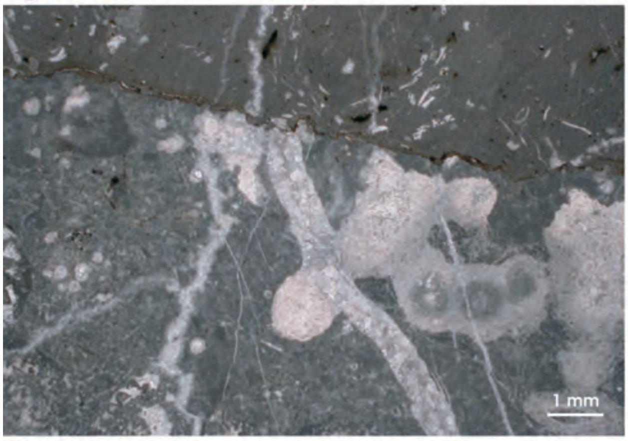

Fig. 7

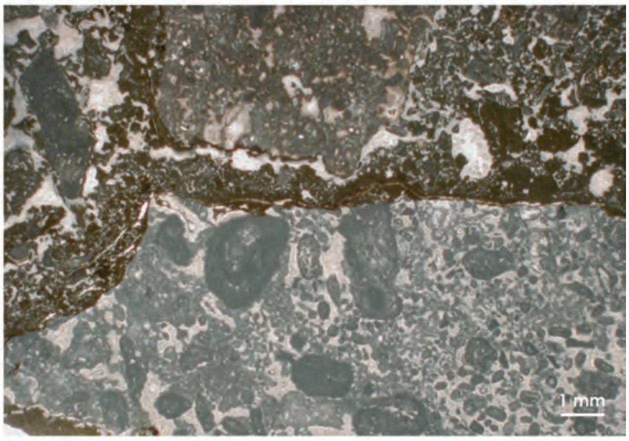

Fig. 8

Plate 3: Wetterstein Plattform - reef and lagoonal environment

Page 492

Fig. 1-5: Topmost horizon of the Wetterstein Fm. in lagoonal facies, Raffelgraben NW, samples A 4691 and A 4692.

Fig. 1: dasycladacean grainstone (Standard Microfacies Type 18).

Fig .2: grapestone facies with oncolithic aggregates, which are arranged around black lithoclasts.

Fig. 4, 5: The occurrence of pisolithic crusts is a good indicator of temporary vadose conditions.

Fig. 6: Wetterstein Fm., cemented reef with small-sized reef-building organisms, which act as nuclei for pervasive lithification; open voids within this construction were later filled by pelagic ooze; Mendlingbach section, sample A 4930.

Fig. 7, 8: Wetterstein Fm., cemented reef, Mendlingbauer forestry road, sample A 4306.

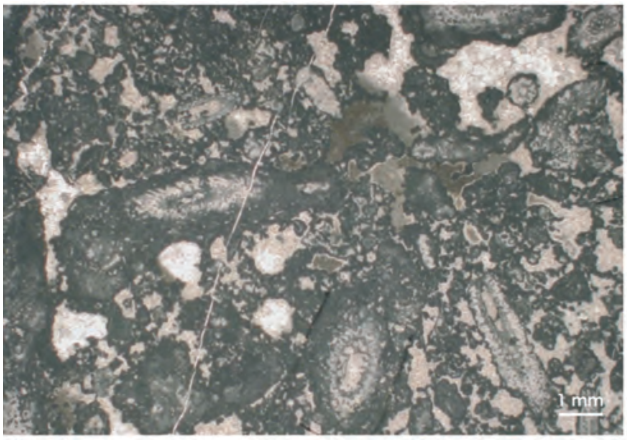

Fig. 1

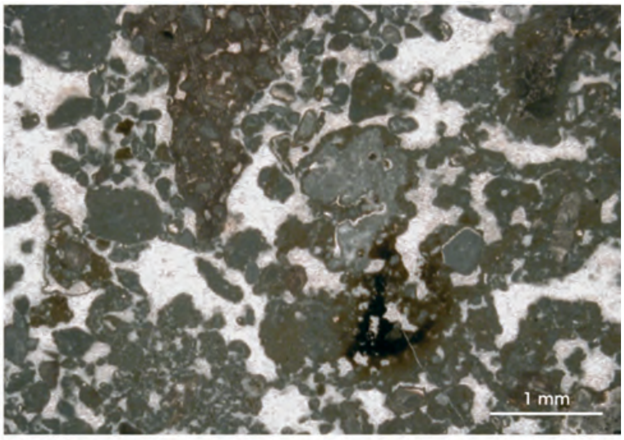

Fig. 2

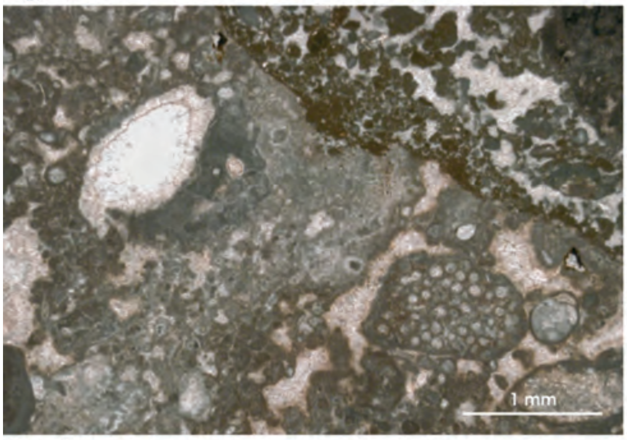

Fig. 3

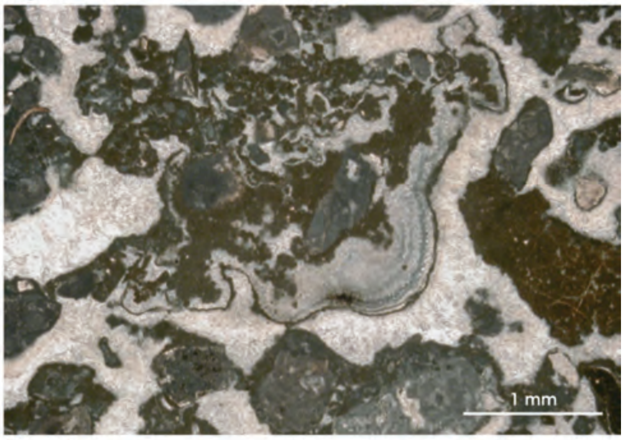

Fig. 4

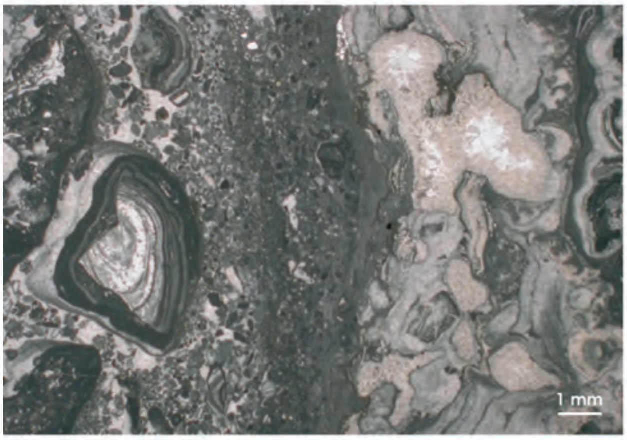

Fig. 5

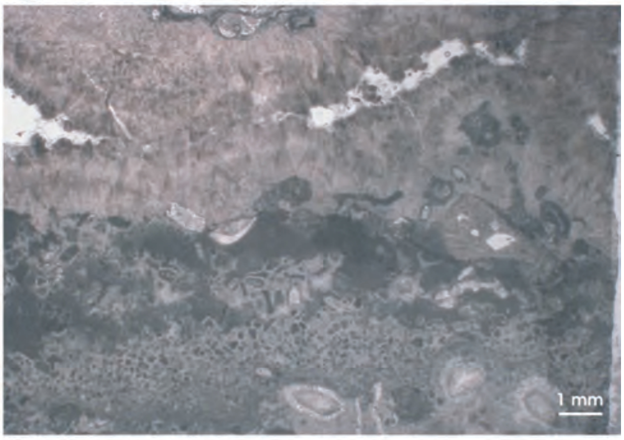

Fig. 6

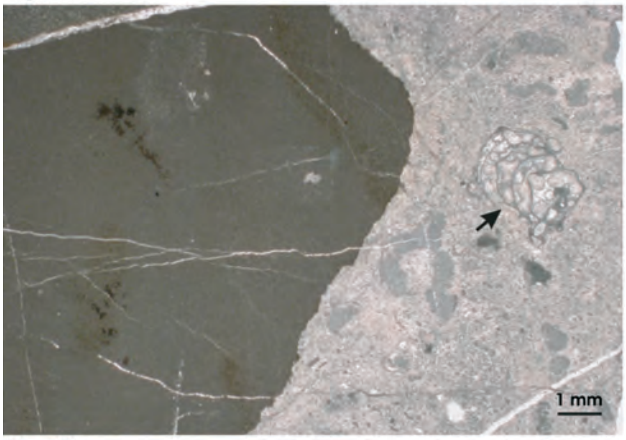

Fig. 7

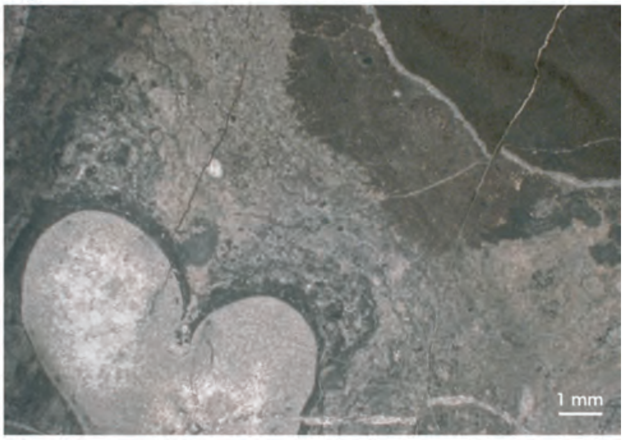

Fig. 8

Plate 4: Basinal environment : Reifling Fm. (Fig. 1-4), Partnach Fm.

Page 494, (Fig. 5-6) and Raming Mb. (Fig. 7-8)

Fig.1-2: Reifling Fm. (Pelsonian), Mendlingbach section (samples 90/20, 90/ 25).

Fig. 3: Reifling Fm. (*Daonella* coqina, late Anisian), Mendling-bach section (sample HL 415).

Fig. 4: Reifling Fm. (late Ladinian, sample 90/15).

Fig. 5-6: (Upper) Partnach Mb. (Longobardian 3, samples 89/28, 90/265).

Fig. 7: Raming Mb. (mass flow at the base, bioturbated), Mendlingbach section (sample 90/13).

Fig.8: Raming Mb. (mass flow), Raffelgraben section (sample HL 34A).

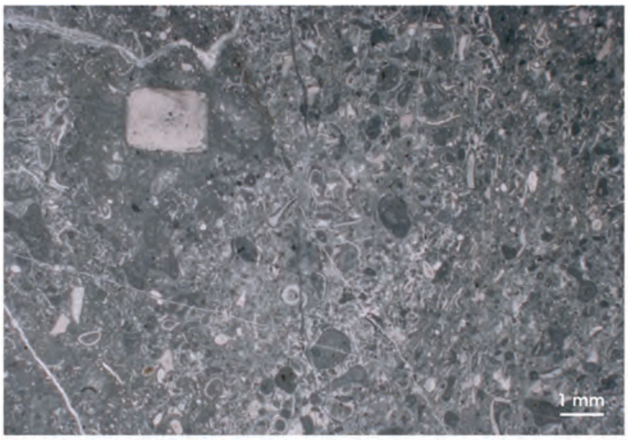

Fig. 1

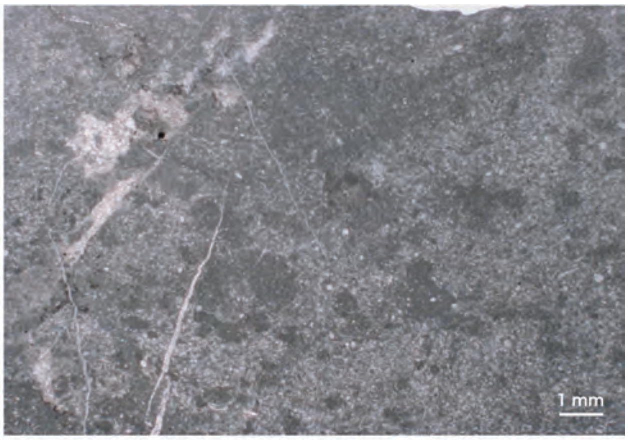

Fig. 2

Fig. 3

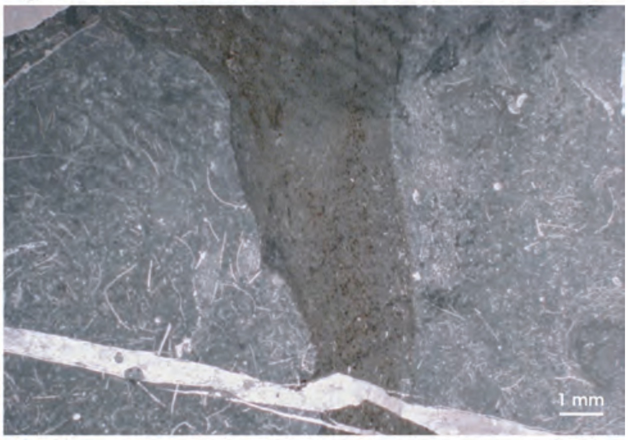

Fig. 4

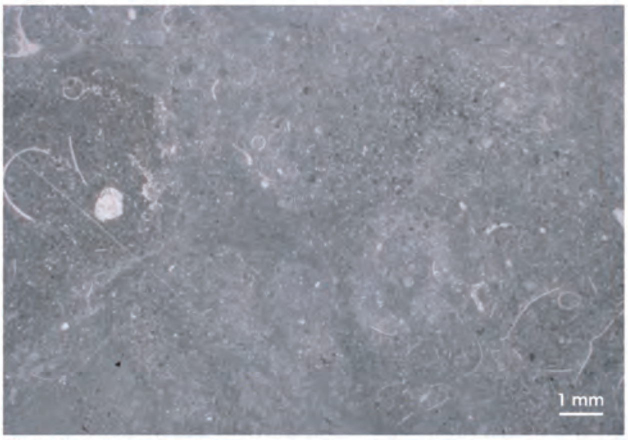

Fig. 5

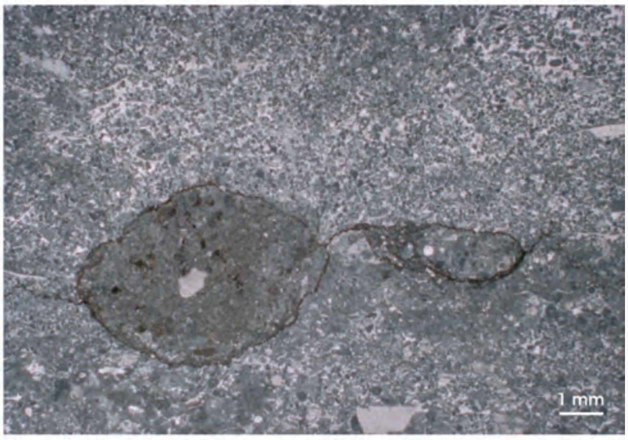

Fig. 6

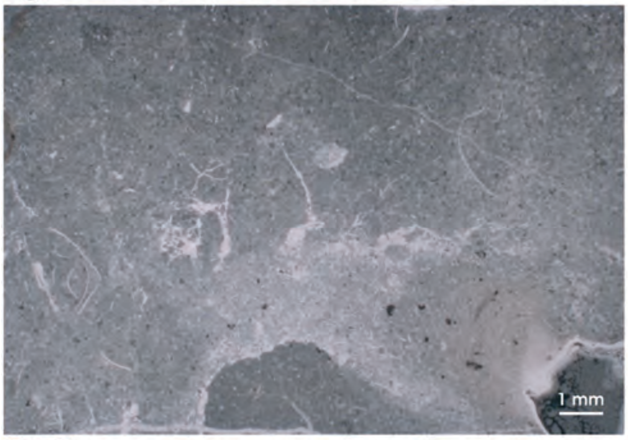

Fig. 7

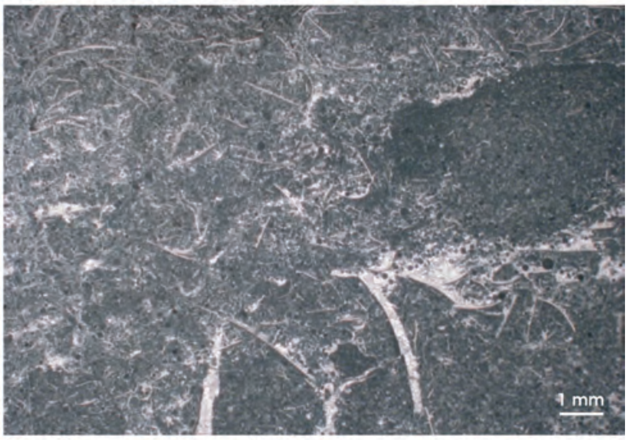

Fig. 8

Plate 5: Reifling Fm. (Fig. 6), Raming Mb. (Fig. 5, 8) Göstling Fm.

Page 496, (Fig. 1-2), Wetterstein Fm. (Fig. 3, 4, 7)

Fig. 1-2: Göstling Fm. (sample A 543, Scheiblinggraben Section), tempestitic sequence: mudstone layers (autochthonous) alternating with bioclastic dumpings.

Fig. 3: Reef limestone (Wetterstein Fm., lower unit), Mendlingbauer forestry road (sample A 4306/1) Infill of a primary cavity within a rapid-growth Wetterstein Fm. reef in the keep-off phase, near its base, with time-equivalent pelagic carbonate mud.

Fig. 4: Infill of a (?karstic) cavity located in the top surface of the Wetterstein Lagoon with arenitic carbonate detritus.

Fig. 5, 8: Allodapic limestone of the Raming Mb. (Fig. 5: Mendlingbauer forestry road section, sample A 4817; Fig. 8: Raffelgraben section, HL 34A). Note the incorporated large-sized components which were eroded from the slope by the bypassing turbidity currents.

Fig. 6: Characteristic microfacies of Late Anisian Reifling Limestone, Mendlingbauer forestry road (sample A 4309b).

Fig. 7: Top of the Wetterstein Reef, Mendlingbauer forestry road (sample 89/267).

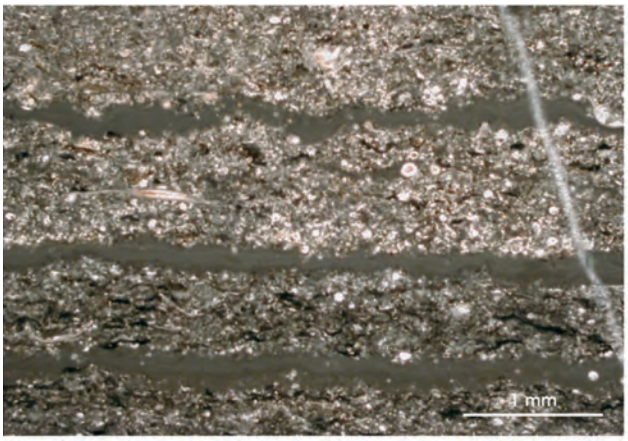

Fig. 1

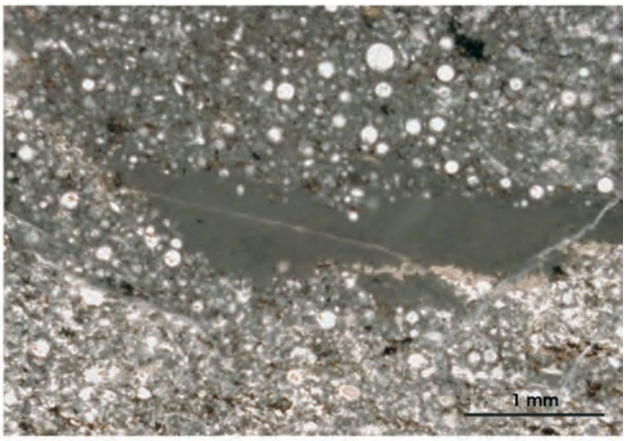

Fig. 2

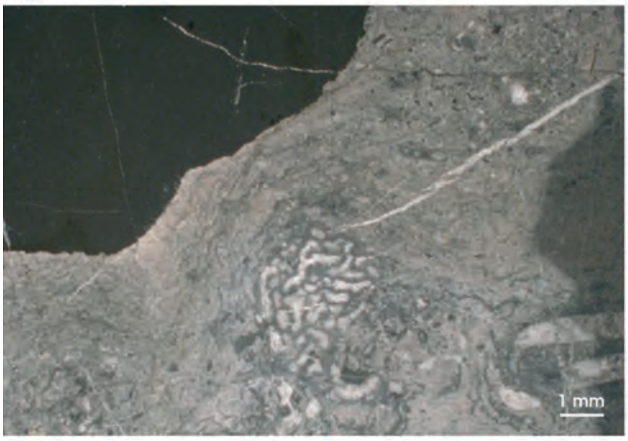

Fig. 3

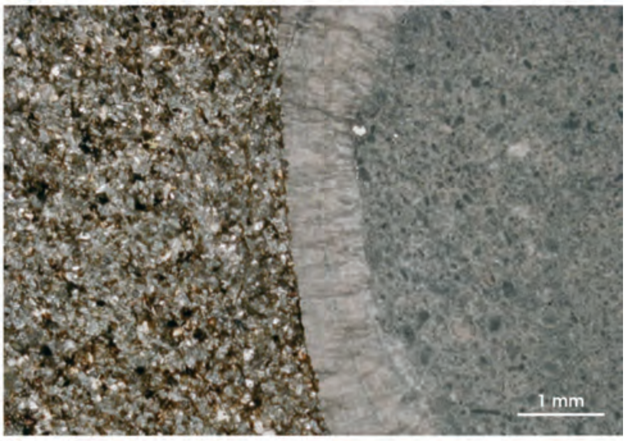

Fig. 4

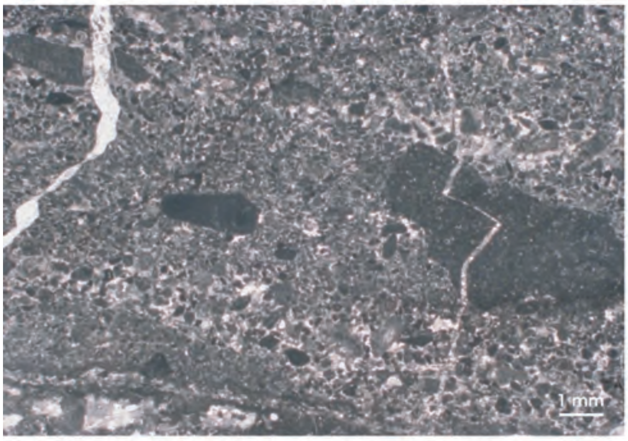

Fig. 5

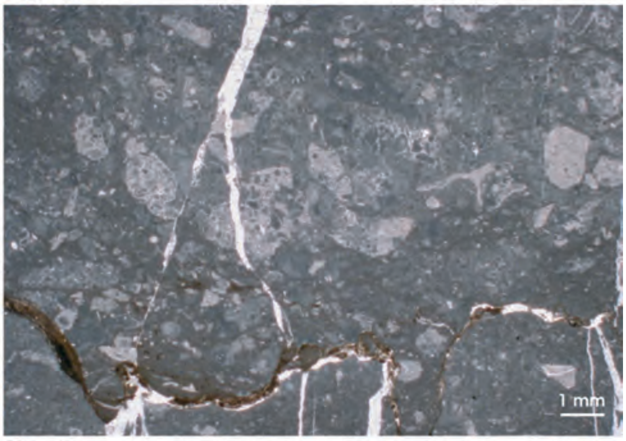

Fig. 6

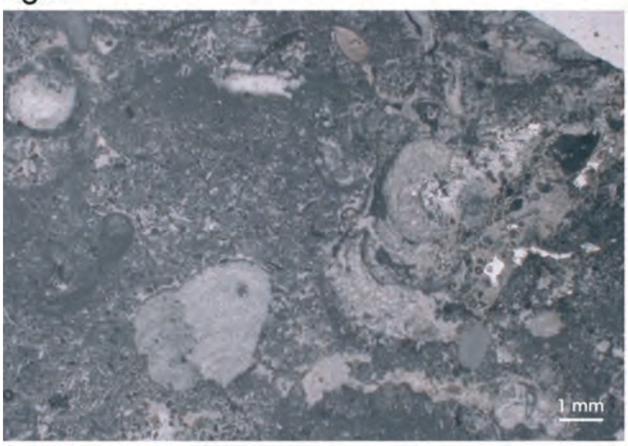

Fig. 7

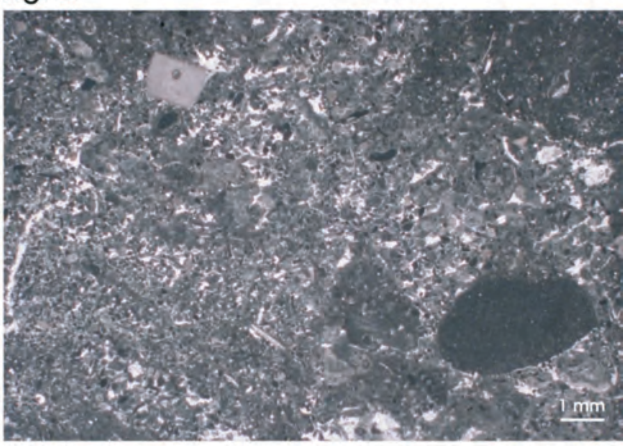

Fig. 8

Plate 6: Post-Wetterstein “special facies“

Page 498

All samples from the Schottgraben section, 2 km SW Niederscheibenberg.

Fig. 1-7: Bioclastic wackestone (samples TT54). The greatest part of the components is reworked material. Crinoids, thick-shelled bivalves, together with lithoclastic material of shallow-water origin (oolitic grains and grapestone). The black dots and small veins which penetrate and crosscut the marine limestone are interpreted as infiltrations of rotten organic material along roots of terrestrial plants thus indicating a interval of subaerial exposition.

Fig. 8: Cavity in the uppermost surface of the Wetterstein lagoon. The filling process with the reddish fine-grained (silt-sized) material occurred under marine conditions, as can be seen by the radiaxial rim on the surface of the cavity.

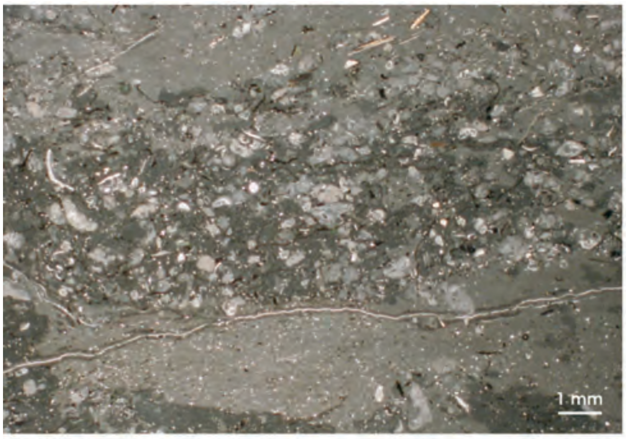

Fig. 1

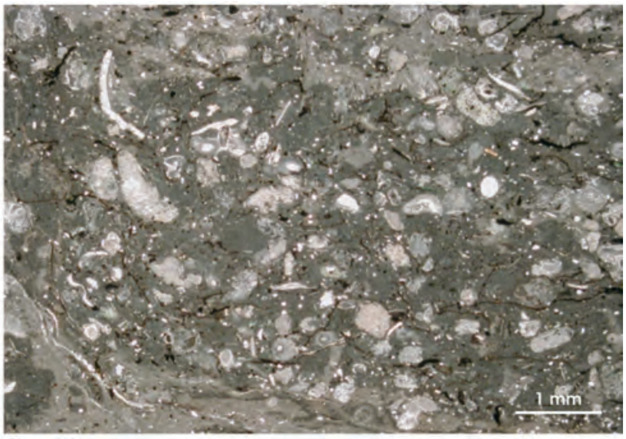

Fig. 2

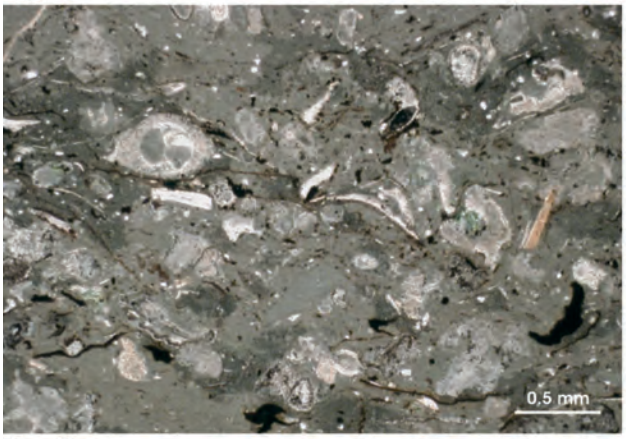

Fig. 3

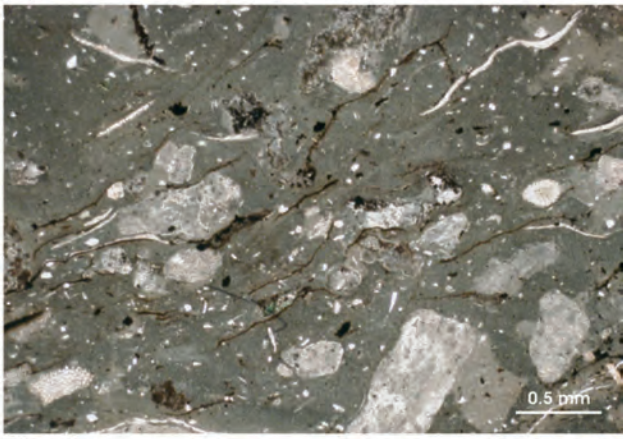

Fig. 4

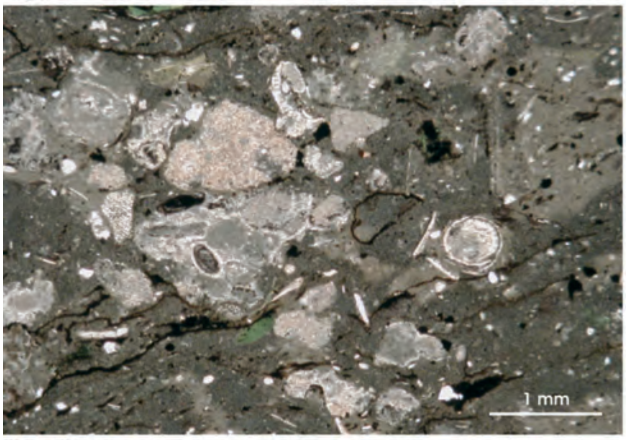

Fig. 5

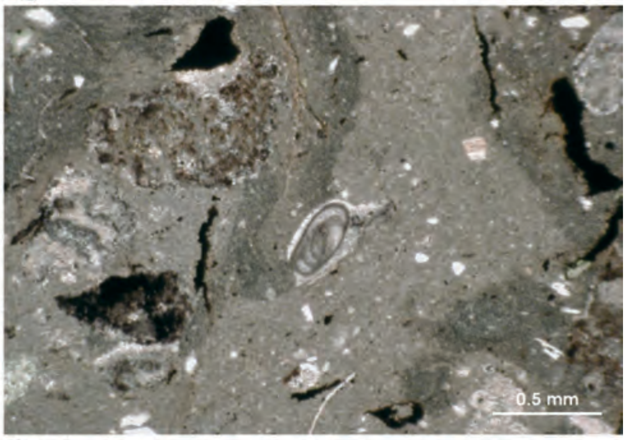

Fig. 6

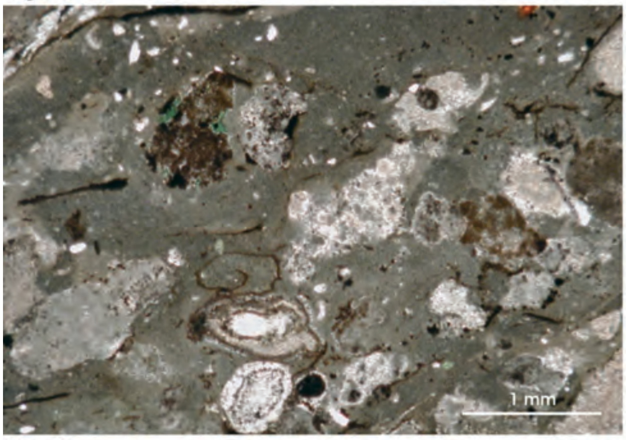

Fig. 7

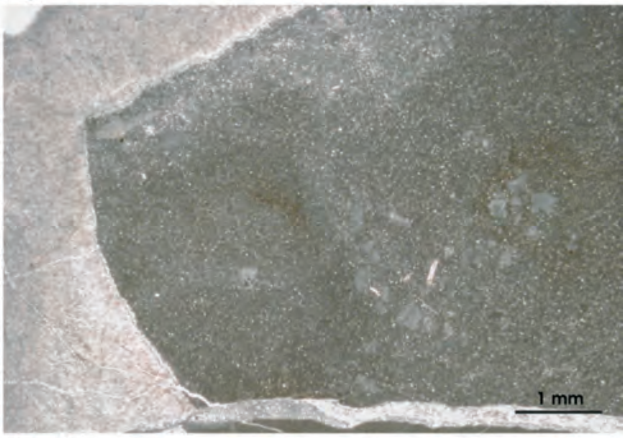

Fig. 8