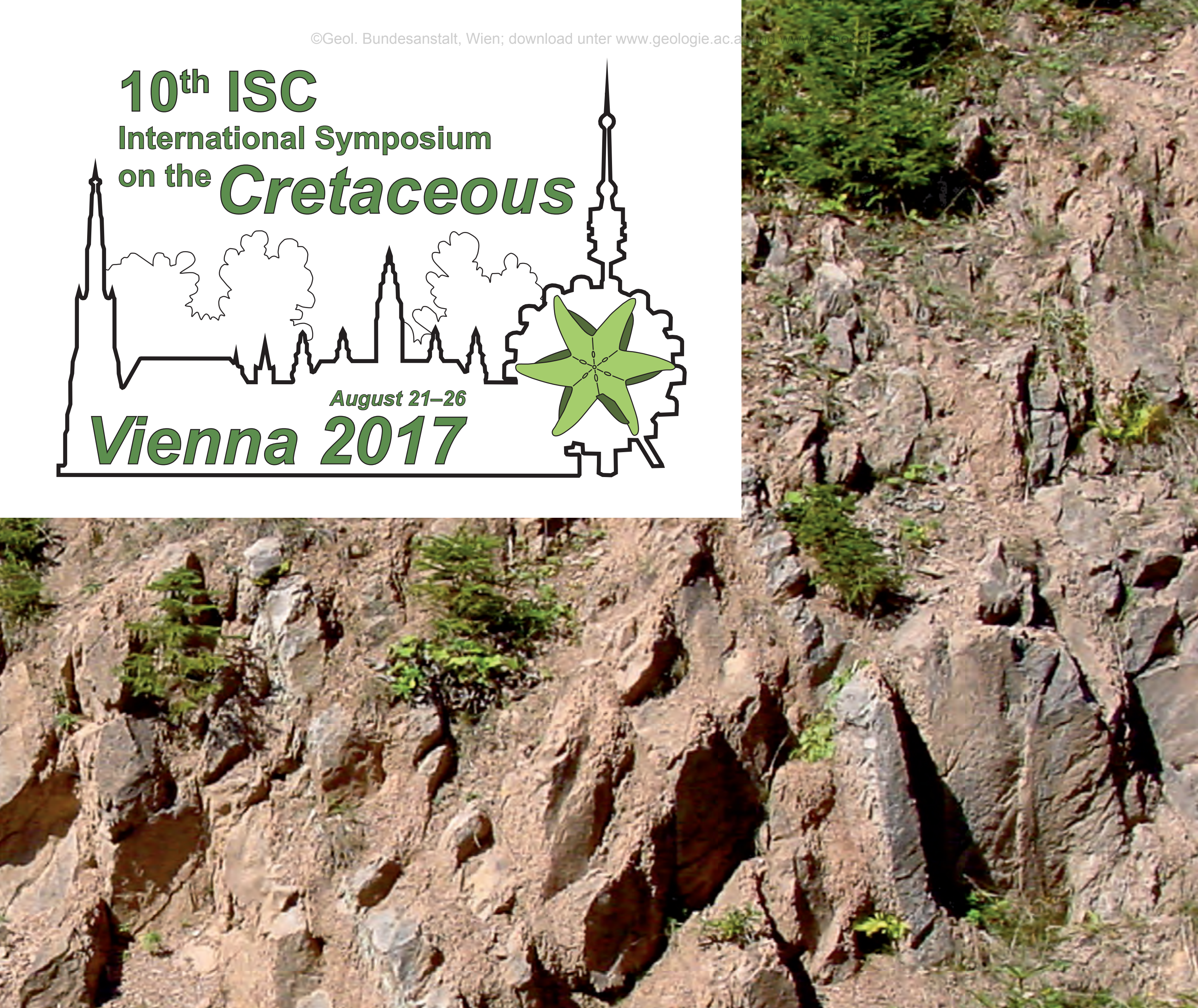
10th ISC
International Symposium on the Cretaceous
Vienna 2017
August 21–26



Michael Wagreich & Holger Gebhardt (Eds.)

FIELD TRIP GUIDEBOOK

Berichte der Geologischen Bundesanstalt, 121

Geological Survey of Austria

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Field Trip Guide Book

10^{th} International Symposium on the Cretaceous

Vienna, 21–26 August 2017

Edited by

MICHAEL WAGREICH & HOLGER GEBHARDT

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10th International Symposium on the Cretaceous Vienna, August 21–26, 2017 – FIELD TRIP GUIDE BOOK

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Frontpage:
Postalm section, Upper Campanian red pelagic limestone-marl cycles (CORBs) of the Nierental Formation, Gosau Group, Northern Calcareous Alps. Photograph: Michael Wagreich (Universität Wien).
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Foreword

In year 2017, the International Symposium on the Cretaceous is held for the second time after the millennium year 2000 in Vienna, Austria. Four field trips cover geological sites from Vienna's imperial monuments to classical Austrian geotopes to neighbouring countries such as Germany and Slovakia. Parts of these field trips follow the footsteps of former field trips, other parts are completely new and introduce recent results from several working groups out of various countries dealing with the Central European Cretaceous.

We thank especially the Geological Survey of Austria (GBA) who made possible the publication of these field trip guides. In addition, of course we thank all the scientists who helped preparing the field guides based on their research.

MICHAEL WAGREICH & HOLGER GEBHARDT — Vienna, 2017-07-12

ISC Field Trip Program

Content

Field Trip PRE-1
Upper Cretaceous and Paleogene at the northwestern Tethyan margin (Austria, S Germany): Boundaries, Events, Cycles and Sequences

MICHAEL WAGREICH[1], ERIK WOLFGRING[1], MARKUS WILMSEN[2], BIRGIT NIEBUHR[2] & THOMAS PÜRNER[3]

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17 August 2017 Upper Cretaceous-Paleogene Gosau Group at Gams/Styria

Route: Vienna–Gams/Styria

Stop 1. Cretaceous/Paleogene boundary at Knappengraben
Stop 2. Cretaceous/Paleogene boundary at Krautgraben/Gamsbach
Stop 3. Mid-Maastrichtian ammonite site E of Haid
Stop 4. Upper Turonian sandstones and rudists at Pitzengraben and along Noth road
Stop 5. Gams Geozentrum Museum

Overnight at Abtenau, Lammertaler Hof, Abtenau, www.lammertalerhof.at

18 August 2017 Upper Cretaceous Gosau Group at Gosau Valley and Rußbach

Stop 6. Lake Gosau (Gosausee) in the Gosau valley
Stop 7. Upper Santonian rudist-limestones above a Santonian transgression
Stop 8. Sandkalkbank/Schattau-Rußbach (Upper Santonian)
Stop 9. Pass Gschütt/Streiteck Formation (lunch stop)
Stop 10. Parking area Rußbach
Stop 11. Section through the Lower Gosau Subgroup, Randograben

Overnight at Abtenau, Lammertaler Hof, Abtenau, www.lammertalerhof.at

19 August 2017 Cretaceous transect from the Alps to the Foreland (Germany)

Stop 12. Postalm road, Abtenau, Gosau Group
Stop 13 Cenomanian–Turonian at Rehkogelgraben/Hagenmühle (Upper Austria)
Stop 14. Schutzfelsen near Pentling
Stop 15. Dantschermühle section near Bad Abbach (Germany)

Overnight at Prösslbräu, Adlersberg, www.adlersberg.com & Hotel Krieger, Mariaort, www.gasthof-krieger.de

20 August 2017 Danubian Cretaceous Group, Bodenwöhrer Senke, Regensburg, Germany

Stop 16. Sandpit near Trischlberg
Stop 17. Parish church in Neubäu am See (optional)
Stop 18. Haimerl quarry near Grub
Stop 19. Obertrübenbach quarry

Obertrübenbach–Vienna, end of field trip

Introduction to the Geology of the Eastern Alps

The Eastern Alps and the Alpine foreland provide a classical area for geology and geologists, being investigated in detail since the 18th century and having been visited and described by eminent geologists like SEDGWICK & MURCHISON (1832). Classical geological concepts have been developed from the study of the Alps and in particular its eastern margin such as the process of "eustasy" by EDUARD SUESS (1888).

Geological Overview

The Eastern Alps represent a highly compressed segment of the Alpine mountain chain, located between the Rhine valley to the west and the Neogene Vienna Basin at the border to Slovakia toward the east. The Eastern Alps comprise a thrust orogen, which originated within the western Tethys paleogeographic domain due to repeated convergence between the European and the African plate and microplates such as the Adriatic/Apulian plate in-between.

The orogenic evolution can be divided into several stages of deformation: a Jurassic to Cretaceous, "Eoalpine" stage, followed by Meso- and Neoalpine deformational events from the Late Eocene and Miocene onwards. The geodynamic evolution is strongly discussed because of polyphase deformation overprinting Mesozoic structures, the incompleteness of the sedimentary record and the less constrained paleogeographic and paleotectonic positions of individual tectonic domains. These led to a variety of proposed models for the evolution of the Eastern Alps during the Mesozoic, differing especially in the inferred positions and timing of subduction zones, collisions and suturing (e.g. FAUPL & WAGREICH, 2000; STÜWE & SCHUSTER, 2010; HANDY et al., 2015).

Five major tectonic units representing different paleogeographic realms can be distinguished from the European foreland to the Eastern Alps (Text-Fig. 1):

(1) The **foreland** represented by the Molasse basin and its underlying **Mesozoic autochthonous strata** representing the northern part of the broad European shelf including the Danubian Cretaceous Group ("Regensburg gulf") above Variscan deformed basement.
(2) The **Helvetic zone**, including Helvetic and Ultrahelvetic units of the European shelf and continental slope, and the Gresten Klippen Zone in the eastern part of the Eastern Alps;
(3) The **Penninic zone**, including the Rhenodanubian Flysch Zone and metamorphosed rocks exposed in tectonic windows in the central parts of the Eastern Alps;
(4) The **Austroalpine zone** including the Northern Calcareous Alps, and
(5) The **Southalpine zone** at the southern border of Austria, both units of the Austroalpine microplate. The Austroalpine zone is subdivided into Lower and Upper thrust complexes and includes both basement and cover units. Within the Upper Austroalpine zone the **Northern Calcareous Alps** (NCA) represent a polyphase structured pile of cover nappes composed of thick Triassic-Jurassic carbonate successions.

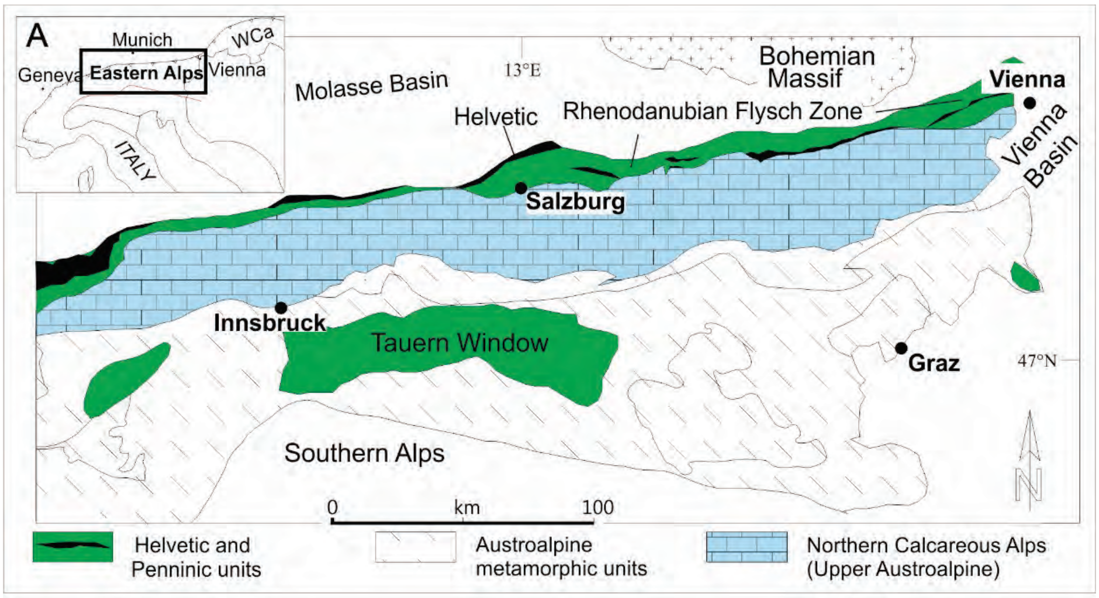
Alpine orogeny commenced with the closure of a Triassic Neo-Tethys oceanic branch ("Hallstatt-Meliata Ocean") within the Austroalpine domain during the Middle to Late Jurassic. Contemporaneously, the Penninic Ocean, a continuation of the Ligurian Ocean (and thus the Atlantic Ocean), opened by oblique rifting and spreading between the European plate and the Austroalpine microplate, connected to the opening of the Atlantic Ocean. Jurassic subduction processes in the Hallstatt-Meliata Ocean resulted in an elevated suture zone towards the present south of the NCA. The Penninic Ocean´s tectonic regime changed to transpression and subduction during the Cretaceous, and an accretionary wedge developed to the north of the NCA. During the Early Cretaceous, the sedimentary cover of the NCA was sheared off from its basement and stacked into a complex nappe pile (Text-Fig. 2). Later on, a second main phase of compression and thrusting during the Eocene–Oligocene structured the Alpine orogen, followed by mountain building and foreland subsidence. Oligocene to Miocene lateral extrusion lead to strike-slip faulting, dismembering and the formation of intramontane basins like the Vienna Basin, on top of Alpine thrust structures.

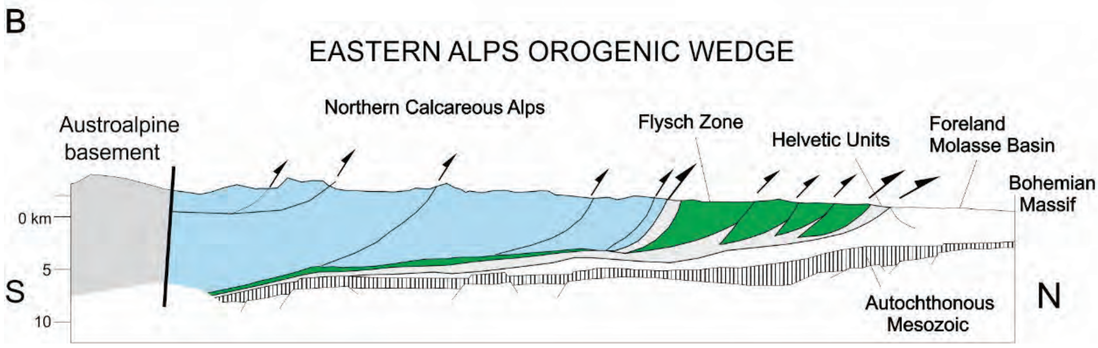
Stratigraphic Overview

European Foreland and Helvetic zones
The Helvetic domain and the European Foreland comprise sedimentary strata deposited on the shelf and upper slope of the European plate in a passive margin setting during the Jurassic to Cretaceous. Upper Jurassic reef limestones crop out north of Vienna due to Alpine thrusting. Marginal marine to shelf sediments from Albian to Cenomanian transgression and strongly influenced by sea-level changes comprise strata of the Regensburg gulf, a broad embayment to the west of the island of the Variscan Bohemian Massif. Lower Cretaceous shallow-water to pelagic deposits of the Helvetic realm are exposed mainly in thrust complexes in the western part of the Eastern Alps, overlain by Upper Cretaceous shallow-water marls and limestones.

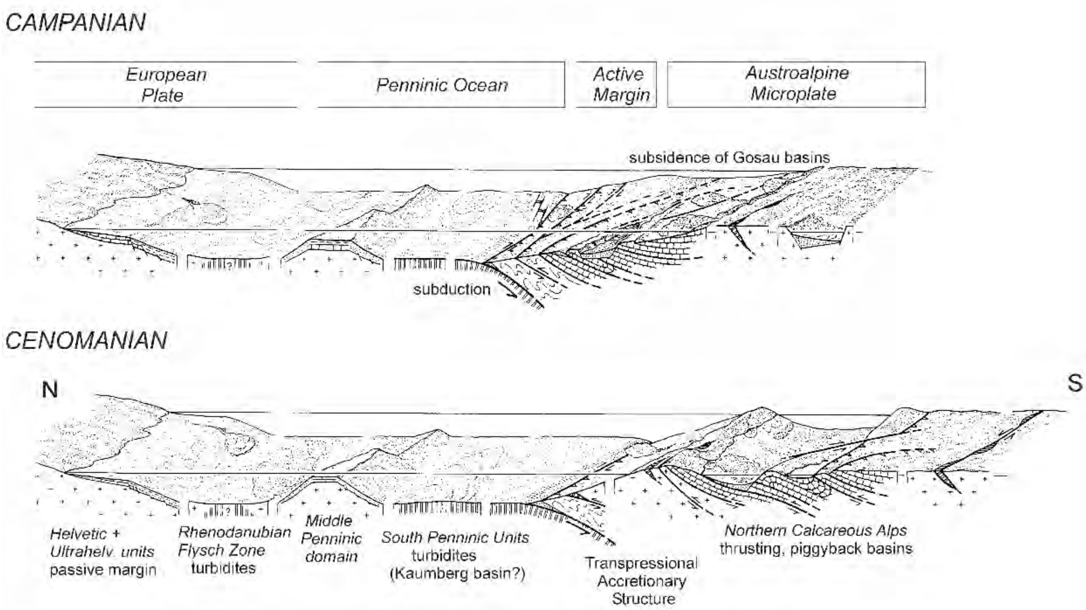
Penninic zones
The Penninic zone developed due to extension and spreading between the European foreland/Helvetic zones and the Austroalpine microplate during the Jurassic (South Penninic units) and Cretaceous (North Penninic units) times (Text-Fig. 2).
During Early Cretaceous predominantly turbiditic deep-water sedimentation began within the North Penninic Rhenodanubian Flysch Zone. The succession started with carbonate-dominated flysch deposits, but passed into turbidites rich in siliciclastic material in the uppermost Early Cretaceous. In the main flysch nappe, the Upper Cretaceous turbidite successions are subdivided by several thin-bedded variegated red pelitic intervals. Sedimentation ranges up to the Early Eocene. Metamorphic South Penninic successions are known from the Tauern Window, including ophiolitic complexes and metamorphosed shales, suggested a fully oceanic basin during the Jurassic.

Austroalpine zones
The Austroalpine domain is considered as a partly individual microplate at the northern margin of the Apulian plate (e.g. FAUPL & WAGREICH, 2000). The best documented sedimentary successions of the Austroalpine domain are preserved within the Northern Calcareous Alps (NCA, Text-Fig. 1). Based upon restoration of Neogene fault tectonics, the Eastern Alps had about half the length of the present-day mountain chain during the Late Cretaceous. Metamorphic units of the Austroalpine, including former basement units of the NCA, are situated to the south of the NCA and its Paleozoic base.
Within the Northern Calcareous Alps (Text-Figs. 2, 3) a wide carbonate shelf/platform succession of Triassic age is preserved. Huge Middle Triassic and Upper Triassic platform carbonates (e.g. Wetterstein Limestone, Hauptdolomite and Dachstein Limestone) characterize the NCA (LINZER & TARI, 2012). Jurassic deepening led to establishment of Ammonitico Rosso (Adnet Formation), radiolarites and siliceous deep-water limestones that grade into deep-water carbonate facies of the Lower Cretaceous (Schrambach Formation). Lower and Upper Cretaceous to Paleogene terrigenous clastics such as the Gosau Group (e.g. FAUPL & WAGREICH, 1996) exemplify the growing influence of (eoalpine) orogeny.





Text-Fig. 1 (A): Tectonic sketch-map of the Eastern Alps.
Text-Fig. 2 (B): Simplified cross-section of the eastern part of the Eastern Alps.



Text-Fig. 3: Palinspastic reconstruction of the Eastern Alps during Late Cretaceous times (Faupl & Wagreich, 2000).

The Gosau Group of Gams

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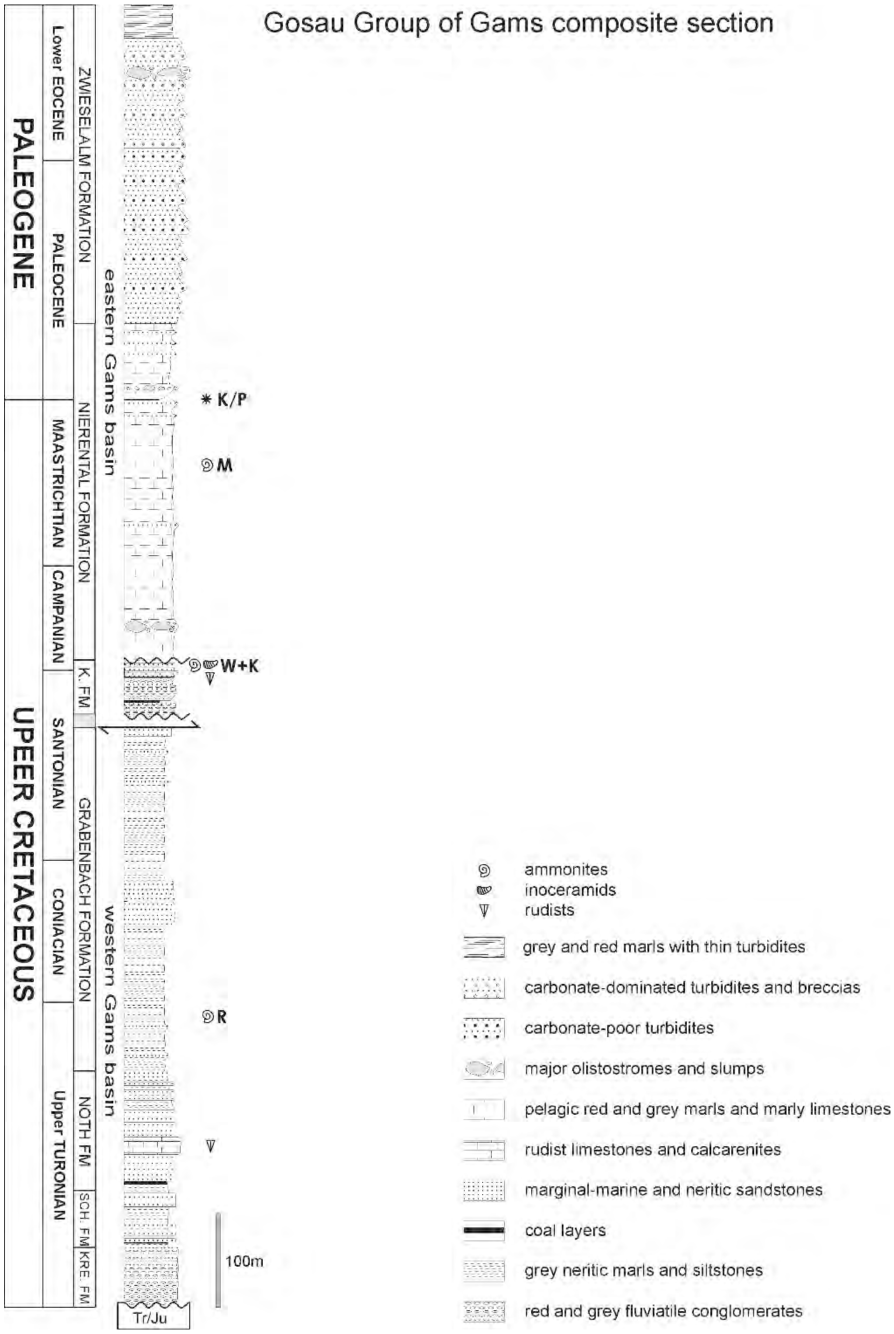
The Gosau Group of Gams consists of a terrestrial to shallow-marine part of Late Turonian to Early Campanian age (Lower Gosau Subgroup) and deep-marine Campanian to Lower Eocene deposits (KOLLMANN, 1964; Upper Gosau Subgroup). Outcrops of the Lower Gosau Subgroup are more or less restricted to the western part of the E–W-elongated outcrop belt ("western basin" of KOLLMANN, 1964; KOLLMANN & SUMMESBERGER, 1982). The following lithostratigraphic units could be distinguished based on KOLLMANN (1964; comp. Text-Fig. 4):



Text-Fig. 4: Composite log of the Gosau Group of the Gams area (modified from SUMMESBERGER et al., 2009). Abbreviations: K. FM = Krimpenbach Formation, SCH. FM = Schönleiten Formation, KRE. FM = Kreuzgraben Formation; Fossil site abbreviations: R = Radstadt, W = Wentneralm, M = Maastrichtian, K/P = Cretaceous/Paleogene boundary).

(1) A basal unit of red alluvial conglomerates up to 70 m thick (Kreuzgraben Formation).
(2) A succession of shales and clays with rarely intercalated sandstones and coaly clays, containing marine fossils, coal and jet (Schönleiten Formation).
(3) A succession up to 400 m thick of grey shales containing coal seams, sandstone with serpentinite sands, *Trochacteon* and rudist (*Hippurites*) limestones ("Noth Formation"; Upper Turonian; see SANDERS & PONS, 1999).
(4) Several hundred meters of grey silty shales with rare sandstone tempestites (Grabenbach Formation; Upper Turonian–Santonian), containing ammonites and inoceramids.
(5) A transgressive succession of conglomerates, sandstones and grey shales (Krimpenbach Formation, Late Santonian–Late Campanian age, SUMMESBERGER et al., 1999; WAGREICH, 2004).
(6) Deep-water shales and turbidites of the Nierental Formation, including turbidites and olisthostromes (Upper Campanian–Lower Paleocene).
(7) Turbiditic successions of the Zwieselalm Formation (Middle Paleocene–Lower Eocene).

Stop 1. Cretaceous/Paleogene boundary at Knappengraben

Coordinates: E 14°51'50", N 47°39'51".
Location: Outcrop along a forest road.
Topic: K/Pg – Cretaceous/Paleogene boundary section.
Lithostratigraphic unit: Nierental Formation (Upper Gosau Subgroup).
Age: Late Maastrichtian (CC26)–Early Paleocene (NP1).
Tectonic unit: Untersberg Nappe/Göller Nappe (Tirolicum), NCA.
Specialities: K/Pg boundary section behind fence; discussion on impact and volcanism.
References: STRADNER & RÖGL (1988), LAHODYNSKY (1988a, b), GRACHEV et al. (2005).

The outcrop is located 700 m south of the farm house at the crossing between the forest road and the Knappengraben torrent. It is protected by a fenced shelter. Detailed studies on the K/Pg boundary of Gams have first been performed at the Knappengraben outcrop. The lithological section has been described by LAHODYNSKY (1988a, b). Nanno- and micropalaeontological work has been performed by STRADNER & RÖGL (1988), EGGER et al. (2004), GRACHEV et al. (2005) and GRACHEV (2009). Up to 9 ppb Ir have been found in the boundary clay.
In the outcrop a section of the Nierental Formation across the K/Pg boundary is exposed. Beds are dipping at 40° towards SSE. The base is formed by pale grey, Upper Maastrichtian shaly limestones with a well-defined ichnofauna (*Chondrites, Zoophycos, Thalassinoides*). The transitional layer consists of dark grey clay containing small mica particles. It is overlain by grey clays and thin, yellowish to brown fine-grained sandstone layers.
The stratigraphically lower part consists of light grey shaly limestones with dark spots of approximately 1 mm in diameter (*Chondrites*). The burrows are filled with dark boundary clay. Foraminifera indicate the *Abathomphalus mayaroensis*- or *Pseudoguembelina hariaensis* zones. The K/Pg boundary clay has a thickness of about 2 cm. It is vertically heterogeneous and its texture varies according to its clastic content and the clay matrix distribution. The lower part of the transitional clay contains an assemblage of small heterohelicids and hedbergellids including *H. holmdelensis* (GRACHEV et al., 2005: holmdelensis Zone) followed by a barren 0.2 cm interval of dark green to black clay and the FO of *Globoconusa daubjergensis* and *Subbotina fringa* (*Globoconusa daubjergensis* and *Subbotina fringa* zones in GRACHEV et al., 2005).

Stop 2. Cretaceous/Paleogene boundary at Krautgraben/Gamsbach

Coordinates: E 14°51'50", N 47°39'51".

Location: Outcrops along a bend of Krautgraben (= upper Gamsbach) main creek.

Topic: Cretaceous/Paleogene boundary section. Stratigraphy, sedimentology, geochemistry and mineralogy data.

Lithostratigraphic unit: Nierental Formation (Upper Gosau Subgroup).

Age: Late Maastrichtian (CC26)–Early Paleocene (NP1).

Tectonic unit: Untersberg Nappe/Göller Nappe (Tirolicum), NCA.

Specialities: New K/Pg boundary section investigated by GRACHEV (2009) and EGGER et al. (2009).

References: GRACHEV (2009), EGGER et al. (2009), PUNEKAR et al. (2016).

The second K/Pg boundary site in the Gams area is found in the Krautgraben, the valley of the Gamsbach about 1.25 km west of the Knappengraben site (Text-Fig. 5). The base of the 6.5 m long section lies 2.5 m below the K/Pg boundary. EGGER et al. (2009) reported results from a combined palaeontological and geochemical analysis of that section; later PUNEKAR et al. (2016) gave a more detailed survey.

The section is part of the Nierental Formation of the Gosau Group. The log of the section is given in Text-Figure 3. The most conspicuous feature is the ca. 2 cm thick boundary clay. The base of this clay has been taken as 0-meter level in the columnar log.

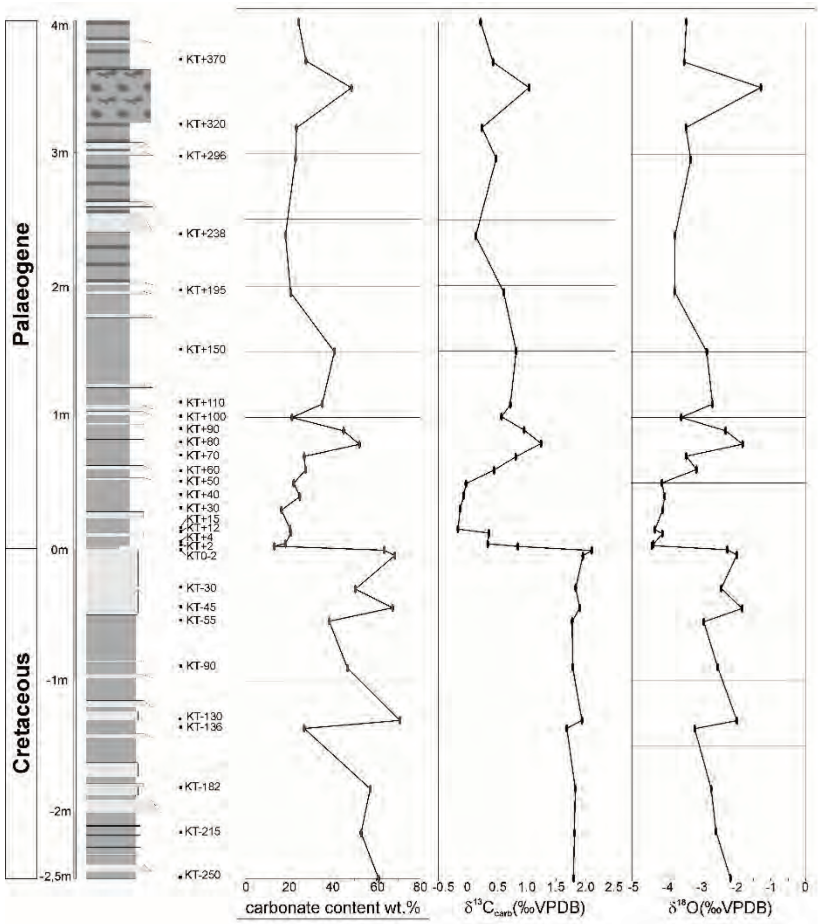
The Gamsbach section consists mainly of fine-grained pelitic rocks. Below the K/Pg boundary light to medium grey marlstones and marly limestones occur (mean carbonate content of 11 samples is 54.9 wt.%), which are interbedded with thin (< 15 cm) sandstone turbidites. Dark grey mottles due bioturbation are present especially in more indurated marly limestone beds. Chondrites- and well indurated, bioturbated marly limestone with an irregular, wavy upper surface. Above this surface, 0.2 to 0.4 cm of yellowish clay marks the base of the Paleocene. The yellowish clay is overlain by grey clay with a maximum carbonate content of about 13 wt.% in the upper part of the layer. The overlying 200 cm thick middle to dark grey marl to marlstone contains ca. 20–50 wt.% carbonate. Twelve thin (0.5 to 5 cm) sandy to silty turbidite layers are intercalated in the first 9 cm of this marlstone. The colour of the marls and marlstones changes upsection from light to medium grey, and they are interbedded with brown to reddish layers. Turbiditic beds become thicker there (up to 14 cm). A variegated marl/marlstone bed (40 cm thick) occurs at 323 cm. It contains clasts of red and brown marly limestone up to 15 cm in diameter and some slump folds. Above this mass-flow bed, the greyish-red marl-marlstone succession extends to the top of the section, 400 cm above the K/Pg boundary.

The section comprises the upper part of the Cretaceous *Nephrolithus frequens* Zone (CC26) and the lower part of the Paleocene *Markalius inversus* Zone (NP1). The boundary is characterized by

(1) enrichment of the contents of the siderophile elements Ir, Co, Ni, and Cr compared to the background and continental crustal values,

(2) sudden decrease of carbonate content and carbon and oxygen isotope values,

(3) an acme of the calcareous dinoflagellate cyst *Operculodinella operculata*, which is succeeded by an acme of the small coccolith species *Neobiscutum parvulum*. The *Neobiscutum* acme is associated with a positive excursion of $\delta^{18}O$ indicating a transient cooling of ocean surface waters due to short-lived changes in the configuration of ocean circulation after the impact.



Text-Fig. 5: Stratigraphic log of the Gamsbach section, with carbonate content and variation in the stable isotope abundances (EGGER et al., 2009).

Stop 3. Mid-Maastrichtian ammonite site E of Haid

Coordinates: E 14°51'35", N 47°40'00".
Location: Outcrops along a forest road and creek northeast of Haid.
Lithostratigraphic unit: Nierental Formation (Upper Gosau Subgroup).
Age: Middle Maastrichtian, upper part of *Gansserina gansseri* Zone, CC25b/ UC20a^{TP}.
Tectonic unit: Untersberg Nappe/Göller Nappe (Tirolicum), NCA.
Specialities: Youngest ammonites of the Gosau Group.
References: SUMMESBERGER et al. (2009).

The investigated outcrop within the Nierental Formation exposes about 5 meters of thin and evenly bedded sandy/silty grey shales and marls with a few intercalations of coarse sandstones below 10 cm thickness. The beds are a few centimetres thick; the bedding planes are more or less even. Some bedding planes are coated by a rusty cover. Bioturbation is common, especially in the lower part of the outcrop. *Chondrites* is a typical trace fossil present at topmost parts of graded sandstone/siltstone turbidite beds. Some bedding planes also show grazing traces by echinoids. Pelitic beds can be subdivided into soft sandy turbiditic shales and more indurated marls, which are interpreted as hemipelagic. The stratigraphic position of the cephalopod-bearing grey marl bed is below a 16 cm thick graded sandstone layer and thus is also interpreted as a hemipelagic, non-turbiditic layer.

Cephalopods and chronostratigraphic correlation

Pachydiscus (*Pachydiscus*) *gollevillensis* (D'ORBIGNY 1850)
Glyptoxoceras cf. *rugatum* (FORBES 1846)
Neancyloceras bipunctatum (SCHLÜTER 1872)

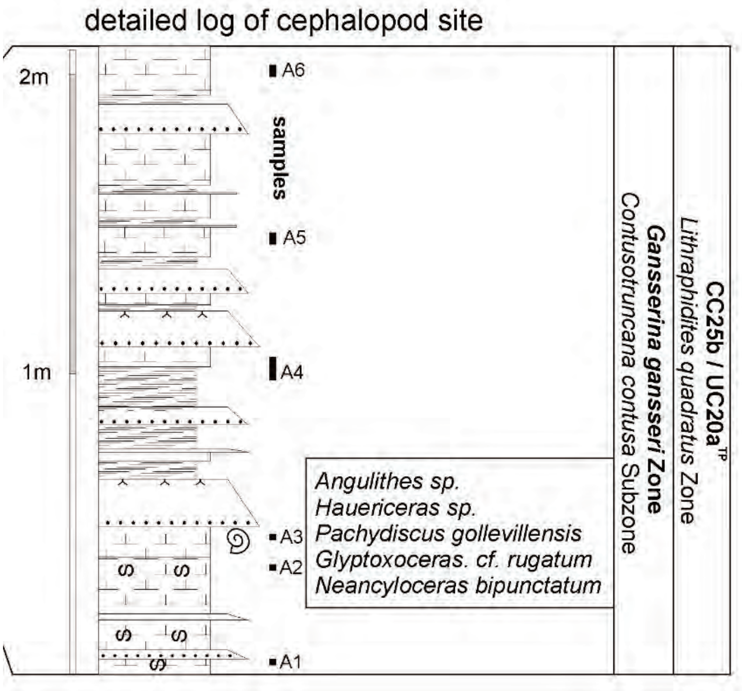
Hauericeras sp. indet. juv.
Angulithes (*Angulithes*) sp. indet.

The most indicative ammonite taxon present is *Pachydiscus* (*P.*) *gollevillensis* (D'ORBIGNY, 1850), which ranges at Zumaya (Spain) from the upper part of the *gansseri* Zone to the middle *mayaroensis* Zone (WARD & KENNEDY, 1993). In terms of ammonite zones this corresponds to the *Anapachydiscus fresvillensis* Zone, which is upper Lower Maastrichtian to lower Upper Maastrichtian. The LO level of *P.* (*P.*) *gollevillensis* at Zumaya is within the Upper Maastrichtian zones of *Anapachydiscus fresvillensis* and *Abathophalus mayaroensis* (WARD & KENNEDY, 1993), and above the FO of *Lithraphidites quadratus*, within nannofossil zone UC20 (BURNETT, 1998). At Sopelana I (Spain) *P. gollevillensis* occurs about 50 m below the K/Pg boundary near the base of the *mayaroensis* Zone (WARD & KENNEDY, 1993). Its extinction level is about 10 m below K/P. Thus, *P. gollevillensis* is mainly a Late Maastrichtian species, appearing at the top of the upper Lower Maastrichtian *gansseri* Zone.

Nannoplankton
The most important marker species recognized is *Lithraphidites quadratus.* This species is rare to very rare (1 specimen in around 100 fields of view). The presence of *L. quadratus* in all the samples and the absence of *Micula murus* and *Nephrolithus frequens* allow the recognition of standard nannofossil zones CC25b (according to SISSINGH, 1977; PERCH-NIELSEN, 1985) and UC20a^{TP} (BURNETT, 1998). The presence of *Corollithion completum* further corroborates this assignment according to BURNETT (1998). An early Late Maastrichtian age is interpreted in correlation to belemnite zonations (*tegulatus /junior* Subzone or younger; BURNETT, 1998). Very rarely, Campanian to early Maastrichtian taxa such as *Broinsonia* and *Uniplanarius* are found, which are interpreted as reworked from older strata.

Planktonic Foraminifera
Samples contain a foraminifera assemblage characterized by high amounts (> 90 %) of planktonic foraminifera. The most characteristic and stratigraphically important taxa present are *Globotruncanita stuarti, Rosita contusa, Abathomphalus intermedius,* and *Racemiguembelina intermedia. Globotruncanita stuarti* and *Rosita contusa* are typical Maastrichtian species. *Abathomphalus intermedius* and *Racemiguembelina intermedia* both have a first occurrence higher up in the Maastrichtian, within the *Gansserina gansseri* Zone. *Racemiguembelina fructicosa* occurs below the *Abathomphalus mayaroensis* Zone.
Thus, the samples can be attributed to the upper part of the *Gansserina gansseri* Zone (Text-Fig. 6), the *Contusotruncana contusa* (Sub-)Zone, within the upper part of the of the *Gansserina gansseri* Zone, just below the first occurrence of *Abathomphalus mayaroensis*.
Combining nannofossil (CC25b/UC20a^{TP}) and planktic foraminiferal data (upper part of *Gansserina gansseri* Zone, *Contusotruncana contusa* (Sub-)Zone, CF5; below the first occurrence of *Abathomphalus mayaroensis*) gives a more precise stratigraphic frame for the cephalopod fauna and allows correlation to other zonations, e.g. the boreal belemnite zonation of northern Europe. The first occurrence of *Lithraphidites quadratus* was recognized within the *Belemnitella junior* Zone of NW Germany, i.e. within the *tegulatus/junior* Subzone, the lowermost subzone of the Upper Maastrichtian. According to the absence of the nannofossil *Micula murus* in our samples, the age cannot be younger than the top of the *Belemnitella junior* Zone. Integrating foraminiferal data, especially the lack of *Abathomphalus mayaroensis*, leads to a correlation of the investigated cephalopod horizon with the interval from the base of the *Spyridoceramus tegulatus /Belemnitella junior*

Subzone to the lower part of the *Tenuipteria argentea/Belemnitella junior* Subzone (BURNETT, 1998).



Text-Fig. 6: Section east of Haid (SUMMESBERGER et al., 2009).

Stop 4. Upper Turonian sandstones and rudists at Pitzengraben and along Noth road

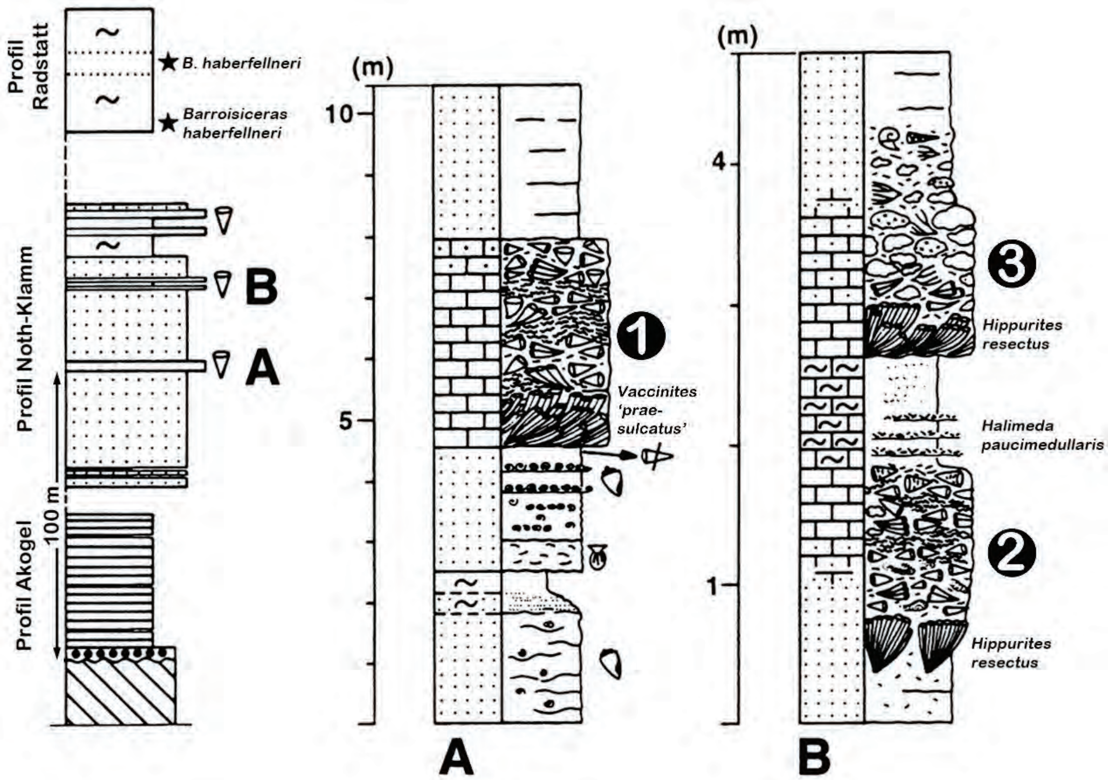
Coordinates: E 14°51'50", N 47°39'51".
Location: Roadside and riverbed outcrops W of the Noth gorge E of Gams (Styria); protected site!
Topic: Rudist reef, *Trochacteon lamarcki*, sandstones.
Lithostratigraphic unit: Noth Formation (Lower Gosau Subgroup).
Age: Late Turonian.
Tectonic unit: Untersberg Nappe/Göller Nappe (Tirolicum), NCA.
Specialities: Natural monument and Geopark.
References: SUMMESBERGER & KENNEDY (1996), SANDERS & PONS (1999), WAGREICH et al. (2009a, b).

The Pitzengraben outcrop shows the development of rudist formations on a wave-dominated, mixed siliciclastic-carbonate shelf. The basal part of the section comprises arenites with layers of paralic coal. One of these layers is exposed at the mouth of an abandoned coal mine.

The section A (Text-Fig. 7) which begins above the coal. Hybrid arenites with small benthic foraminifers and accumulations of *Trochacateon lamarcki* (SOWERBY) are sharply overlain by biostrome 1. In its lower part it is composed of densely packed hippuritids (*Vaccinites* cf. *sulcatus*). The upper part consists of an open to packed parautochthonous fabric of radiolitids and subordinate hippuritids. Lenses of floatstone composed of fragments from the radial funnel plates of radiolitids recognizable by their zig-zag pattern are intercalated. In the topmost part of the biostrome, the wackestone- to floatstone-matrix contains a few percent of siliciclastic sand and is mottled with burrows that are filled with sandstone. The biostrome is overlain by sandstone.

The higher part of the section (B) shows a monospecific thicket (biostrome 2) of *Hippurites resectus* in hybrid arenites with abundant *Quinqueloculina* and *Cuneolina* (Text-Fig. 7). The thicket is overlain by burrow-mottled sandy limestone with toppled *H. resectus* and *Radiolites*. Above follows a bioturbated, open parautochthonous biostrome of radiolitids. At the top, the biostrome grades into an interval of organic-rich, marly wackestones with

miliolids, *Cuneolina*, ostracods and coalified plant fragments. To save this outcrop it is protected by Austrian nature conservation law. Any kind of alteration is prohibited.
Serpentinitic sandstones are a conspicuous feature of this outcrop. Modal analysis indicates that serpentinitic grains make up more than 50 percent of particles. Chrome spinel is the predominating heavy mineral. Although no present-day local source for the serpentinitic grains is known, serpentinized ophiolitic bodies, which were interpreted as remnants of a Tethys (Hallstatt-Meliata) suture, must have been present within the NCA during the Cretaceous.



Text-Fig. 7: Rudist formations in mixed siliciclastic-carbonate environments, Pitzengraben, Gams (modified from SANDERS & PONS, 1999).

The overlying Radstadt section is nowadays fully covered by road construction material. It yielded a macrofauna characteristic of the Turonian/Coniacian boundary interval (KOLLMANN & SUMMESBERGER, 1982; SUMMESBERGER, 1985; SUMMESBERGER & KENNEDY, 1996). The bivalve *Didymotis costata* was found together with the ammonites *Barroisiceras haberfellneri and Reesidites minimus*. The occurrence of *Didymotis costata* is regarded as a marker for the base of the Coniacian. The lower part of the section is characterized by the presence of *Marginotruncana* taxa of the *coronota-pseudolinneiana*-group, the *sigali-renzi*-group, rare *Marginotruncana schneegansi* and the absence of both *Helvetoglobotruncana helvetica* and *Dicarinella primitiva*. This indicates the Late Turonian *Marginotruncana sigali* zone. The Turonian/Coniacian boundary with *Didymotis* at the Radstadt section is within nannofossil zone CC13 (*Marthasterites furcatus* zone). Up to this level *M. furcatus* is accompanied by common *Quadrum gartneri*. *Micula decussata* occurs further upwards in the Middle Coniacian.

Optional Stop 5 may include a visit to the Geozentrum, a museum that is connected to the Gams Geopark.

The type locality of the Gosau Group near Gosau

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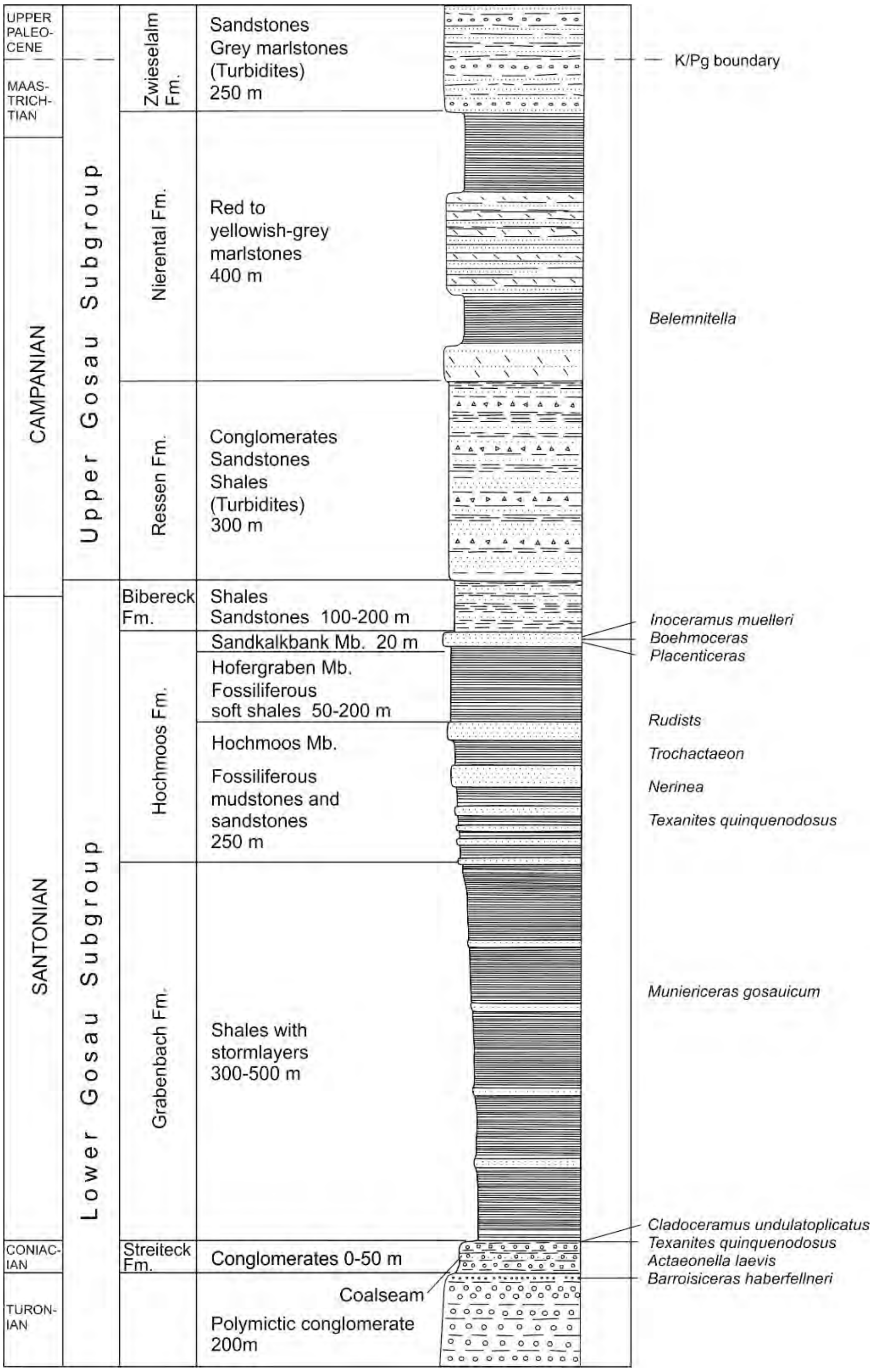
Upper Cretaceous deposits of the area of the villages Gosau (Upper Austria), Rußbach and Abtenau (Salzburg) comprise the type locality of the Gosau Group (Text-Fig. 8). Classical descriptions include SEDGWICK & MURCHISON (1832) and REUSS (1854).

The basin fill comprises about 1,000 m of Upper Turonian to Lower Campanian terrestrial and shallow-water sediments of the Lower Gosau Subgroup, which are unconformable overlain by more than 1,200 m thick deep-water deposits of the Upper Gosau Subgroup. The Upper Gosau Subgroup clearly seals Upper Turonian–Santonian basin bounding structures, as deep-water deposits of the UGS onlap the Triassic substrata. A reconstruction of the basin geometry of the Lower Gosau Subgroup results in an original basin about 8 to 10 km wide and 10 km long. Deposits in the area of Abtenau indicate that the composite Upper Cretaceous basin extended at least over 25 km.

The biostratigraphy, lithostratigraphy and sedimentology of the basin fill have been discussed in detail by HÖFLING (1985), TRÖGER & SUMMESBERGER (1994), SUMMESBERGER & KENNEDY (1996), WAGREICH (1992) based on WEIGEL (1937) and KOLLMANN (1982). At the base an up to 350 m thick interval of red alluvial conglomerates (**Kreuzgraben Formation**) of probably Late Turonian age is overlain by a transgressive succession of shallow-marine shales and backstepping coarsening-upward paracycles of the Upper Turonian to Coniacian **Streiteck Formation.** Conglomerates of the Kreuzgraben Formation were interpreted to record progradation and retrogradation of alluvial fans whereas parasequences of the Streiteck Formation are the result of fan-delta progradation. Foraminiferal assemblages suggest water depths of about 150 to 300 m at maximum flooding in early Santonian time, at the base of **Grabenbach Formation**. Storm-influenced shelf and near-shore sediments of up to 500 m, including rudist bioherms (HÖFLING, 1985), fill the basin in Santonian to early Campanian times, but are interrupted by a short erosional phase in early Campanian time (Grabenbach, **Hochmoos** and **Bibereck Formations**). The overlying Upper Gosau Subgroup starts with a sandstone-rich turbidite fan interval (**Ressen Formation**, Lower Campanian), followed by (hemi)pelagic shales and marly limestones (**Nierental Formation**, Upper Campanian–Maastrichtian) and a turbiditic interval (**Zwieselalm Formation**, Upper Maastrichtian–Paleocene/Eocene).



Text-Fig. 8: Composite lithostratigraphic section of the Gosau Group of Gosau and Rußbach including a selection of macrofossils; modified from SUMMESBERGER et al. (2017a, b, c).

Stop 6. Lake Gosau (Gosausee) in the Gosau valley

Coordinates: E 13°29'51", N 47°31'58".

Location: Parking area of Gosausee cable car near Gosausee (Upper Austria).

Topic: Dachstein Mountain scenery; Triassic of the NCA; Nierental Formation of the Rote Wand section.

Lithostratigraphic unit: Nierental Formation.

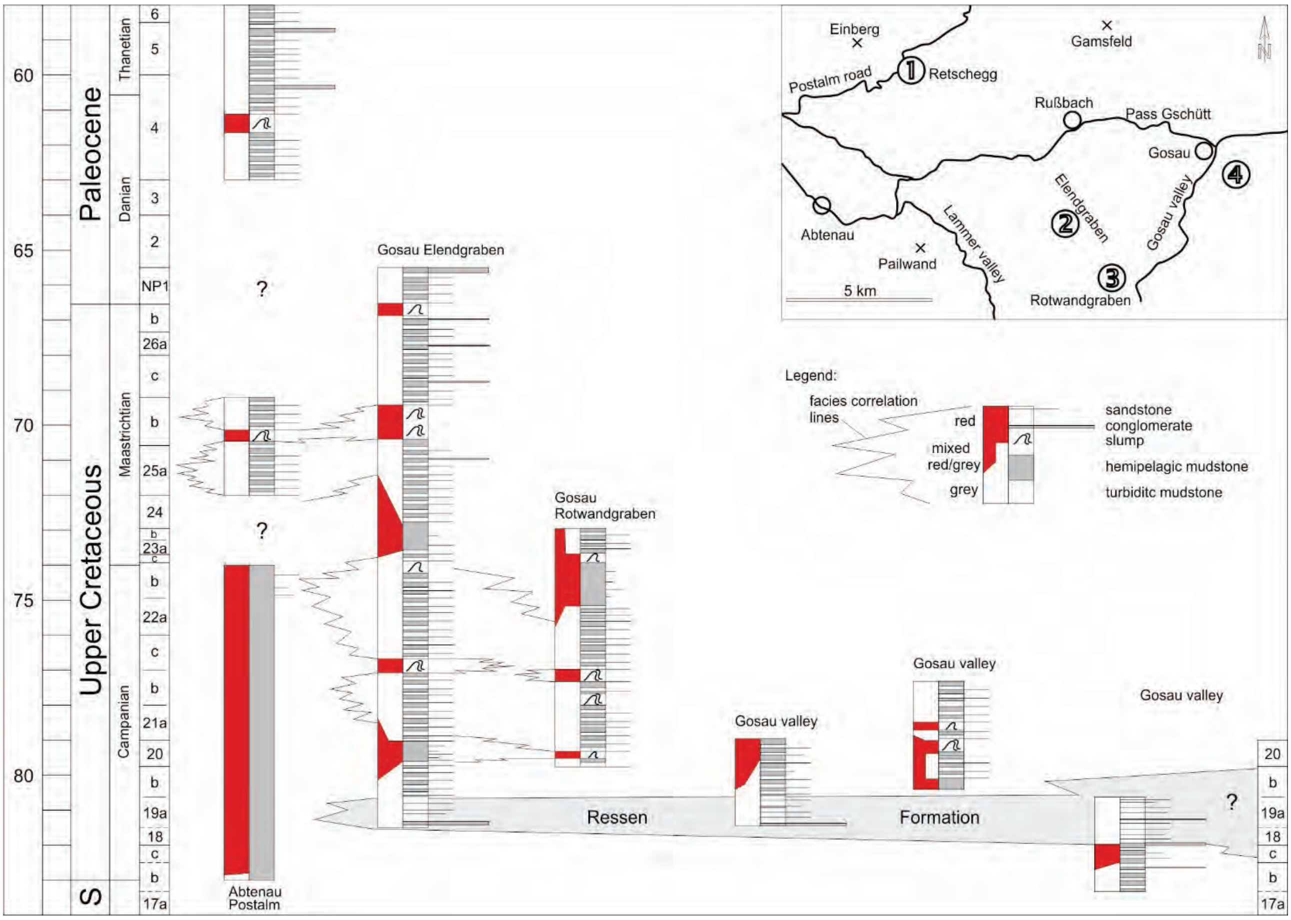
Age: Campanian–Maastrichtian.

Tectonic unit: Dachstein Nappe, NCA.

Specialities: View and photo stop.

References: PREISINGER et al. (1986), PERYT et al. (1997), WAGREICH & KRENMAYR (1993, 2005).

The scenery of the Lake Gosau and the Hohe Dachstein Mountain (3,004/2,996 m) is one of the most spectacular views of the Salzkammergut. The Triassic carbonates surrounding the lake comprise reef limestones of the Dachsteinkalk at the Gosaukamm, bedded cyclic Dachstein limestone of the Dachstein itself and deeper-water limestones (Pötschenkalk).
The not so famous view from the Gosausee to the north shows the "Rote Wand": interbedded hemipelagic and turbiditic red and grey shaly limestones of the Nierental Formation (Upper Campanian–Maastrichtian–Danian), including a complete K/Pg-boundary section (PREISINGER et al., 1986; Text-Fig. 9). Nannofossil biostratigraphy (WAGREICH & KRENMAYR, 1993, 2005) prove significant diachroneity of red, (hemi)pelagite rich intervals even in nearby sections, thus indicating the predominance of local factors (tectonics, sediment supply) in the control of pelagic CORB (Cretaceous Oceanic Red Beds) intervals rather than global processes like eustatic sea-level changes.



Text-Fig. 9: CORBs and nannofossil biostratigraphy of the Nierental Formation including the Rote Wand section (Rotwandgraben, modified from WAGREICH & KRENMAYR, 2005).

Stop 7. Upper Santonian rudist-limestones above a Santonian transgression

Coordinates: E 13°30'54", N 47°32'60".
Location: Outcrops along the Gosau valley main road at inn Gosauschmied.
Topic: Upper Santonian rudist-limestones above a Santonian transgression.
Lithostratigraphic unit: Hochmoos Formation (Lower Gosau Subgroup).
Age: Late Santonian CC17/ UC12-13.
Tectonic unit: Dachstein Nappe, NCA.
Specialities: Transgressive dolomite sands, rudists, large but rare radiolitids.
References: EGGER et al. (2000).

The rudist limestones at Gosauschmied (Gosau Hintertal) record a Santonian transgression starting with conglomerates, dolomitic sandstones and brackish marls, overlain by limestones rich in miliolids and rudists.

Stop 8. Sandkalkbank/Schattau-Rußbach (Upper Santonian)
Coordinates: E 13°30'48", N 47°34'50".
Location: Forest road to the Finstergraben N of village Gosau (Upper Austria).
Topic: Sandy to silty shales with macrofauna.
Lithostratigraphic unit: Hochmoos Formation.
Age: Late Santonian.
Tectonic unit: Dachstein Nappe, NCA.
Specialities: Fossils.
References: EGGER et al. (2000), WAGREICH et al. (2009a, b).

Outcrops along the Zwieselalm forest road expose fossiliferous silty to sandy shales of the Hochmoos Formation (Hofergraben Member, SUMMESBERGER et al., 2017a), interpreted as shallow marine pelitic deposits of the transition zone between nearshore and offshore sea. Sandstones of the Hochmoos Formation include nearshore/shoreface sediments, burrowed by *Ophiomorpha*-type burrows. Immediately above the silty shales the sandstones of the 20 m thick Sandkalkbank Member is visible. It yielded an abundant mollusk fauna with 23 gastropod taxa (KOLLMANN, 1980), 50 bivalve taxa (DHONDT, 1984) and 22 ammonite taxa (SUMMESBERGER, 1985). *Pinna* in life position and the articulated infauna of bivalves indicates a soft substratum and a low water energy level together with a fast sedimentation rate. The stratigraphic position in the upper part of the Late Santonian is based upon correlation of the heteromorph ammonite *Boehmoceras* with the Münster basin (Germany). Palaeobiogeographical connections to the Münster basin, North America (Gulf coast, Western Interior), Japan and Madagascar indicate a worldwide system of open waterways in Late Santonian times. Subtropical to tropical climate can be concluded from the occurrence of hermatypic corals and rudists in the Hochmoos Formation. The gastropod *Pleurotomaria* indicates the presence of cooler water temperatures at slightly greater depths; scaphitids and belemnites are absent.
Biostratigraphically the Sandkalkbank Member of the Hochmoos Formation belongs to the Upper Santonian *Boehmoceras arculus* Zone. The occurrence of *Boehmoceras arculus* allows precise correlation to the Münster basin (Germany) and to the Tombigbee Sand of Mississippi and Alabama. The correlative Schattau section was described by WAGREICH et al. (2009a) and more recently in detail by SUMMESBERGER et al. (2017c). There, the Upper Santonian Sandkalkbank Member is overlain by silty marls of the Bibereck Formation, yielding abundant echinoids including remnants of *Marsupites laevigatus* indicating still the *Dicarinella asymetrica* Zone below the base of the Campanian.

Ammonites
Gaudryceras mite (HAUER)
Saghalinites nuperus (VAN HOEPEN)
Damesites sugata (FORBES)
? *Parapuzosia* cf. *seppenradensis* (LANDOIS)
Kitchinites stenomphalus SUMMESBERGER
Hauericeras welschi GROSSOUVRE
Eupachydiscus isculensis (REDTENBACHER)
Nowakites draschei (REDTENBACHER)
Diaziceras austriacum (SUMMESBERGER)

Placenticeras polyopsis (DUJARDIN)
Placenticeras maherndli SUMMESBERGER
Placenticeras paraplanum (WIEDMANN)
Reginaites gappi WIEDMANN
Amapondella amapondensis (VAN HOEPEN)
Nostoceratide gen. et sp. indet. (? *Jouaniceras*)
Glyptoxoceras crispatum (MOBERG)
Baculites fuchsi REDTENBACHER
Baculites tanakai MATSUMOTO & OBATA
Baculites sp.
Boehmoceras arculus (MORTON)
Boehmoceras krekeleri (WEGNER)

Gastropods
Pleurotomaria sp.
Bathrotomaria subgigantea (D'ORBIGNY)
Keilostoma tabulata (ZEKELI)
Climacopoma quadrata (SOWERBY)
Torquesia rigida (SOWERBY)
Exechocirsus reticosus (SOWERBY)
Quadrinervus subtilis (ZEKELI)
Cyphosolenus sp.
Helicaulax gibbosus (ZEKELI)
Xenophora plicata (ZEKELI)
Pseudamaura sp.
Lunatia semiglobosa (ZEKELI)
Mesorhytis cancellata (SOWERBY)
?Palaeopsephaea sp.
Fusinus reussi (ZEKELI)
Fusinus subabbreviatus (ZEKELI)
Woodsella turbinata (ZEKELI)
Fuside indet.
Tudicla indet.
Volutide indet.
Gosavia squamosa (ZEKELI)
Licoarenus sp.
Acteonella elongata KOLLMANN

Bivalves
Nucula concinna SOWERBY
Nucula redempta ZITTEL
Nucula cf. *N. stachei* ZITTEL
Arca aquisgranensis J. MUELLER
Barbatia? inaequidentata (ZITTEL)
Cucullaea cf. *matheroniana* (D'ORBIGNY)
Limopsis calva SOWERBY
Glycymeris marrotianus (D'ORBIGNY)
Glycymeris noricus (ZITTEL)
Inoperna flagellifera (FORBES)
Modiolus typicus (FORBES)
Modiolus capitatus (ZITTEL)

Modiolus cf. *siliquus* (MATHÉRON)
Pinna cf. *cretacea* (SCHLOTHEIM)
Gervillia solenoides DEFRANCE
Gervbillaria neptuni (GOLDFUSS)
Pseudoptera raricosta (REUSS)
Aguileria ? falcata (ZITTEL)
Cordiceramus muelleri (PETRASCHECK)
Sphenoceramus angustus (BEYENBURG)
Platyceramus cycloides ahsenensis (SEITZ)
Camptonectes virgatus (NILSSON)
Merklinia septemplicata (NILSSON)
Neithea coquandi (PÉRON)
Spondylus coquandianus D'ORBIGNY
Spondylus requienianus MATHÉRON
Plagiostoma cretaceoum (WOODS)
Pycnodonte vesiculare (LAMARCK)
Ceratostreon pliciferum (DUJARDIN)
Mutiella ? coarctata (ZITTEL)
Astarte similis (MUENSTER in GOLDFUSS)
Crassatella macrodonta (J. SOWERBY)
Granocardium productum (J. SOWERBY)
Linearia costulata (GOLDFUSS)
Icanotia impar (ZITTEL)
Proveniella testacea (ZITTEL)
Ambocardia planidorsata (ZITTEL)
Pitar s.l. *matheroni ?* (ZITTEL)
Cytherea cf. *polymorpha* (ZITTEL)
Cyprimeria ? discus (MATHÉRON)
Legumen martinianus (MATHÉRON)
Cyclorisma ? dubiosa (ZITTEL)
Corbula ? angustata J. SOWERBY
Pholadomya nodulifera ? MUENSTER in GOLDFUSS
Cercomya ? producta (ZITTEL)
Poromya frequens (ZITTEL)

Stop 9. Pass Gschütt/Streiteck Formation (lunch stop)
Coordinates: E 13°29'13", N 47°35'33".
Location: Parking area at Streiteck, E Russbach (Salzburg), W Pass Gschütt.
Topic: Fan-delta cycles and shallow-marine sands.
Lithostratigraphic unit: Streiteck Formation.
Age: Coniacian.
Tectonic unit: Dachstein Nappe, NCA.
Specialities: Late Cretaceous basin formation, lunch stop.
References: WAGREICH & DECKER (2001).

Cyclic fan-delta conglomerates and sandstones and shallow-marine bioturbated sands including Skolithos are exposed along the Pass Gschütt road. A view to northwest reveals a large normal fault that formed the Gosau basin margin in Late Turonian to Santonian times.

Stop 10. Parking area Rußbach

Coordinates: E 13°27’42”, N 47°35’19”.
Location: Parking area of cable car to Horneck, SW Rußbach (Salzburg).
Topic: Tempestites and shales of the Grabenbach Formation; transgression onto Triassic limestones.
Lithostratigraphic unit: Grabenbach Formation.
Age: Early Santonian.
Tectonic unit: Dachstein Nappe (Juvavicum).
Specialities: Not much to see any more.
References: EGGER et al. (2000).

At the parking area of the cable car Rußbach/Horneck a reduced succession of the Lower Gosau Subgroup was exposed (Text-Fig. 10). A thin interval of conglomerates and coals is followed by shales and fine grained sandstones of the Grabenbach Formation. Ammonites and inoceramids prove an early Santonian age. Planktonic foraminifera give evidence for the *Dicarinella concavata* Zone, nannofossils indicate standard zone UC11/CC14-15 (e.g. *Marthasterites furcatus*, *Micula decussata*). Sandstones of the Grabenbach Formation show features of tempestites (e.g. small-scaled hummocky cross stratification, wave ripples, flute casts). The outcrop yielded *Cladoceramus undulatoplicatus* (ROEMER), *Platyceramus cycloides cycloides* (WEGNER) and Texanites quinquenodosus (REDTENBACHER) besides other species.

Text-Fig. 10: Rußbach, parking area at the cable car station (Hornspitzbahn). Basal Grabenbach Formation with ammonites and inoceramids, resting upon layers of shales with pebbles, coalseam, corals, gastropods (Streiteck Formation). Transgression upon Triassic rocks (right side).

Stop 11. Section through the Lower Gosau Subgroup, Randograben

Coordinates: First part at E 13°28'42", N 47°36'02".
Location: Section along the forest road to Randobach, NW Rußbach (Salzburg), to Stöcklwaldgraben and Schneckenwand.
Topic: Section within the Lower Gosau Subgroup; red terrestrial conglomerates of alluvial fans, fan-delta sediments, shelf shales and tempestites, rudist bioherm.
Lithostratigraphic units: Kreuzgraben Formation, Streiteck Formation, Grabenbach Formation, Hochmoos Formation (Lower Gosau Subgroup).
Age: Late Turonian–Santonian.
Tectonic unit: Dachstein Nappe, NCA.
Specialities: Hiking tour through stratigraphy with future natural monument (Schneckenwand).
References: KOLLMANN & SUMMESBERGER (1982), EGGER et al. (2000).

Outcrops within the Randograben provide a nearly complete section within the lower part of the Lower Gosau Subgroup. Outcrops include fan-delta conglomerate cycles, shelf shales and marls with a few siliciclastic tempestites of the Grabenbach Formation and fossiliferous marls and limestones of the Hochmoos Formation. Walk upstream (at first stratigraphically downwards) along forest road to junction to the Stöcklwaldgraben and (from now stratigraphically upwards) up to the Schneckenwand.

Stop 11/1. Hochmoos Formation with coarse and fine-grained tempestites.
An 80 m coarsening/thickening upward succession within the Hochmoos Formation grades from silty shales to sandstones and ends with fine conglomerates. The sandstones are strongly bioturbated, including *Ophiomorpha*- and *Thalassinoides*-burrows and show shell-layers at their bases and hummocky cross-stratification. The microfauna is predominated by miliolids and ostracods. Nannofossil data indicate CC16 to CC17 by the presence of *Lucianorhabdus cayeuxii* and rare *Calculites obscurus*. Bivalves (*Pinna*, Pholadidae) in life position.

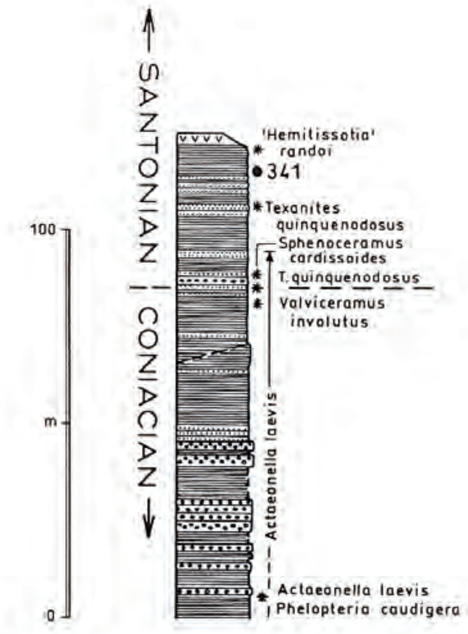
Stop 11/2. Exposures in the streambed, visit depending on water conditions: relatively fossiliferous Grabenbach Formation.
70 m upstream from the first bridge over the Randobach creek. Hard sandstone on the left side of the riverbed containing:
Muniericeras gosauicum (HAUER)
Texanites quinquenodosus (REDTENBACHER)
Baculites sp.
Fossils are typical of Santonian, possibly Middle Santonian age.

Stop 11/3. Coniacian/Santonian boundary in the transition from marly fossiliferous Streiteck Formation to shaly Grabenbach Formation in streambed. Marls include (after TRÖGER & SUMMESBERGER, 1994):
Cladoceramus undulatoplicatus (ROEMER)
Platyceramus cycloides cycloides (WEGNER)
Sphenoceramus cardissoides (GOLDFUSS)
Parapuzosia daubreéi (GROSSOUVRE)
Eulophoceras natalensei
Texanites quinquenodosus (REDTENBACHER)
All fossils are indicative of early Santonian age. The FO of *Dicarinella asymetrica*, *Sigalia carpatica* and nannofossils of the *Amphizygus* group characterize the boundary interval. The content of planktonic foraminifera is gradually increasing into the Santonian.

Stop 11/4. Roadside exposure in Streiteck Formation possibly of top Coniacian age with abundant *Acteonella laevis.*

Stop 11/5. Overgrown exposure in lower part of the Streiteck Formation with fine conglomerates and clayey intercalations with coal seams (Coniacian), and red conglomerates of the Kreuzgraben Formation (Upper Turonian).

Stop 11/6. Streiteck Formation in the Stöcklwaldgraben (Text-Fig. 11) including Top-Coniacian.
The content of planktonic foraminifera is gradually increasing up to 40 % from the Coniacian into the Santonian, where the planktonic foraminiferal fauna consists mostly of large sized marginotruncanids, biserial planktonics, dicarinellids and archeoglobigerinids. The assumed waterdepth ranges from approximately 20 meters to a maximum of 150 meters and is based on foraminiferal paleoecology.



Text-Fig. 11: The Coniacian/Santonian boundary in the Stöcklwaldgraben, a subsidiary of the Randograben. Top-Coniacian is proved by the occurrence of *Volviceramus involutus*, basal Santonian by the co-occurrence of *Texanites quinquenodosus*, *Sphenoceramus cardissoides* and *Cladoceramus undulatoplicatus*; *Eulophoceras natalense* ("*Hemitissotia randoi*" of older literature) is a useful local marker of the Lower Santonian (TRÖGER & SUMMESBERGER, 1994); according to WAGREICH (1992) *Dicarinella asymetrica* starts in the topmost part of the section.

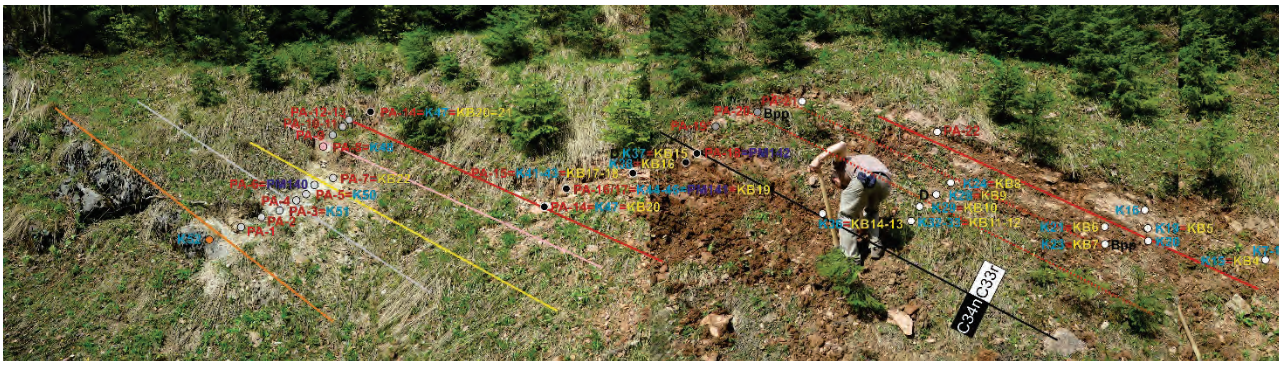
Stop 11/7. Schneckenwand outcrop of Hochmoos Formation (Upper Santonian) with abundant *Trochactaeon giganteus*. A lagoonal setting is interpreted for these gastropod mass occurrences (Natural Monument, no hammering allowed).

Stop 12. Postalm road, Abtenau, Gosau Group

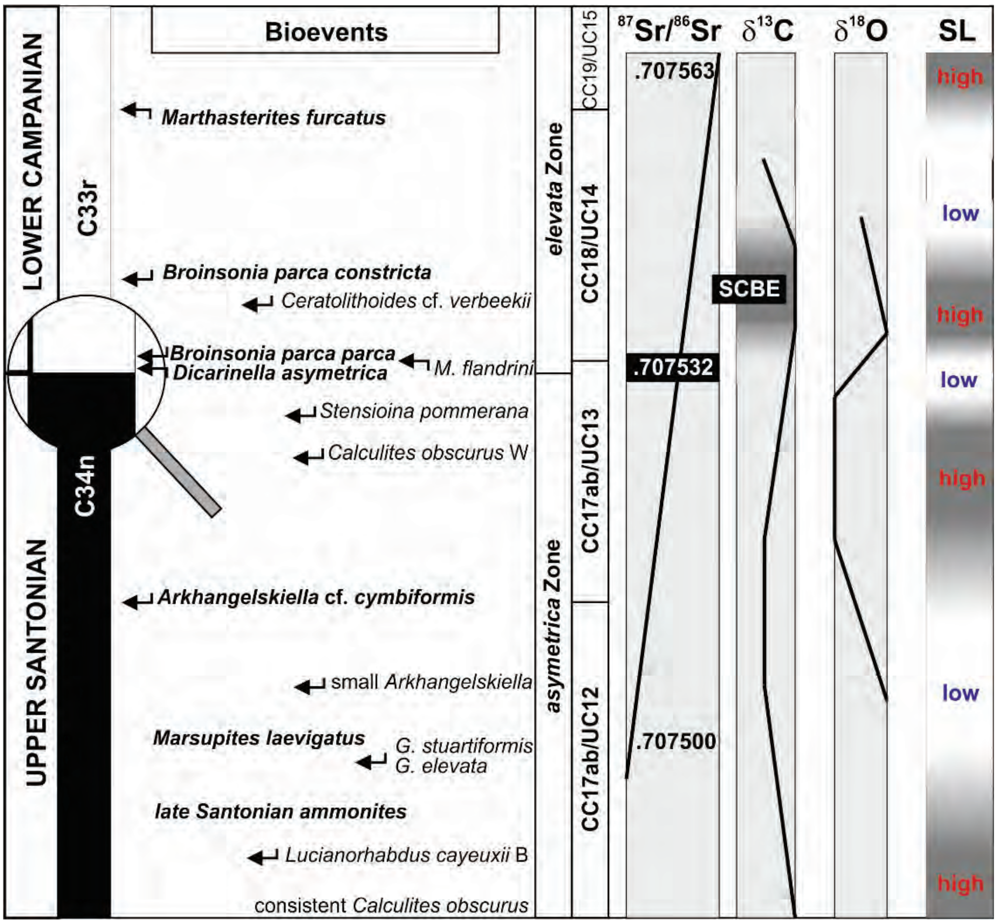
Coordinates: E 13°23'11", N 47°36'44".
Location: Postalm roadcut (Salzburg) near Rigaus, 7 km NNW of Abtenau (Salzburg).
Topic: Section through the upper part of the Gosau Group; sequence boundary on top of Hochmoos Formation; red marly cyclic limestones of Nierental Formation; Zwieselalm Formation.
Lithostratigraphic units: Gosau Group, Hochmoos-, Bibereck- and Nierental Formation.
Age: Late Santonian–Campanian.
Tectonic unit: Lammer Unit, NCA.
Specialities: Mountain road to one of the largest alpine meadow areas of the Postalm.
References: KRENMAYR (1996), WAGREICH et al. (2012), WOLFGRING et al. (2015), WOLFGRING & WAGREICH (2016), NEUHUBER et al. (2016).

Stop 12/1. Santonian/Campanian boundary

The boundary between the Lower Gosau Subgroup and the Upper Gosau Subgroup is characterized by short-time uplift and erosion at this basin-marginal setting, followed by fast subsidence into bathyal depths. A robust magnetostratigraphy was established. Including nearby complementary sections, palaeomagnetic data can be integrated with stable isotope data, planktonic foraminifera and calcareous nannoplankton biostratigraphy, strontium isotope stratigraphy, and ammonite, crinoid and inoceramid data. The Postalm section (Text-Fig. 12) shows a deepening trend from Upper Santonian conglomerates (Hochmoos Formation) and grey shelf marls (Bibereck Formation) to pelagic bathyal red marly limestones (Nierental Formation) of Campanian age. Palaeomagnetic data allow identifying the top of Chron C34n and the following reversal in the lower part of the red marly limestones. A 1 m-thick interval of high magnetic susceptibility is present at the end of C34n. Two of the main suggested biomarkers to pinpoint the Santonian/Campanian boundary, i.e. the last occurrence of the planktonic foraminifer *Dicarinella asymetrica* and the first occurrence of the nannofossil *Broinsonia parca parca*, occur in close proximity to the reversal, which is suggested herein as the primary marker event for the base of the Campanian. Strontium isotope stratigraphy indicates a value of 0.707534. Both carbon and oxygen isotope values show a negative excursion just below the boundary. The positive Santonian/Campanian boundary carbon isotope event (SCBE) starts probably just at the boundary level. This interval is considered to correspond to a short sea-level high in the Late Santonian followed by a lowstand at the Santonian/Campanian boundary (Text-Fig. 13). Macrofossil data from the nearby Schattau section (WAGREICH et al., 2009a; SUMMESBERGER et al., 2017b, c) indicate the Late Santonian *Paraplanum* ammonite Subzone, the presence of the crinoid *Marsupites laevigatus* and inoceramids, e.g. *Cordiceramus muelleri muelleri,* below the boundary as defined by magnetostratigraphy.



Text-Fig. 12: Postalm-road near Abtenau-Rigaus, Top of Hochmoos Formation to the left, followed by grey marls of Bibereck Formation and red marly limestones of the Nierental Formation, including the base of the Campanian as defined by the base of magnetochron C33r.

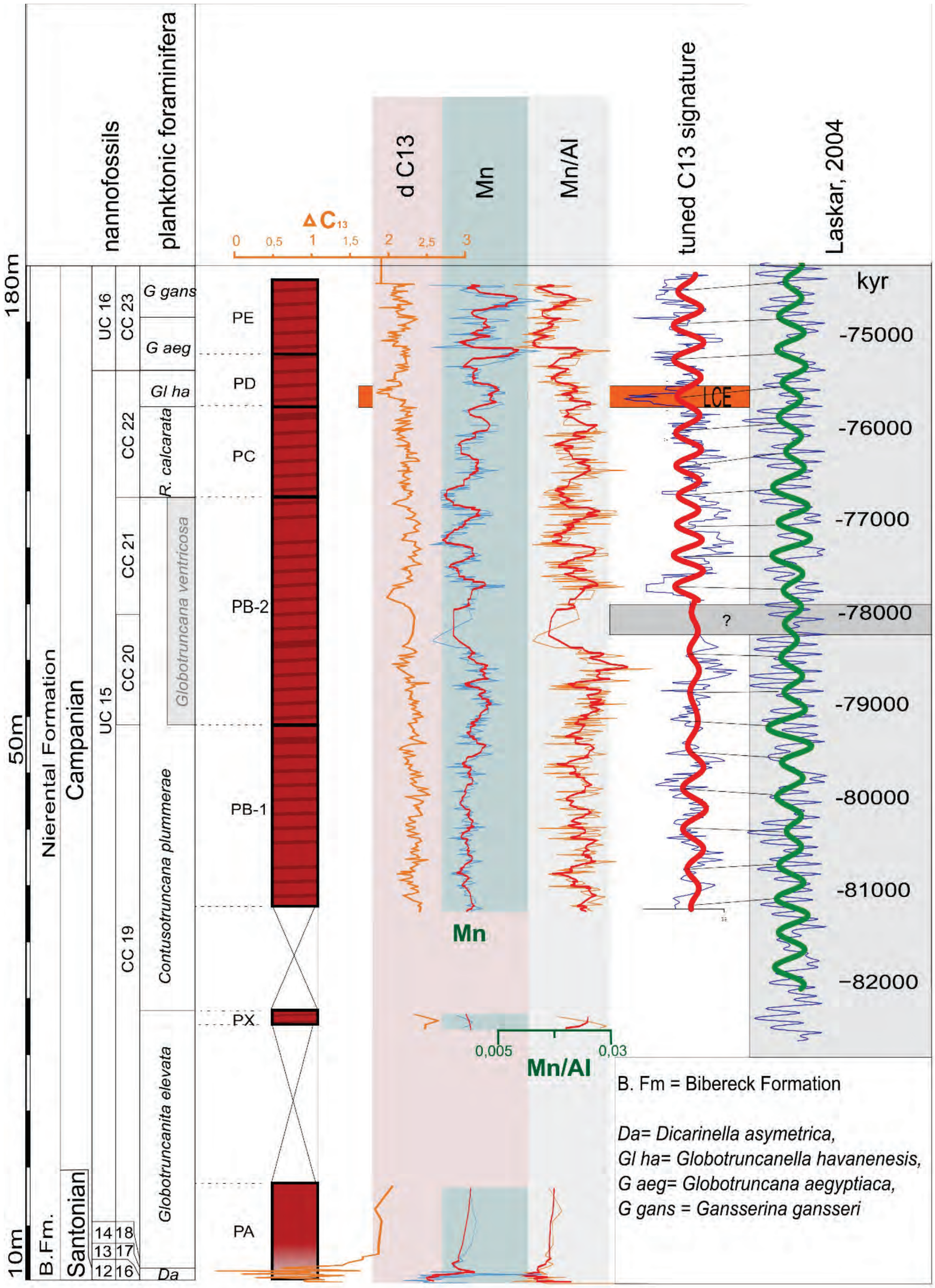


Text-Fig. 13: Composite stratigraphy and events around the Santonian/Campanian boundary interval at the Postalm PA and nearby Gosau Group sections.

Stop 12/2. Campanian Nierental Formation

The Nierental Formation (Upper Gosau Subgroup) is characterized by marlstones and red marly limestones (Text-Fig. 14). The red marly limestones (carbonate contents 67–80 %) are interpreted as pelagites (KRENMAYR, 1996). Percentages of planktonic foraminifera of the total sediment are more than 10 %. No grain size trends within the siliciclastic fraction was detectable. Sedimentation rates are about 20 mm/1,000 a. Fragments of inoceramids concentrated by bottom currents increase upsection. In the uppermost part of the section, mm-thick grey, fine sandstone to siltstone turbidite layers are intercalated. They represent distal turbidites of a small, but sandstone-rich deep-water fan of the Ressen Formation of the Gosau area.

Biostratigraphic data are based on moderately preserved nannofossil assemblages, which indicate a complete Campanian section from UC14/CC18 (FO of *Broinsonia parca*) to UC16/CC23. Planktonic foraminifera include the *D. asymetrica* to *G. gansseri* Zones. A complete cyclic record of the Upper Campanian is preserved.

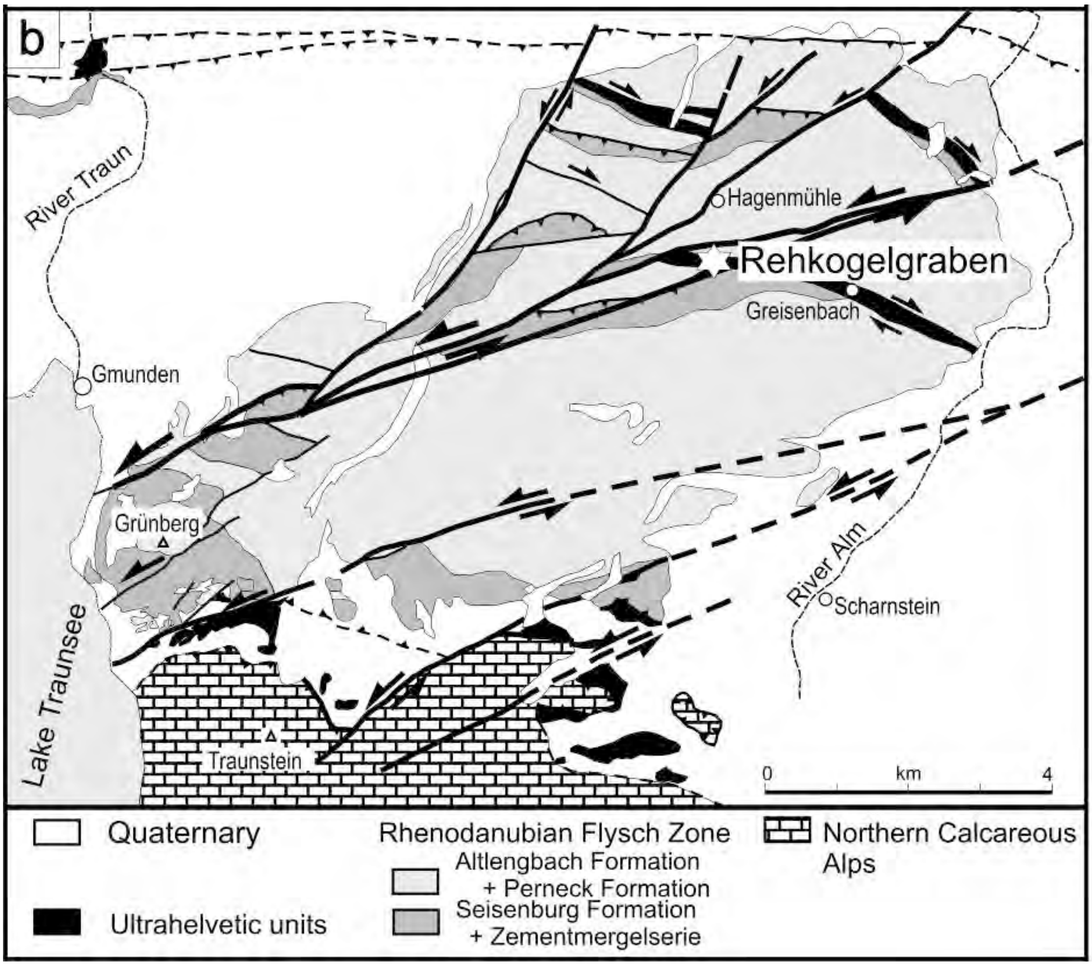


Text-Fig. 14: Postalm section along the road cut. Although the lower part of the Campanian is partly covered, the upper part is continuously exposed and shows a highly cyclic record including the *calcarata* Zone.

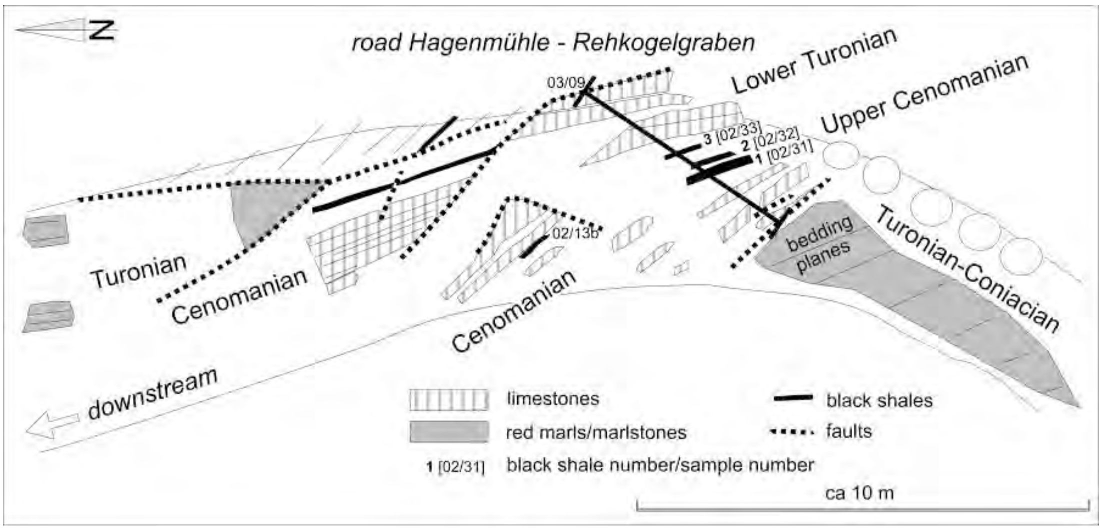
Stop 13. Cenomanian–Turonian at Rehkogelgraben/Hagenmühle (Upper Austria)
Coordinates: E 13°55'30", N 47°56'08".
Location: Outcrops in Rehkogelgraben creek.
Topic: Hemipelagic sediments, black shales and the Cenomanian-Turonian transition, CORBs.
Lithostratigraphic unit: "Buntmergelserie" (Upper Gosau Subgroup).
Age: Upper part of *Gansserina gansseri* Zone, CC25b/ UC20a^{TP}.
Tectonic unit: Ultrahelvetic Unit.
Specialities: Black shales below water table and cyclicity including CORBs.
References: RÖGL in KOLLMANN & SUMMESBERGER (1982), WAGREICH et al. (2008), GEBHARDT et al. (2010), PAVLISHINA & WAGREICH (2012).

The Ultrahelvetic units of Austria preserve remnants of the European continental slope sediments, positioned originally between the foreland and Helvetic shelf to the north and the abyssal Rhenodanubian/Penninic Flysch basins, a part of the Alpine Tethys. The Rehkogelgraben section (KOLLMANN & SUMMESBERGER, 1982) belongs to an Ultrahelvetic tectonic slice within the Rhenodanubian Flysch Zone between Hagenmühle and Greisenbach, to the east of Gmunden (Upper Austria, Text-Fig. 15). Strata within these tectonic windows have been traditionally attributed to the "Buntmergelserie", an informal lithostratigraphic unit comprising Aptian/Albian to Eocene pelagic and hemipelagic shales, marlstones, and marly limestones with rhythmic limestone and marl alterations. Upper to middle bathyal water depths have been inferred for the Ultrahelvetic units. The Cenomanian/Turonian boundary section includes distinctive black shale horizons and a transition from black shales into marly limestones and red marls, which are typical for Ultrahelvetic sections in Upper Austria (Text-Fig. 16). Above this succession, a distinct red pelagic interval follows from the Lower/Middle Turonian onwards, a typical CORB (Cretaceous Oceanic Red Beds) facies, including Santonian cyclic CORBs with red marlstones and white marly limestones (NEUHUBER & WAGREICH, 2009, 2010).

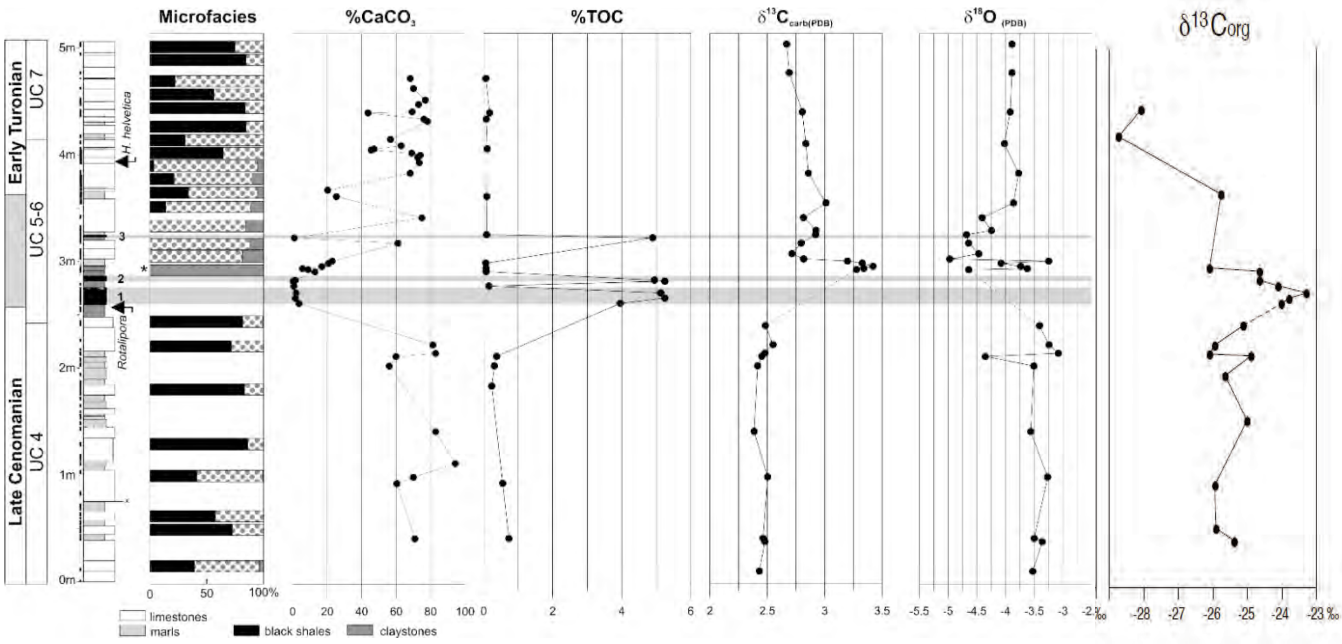
The Cenomanian/Turonian boundary section comprises a 5 m thick succession of Upper Cenomanian marl-limestone cycles overlain by a black shale interval composed of three black shale layers and carbonate-free claystones, followed by Lower Turonian white to light grey marly limestones with thin marl layers (Text-Fig. 17). The main biostratigraphic events in the section are the last occurrence of *Rotalipora* and the first occurrences of the planktonic foraminifer *Helvetoglobotruncana helvetica* and the nannofossil *Quadrum gartneri*. The thickest black shale horizon has a TOC content of about 5 %, with predominantly marine organic matter of kerogen type II. Vitrinite reflectance and Rock-Eval parameter T_{max} (< 424° C) indicate low maturity. HI values range from 261 to 362 mg HC/g TOC. $\delta^{13}C$ values of bulk rock carbonates and organic matter display the well-documented positive shift around the black shale interval, allowing correlation of the Rehkogelgraben section with other sections such as the GSSP succession at Pueblo, USA. In the lower part of the section, $\delta^{13}C_{carb}$ values lie uniformly around 2.5 ‰ and show a slight decrease before the first minor peak of 2.6 ‰, which is associated with the LO of the nannofossil *Lithraphidites acutus.* The FO of the nannofossil *Eprolithus octopetalus*, above black shale 2, is associated with a second carbon isotope peak of up to 3.4 ‰, followed by a small peak below 3 ‰ immediately after last the increase in TOC, succeed by a final peak of 3 ‰. Towards the top of the section, values progressively decrease down to 2.7. Sedimentation rates at Rehkogelgraben (average 2.5 mm/ka) are significantly low.



Text-Fig. 15: Geological sketch map of the area east of Gmunden, including outcrop Rehkogelgraben.



Text-Fig. 16: Map view sketch of the Cenomanian-Turonian outcrop in the creek Rehkogelgraben.



Text-Fig. 17: Sedimentological log of the Rehkogelgraben Cenomanian–Turonian section, including microfacies data based on counts of planktonic foraminifera (black), calcispheres (stippled) and radiolaria (grey) in selected thin sections, carbonate and TOC contents, carbon and oxygen isotope values (WAGREICH et al., 2008; GEBHARDT et al., 2010).

The Danubian Cretaceous Group of Bavaria

(Markus Wilmsen[1], Birgit Niebuhr[1] & Thomas Pürner[2])

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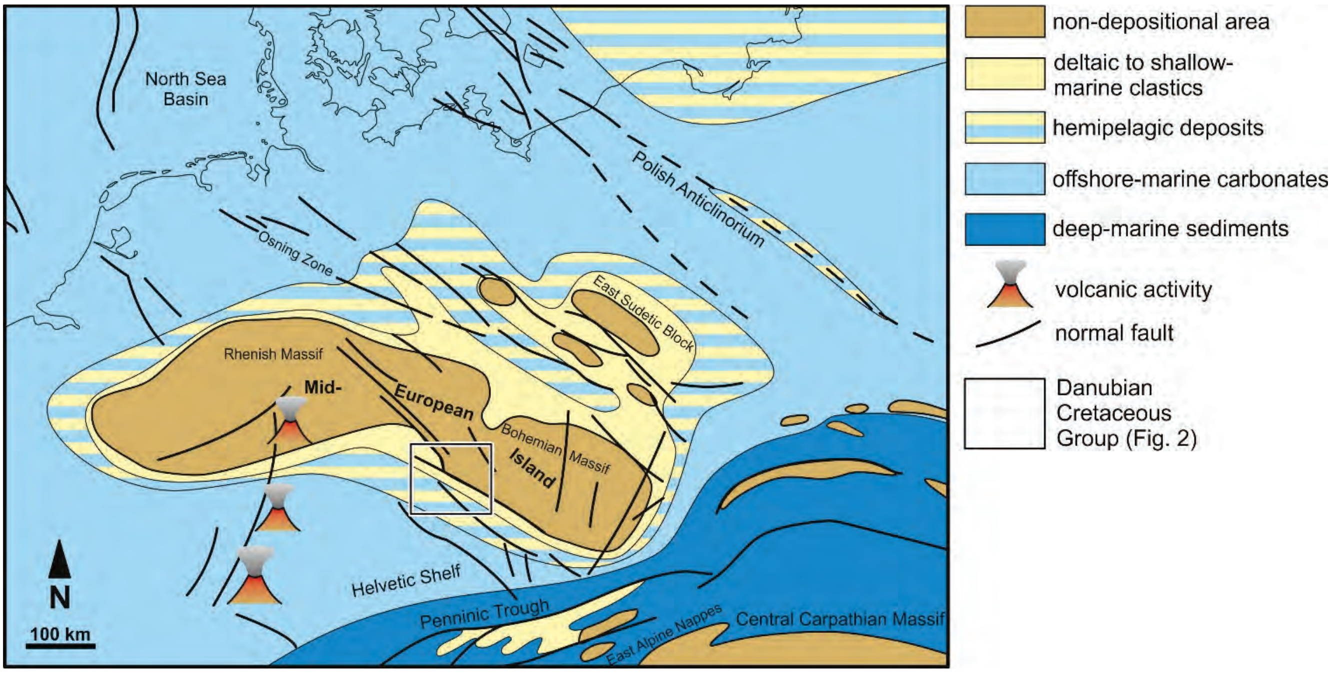
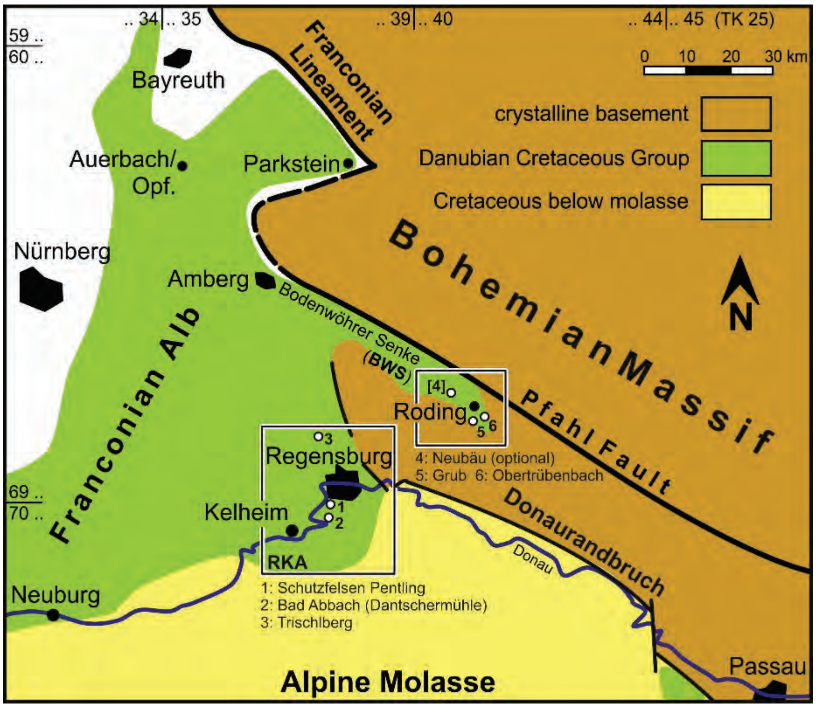
Geological setting and lithostratigraphic framework

At the southern margin of the Mid European Island (MEI), a large, E–W trending positive structure in Central Europe (Ziegler, 1990; Vejbaek et al., 2010), Cretaceous strata of the Danubian Cretaceous Group (Niebuhr et al., 2009) reflect dynamic depositional conditions in a peri-continental setting at the northern margin of the Alpine Tethys (Text-Fig. 18). Related to the rather proximal position close to elevated topography of the Bohemian Massif, sediments of highly variable facies and thickness accumulated, representing various depositional environments including continental, marginal marine and neritic settings (e.g. Niebuhr et al., 2009, 2011, 2012, 2014; Wilmsen et al., 2010a; Richardt et al., 2013). 3rd-order sea-level changes superimposed onto the general 2nd-order rise during the early Late Cretaceous are well represented by conspicuous sedimentary unconformities (e.g., Wilmsen et al., 2014) defining in total ten Cenomanian and Turonian depositional sequences that almost exclusively consist of transgressive and highstand systems tracts only (Niebuhr et al., 2014). Their correlative nature across different basins in the periphery of the Mid-European Island suggest eustatic sea-level changes as one of the main drivers of stratigraphic architectures and onlap patterns during the early Late Cretaceous (Niebuhr et al., 2014; Janetschke et al., 2015). Further control on basin development and sedimentation was related to the onset of tectonic inversion along the marginal faults of the Bohemian Massif in the Middle Turonian (Niebuhr et al., 2011). The onset of this widespread Late Cretaceous inversion phase (e.g., Ziegler et al., 1995) was related to a change in relative motion between the European and African plates (NE-directed convergence) at ca. 90 Ma, i.e. within the Turonian (Kley & Voigt, 2008).



Text-Fig. 18: Late Cretaceous palaeogeography in Central Europe (modified after Vejbaek et al., 2010). The area of Text-Figure 19 is framed.

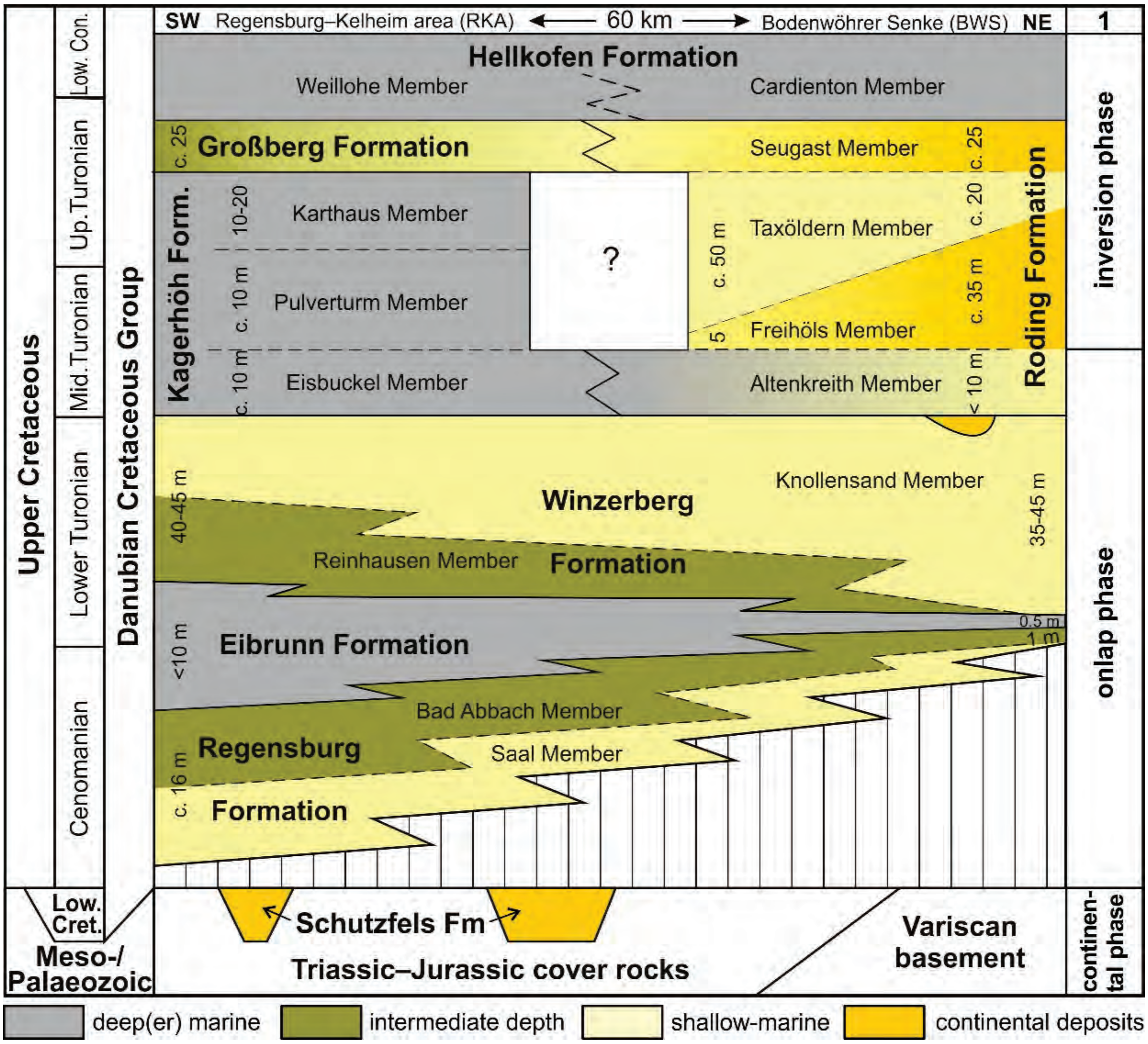
The extra-Alpine Cretaceous sedimentary strata of northern and north-eastern Bavaria (i.e., the Danubian Cretaceous Group) attain thicknesses of up to 500 m and comprise clays, marls, opokas, limestones, calcarenites, sandstones and conglomerates (e.g., NIEBUHR et al., 2009, 2011, 2012; WILMSEN et al., 2010a, b; RICHARDT et al., 2013). Initial marine transgression from the Tethyan Ocean in the south into southern part of the Danubian Cretaceous Basin (Regensburg–Kelheim area, Text-Fig. 19) occurred in Early Cenomanian times across a peneplained landscape mainly composed of Upper Jurassic carbonates (WILMSEN & NIEBUHR, 2010; WILMSEN et al., 2010a). The onlapping deposits are represented by the glauconitic sandstones (Saal Member) and silty to spiculitic marlstones (Bad Abbach Member) of the time-transgressive Regensburg Formation (WILMSEN et al., 2010a; Text-Fig. 20). The preceding continental episode during the Early Cretaceous is documented by a major paleokarst on top of the widespread Upper Jurassic carbonates (Weißjura Group of NIEBUHR & PÜRNER, 2014) and the patchily distributed pre-Cenomanian Schutzfels Formation, the oldest continental deposits of the Danubian Cretaceous Group, which is mainly preserved in sinkholes (Text-Fig. 20). With a north-eastward-directed trend, the early Late Cretaceous sea arrived in the proximal regions of the Danubian Cretaceous Basin, i.e., the Bodenwöhrer Senke (Text-Fig. 19) not before the mid-Late Cenomanian to earliest Turonian (WILMSEN et al., 2010a, b; RICHARDT et al., 2013), resulting in the onlap of the Regensburg Formation onto older Mesozoic strata (Triassic, Jurassic) and Variscan basement rocks of the Bohemian Massif (eastern part of the Mid-European Island). Following a maximum flooding episode in the earliest Turonian (marly offshore deposits of the Eibrunn Formation), the spiculitic calcareous siltstones (Reinhausen Member) and sandstones (Knollensand Member) of the Lower Turonian Winzerberg Formation filled the accommodation generated by the latest Cenomanian–earliest Turonian sea-level rise with more or less equal thicknesses in the entire depositional area (Text-Fig. 20). The onlap phase of the Danubian Cretaceous Group continued into the early Middle Turonian with the lower Middle Turonian Eisbuckel Member of the lower Kagerhöh Formation and the Altenkreith Member of the lower Roding Formation, respectively (NIEBUHR et al., 2014; Text-Fig. 20).



Text-Fig. 19: Distribution of the principal geological units in northeastern Bavaria (modified after NIEBUHR et al. 2014).
The Regensburg–Kelheim area (RKA) and the Bodenwöhrer Senke (BWS) as well as the six visited outcrops are indicated.

From the mid-Middle Turonian onwards, strong facies differentiation between proximal and distal areas started to develop, caused by the onset of initial inversion tectonics at the southwestern margin of the Bohemian Massif (NIEBUHR et al., 2011) related to SW/NE-directed compression (KLEY & VOIGT, 2008) and beginning the inversion phase in the

deposition of the Danubian Cretaceous Group (NIEBUHR et al., 2014). Until Coniacian times, predominantly marine influenced deposition continued, interrupted in the Bodenwöhrer Senke by some non-marine to estuarine episodes during the Middle–Late Turonian (Freihöls and Seugast members of the Roding Formation; NIEBUHR et al., 2011; Text-Fig. 20). In the Regensburg–Kelheim area, the calcareous upper Middle to Upper Turonian Pulverturm and Karthaus members of the Kagerhöh Formation as well as the Upper Turonian Großberg Formation correspond to the coeval Freihöls, Taxöldern and Seugast members of the Roding Formation in the proximal Bodenwöhrer Senke. The uppermost Turonian to Lower Coniacian Hellkofen Formation is again distributed across both principal depositional domains (Text-Fig. 20).
The outcrops visited during this field trip are located in the Regensburg–Kelheim area (stops 1–3) and within the Bodenwöhrer Senke (stops 4–6). Their study allows a reconstruction of the Early Cretaceous continental phase and the Cenomanian to early Middle Turonian onlap phase of the Danubian Cretaceous Group (cf. NIEBUHR et al., 2014; Text-Fig. 20). Due to the limitation of time, the inversion phase will not be treated in the framework of this field trip (see NIEBUHR et al., 2011 for details).



Text-Fig. 20: Lithostratigraphy of the Danubian Cretaceous Group (modified after NIEBUHR et al., 2014). Note the distal–proximal trends from the Regensburg–Kelheim area (RKA) to the Bodenwöhrer Senke (BWS). 1: tectono-sedimentary stratigraphic phases of NIEBUHR et al. (2014). See text for further explanation.

Stop 14. Schutzfelsen near Pentling

Coordinates: E 12°02'48", N 48°59'31".

Location: Outcrops along the outer bank of the River Danube northwest of Pentling, southwest of Regensburg.

Topic: Depositional setting and stratigraphy of Lower Cretaceous terrestrial deposits.

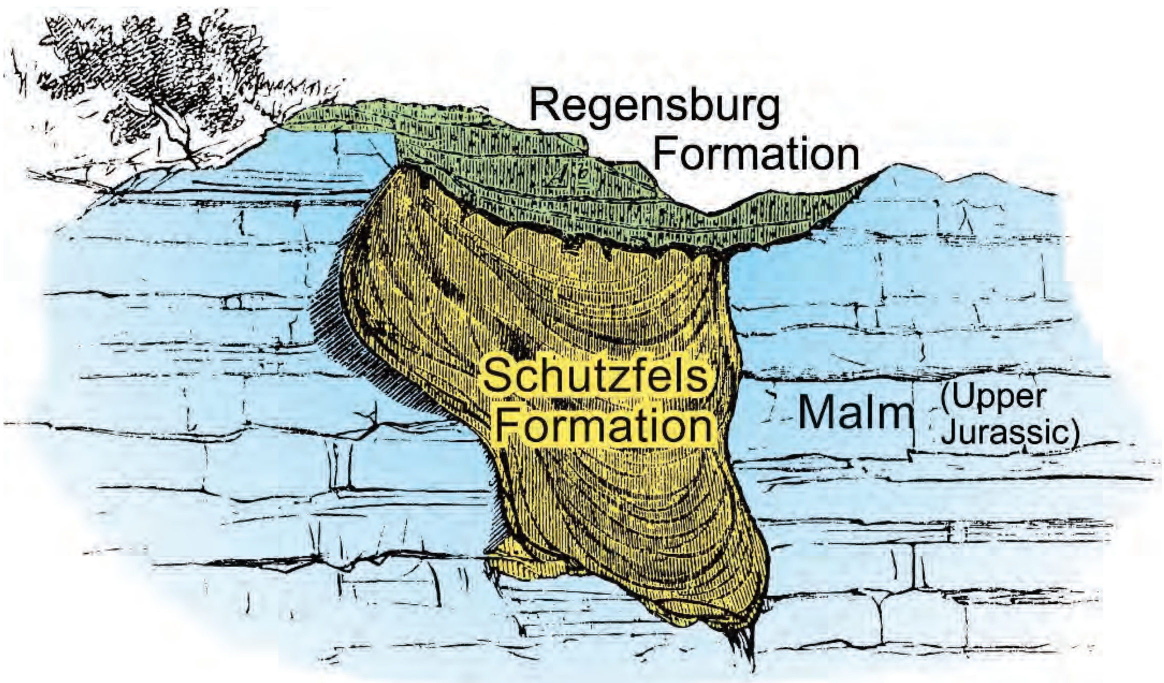
Lithostratigraphic units: Schutzfels- and Regensburg Formation.

Age: Early Cretaceous (post-Early Tithonian to pre-Cenomanian) and Early Cenomanian.

Specialities: Deposition and preservation of Lower Cretaceous terrestrial deposits in pre-Cenomanian sinkholes covered by shallow-marine Cenomanian greensands of the Regensburg Formation.

References: GÜMBEL (1854, 1868), TRUSHEIM (1935), NIEBUHR et al. (2009), BAYERISCHES LANDESAMT FÜR UMWELT (2011).

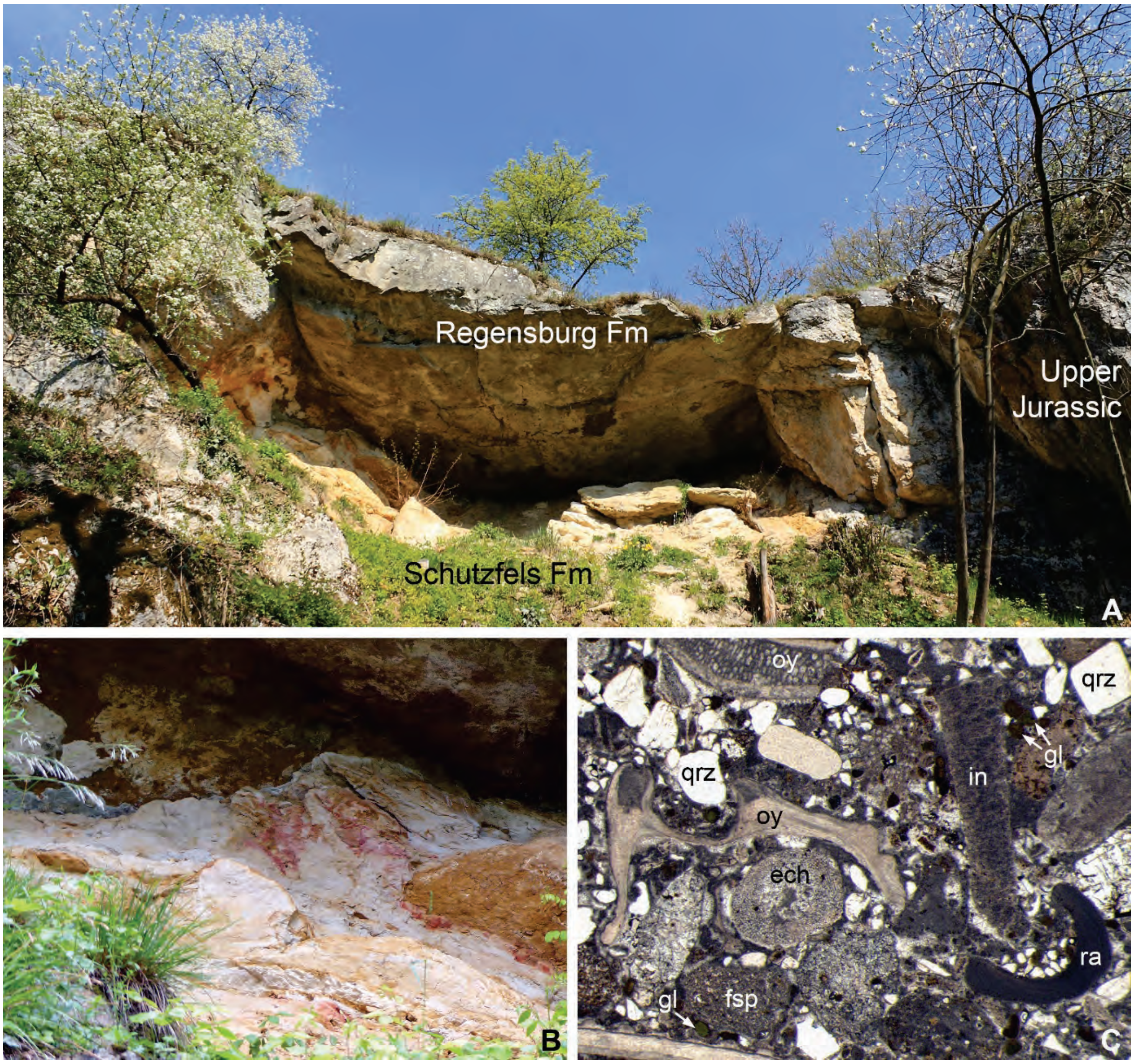
The Schutzfelsen exposes a poorly lithified succession of varicoloured continental siliciclastics that rest within an Early Cretaceous sinkhole that formed in massive Upper Jurassic dolomites of the Frankenalb Formation of NIEBUHR & PÜRNER (2014). Both units are covered by Lower Cenomanian strata of the shallow marine Regensburg Formation. It was the well-known Bavarian geologist Carl Wilhelm Gümbel (1823–1898) who coined in 1854 the name "Schutzfelsschichten" (Schutzfels beds) for these continental strata (Text-Fig. 21), and the Schutzfelsen is thus the type locality of the Lower Cretaceous Schutzfels Formation (NIEBUHR et al., 2009). The name "Schutzfelsen" (rock shelter) is related to the botanist David Heinrich Hoppe (1760–1846) who used the cave-like outcrop as shelter when he was overtaken by a heavy thunderstorm during a botanical hike in the area. While waiting for the waning of the storm, Hoppe got the idea for the inception of a botanical society in Regensburg, and somewhat later on the 14th of May 1790, he and three other naturalists founded the oldest still-existing botanical society of the world at the Schutzfelsen – the "Regensburgische Botanische Gesellschaft" (http://www.regensburgische-botanische-gesellschaft.de/). The Schutzfelsen is classified as Geotop no. 56 of the 100 most important geological heritage sites of Bavaria (BAYERISCHES LANDESAMT FÜR UMWELT, 2011). So please do not use your hammers.



Text-Fig. 21: The geological situation at the Schutzfelsen near Pentling (modified after GÜMBEL, 1854).

Generally, the Schutzfels Formation consists of siliciclastic sediments, commonly clays, silts, sands and gravels (and mixtures of it) that are only partially or locally lithified (kaolinitic and siliceous cements may occur). Quartz predominates with 90–95 %, but feldspar, clay minerals and organic remains also occur. In some areas, e.g. near Auerbach and Sulzbach-Rosenberg (Oberpfalz), sedimentary iron ores have been deposited in elongated troughs, forming the Amberg Member of the Schutzfels Formation and providing the basis for regionally important iron mining and smelting for more than a thousand years (the last mines have been shut-down towards the end of the last century). The strata of the Schutzfels Formation are often very variegated with colours ranging from white, yellow to brown, red, violet, green and black. The source of the clastics were the basement rocks of the Bohemian Massif (Moldanubian Zone) in the northeast as shown by SCHNITZER (1953) on the basis of heavy mineral associations. The material was transported by rivers across a karst landscape towards the south and southwest and deposited in fluvial to limnic environments. Originally, the Schutzfels Formation was much more widespread in distribution (e.g. between Neuburg an der Donau und Solnhofen). In many areas, however, it has been eroded prior to or by the transgression of the marine strata of the Danubian Cretaceous Group. As a consequence, the Schutzfels Formation is today very patchily distributed and mainly preserved in sinkholes that formed during the Early Cretaceous in Upper Jurassic carbonates. Unfortunately, it is nearly barren of fossils, only plant debris and a few poorly diagnostic leaf imprints have been reported (TRUSHEIM, 1935). Thus, the age of the Schutzfels Formation can only be inferred from its stratigraphic position, post-dating the deposition of the Upper Jurassic carbonates (see NIEBUHR & PÜRNER, 2014, for a regional synopsis of the Upper Jurassic Weißjura Group) and pre-dating Early Cenomanian transgressive deposits of the marine Regensburg and Wellheim Formations (WILMSEN & NIEBUHR, 2010; WILMSEN et al., 2010a; SCHNEIDER et al., 2013).

At the type locality, the Schutzfels Formation occurs as an infill into a ca. 10-m-wide and > 5-m-deep sinkhole within massive Upper Jurassic dolomites (Text-Fig. 22A). It consists of a chaotic mixture of poorly lithified silty/argillaceous to sandy deposits with scattered quartz pebbles up to a few centimetres in diameter. Colours vary from yellow-brown to red-violet (Text-Fig. 22B). Spectacular are the sharp, near-vertical primary contacts between the massive Upper Jurassic dolomites and the Schutzfels Formation at the walls of the sinkhole. Downward-convex infill structures, however, as indicated in the original drawing of GÜMBEL (1854) are hardly discernable today (Text-Fig. 21). The overlying Regensburg Formation consists of pebble- and granule-bearing bioclastic rudstones and bioclastic sandstones (Text-Fig. 22C). The green colour is related to glaucony that forms a considerable portion of the rock (10–20 %). Oyster, inoceramid, echinoderm, bryozoan and red algae debris (Text-Fig. 22C) confirm the fully marine high-energy environment of the lower Regensburg Formation. The increasing thickness of the Regensburg Formation across the Schutzfelsen and its thinning onto the hard Upper Jurassic dolomites (Text-Figs. 21, 22A) indicate a preferential erosion of the soft Schutzfels Formation during initial transgression. Downward-oriented veins of greensands into the upper Schutzfels Formation are difficult to explain but may be related to the injection of overlying soft, still water-saturated Regensburg Formation caused by renewed synsedimentary collapse of the underlying sinkhole.



Text-Fig. 22: Field and microfacies aspects of the Schutzfelsen near Pentling. A: outcrop situation in 2011: The Schutzfels Formation is embraced between Upper Jurassic carbonates and the Regensburg Formation forms the roof of the rock shelter (view to the east). B: close-up of the Schutzfels Formation showing varicoloured siliciclastic sediments infilling a karst sinkhole within the Upper Jurassic carbonates (field of view ca. 4 m). C: microfacies image showing the bioclastic rudstone fabric of the lower Regensburg Formation at the Schutzfelsen (width of photomicrograph is 8 mm). Abbreviations: ech = echinoderms, fsp = feldspar, gl = glauconite, in = inoceramids, oy = oysters, qrz = quartz, ra = red algae.

Stop 15. Dantschermühle section near Bad Abbach (Germany)

Coordinates: E 12°00’56”, N 48°55’29”.

Location: Abandoned quarry near Dantschermühle, south of Bad Abbach.

Topic: Depositional setting and stratigraphy of Cenomanian to lowermost Turonian transgressive deposits.

Lithostratigraphic units: Regensburg, Eibrunn and lowermost Winzerberg Formations.

Age: Early Cenomanian to Early Turonian.

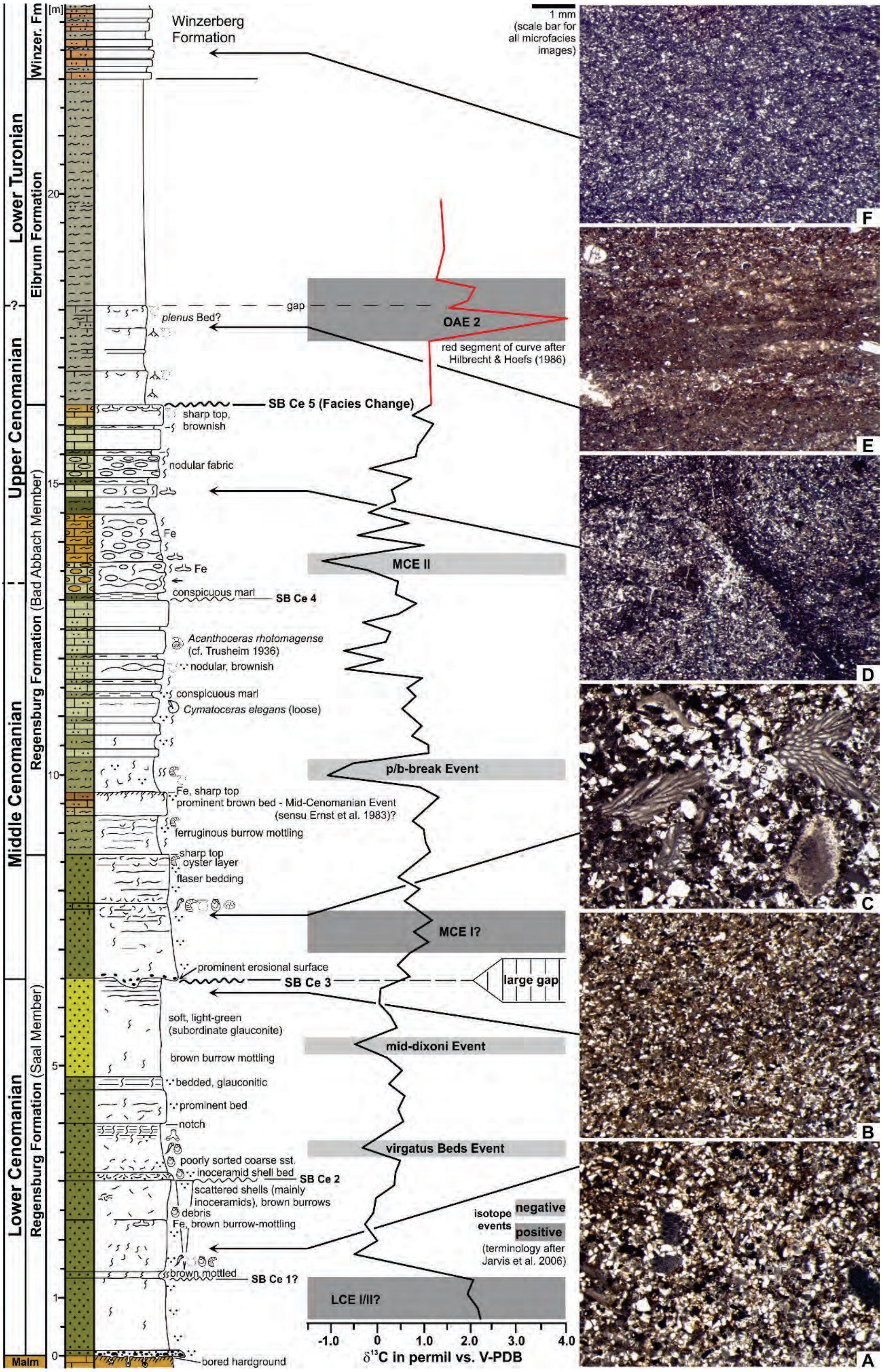
Specialities: Early Cenomanian abrasion platform overlain by retrogradational stacked shelf sediments.

References: GÜMBEL (1854), TRUSHEIM (1935), DACQUÉ (1939), NIEBUHR et al. (2009, 2014), WILMSEN & NIEBUHR (2010), WILMSEN et al. (2010a).

The section is located on the southern flank of the Mühlberg near the Dantschermühle, south of Bad Abbach, ca. 10 km south-southwest of Regensburg (Text-Fig. 19). In the abandoned quarry, a ca. 25 m thick succession of the lower Danubian Cretaceous Group is exposed, including the Regensburg, Eibrunn and lower Winzerberg Formations (Text-Fig. 20). The succession at Dantschermühle includes the type section of the Regensburg Formation and likewise that of the upper Bad Abbach Member of the formation (NIEBUHR et al., 2009). Until the early nineteenth century, the thick-bedded glauconitic sandstones of the lower Saal Member of the Regensburg Formation have been quarried here as freestones. This so-called "Regensburger Grünsandstein" was in great demand since Roman times and quarried in many places south of Regensburg. Many world-famous historical buildings in Bavaria are constructed from this freestone, e.g., the Dom (cathedral) and the Steinerne Brücke in Regensburg as well as the Pinakothek in Munich.

In the Dantschermühle section (Text-Fig. 23), the Regensburg Formation starts with a thin microconglomerate (currently poorly exposed) on a flat and bored surface on top of thick-bedded to massive Upper Jurassic carbonates (Kelheim Member of the Frankenalb Formation of NIEBUHR & PÜRNER, 2014). The borings can be related to lithophagous bivalves and have been termed "Pholadenlöcher" in the old literature (TRUSHEIM, 1935). In modern ichnotaxonomy, this trace fossil is termed *Gastrochaenolites torpedo.* The lower 8.50 m-thick Saal Member consists of bioturbated, fine- to medium-grained, calcareous glauconitic sandstones (Text-Fig. 23A). Noteworthy are a strongly bioturbated horizon 1.40 m above the base, a sharp-based inoceramid layer 3 m above the base and a conspicuous erosion surface at the 6.50 m-level. The latter surface cuts into fine-grained, poorly glauconitic calcareous sandstones (Text-Fig. 23B) and is overlain by medium- to coarse-grained, strongly glauconitic bioclastic sandstones yielding fragments of serpulids, oysters, inoceramids, pectinids, brachiopods, and bryozoans (Text-Fig. 23C). The top of the Saal Member is sharp and marked by an oyster layer. Ammonites (*Mantelliceras mantelli*) and inoceramid bivalves (*Inoceramus virgatus*) from strata of nearby sections equivalent to the Saal Member below the erosion surface at the 6.50 m-level at Dantschermühle indicate an Early Cenomanian age (TRÖGER et al., 2009; WILMSEN et al., 2009; WILMSEN & NIEBUHR, 2010).

The following 7.60 m-thick Bad Abbach Member consists of an intercalation of silty to fine-sandy bioturbated marls and silty, spiculitic marly limestones (Text-Fig. 23D), the fabric of which becomes more nodular upsection. Macrofossils are comparatively scarce, comprising oysters and thin-shelled pectinids as well as very rare nautilids and ammonoids (TRUSHEIM, 1935; DACQUÉ, 1939) typically for Middle and lower Upper Cenomanian strata elsewhere. A limestone bed topped by a strongly bioturbated, ferruginous omission surface occurs at 9.70 m and a conspicuous marl bed at 13 m caps a thickening-upward trend commencing above a thick marl bed overlying the omission surface. The Bad Abbach Member of the Regensburg Formation is terminated at another ferruginous and bioturbated omission surface at 16.30 m.



Text-Fig. 23: Stratigraphic log, carbon stable isotopes and microfacies (A–F) of the succession at Dantschermühle near Bad Abbach (modified after WILMSEN et al., 2010a). The scale bar at the top applies to all microfacies images. For key to symbols, see Text-Figure 24.

The succession continues with silty-argillaceous marls of the Eibrunn Formation (ca. 6.50 m thick) that may show faint laminations (Text-Fig. 23E). In its lower part, bioturbation by *Chondrites* is common and ca. 1.60 m above the base, a slightly more calcareous, one to two dm-thick nodular horizon ("Kalkmergelbank" of FÖRSTER et al., 1983) has been recorded, yielding the belemnite *Praeactinocamax plenus* and, slightly below, a mid-Upper Cenomanian (*Metoicoceras geslinianum* zonal) ammonite fauna (FÖRSTER et al., 1983; RÖPER & ROTHGAENGER 1995). Above, lowermost Turonian planktic foraminifera and inoceramids have been recorded from the upper Eibrunn Formation (FÖRSTER et al., 1983; HILBRECHT, 1986; TRÖGER et al., 2009). The intercalation of fine-grained siliceous marly limestone beds at 22.50 m mark the base of the Lower Turonian Winzerberg Formation, the lower few metres of which are exposed at the top of the section (Text-Fig. 23F).

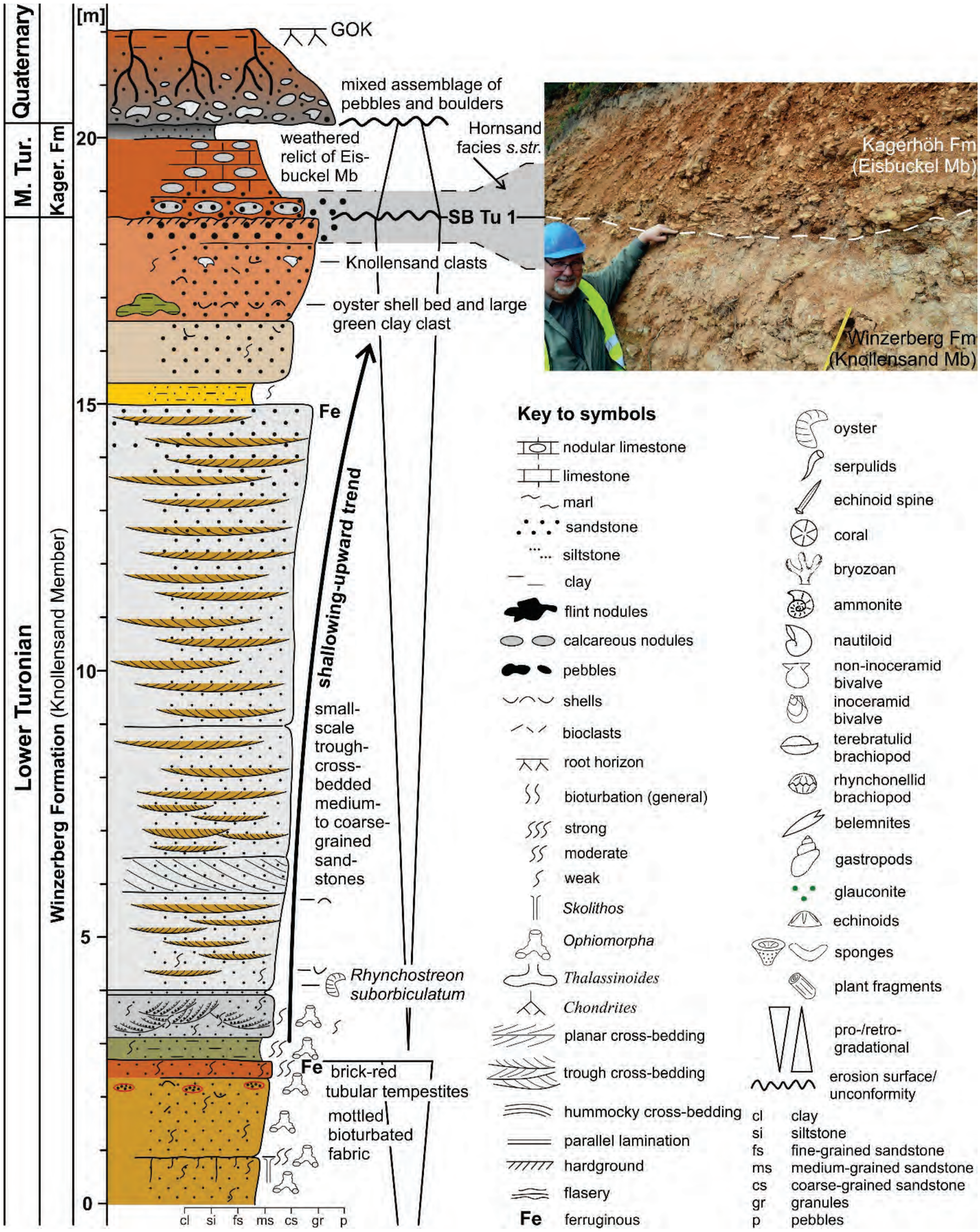
The carbon stable isotope curve of the Regensburg Formation at Dantschermühle is characterized by a relatively flat signature with low values between -1.0 and +1.0 ‰ $\delta^{13}C$ vs. V-PDB (Text-Fig. 23), typical for basin margin sections (e.g. VOIGT & HILBRECHT, 1997). Merely in the lowermost part, values of +2.0 to +2.2 ‰ $\delta^{13}C$ are recorded. Above the erosional surface at 6.50 m there is a slight shift towards heavier values of +0.5 to +1.0 ‰ $\delta^{13}C$ above that level up to c. 11.50 m with a major negative peak in the marl above the brown omission surface at 10 m. The succession from 12 m to the top of the formation is characterized by relatively strong fluctuations and an increase to values between +1.5 to +2.0 ‰ $\delta^{13}C$. For the lower Eibrunn Formation, the curve of HILBRECHT & HOEFS (1986) was used. It is characterized by a major positive excursion up to +4.0 ‰ $\delta^{13}C$ between 1.10 m to 2.20 m above the formational boundary. Based on the bio- and event stratigraphical tie-points, the carbon stable isotope curve of the Regensburg Formation at Dantschermühle can be correlated to condensed successions elsewhere and a number of the Cenomanian isotope events of JARVIS et al. (2006) have been identified (Text-Fig. 23).

The Dantschermühle section documents the early Late Cretaceous transgression of the lower Danubian Cretaceous Group in the Regensburg–Kelheim area (WILMSEN et al., 2010a). The initial stages of transgression are recorded by means of an Early Cenomanian abrasion platform with borings of lithophagous bivalves. Relatively fine-grained sediments started to accumulate not before the fair-weather wave base rose above the sea floor (bioturbated glauconitic sandstones of the Saal Member). Continuous sea-level rise resulted in further deepening of the depositional setting and the accumulation of increasingly distal facies during the Cenomanian (Bad Abbach Member and Eibrunn Formation) with a (second order) maximum flooding interval in the earliest Turonian part of the Eibrunn Formation. Short-lived periods of sea-level fall and lowstand are recorded by intercalated sedimentary unconformities, the most prominent of which are the erosional surface at 6.50 m (sequence boundary SB Ce 3 in the Early/Middle Cenomanian boundary interval) and the top surface of the Regensburg Formation (SB Ce 5 in the mid-Late Cenomanian, Text-Fig. 23; see NIEBUHR et al., 2014 and JANETSCHKE et al., 2015, for recent sequence stratigraphic synopses).

Stop 16. Sandpit near Trischlberg

Coordinates: E 12°01'22", N 49°08'23".
Location: Active sandpit of the Erutec GmbH near Trischlberg.
Topic: Depositional setting and stratigraphy of the Winzerberg Formation.
Lithostratigraphic units: Knollensand Member of the Winzerberg Formation and lowermost part of the Eisbuckel Member of the Kagerhöh Formation.

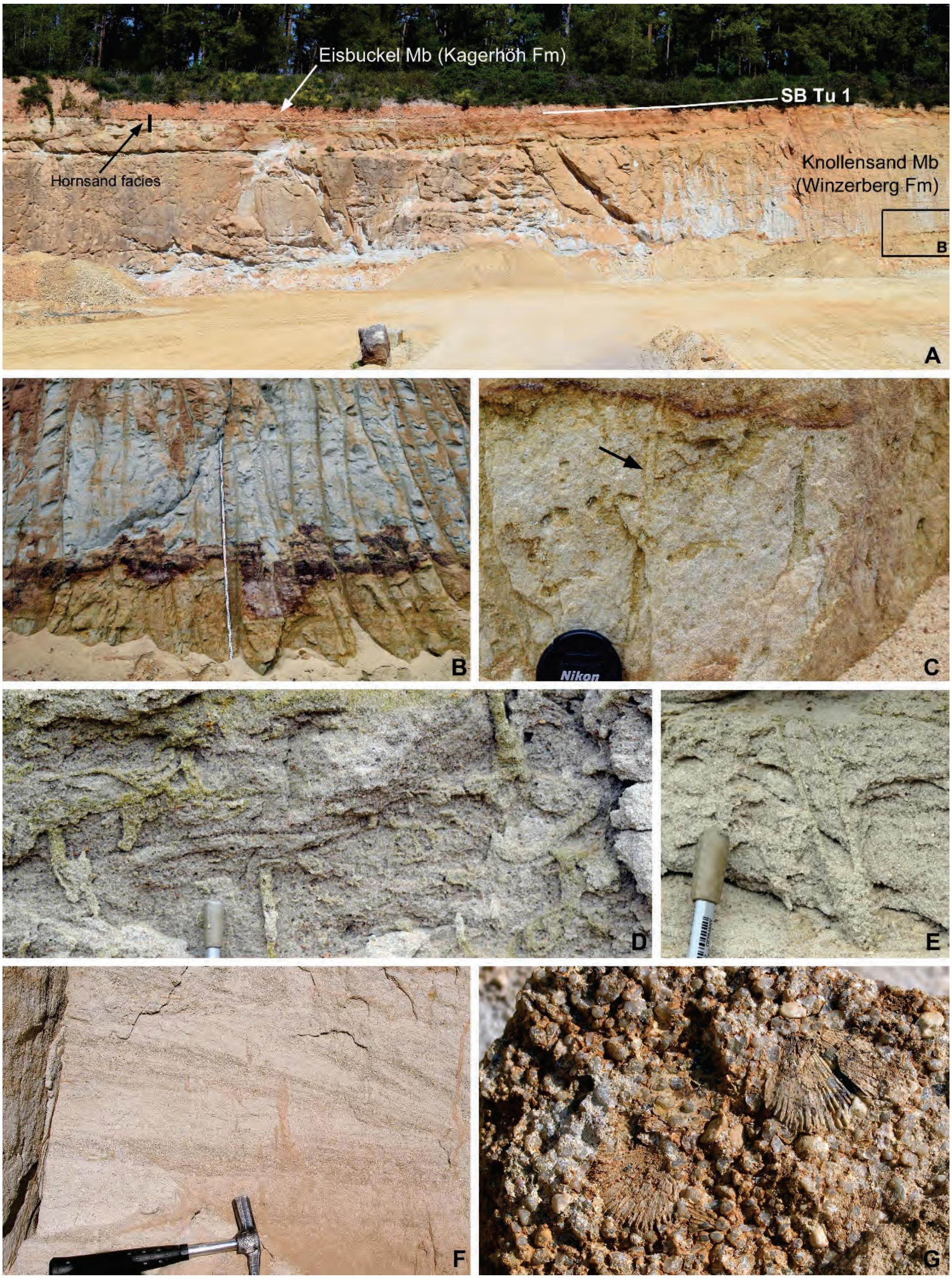
Age: Early to earliest Middle Turonian.
Specialities: Dynamic deposition on a graded siliciclastic shelf system, sea-level development during the Early to Middle Turonian.
References: NIEBUHR et al. (2009, 2014), RICHARDT et al. (2013), WILMSEN et al. (2014).



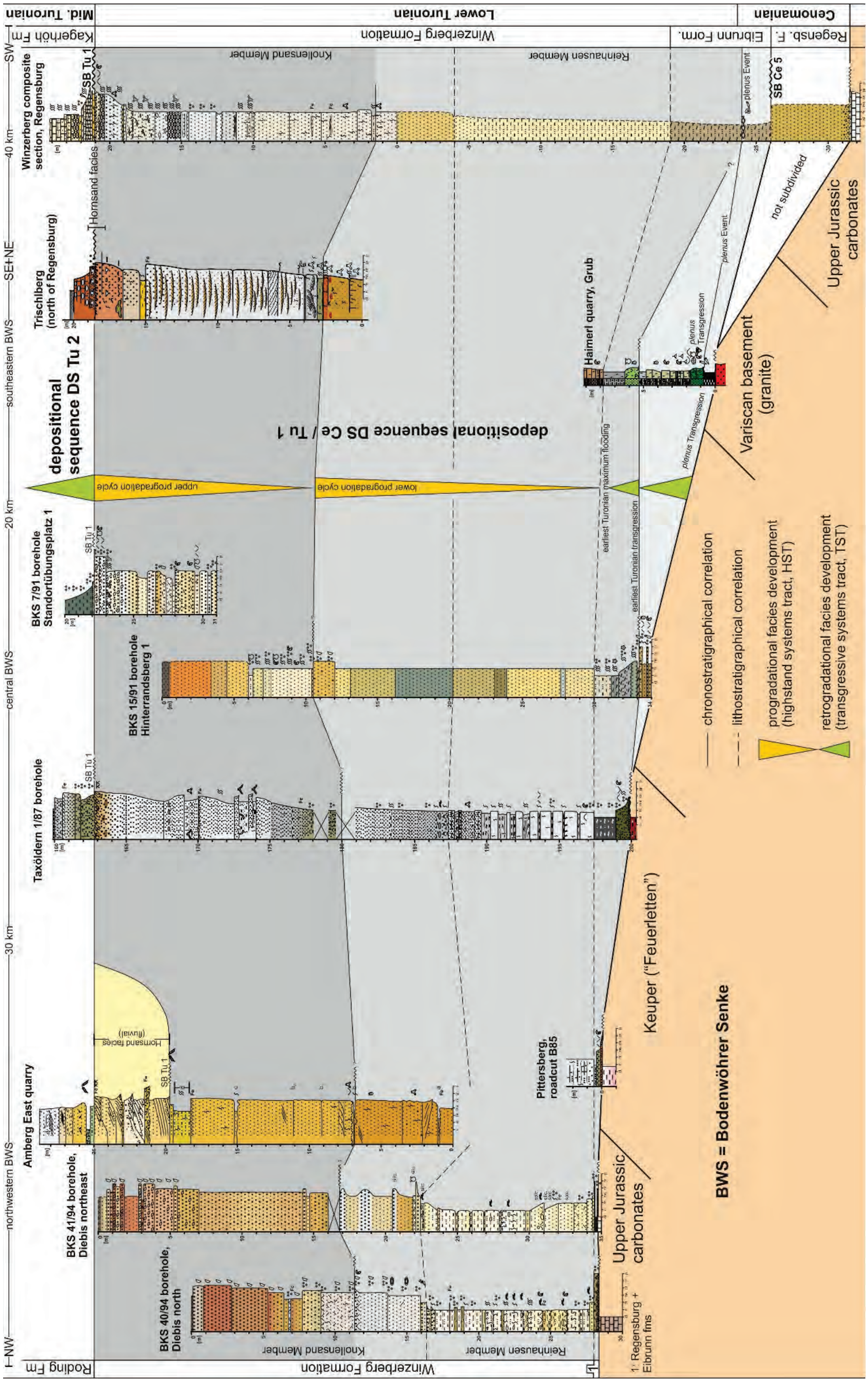
Text-Fig. 24: Stratigraphic log of the Trischlberg sandpit. The unconformable contact of the Winzerberg and Kagerhöh formations (SB Tu 1) is shown by Tom Pürner in the inset photograph. The key to symbols applies for all other figures, too.

The Lower Turonian Winzerberg Formation represents an Early Turonian graded shelf system that developed in the Danubian Cretaceous Basin after the earliest Turonian maximum flooding of depositional sequence DS Ce/Tu 1 (WILMSEN, 2010a, b; RICHARDT et al., 2013; NIEBUHR et al., 2014). During the earliest Turonian maximum flooding interval that corresponds to a global eustatic peak (e.g., correlating to the K140 maximum flooding surface of SHARLAND et al., 2001 on the Arabian Plate), the offshore marls of the Eibrunn Formation even spread into the proximal Bodenwöhrer Senke, forming the distal facies of the shelf system. The mid- and inner shelf facies are represented by the Reinhausen Member (silty spiculites and calcareous siltstones) and the Knollensand Member (fine- to coarse-grained sandstones) of the Lower Turonian Winzerberg Formation forming the highstand systems tract of DS Ce/Tu 1. The formation is overall progradational, filling the accommodation generated by the sea-level rise of of DS Ce/Tu 1, and consists of two stacked progradational cycles (high-frequency sequences) corresponding to the 400-kyr long-eccentricity cycle of the Milankovitch Band (RICHARDT et al., 2013). The depositional sequence is capped by a conspicuous subaerial unconformity in the Lower–Middle Turonian boundary interval (SB Tu 1; RICHARDT et al., 2013; NIEBUHR et al., 2014; WILMSEN et al., 2014). It is associated with the coarse-grained Hornsand facies ("Hornsand unconformity") and comprises a stratigraphic gap within the earliest Middle Turonian (see WILMSEN et al., 2014 for details). From the Amberg area, fluvial incision and the backfilling of the incised valleys during the Middle Turonian base-level rise have been reported as well (RICHARDT et al., 2013). The Hornsand (facies) is a regional marker bed that has been mainly used for mapping purposes. Lithologically, it is microconglomerate predominantly consisting of well-rounded granules of quartz with subordinate rock fragments such as lydite. It forms a kind of lag deposit within the latest highstand deposits below and the early transgressive deposits above SB Tu 1 (NIEBUHR et al., 2009).

The Trischlberg sandpit exposes a ca. 20 m-thick succession of the upper Winzerberg Formation (Knollensand Member, upper Lower Turonian) and the lower Eisbuckel Member (lower Middle Turonian) of the Kagerhöh Formation (Text-Figs. 24, 25A). In the lower part of the section, intensively bioturbated, yellow-brownish, medium-grained sandstones are exposed; *Ophiomorpha* and *Skolithos* traces can be recognized (Text-Fig. 25B, C). Above a brick-red ferruginous horizon, cross-bedded, grey to greenish-grey medium- to coarse-grained sandstones with well-developed *Ophiomorpha saxonica* burrows follow (Text-Figs. 25B, D, E). Upsection, the grain size gradually increases, bioturbation disappears and small- to medium-scale trough cross-bedding predominates (Text-Fig. 25F). Occasionally interstratified silicified shell remains (mainly oyster fragments) testify the marine origin of the Knollensand Member. The development culminates in a very coarse-grained, microconglomeratic sandstone bed with scattered oyster shells of *Rhynchostreon suborbiculatum* that develops into the Hornsand facies towards the top (Text-Fig. 25G). The bed also contains a large clast of greenish clays. At a sharp surface representing sequence boundary SB Tu 1, the Winzerberg Formation is overlain by upsection fining (calcareous) sandstones of the Eisbuckel Member of the Kagerhöh Formation. In its lowermost part, granules and coarse sand grains of the underlying Hornsand facies are disseminated. The Eisbuckel Member is a strongly decomposed erosional relict of Tertiary weathering processes (evident by the reddish colour) and overlain by medium- to dark-brown loamy Quaternary deposits containing a mixed assemblage of pebbles and boulders, capped by a soil horizon (Text-Fig. 24).



Text-Fig. 25: Field aspects of the Lower to lower Middle Turonian succession in the Trischlberg section. A: overview of the exposure situation in May 2017 at the northern wall of the sandpit. Important units and surfaces as well as the close-up seen in B are marked. B: contact of the lower part of the Knollensand Member (bioturbated brownish sandstones) and the upper part consisting of grey, trough cross-bedded sandstone (scale is three meters long). C: lower part of the Knollensand Member showing intensely bioturbated medium-grained sandstones; a *Skolithos*-like vertical burrow is marked by an arrow (lens cap for scale). D: in the upper part of the Knollensand Member, bioturbation becomes increasingly rare upsection; in the lowermost part, *Ophiomorpha* burrows are still common (pencil for scale). E: sub-vertical shaft of *Ophiomorpha saxonica* (pencil for scale). F: cross-bedded coarse-grained sandstones predominate the upper part of the Knollensand Member (hammer for scale). G: typical textural feature of the Hornsand facies that is developed at the contact of the Winzerberg and Kagerhöh Formations including two small pectinid bivalves (field of view ca. 10 cm).



Text-Fig. 26: Regional correlation diagram of the Winzerberg Formation (modified and supplemented after RICHARDT et al., 2013). Note the onlap into the Bodenwöhrer Senke (BWS) during the transgressive systems tract of DS Ce/Tu 1 and the infilling of the accommodation during the highstand systems tract (for key to symbols, see Text-Figure 24).

The Trischlberg section can be nicely integrated into the regional facies model and correlation panel of the Winzerberg Formation (cf. RICHARDT et al., 2013; Text-Fig. 26). It exposes the (late) highstand interval of depositional sequence DS Ce/Tu 1. This is indicated by the overall progradational facies development from bioturbated to cross-bedded sandstone, the upwards increasing grain size and the decrease in trace fossils. *Ophiomorpha* burrows are typical for instable sandy substrates of the proximal mid- to inner shelf. The ferruginous bed in the lower part of the section probably corresponds to the top of the lower progradational cycle within the Winzerberg Formation (Text-Fig. 26). The upper cycle is fully exposed in the Trischlberg sandpit and capped by SB Tu 1, most likely representing a subaerial unconformity (WILMSEN et al., 2014). The overlying, upwards-fining Eisbuckel Member of the Kagerhöh Formation demonstrates the renewed marine onlap during the early Middle Turonian transgression.

Stop 17. Parish church in Neubäu am See (optional)

Coordinates: E 12°24'59", N 49°14'10".

Location: Catholic parish church (Pfarrkirche) "Mariä Namen" in Neubäu am See near Roding.

Topic: Marginal facies of the Danubian Cretaceous Basin during the Middle to Late Turonian inversion phase.

Lithostratigraphic unit: Freihöls Member of the Roding Formation.

Age: Middle to Late Turonian.

Specialities: Coarse-grained siliciclastic deposits of the proximal Bodenwöhrer Senke used as a local freestone.

References: NIEBUHR et al. (2009, 2011).

The parish church "Mariä Namen" (Marian name) in Neubäu (sometimes also termed "Maria-Hilf-Kirche") was built in 1901 in new Romanesque (Neuromanik) style by the famous architect Johann Baptist Schott (1853–1913) from Munich. The church was consecrated on 20th of July, 1907. Schott also built the Basilica of St. Anna in Altötting, St. Josef in Weiden, or the parish churches in Teisnach and Zwiesel, and is one of the outstanding church architects in Bavaria during the Historicism. The parish church in Neubäu is justifiably one of the most beautiful new Romanesque buildings in East Bavaria (Text-Fig. 27A). At the turn of the nineteenth and twentieth centuries, many people wanted the old art styles back. In the emerging industrial age, which demanded inhumane working conditions and in which child labor was customary, people deliberately fled into the emotional and romantic – time was not yet ripe for a breakthrough to modernity. The church building of Neubäu should therefore be like a heavenly fortress and anticipate the splendor of heaven. Strong round arches rest on consoles and give a view of the church ship and the altar. Schott has truly left a great impression in Neubäu by creating a really harmonious space.

The Middle to Upper Turonian Roding Formation in the Bodenwöhrer Senke was deposited close to the southwestern margin of the Bohemian Massif. It has a thickness ranging from 75 m in the northwest to 120 m in the central and southeastern parts of the Bodenwöhrer Senke (NIEBUHR et al., 2011). The Roding Formation nearly exclusively comprises siliciclastic strata (clays, silt- and sandstones, reddish to brown lithic-arkosic pebble sandstones and gravelstones) and is subdivided into the Altenkreith, Freihöls, Taxöldern and Seugast members (from base to top; Text-Fig. 20). The Altenkreith and Taxöldern members are marine in origin (inner to mid-shelf sediments) while the Freihöls and Seugast members are (predominantly) non-marine units (alluvial fan and river deposits, occasional estuarine influence). The Roding Formation rests with a major unconformity (sequence boundary SB Tu 1) on the Lower Turonian Winzerberg Formation and is sharply overlain by the upper uppermost Turonian–Lower Coniacian deeper marine clays and marls of the Hellkofen Formation (Text-Fig. 20). Also the boundaries of the Freihöls and Seugast members are significant erosional unconformities resulting from rapid and substantial relative sea-level falls. Based on erosional and/or non-depositional unconformities (sequence boundaries, SB Tu 1–5), four depositional sequences (DS Tu 2–5) have been identified in the Middle–Upper Turonian succession of the Bodenwöhrer Senke with a 2nd-order maximum flooding in DS Tu 3 in the late Middle Turonian (NIEBUHR et al. 2011). Correlative surfaces have also been recognized in the Regensburg–Kelheim area in the contemporaneous Kagerhöh and Großberg formations, and sequence stratigraphy thus offers an important tool for correlation (NIEBUHR et al. 2014). However, based on conspicuous changes in basin configuration, subsidence patterns and sediment supply, the base of the mid-Middle Turonian Freihöls Member indicates the onset of Late Cretaceous inversion at the southeastern margin of the Bohemian Massif. Consequently, the mainly eustatically-controlled onlap phase and the tectonically-influenced inversion phase of the Danubian Cretaceous Group have been delimited at this level (NIEBUHR et al., 2014; see Text-Fig. 20).

Text-Fig. 27: Freihöls Member of the Roding Formation (Middle to Upper Turonian) used as freestone at the parish church “Mariä Namen” in Neubäu am See. A: the church as seen from the south. B: door frame showing the immature, coarse-grained fabric (field of view ca. 1 m). C: better sorted facies consisting of dm-scale units grading from quartz (micro-)conglomerate to coarse-grained sandstone; note the good rounding of the quartz granules and pebbles in the upper bed (lens cap for scale). D: close-up view of the poorly sorted pebbly coarse-grained sandstone facies of the Freihöls Member (lens cap for scale).

Due to its commonly poor lithification, the strata of the Roding Formation have mostly been excavated in shallow sandpits as local construction sands. The unit is thus poorly exposed and almost all of the more continuous sections studied by NIEBUHR et al. (2011) are cores. The inhomogenous poorly sorted fabric, the coarse grain size and the variable component spectrum furthermore complicate the potential use of the Roding Formation for construction purposes. Consequently, it is rare to find it as a freestone. The church in Neubäu is thus an exception, most likely owing to the fact that it would have been much more expensive to use better material from other sources that are quite distant (e.g. Triassic sandstones from Franconia) and/or very costly (e.g. greensands of the Regensburg Formation). The parish church in Neubäu thus offers a good opportunity to study the lithofacies of the Roding Formation. A quick inspection of the door frames and outer walls readily shows the poorly sorted, coarse-grained pebbly sandstone to conglomerate fabric of the rocks (Text-Figs. 27B, D). Poorly rounded (milky) quartz is the main component, with subordinate rock fragments and rare feldspar grains. Sharp-based graded beds with better sorting and rounding of the quartz grains can also be observed (Text-Fig. 27C). The lithofacies shows the proximity of the source area (the boundary fault to the Bohemian Massif, the Pfahl Fault, is only a few kilometers to the northeast). Based on the observations and the comparison to the core sections Roding 1/06 and Pösing 9/02 (the composite type section of the Roding Formation) and another nearby borehole section (BKS 7/91; see NIEBUHR et al., 2011 for details), the rocks used as freestones for the church at Neubäu can be assigned to the non-marine Freihöls Member of the Roding Formation (Text-Fig. 20). At the beginning of the 20th century, when the church was built, there was only one larger quarry in the vicinity, i.e. at Lindtach, ca. 4 km east-northeast of Neubäu. In this now abandoned quarry, ca. 10 m of a beige-brown to reddish medium- to coarse-grained, in part pebbly sandstone with occasional layers of quartz pebbles are exposed, assigned to the Freihöls Member.

Stop 18. Haimerl quarry near Grub

Coordinates: E 12°30’45”, N 49°09’10”.

Location: Active quarry of the Haimerl gravel works, south of Roding.

Topic: Late Cenomanian to Early Turonian sea-level history in the Bodenwöhrer Senke.

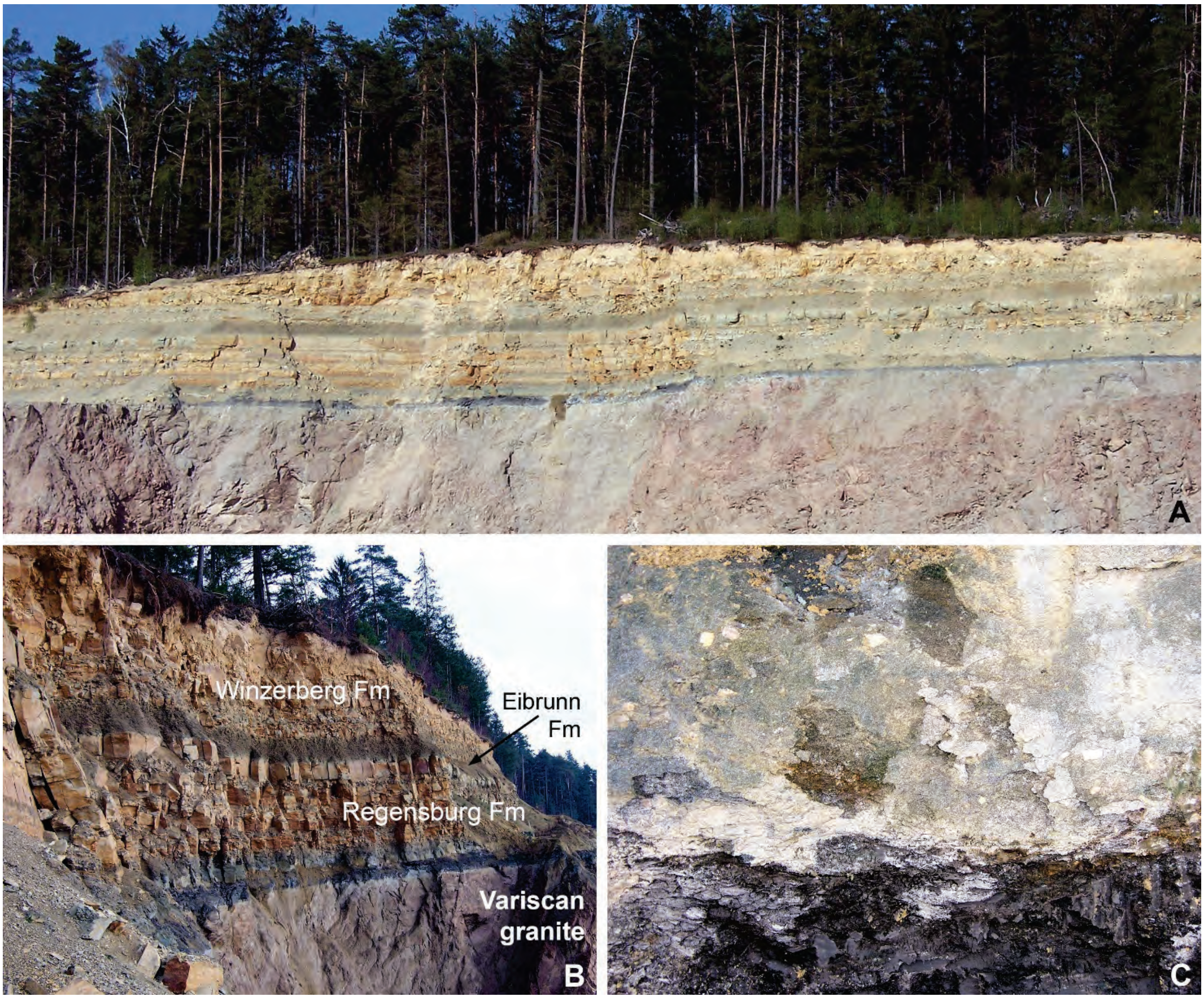
Lithostratigraphic units: Regensburg, Eibrunn and lowermost Winzerberg Formations (Reinhausen Member).

Age: Late Cenomanian (*Metoicoceras geslinianum* Zone) to Early Turonian.

Specialities: Onlap pattern of the Regensburg Formation onto a peneplain of Variscan basement rocks; earliest Turonian maximum flooding interval; carbon stable isotopes and bioevents.

References: NIEBUHR et al. (2009, 2014), WILMSEN & NIEBUHR (2010), WILMSEN et al. (2010a, b), RICHARDT et al. (2013).

The Grub section is located in the active quarry of the Haimerl gravel works, ca. 5 km south of Roding (Bodenwöhrer Senke). It exposes a ca. 10 m thick succession of the Regensburg, Eibrunn and lower Winzerberg Formations, which rests on a flat-topped Variscan granite (Text-Figs. 28A, 29). In contrast to the situation in the Regensburg–Kelheim area, the onlap of Upper Cretaceous marine deposits onto Triassic–Jurassic strata or Palaeozoic basements rocks is much younger in the Bodenwöhrer Senke (WILMSEN et al., 2010a, b; RICHARDT et al., 2013; NIEBUHR et al., 2014). In the Roding area, the Regensburg Formation transgresses onto a medium- to coarse-crystalline, partly porphyric granite (Wald Pluton) of the Moldanubian Zone that intruded in the Carboniferous (ca. 325 Ma) during the late stages of the Variscan orogeny in considerable crustal depth. By early Late Cretaceous times, the granites have been exhumed and formed the substrate for the Late Cenomanian and earliest Turonian transgressions. The integrated stratigraphy and facies analysis of the two exposures in Grub and Obertrübenbach allows an understanding of the sea-level dynamics during this crucial interval of Earth history including a shallow-water record of the oceanic anoxic event (OAE) 2.

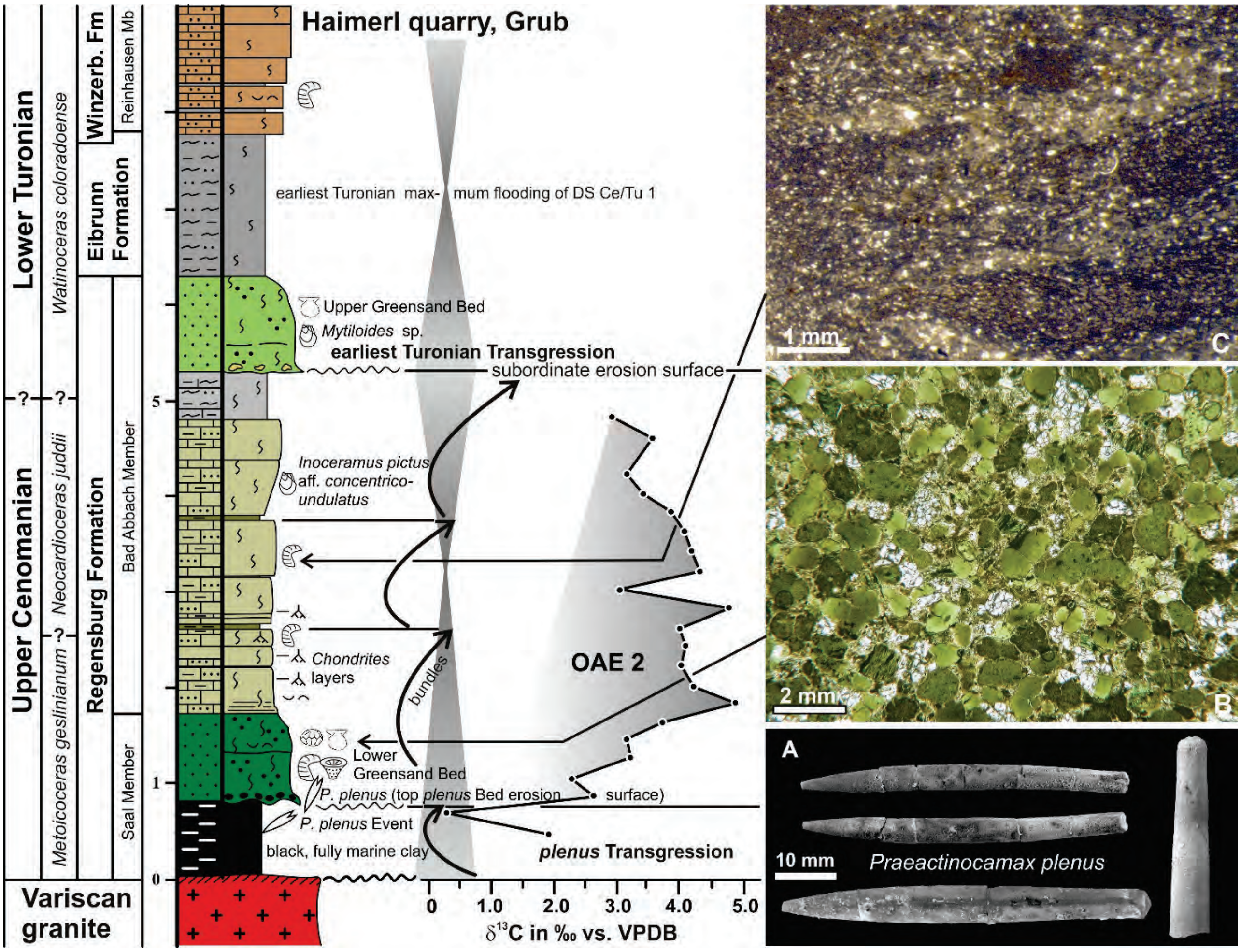


Text-Fig. 28: Upper Cenomanian to Lower Turonian succession in the Haimerl quarry near Grub. A: view of the northeastern quarry wall showing the Upper Cretaceous strata resting on a flat surface atop a red-brown Variscan granite ("Kristallgranit"); see image B for details. B: close-up view of the stratigraphic succession at Grub: The Regensburg Formation (here upper Upper Cenomanian) is resting with a basal black clay horizon on the Variscan granite and is overlain by a ca. 1.5 m-thick tongue of the Eibrunn Formation (lowermost Turonian) that, in turn, grades into the lower Reinhausen Member of the Lower Turonian Winzerberg Formation. C: contact of the basal black clay horizon and the Lower Greensand Bed of the Regensburg Formation; the interval contains the *Praeactinocamax plenus* Event (field of view ca 0.5 m wide).

The succession in the Haimerl quarry (Text-Fig. 29) starts upon a peneplain at the top of the granite with a 0.80 m thick black calcareous clay (Text-Fig. 28A), at the base of which patchily distributed granules and pebbles of reworked Liassic iron ores may occur. The clay contains sponge spicules, benthic foraminifera and, in its upper part, the belemnite *Praeactinocamax plenus* (Wilmsen et al., 2010b; Text-Fig. 29A). Furthermore, it yielded some glauconite, well-preserved calcareous nannoplankton and a varied association of palynomorphs, including a fully marine, diverse assemblage of Cenomanian dinoflagellates (det. P. Hochuli, Zürich). Pollen and spores are relatively rare compared to marine palynomorphs. Other marine palynomorphs than dinoflagellates include acritarchs (common), *Tasmanites* spp. and organic chamber linings of foraminifers.

The black clay is unconformably overlain along an irregular erosion surface by a 0.80 to 0.90 m thick, medium- to coarse-grained glauconitic-bioclastic sandstone bed with a basal lag of dark phosphatitic clasts and poorly rounded orange alkali feldspar granules as well as fragments of belemnite guards (Lower Greensand Bed, Text-Figs. 28C, 29). In its upper part it is a glauconitite, consisting of more than 50 % glaucony grains (Text-Fig. 29B). In addition, the bed is heavily bioturbated and contains oysters, pectinids, siliceous sponges, brachiopods and plant remains. It fines upwards, grading into the overlying silty, siliceous, bioturbated marls and marly limestones (Text-Fig. 29C) of the 4.60 m-thick Bad Abbach Member which contains relatively abundant fish remains but is otherwise relatively poor in fossils. In the lower part of the member, *Chondrites* layers are common and some small oysters [*Pycnodonte* (*Phygraea*) *versicularis vesiculosa*] occur; in the upper part, the inoceramid bivalve *Inoceramus pictus* aff. *concentricoundulatus* was found (TRÖGER et al., 2009). Five to ten cm-thick silty marl seams subdivide the Bad Abbach Member into bedding bundles. The member is terminated by a ca. 0.90 m thick, fine- to medium-grained glauconitic sandstone bed (Upper Greensand Bed). Its base is clearly erosional and rip-up-clasts of up to 50 mm from the underlying strata occur in its lower part. Fossils are very scarce, only rare pectinids and an inoceramid bivalve (*Mytiloides* sp.) have been found. The bed grades into the overlying dark-grey, silty to fine-sandy marls of the only 1.50 m-thick Eibrunn Formation. The section is terminated by a few metres of fine-grained siliceous, marly siltstones of the lower Winzerberg Formation (Reinhausen Member).

The bulk-rock carbon stable isotope record of the Regensburg Formation at Grub is characterized by a major positive excursion reaching values of up to +5.0 ‰ $\delta^{13}C_{carb}$. The $\delta^{13}C$ values start to increase within the Lower Greensand Bed from relatively low values at the top of the underlying black clay and reach an initial maximum at the transition into the Bad Abbach Member (Text-Fig. 29). A second maximum occurs 2.75 m above the base of the section. The $\delta^{13}C$ values stay high (above +3 ‰ $\delta^{13}C$) up to the 5 m-level, below the Upper Greensand Bed. Upsection, samples had too low carbonate contents and did not provide meaningful $\delta^{13}C$ results.
The succession at Grub documents the Late Cenomanian and Early Turonian flooding of the Bodenwöhrer Senke. Initial onlap of the Regensburg Formation occurred during the plenus Transgression (*Metoicoceras geslinianum* Zone) as evident from the *plenus* Event that has been recorded in Grub in the uppermost part of the black basal clay horizon (Text-Fig. 29). In Regensburg, this event has been recorded from the lower Eibrunn Formation (HILBRECHT, 1986; WILMSEN et al., 2010b), highlighting the diachronous character of lithostratigraphic units, especially during transgressions. The direct superposition of a granite peneplain by offshore marine clay demonstrates the extraordinary high rate of the plenus Transgression (WILMSEN et al., 2010a; RICHARDT et al., 2013). The base of the Lower Greensand Bed indicates an intermittent shallowing with erosion, corresponding to the erosion surface at the top of bed 3 in the classical southern English plenus Marls succession (JEFFRIES, 1963). Above, a considerable deepening is recorded by the fine-grained deposits of the Bad Abbach Member that ranges (according to the isotope stratigraphy) into the latest Cenomanian *Neocardioceras juddii* Zone (Text-Fig. 29).



Text-Fig. 29: Stratigraphic log, integrated stratigraphy (litho-, bio- and event stratigraphy as well as carbon stable isotopes) and microfacies of the Grub section. A: adolescent specimens of *Praeactinocamax plenus* from the plenus Event of Grub. B: thin-section photomicrograph from the upper part of the Lower Greensand Bed showing the glauconitite fabric (Saal Member of the lower Regensburg Formation). C: thin-section photomicrograph from the Bad Abbach Member of the upper Regensburg Formation showing the fine-grained, silty wackestone fabric. For key to symbols, see Text-Figure 24.

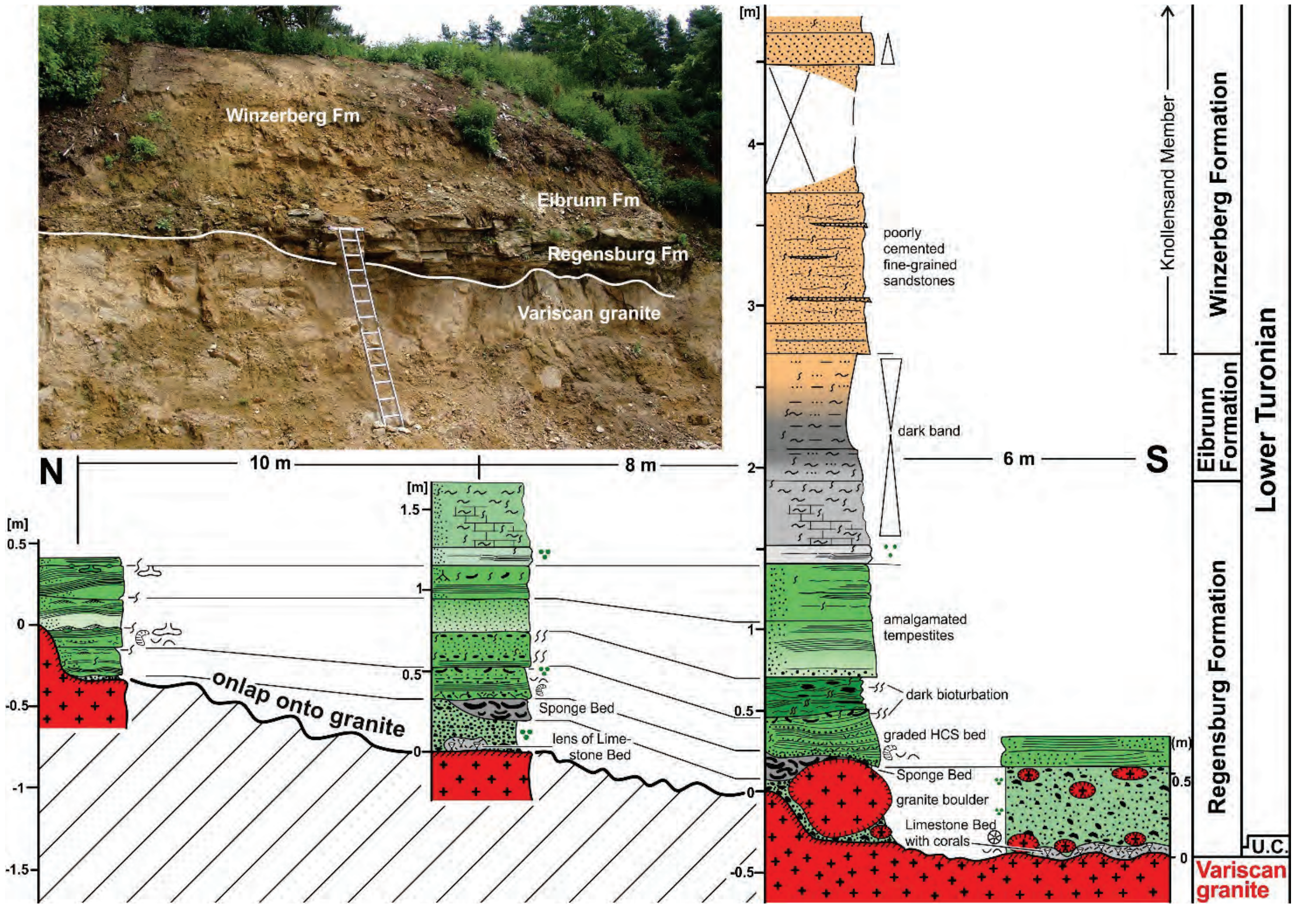
The unconformable base of the Upper Greensand Bed indicates another short-lived period of shallowing in the Cenomanian–Turonian boundary interval. The transgressive facies development into the overlying Eibrunn Formation is of earliest Turonian age, supported by the record of *Mytiloides* sp. from the Upper Greensand Bed. The earliest Turonian maximum flooding recorded by the tongue of the Eibrunn Formation corresponds to a global eustatic peak (i.e. the K140 maximum flooding surface of Sharland et al., 2001, on the Arabian Plate). The major positive δ^{13}C excursion in the Regensburg Formation at Grub corresponds to the oceanic anoxic event (OAE) 2 (Schlanger et al., 1987) and can be used to calibrate the stratigraphic succession, e.g. to the classical *plenus* Marls succession of southern England (Paul et al., 1999; Gale et al., 2005; Jarvis et al., 2006) or northern Germany (Voigt et al., 2007, 2008).

Stop 19. Obertrübenbach quarry

Coordinates: E 12°32’53”, N 49°10’03”.
Location: Abandoned quarry near Obertrübenbach, south of Roding.
Topic: Latest Cenomanian to Early Turonian sea-level history in the Bodenwöhrer Senke.
Lithostratigraphic units: Regensburg-, Eibrunn- and lowermost Winzerberg Formation.

Age: Early Turonian (latest Cenomanian erosional remnants currently not exposed).
Specialities: Small-scale onlap patterns of the Regensburg Formation onto basement rocks, earliest Turonian cliff drowning and maximum flooding interval; carbon stable isotopes.
References: TRUSHEIM (1935), NIEBUHR (2008), NIEBUHR et al. (2009, 2014), WILMSEN & NIEBUHR (2010), WILMSEN et al. (2010a, b), BAYERISCHES LANDESAMT FÜR UMWELT (2011).

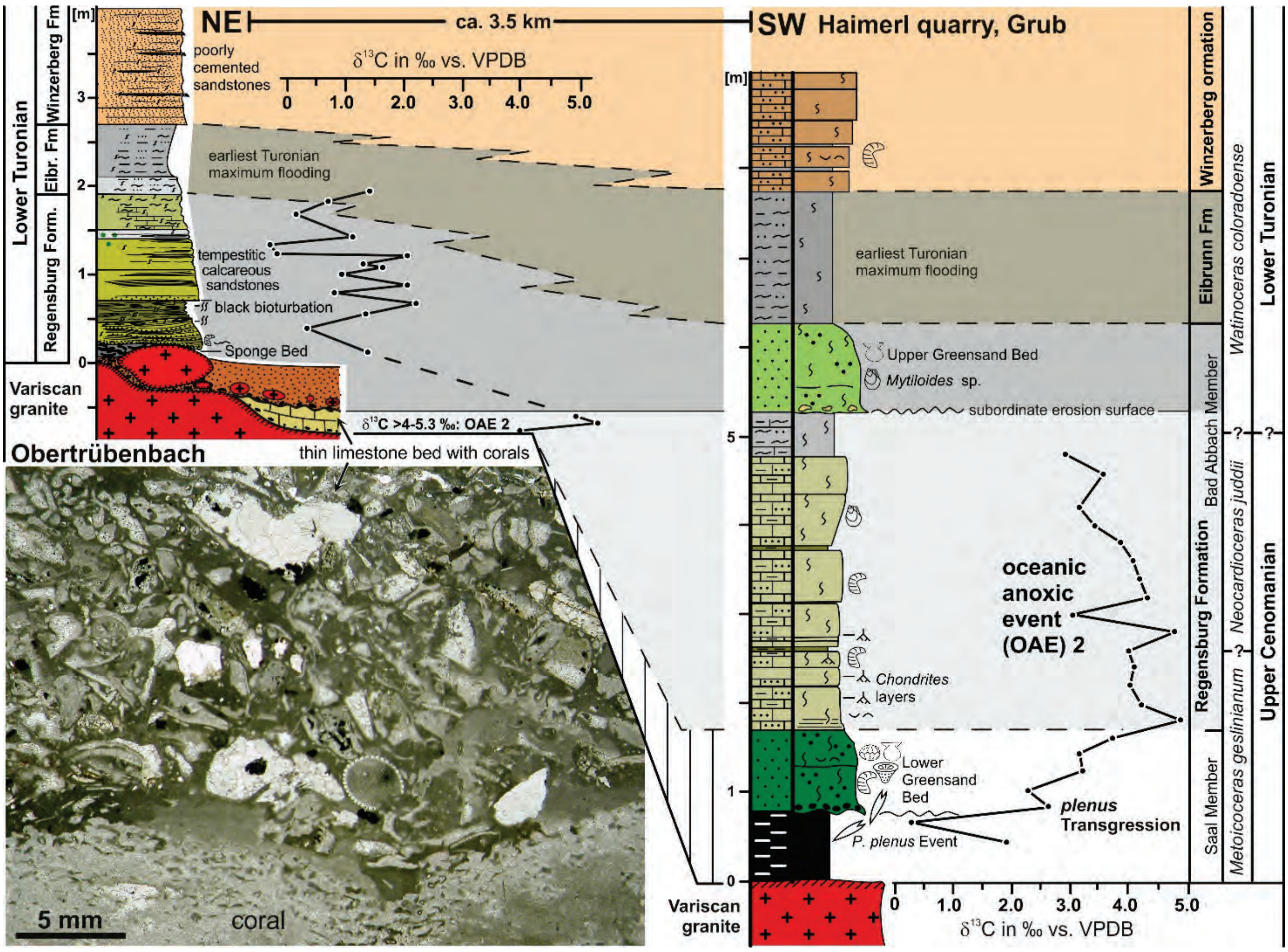
The abandoned Obertrübenbach quarry is located 3.5 km south-southeast of Roding near a small local road connecting Unter- and Obertrübenbach. It exposes a thin succession of the Regensburg, Eibrunn and lowermost Winzerberg Formations resting on a Variscan granite. The exposure is classified as Geotop no. 75 of the 100 most important geological heritage sites of Bavaria (BAYERISCHES LANDESAMT FÜR UMWELT, 2011) – so please do not use your hammers. Lithostratigraphically, the succession at Obertrübenbach is equivalent to the section at Grub. However, as will be shown below, the onlap at Obertrübenbach occurred even later than in Grub, i.e. mainly during the earliest Turonian.



Text-Fig. 30: Stratigraphic logs and onlap patterns in the Obertrübenbach quarry (outcrop situation as of 2008, view to the east; modified after NIEBUHR, 2008). For key to symbols, see Text-Figure 24.

The top surface of the granite at Obertrübenbach shows, in contrast to the situation at Grub, a strong relief (Text-Fig. 30). In the southern part of the small quarry, the succession starts with a thin (ca. 0.15 m) Limestone Bed of bioclastic float- and packstone yielding solitary and colonial (i.e. microsolenid) corals, siliceous sponges, oysters, spines of regular echinoids, serpulids, terebratulid brachiopods, bryozoans and shark teeth. The Limestone Bed is erosionally overlain by a several dm-thick unit of immature, pebbly sandstones/ conglomerate which thins towards the northern part of the outcrop where it directly onlaps the granite as a basal conglomerate (Text-Fig. 30). The unit also contains scattered rounded granite cobbles and boulders up to 0.80 m in diameter. The succession continues with a siliceous sponge biostrome (Sponge Bed; Text-Fig. 30), likewise pinching out towards the north, followed by a graded, hummocky cross-stratified, fine- to medium-grained, lithoclastic glauconitic sandstone bed with black, colour-contrasting bioturbation at the top. Upsection, a unit of dm-thick, parallel-laminated and/or hummocky cross-bedded, fine-grained calcareous sandstones with glauconite and oyster debris follows, terminating the Regensburg Formation. The strata of the Regensburg Formation show conspicuous onlap patterns from South to North within the quarry with a minimum relief of 2 m in a distance of ca. 25 m (Text-Fig. 30). The transition into the only 0.80 m thin silty Eibrunn Formation is gradual, and the lower Winzerberg Formation, consisting of medium- to coarse-grained sandstones (Knollensand Member), concludes the Obertrübenbach section.

The carbon stable isotope curve of the Regensburg Formation at Obertrübenbach (cf. Niebuhr, 2008; Wilmsen et al., 2010a) is characterized by very high values of +3.8 to +5.4 ‰ $\delta^{13}C_{carb}$ only in the thin erosional remnant of the Limestone Bed resting directly on the granite in the southern part of the quarry (Text-Fig. 31). The parallel-laminated/hummocky cross-stratified calcareous sandstones above the erosion surface yielded relatively low values ranging between -1.0 and +2.3 ‰ $\delta^{13}C$. Samples from the Eibrunn Formation provided no data due to their low carbonate contents.



Text-Fig. 31: Correlation of the Grub and Obertrübenbach sections (modified and supplemented after Wilmsen et al., 2010a). The thin uppermost Cenomanian coral-bearing limestone bed at the southern margin of the Obertrübenbach quarry is shown as thin-section photomicrograph; note microsolenid coral in the lower part and the bioclastic packstone fabric. For key to symbols see Fig. 24.

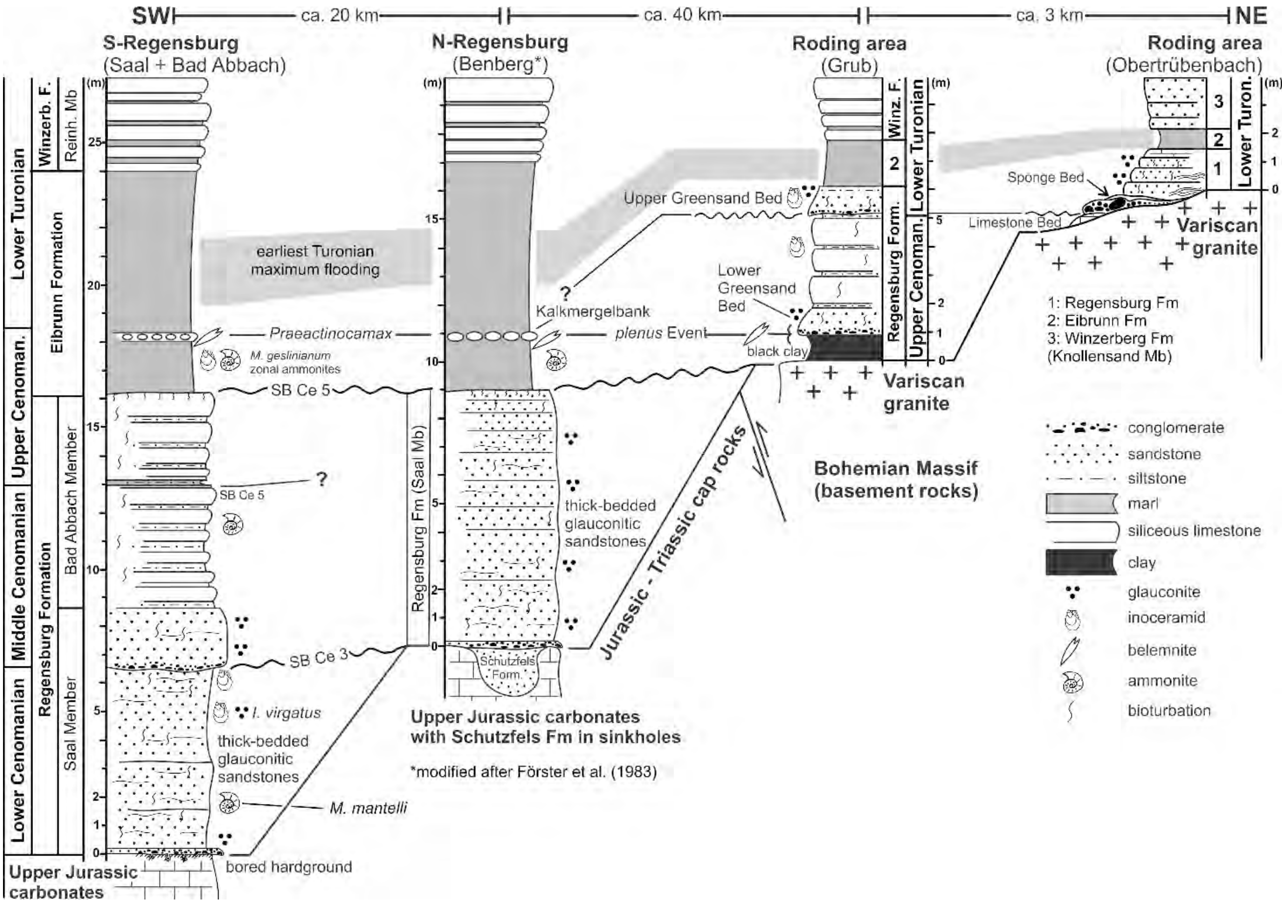
The succession at Obertrübenbach further details the Late Cenomanian–Early Turonian transgression history of the Bodenwöhrer Senke, especially when compared to the section of Grub, ca. 3 km to the southwest (Text-Fig. 31). The thin coral-bearing limestone bed occurring at the southern margin of the Obertrübenbach quarry yielded high $\delta^{13}C$ values typical of the OAE 2 and is thus a proximal (lagoonal?) shallow-water equivalent of the Saal Member of the Regensburg Formation at Grub (Text-Fig. 31). The erosion surface at the top of this bed corresponds to subordinate unconformity at the base of the Upper Greensand Bed at Grub (Cenomanian–Turonian boundary interval). The main onlap at Obertrübenbach thus corresponds to the earliest Turonian Transgression, supported by the low, i.e. post-OAE 2 $\delta^{13}C$ values (Text-Fig. 31). The Regensburg Formation at Obertrübenbach is equivalent to the Upper Greensand Bed and possibly parts of the Eibrunn Formation at Grub. The maximum flooding in the earliest Turonian is reflected by the deposition of a very thin and proximal tongue of the Eibrunn Formation. This event, corresponding to the maximum flooding of depositional sequence DS Ce/Tu 1, can be correlated across the north-western part of the Bodenwöhrer Senke where it is associated with the first onlap of marine strata (RICHARDT et al., 2013; see Text-Fig. 26). The relative proximity of the source area at Obertrübenbach during the Early Turonian is reflected by the fact that the Winzerberg Formation directly starts with the sandy Knollensand Member (Text-Figs. 20, 30). An identical sequence of sea-level changes can be recognized of the other side of the Bohemian Massif in the Saxonian Cretaceous Basin (WILMSEN et al., 2011).

The Danubian Cretaceous Group – some conclusions

The strata of the Danubian Cretaceous Group reflect dynamic depositional conditions in a peri-continental setting at the northern margin of the Alpine Tethys, representing various depositional environments including continental, marginal marine and neritic settings. According to the tectono-sedimentary background, three major phase can be differentiated (NIEBUHR et al., 2014): An Early Cretaceous continental phase, a Cenomanian–early Middle Turonian onlap phase mainly governed by eustatic sea-level fluctuations, and an inversion phase starting in the late Middle Turonian (Text-Fig. 20).

The Early Cretaceous continental phase is documented by the Schutzfels-Formation which consists of siliciclastic sediments, commonly varicoloured clays, silts, sands and gravels. The sources of the sediments were the basement rocks of the Bohemian Massif (Moldanubian Zone) in the northeast. The material was transported across a karst landscape towards the south and southwest and deposited in fluvial to limnic environments. Originally, the Schutzfels Formation was much more widespread in distribution but has been eroded prior to or by the transgression of the marine strata of the Danubian Cretaceous Group. Consequently, the Schutzfels Formation is today very patchily distributed and mainly preserved in sinkholes that formed during the Early Cretaceous continental phase in widespread Upper Jurassic carbonates (Weißjura Group of NIEBUHR & PÜRNER, 2014).

The Cenomanian–early Middle Turonian onlap phase is related to the major global early Late Cretaceous sea-level rise (e.g. HANCOCK & KAUFFMAN, 1979; HANCOCK, 1989). The distribution of sedimentation areas and facies as well as stratigraphic architectures was thus mainly governed by eustatic sea-level changes and the pre-transgression topography. Onlap of marine strata of the Regensburg Formation started in the Regensburg–Kelheim area in the early Early Cenomanian (*M. mantelli* Zone) and nearshore glauconitic-bioclastic sandstones predominated (Saal Member), followed by Middle to lower Upper Cenomanian mid-shelf siliceous carbonates intercalated with fine-sandy to silty marls (Bad Abbach Member, Text-Fig. 32). Starting the mid-Late Cenomanian *M. geslinianum* Zone, a considerable deepening pulse during the mid-Late Cenomanian (plenus Transgression) led to the deposition of the deeper shelf silty marls of the Eibrunn Formation which range into the Early Turonian. During the *plenus* Transgression, also the proximal Bodenwöhrer Senke was flooded, indicated by the onlap of the Regensburg Formation onto Variscan granites of the Bohemian Massif, overlain by a thin tongue of lowermost Turonian Eibrunn Formation (Text-Fig. 32). The early Late Cretaceous sea-level rise culminated in an earliest Turonian maximum flooding interval (Text-Fig. 32). The accommodation generated by the Late Cenomanian–Early Turonian sea-level rise was subsequently filled by the Lower Turonian Winzerberg Formation that is capped by the inter-regional sequence boundary SB Tu 1 (Text-Fig. 26).



Text-Fig. 32: Schematic correlation of Cenomanian–Lower Turonian sections from the Regensburg–Kelheim area to the Bodenwöhrer Senke (modified and supplemented after WILMSEN et al., 2010b). Note the regional onlap patterns.

The Regensburg and Eibrunn formations are highly diachronous lithostratigraphic units. Their regional distribution and northeast-directed onlap pattern onto the southwestern margin of the Bohemian Massif can be related to roughly coast-parallel (i.e. NW/SE-trending) facies belts shifting landward on an inclined surface in time (Text-Fig. 32; WILMSEN et al., 2010a). It lasted ca. 6 Ma that the coastline transgressed from southwest of the Regensburg–Kelheim area to the cliff-forming basement rocks southeast of Roding (= 60 km distance), resulting in a mean rate of coastal shift of 10 km/Ma. Additional support for this model of coast-parallel facies belts comes from the considerable subsurface extension of the Regensburg and Eibrunn formations along the strike of the Bohemian Massif to the southeast into the North Alpine Foreland Basin of Austria where the Regensburg Formation forms the reservoir rock and the Eibrunn Formation the seal of a petroleum system (GROSS et al., 2015).

During the inversion phase starting in the Middle Turonian, SW/NE-directed compressional tectonics became of increasing importance for the deposition of the Danubian Cretaceous Group. However, this phase in the evolution of the Danubian Cretaceous Basin has not been detailed here (see NIEBUHR et al., 2011, 2014, for additional information).

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Field Trip PRE-2
Lower to mid-Cretaceous of the Western Carpathians, Slovakia – Cretaceous sediments in the western part of the Central Carpathians

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19 August 2017

Route: Vienna–Bratislava

Stop 1. Devinska Nova Ves
Stop 2. Tmavý Jarok, Vysoká Hill
Stop 3. Hrušové, Nové Mesto Nad Váhom
Stop 4. Vršatec, top of the Javornik hill at Pruské, Vršatské Podhradie village
Stop 5. Butkov Quarry, Ladce
Stop 6. Mojtin Valley, road cuts Beluša–Belušské Slatiny–Mojtín
Stop 7. Skalica Rock, Dolný Moštenec village near Povaszka Bystrica

back to Vienna

Introduction to the central Western Carpathians geological structure

The pre-Senonian (pre-Coniacian) nappe edifice of the Central West Carpathians consists of three principal superunits from bottom to top: the Tatricum, the Fatricum and the Hronicum. The Tatricum is built of pre-Alpine crystalline basement and its Mesozoic (locally also Upper Paleozoic) sedimentary cover, both the Fatricum (Krížna Nappe s.l.) and the Hronicum (Choč Nappe s.l.) turned into superficial cover nappe systems. The youngest, generally synorogenic flysch sediments involved in these nappe systems are dated as Early Turonian in the Tatricum, Cenomanian in the Fatricum and Hauterivian in the Hronicum (see PLAŠIENKA in MICHALÍK et al., 2000). As the Gosau sediments sealing the nappe structure in the northern part of the Malé Karpaty started with Coniacian clastics, the “pre-Gosau” or “Mediterranean” orogenic phase is assumed as the main thrust phase in the Central Western Carpathians. However, this is valid only for the final, rather short-termed emplacement event of superficial nappe sheets, while the preceding shortening of their original basement should have lasted several to several tens of m.y.
The Tatric system was associated with a thick ribbon of sialic crust which was responsible for paleogeographic, sedimentological and structural pecularities of their sequences. The Fatric Nappe system is composed of décollement cover nappes originated in areas south of the present Tatricum. By definition, the Fatricum is composed of both the Vysoká and Krížna partial nappes. Fatric nappes clearly overlie the Tatric cover and are usually overlain by rocks of the “higher” (generally Hronic) nappes. Intrinsic complications arise in the frontal Fatric parts and in the Periklippen area, where the relationships of Fatric units to their substratum cannot be defined in a rigorous way. Unlike the Krížna Nappe proper, the Klape and Manín units underwent repeated subsidence, deep-sea sedimentation and strong deformation after their final nappe emplacement.
Considerations of Triassic sedimentary formations in the “higher” nappes sometimes inferred a presence of nappes of the “ultra-Hronic” affiliation (the Strážov Nappe in the Strážov Mts, or the Nedze Nappe in the Malé Karpaty Mts). These units would be

characterized by involvement of Wetterstein and Dachstein Formations as diagnostic Triassic facies and were therefore regarded as the "Gemeric", and later, after both the Silica Nappe and the Silicicum were defined, as the "Silicic". However, sedimentation in higher nappes of both the Malé Karpaty and Strážov Mts continued until late Early Cretaceous. Therefore, all "higher" nappes in the "core mountains area" are regarded here as constituents of the Hronicum sequence, i.e. the Choč Nappe s.l., which usually starts with a thick Upper Paleozoic volcano-sedimentary complex – the Ipoltica Group ("Melaphyre Series"), nowhere present below the Silicic Unit, spatially restricted to the southern Central West Carpathian zones (the Veporic and the Gemeric domains).

The nappe structure of the northern Tatricum

The Tatricum is a thick-skinned upper crustal sheet comprising pre-Alpine crystalline basement and its Upper Paleozoic to Mesozoic sedimentary cover. The basement consists of low to medium grade, locally high grade metamorphosed Lower Paleozoic volcano-sedimentary complexes and Variscan granitoid plutons. Upper Carboniferous and Permian sedimentary and volcanic rocks form thick complexes in the northern part of the Považský Inovec Mts. only, and these of Permian age in the Kozel Unit of the Malá Fatra Mts. Elsewhere, the Alpine cover sequence started usually with Scythian transgressive clastics (the Lúžna Formation).

The Tatric Superunit was individualized as a composite, fault-dissected domain with attenuated the continental crust during two-phase Early Jurassic rifting and inverted to an imbricated crustal thrust stack during Late Cretaceous shortening (PLAŠIENKA in MICHALÍK et al., 2000). The present northern edge of the Tatricum represents one of the principal tectonic boundaries in the Western Carpathians; it is analogous to the thrust faults separating Penninic and Lower Austroalpine units in the Alps. However, it is usually hidden below superimposed cover nappes and Upper Cretaceous to Tertiary (post) orogenic basin fills. Therefore, the reconstruction of paleotectonic evolution of this boundary zone has to be based on indirect criteria.

Latest Cretaceous to Paleogene dextral transpression and Neogen sinistral transtension obliterated many of primary nappe structures. NW parts of the Malé Karpaty and the Považský Inovec Mts were also affected by the backthrust of cover nappes along the SE margin of a broad wrench corridor which encompasses the northernmost Tatric elements, the NE prong of the Northern Calcareous Alps in the basement of the Vienna Basin and in the Brezovské Malé Karpaty Mts, the Periklippen and Pieniny Klippen belts and the Biele Karpaty Subunit of the Magura Unit (PLAŠIENKA et al., 1991).

The Fatric (Krížna) cover nappe system

The Krížna Nappe is a relatively thin (1–3 km), but widespread overthrust sheet composed of Lower Triassic to mid-Cretaceous sediments of diverse, but mostly carbonate lithologies. They were sheared off their mostly disappeared original basement and tegument along décollement horizons of Scythian and Keuper shales and evaporites to form a far-reaching allochthonous body. The nappe consists of numerous dismembered slices, recumbent folds and imbricates, but large areas with relatively undisturbed stratigraphic successions are present as well.

The Krížna Nappe is generally subdivided into the Vysoká and Zliechov-type successions. The Vysoká Succession contains shallow-water Jurassic sediments similar to the Tatric (High Tatra-type successions), while the Zliechov one is a deep-water Jurassic-Cretaceous succession. In central Slovakia, both units form independent nappe bodies, the Vysoká-type forming slices or duplexes (Belá-, Ďurčiná-, Havran units) at the sole of the huge Zliechov Nappe. At the western (Malé Karpaty Mts) and eastern termination of the Central Western Carpathians (the Branisko and the Humenné Mts) the Vysoká type becomes the main constituent of the Fatricum and the Zliechov type gradually wedges out.

According to the evolutionary tectonic model of the Krížna Nappe, the principal Zliechov Unit was formed at the expense of a wide basinal area floored by strongly stretched and thinned continental crust (MICHALÍK, 2007). In mid-Cretaceous times, the Zliechov Basin was progressively shortened through underthrusting of its basement and tegument complexes below the Veporic thrust wedge. The sedimentary fill was detached along the Upper Scythian shale and evaporite complex and formed an initial fold-and-thrust stack prograding outwards. After complete elimination of the Zliechov Basin substratum, its Tatric and Veporic margins came into collision and the Krížna stack was pushed over the frontal South Tatric ramp, from which frontal Fatric elements (Vysoká and Manín-type), with slope and ridge-related sedimentary successions, were torn off. Finally, during Late Turonian, Fatric nappe elements gravitationally glided northwards in a diverticulation manner from the South Tatric elevation over the unconstrained basinal northern Tatric areas.

From the paleogeographical point of view, the Vysoká Nappe was derived from northern marginal parts of the Zliechov Basin in which slope and ridge facies prevailed (PLAŠIENKA et al., 1991). The Anisian Vysoká Formation represents 200–250 m thick carbonate ramp sediments of the Gutenstein type. The upper member of this formation bears marks of hypersaline environment, such as dolomitization and pseudomorphs after evaporite minerals. The successive Ramsau Dolomite is about 40–60 m thick. Limestones in the uppermost part of this carbonate complex are comparable with the Opponitz Limestone laterally passing into brecciated and cellular dolomites. The Carpathian Keuper complex, although tectonically reduced, attains 200–300 m thickness in several places. The Upper Rhaetian Fatra Formation is represented by a sequence of neritic fossiliferous limestones, overlain by Hettangian thick shaly sediments (about 100 m) of the Kopieniec Formation. Lower Jurassic sandy crinoidal limestones pass into well-bedded cherty crinoidal limestones (the Vývrat Formation), nodular crinoidal limestones and red nodular marlstones (the Prístodolok Formation) and massive crinoidal limestones with ripple- and oblique bedding and with Bathonian fossils. They represent debris aprons along a submarine slope on the basin margin.

The topmost part of Upper Jurassic nodular limestones is dated as the Late Tithonian by a rich microplankton association of the *Crassicolaria* Zone. Lower Cretaceous sequence consists of the massive Padlá Voda Limestone Formation and of schistose marly limestones of the Hlboč Formation. Pelagic formations are terminated by biodetrital Bohatá Limestone Formation. The carbonate complex is terminated by the Albian Poruba Formation of pelagic marls (frequently silicified or tectonically reduced).

During Late Cretaceous–Paleogene dextral transpression, mostly Mesozoic Fatric and Hronic nappes complexes in the NW part of the Malé Karpaty Mts were dissected into numerous duplexes, slices or even "immature" klippen and partly thrust back over the Tatric. The bedding is steeply NW-wards dipping in the eastern parts of the mountains, but the dip decreases eastwards.

The Hronic (Choč) cover nappe system

Pre-progenitor of the term Choč Nappe and/or Hronicum is the "alpinähnliche Fazies" distinguished in the Malé Karpaty Mts. As in all concepts, the "higher Subtatric nappes" are considered as the highest tectonic units in the "core mountains belt", the main contradiction and/or difference lies in their assignment to a superior unit. On the other hand, these complexes show many similarities with sequences of the Ötscher-, or the Göller Nappes of the Northern Calcareous Alps.

Cretaceous sequences in the nappes of the Central Western Carpathians

Lower Cretaceous sequences in the Western Carpathians were mainly deposited in hemipelagic basinal environments. Shallow marine sediments occuring mainly in pebbles of younger conglomerates point out on increased importance of transitional facies – olistoliths, slope debris, slumped bodies, near-slope fans, fluxoturbidites, etc. Top Jurassic/lowermost Cretaceous Outer Carpathian carbonate platforms, including the famous Štramberk reef, were destroyed during Early Cretaceous tensional basins formation. On the other hand, Upper Hauterivian to Lower Albian carbonate platforms, mostly connected by elevated crustal blocks, developed in the Central Carpathians. Subsequently, they were mostly destroyed by erosion following tectonic uplift.

Lower Cretaceous sequences

The Upper Jurassic/Lower Cretaceous limestone sequence in the Tatric Unit of the Malé Karpaty Mts starts with (Kimmeridgian) nodular limestone, and the Tithonian/Berriasian Oberalm Formation with intercalations of turbiditic Barmstein Limestone. The Oberalm Formation consists of brownish grey micritic wackestones. Locally, even Late Berriasian age (*Calpionellopsis* Zone) is proved. In the Kuchyňa Unit, a proximal facies with calciturbidite beds is developed, named as the Staré Hlavy Formation. The source platform limestone complex correlated with the Raptawicka Turnia Formation was studied in the Kadlubek Unit. The major part of the Lower Cretaceous sedimentary record is represented by Berriasian-Barremian schistose marly limestones similar to the Schrambach Formation or by well-bedded cherty limestone sequence of the Lučivná Formation.

The Upper Jurassic and Lower Cretaceous sequence of the Vysoká Nappe (the Fatric Unit) is represented by pelagic limestone facies. Kimmeridgian and Tithonian limestones belong to the condensed “Ammonitico Rosso” complex of reddish nodular limestone with sole limestone breccia beds.

The Padlá Voda Formation consisting of almost massive, pale wackestone to packstone represents the Early Berriasian *Calpionella* Zone. Several layers contain microbreccia composed of Tithonian and Lower Berriasian limestone clasts. The microfauna is rare, being represented by poorly preserved aptychi, fragments of belemnites or ammonite nuclei remnants. Valanginian–Lower Barremian Hlboč Formation is represented by well-bedded marly biomicrites (partly silicified wackestone–packstone) with dark chert nodules. The pelagic formations are covered by organogenic limestones of neritic origin called the Bohatá Formation. The overlying Albian Poruba Formation is more or less preserved (frequently silicified) and consists of brownish grey marls and siltstones.

Upper Cretaceous sequences

Small cavities, fissures and depressions on the surface of carbonate complexes in this part of the mountains are filled by variegated breccias consisting of angular clasts derived from local material, cemented by yellowish and red argillaceous matrix. Breccias resting on Tatric and Fatric units and composed of few types of Mesozoic carbonate and clastic rocks (subordinately also of crystalline schists) with low content of matrix have been named as the Bartalová Breccia. Another type of breccia occurs on Triassic carbonates belonging to the Ötscher (?Göller) Nappe. It is named as the Kržľa Breccia: it consists of angular and semirounded clasts of Annaberg Limestone and Gutenstein Dolomite embedded in red argillaceous or clayey matrix. In several places, an alternation of this breccia with monomict dolomite breccia has been observed. The Kržľa Breccia is covered by the transgressive Late Paleocene sequence.

The Gosau development in the northern part of the Malé Karpaty Mts

The oldest (? Late Turonian–Early Coniacian) sediments of the Late Cretaceous (Gosau) megacycle are represented by fresh-water oncolite limestones of the Pustá Ves Formation. However, the distribution of these rocks is not congruent with the configuration of successive „Gosau-type“ basins. Three outcrops are known in both the Brezovské- and Čachtické Karpaty Mts area.

The Gosau-like Brezová Group sequence in the Brezová region starts with the tripartite Ostriež Formation. The basal Valchov Conglomerate Member with red matrix rests on eroded surface of Triassic carbonates of the Jablonica Nappe. This facies (probable equivalent of the Kreuzgraben Formation or of the lower part of the Streiteck Formation of the Gosau Group in the Eastern Alps) of braided rivers and subaerial deltas contain local material derived almost exclusively from carbonate rocks. The Valchov Conglomerate is heterochronous: while the Early Coniacian age is indicated by foraminifers close to Brezová, intercalations with Campanian microfaunas have been reported E of Bzince. When streams or deltas were lacking on the ancient dolomitic seashore, the Baranes Sandstone Member overlies directly the substratum. The conglomerates are overlain by the Baranec Sandstone Member. The sequence, 50–150 m thick, consists of thick-bedded (250–400 cm) coarse, indistinctly graded sandstones to microconglomerates and sandy limestone with *Actaeonella gigantea*. The Ostriež Formation is capped by the Štverník Marl Member (150 m). Grey marls are intercalated by calcareous fine-grained sandstones and fine conglomeratic beds.

The Hurbanova Dolina Formation is represented by a 500–600 m thick flysch sequence of alternating graded calcareous sandstones, sandy marls and sandy limestones correlable with the Grabenbach Formation of the Northern Alps. Lower Campanian Košariská Formation (~ Púchov Marl Formation) is characterized by variegated (mostly red) marls containing a foraminiferal microfauna ("*Globotruncana*" biomicrite). Upper Campanian and Maastrichtian flysch sequences comprise calcarenite sandstones, sandy *Orbitoides* limestones, microconglomerates with "exotic" pebbles and *Inoceramus* limestones and limestone turbidites (the Široké Bradlo Member).

Outline of the mountains structure

The Malé Karpaty Mountain

Several superposed nappe units comprising the Prealpine basement, its Mesozoic cover, superficial nappes and post-tectonic cover complexes were affected by Alpine crustal dissection produced by long-term extensional tectonic regime. It controlled Tatric dismembering into individual basement sheets. The Paleoalpine superficial nappes with their Upper Cretaceous and Paleogene post-tectonic cover were overprinted by Neoalpine back-thrust tectonics. The nappe structure of the Biele Hory mountain group is covered by a sequence comparable to the Gosau Group of the Northern Calcareous Alps. During Miocene, with the opening of the Vienna and Danube basins, both the Paleogene and Lower Miocene complexes were incorporated into the Malé Karpaty horst structure (MICHALÍK, 1984).

The Triassic carbonates in the Brezovské Karpaty Mts are traditionally ascribed to the Jablonica Nappe. This presumption, although not supported by geometrical analysis of the mountain structure, has been based on facies correlation. There are affinities of this sequence with the Strážov-, Havranica-, and Veterlín Nappes of the Central Western Carpathians, but also with the Ötscher (?Göller) Nappe of the Northern Alps.

The Brezovské Karpaty Mts form an extensive horst-like morphostructure emerging through the Upper Cretaceous and Miocene sedimentary cover. The Jablonica Nappe has a simple monoclinal structure, distorted by faults. Underlying slices belonging probably to the Choč Nappe crop out in two deformed elevated zones along the border of the Dobrá Voda- and the Hradište depressions. Strong tectonization and general vergency proved back-thrusting movements of the platform carbonate block of the Jablonica Nappe.
The Myjava Upland along with adjacent hilly mountains are considered as a continuation of oil-producing basement of the Vienna Basin. Analogous to the Gosau Group of the Northern Calcareous Alps, the Upper Cretaceous–Paleogene complexes in the Myjava Upland represent a distal part of the accretionary belt of the Central Carpathian orogene system. They are in contact with the frontal parts of the Centrocarpathian superficial nappes and with the margin of the Pieniny Klippen Belt. They have been affected by Neoalpine orogenetic deformations.

Triassic carbonate complexes of the Brezovské Karpaty Mts are affected by three systems of transversal faults. The oldest system (N–S or NNW–SSE, respectively) is concentrated near both Hradište pod Vrátnom- or Dobrá Voda villages, where it creates a series of narrow slice bodies. The next system (E–W) divides blocks of different elevation amplitude. Similar movements created also the Dobrá Voda Depression itself. The post-Oligocene or post-Savian age is assumed as source of all disjunctive structures described. The youngest "Sudetian" system (NW–SE), probably Late Miocene in age, cuts all the structures observed.

Geological structure of the Strážovské Vrchy Mts
An extensive, dissected mountain range fringes the left bank of the Váh River between the towns of Žilina and Trenčín. The mountain is separated by the Jastrabie Saddle from the Považský Inovec Mts on the S, by the Fačkov Saddle from the Lúčanská Malá Fatra on E. Mountains slopes on NE, N and W are limited by four basins: Rajec-, Žilina-, Púchov- and Ilava basins. The relief of the mountains is moderate, ranging in altitude from 250 to 1214 above the s.l. Most water streams issuing in the mountains (Rajčianka, Pružinka, Mojtín, Podhradie and Teplička brooks drain into the Váh River. Only streams issuing on the s slopes (Nitra, Tužinka, Nitrica, Belianka, Radiša, Bebrava) flow through both the Bánovce- and Upper Nitra depressions into the Nitra River.

The Strážovské Vrchy Mts is a typical "core" mountains range. Its geological structure can be traced on 300 square kilometers large area with several megasynclines and megaanticlines. In spite of its particularity, the mountain structure is asymmetric with a crystalline "core" situated far on the SE periphery. The Mesozoic complexes comprise almost all Centro-Carpathian units starting with the Tatric through the Manín Unit, Fatric Belá and the Krížna nappes, the Choč Unit of Hronic with the Čierny-, Biely Váh and the Bebrava partial nappes, or with the Middle and Upper Cretaceous sequences of the Accretionary ("Periklippen") Belt including olistostromatic Kostelec and Klape bodies. The Paleogene and Neogene covers are preserved in rests of intra-mountain basins.
The superfial nappe structure is characterized by partial imbrications and nappe slices, the masses of Choč and Strážov nappes were affected by the Savian back thrusting. Finally, the area was dissected by NW–SE and NNW–SSE transversal fault systems concealing the original zonal architecture.

The Tatric crystalline core is typical of migmatite, amphibolite and paracrystalline mantle rocks dominating over granitoids. Neosome layers (or intrusions?) pass through migmatites of several types in paraschists complexes preserving its original pre-Alpine structure. Its Mesozoic cover sequence commences with Scythian quartzose sandstones of the Lúžna Formation overlain by Middle Triassic carbonates (Gutenstein Limestone, Ramsau

Dolomite). The Carpathian Keuper is transgressively overlain by Jurassic complex of black shales with limestone and silicite intercalations (rests of Rhaetian sediments are preserved near to the Valaská Belá village only) and by Lower Cretaceous cherty limestones. The Albian claystones contain large paraconglomerate bodies.
The Manín Unit regarded as a marginal element of either Tatric or Fatric tectonic system. The sequence starts with Triassic members in the SW part of the mountains, whereas Lower Jurassic limestones lie on the base of the sequence in northernmore areas. There are at least three different structures recognizable in the area: the Manín zone, the Jelenia skala/Podmanín-Skalica Zone and the Butkov body. The Manín type of the sequence is developed in shallower facies (red nodular limestones prevail in the Jurassic sequence), the Butkov type comprises also Middle Jurassic silicites. Lower Cretaceous sequence consists of pelagic limestone facies, followed by carbonate platform products (it started during Late Hauterivian in Manin, but as late as in Aptian in the Butkov area). The sequence is covered by Late Albian–Cenomanian marls and by Upper Cretaceous flysch facies.
Development of Triassic sequences in both the Belá (marginal nappe slice) and Zliechov units of the Krížna Nappe is comparable. However, Jurassic sediments are represented by crinoidal limestones in the Belá Unit, while the Jurassic sequence of the Zliechov Unit consists of Hettangian Kopieniec Formation, Liassic "Fleckenkalk", Adnet limestone, Dogger silicites of the Ždiar Formation, and by Malm dark marlstones of the Jasenina Formation. Similarly, Lower Cretaceous carbonates with frequent gaps are covered by "Urgonian" limestones and by black Albian limestones (resembling the Manín sequence) in the Belá Unit, while Berriasian hemipelagic biancone (Osnica Formation) and spotted Valanginian to Aptian limestones (Mráznica Formation) with small volcanoclastic bodies represent Lower Cretaceous sequence of the Zliechov Unit. Albian and Cenomanianstrata are represented by shaly Poruba Formation passin upwards into distal flysch.

The Choč Unit is represented by Permian shales with paleobasalt bodies and by thick complex of Triassic carbonates. In frontal part of the nappe, Jurassic and Lower Cretaceous limestone sequence is preserved. It terminates with Hauterivian/Barremian marls with sandy admixture containing abundant grains of chromium spinels. The Bebrava Unit is characterised by the Anisian Steinalm Limestone with small bioherm bodies and by frequently brecciated Wetterstein and Upper Triassic dolomites. The Strážov Nappe is the highest tectonic unit in the nappe structure. The sequence commences with Anisian grey foraminiferal, crinoidal and bioherm limestones of the Wetterstein type. They are overlain by Upper Triassic dolomites.

Paleogene sequences fill rest of basins both in the Paleoalpine suture (the Hričov Zone) and in the intra-Carpathian Rajec Basin. The Mesozoic substrate was karstified prior to the transgression, the karstic holes were filled by bauxite and laterite. The base of the Paleogene sequence is diachronic, becoming younger from outer zones into orogene. The sequence consists of thick carbonate breccias and conglomerates with occasional algal reef bodies (in the marginal zone).
Neogene sediments fill several pull-apart basins on the Peri-Pieninian Fault separating the mountain range from the Pieniny Klippen Belt. In the mountains, they form only small erosive relics on levelled surfaces and denudation terraces.

Itinerary of the Field Trip

(Jozef Michalík[1], Daniela Reháková[2] & Roman Aubrecht[2])

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Stop 1. Devínska Nová Ves – Slovinec rock cliff (D. Reháková & J. Michalík)
Coordinates: E 16°58'16.9", N 48°12'05.2".
Location: Devínska Kobyla Hill.
Tectonic unit: Tatric Superunit, Devín Unit.

An Upper Jurassic and Lower Cretaceous succession is exposed in the Slovinec rock cliff wall near the Sandberg pit and Devínska Nová Ves village. Thirty-seven samples were taken in meter-intervals from the rock wall for microfacies analysis and detection of stratigraphically important microfossils. The profile line starting from the gallery entrance in the western part of the Slovinec cliff toward right upper edge of the rock documented Upper Jurassic to Lower Berriasian microfacies. The microfacies study confirmed its overturned position already supposed by tectonic study of the Devín Unit (PLAŠIENKA, 1989).

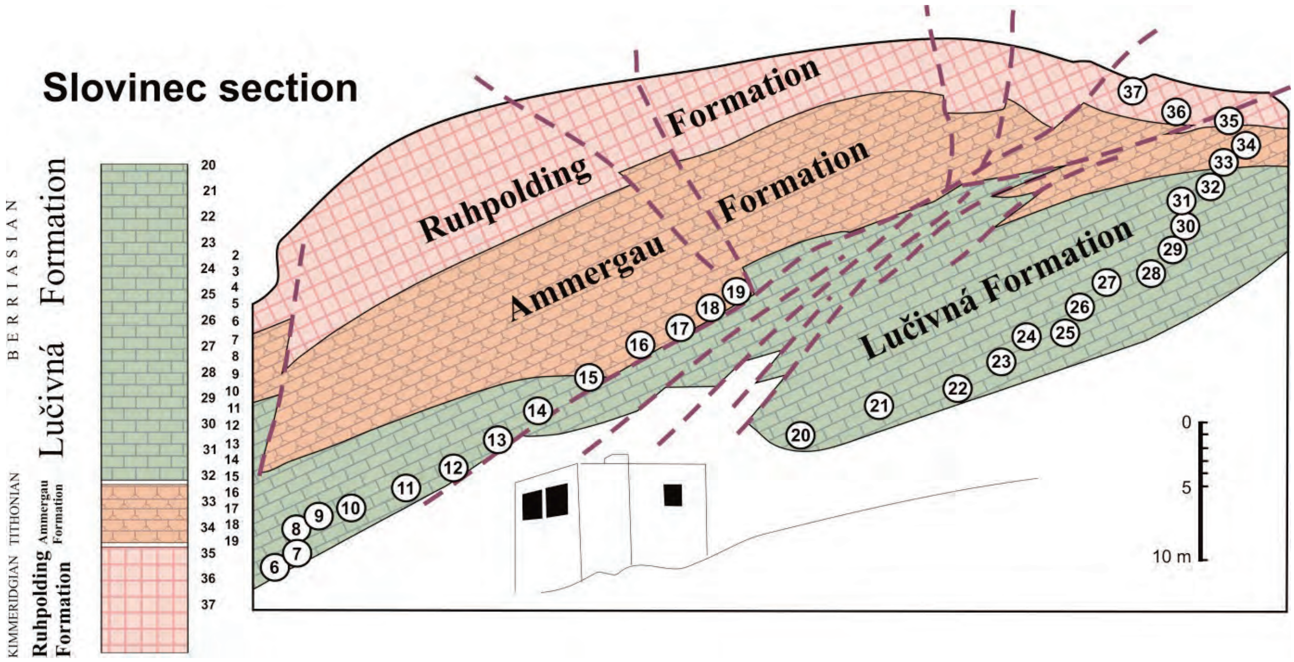
The upper part of the outcrop is built of the oldest part of the sequence attributed to the Ammergau Formation. It consists of reddish-grey to grey-brown fine grained cherty limestone. The sequence of beds 35–37 consists of marly pseudomicrosparitic wackestone to mudstone, passing into thin shales with thin silicite lenses. It contains fine scattered detritus, locally concentrated in thin laminae.

Lučivná Formation (Text-Fig. 1: Beds 1–15, 20–32)
This part of the sequence is formed by grey to greyish brown cherty limestones. They represent recrystallized mudstone (microsparite) to biomicrosparitic wackestone passing to the bedded and thin-bedded limestone above bed 5. Limestone beds are locally intercalated by thin marly laminae. Some beds contain thin fine detrite bands. Cherts are dark black grey in colour, forming nodules or stratiform layers. In beds 8 to 10 slump structures could be indicated by imbrication of cherts.

The rock is locally penetrated by abundant fractures filled by calcite; the matrix is silicified in cherty intervals. Epigenetic pyrite is scattered in matrix. Pyrite and clay minerals concentrate in frequent thin stylolites and it locally cuts contours of bioclasts. Very rare silty clastic quartz grains and muscovite leaflets are present, too. The matrix is locally slightly silicified being penetrated by calcite fractures oriented perpendicularly to metamorphous lamination.

Very rare and mostly fragmented calpionellid loricas (often hardly determined due to damage of collars) are represented by *Calpionella alpina* LORENZ, seldom *Calpionella elliptica* CADISCH, *Crassicollaria parvula* REMANE, *Crassicollaria* sp., *Tintinnopsella carpathica* (MURGEANU & FILIPESCU), microproblematicum *Didemnum carpaticum* MIŠÍK & BORZA, spores of *Globochaete alpina* LOMBARD, calcified radiolarians, fragments of crinoids, ophiuroids, ostracods, bivalves and aptychi were identified. Bioclasts are indistinctly oriented by pressure. This part of the sequence was correlated with the Lučivná Limestone Formation, its Early Berriasian age being indicated by calpionellid association of the standard *Calpionella* Zone (*Calpionella* Zone, *Alpina*- and the *Elliptica* subzones in REHÁKOVÁ & MICHALÍK, 1997).

Ammergau Formation (Text-Fig. 1: Beds 16–19, 30–34)
Globochaete-Saccocoma microfacies was recognized in grey-greenish limestones with indistinctly nodular texture. Spores of *Globochaete alpina*, and *Saccocoma* sp. planktonic crinoids are accompanied by rare aptychi, bivalves, ostracods and very seldom oblique sections resembling calpionellid loricas. Silicified beds contain silicified sponge spicules and radiolarians. Kimmeridgian to Tithonian age of this part of sequence is supposed on the base of microfossils mentioned above.



Text-Fig. 1: Schematic view from eastern side on the Slovinec rock cliff near the Devínska Nová Ves interpreting lithological and tectonic situation (MICHALÍK in PLAŠIENKA, 1989, adapted). Ruhpolding Formation (Beds 35–37).

Stop 2. Tmavý Jarok (J. Michalík & D. Reháková**)**
Coordinates: E 17°13'45.0", N 48°25'50.2".
Location: Rohožník, small narrows in a valley below the Vysoká Hill.
Tectonic unit: Fatric Superunit, Vysoká Nappe.

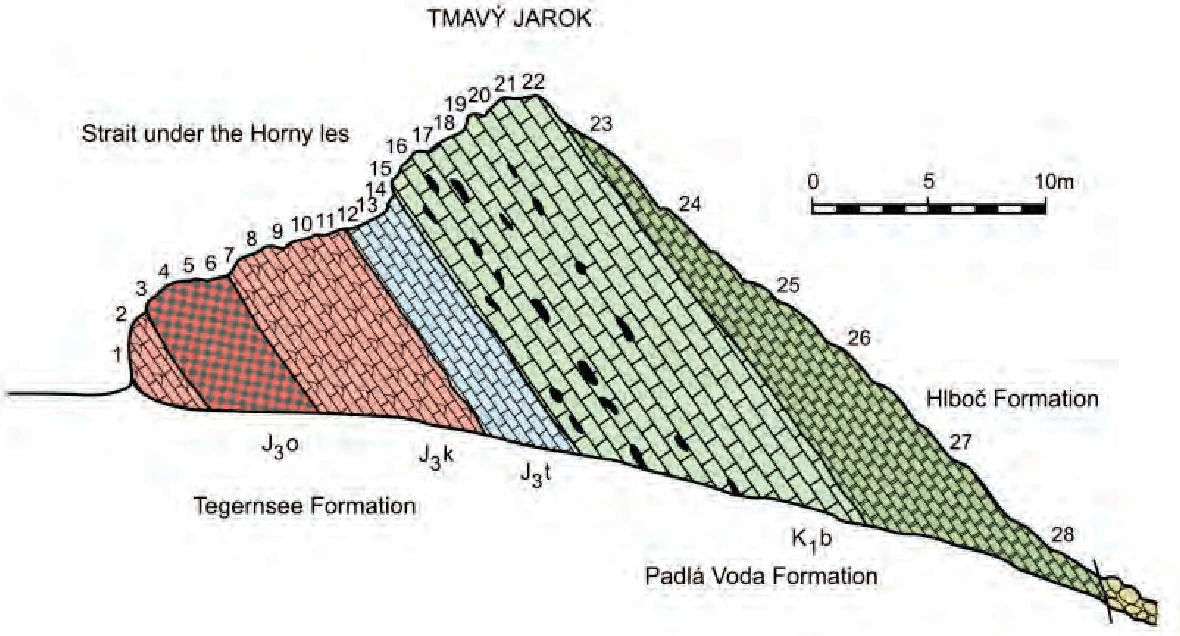
Small creek cut small narrows in Upper Jurassic and Lower Cretaceous carbonate sequence of the Vysoká Nappe. 28-meter-long section documents steep monoclinal dip studied in detail (BORZA et al., 1987; KOVÁČ et al., 1991).

Oxfordian reddish brown and pink nodular cherty limestones (1–8.5 m) attributed to the Tegernsee Formation (or Niedzica Limestone Formation sensu BIRKENMAJER, 1977). Limestones pass upwards into irregularly bedded cherty limestone with radiolarite layer (Text-Fig. 2). The nodules consist of pelbiomicrosparite or pelsparite with fragments of bivalves, ostracods, crinoids, foraminifera, cherty limestones contain calcified radiolarians and sponge spicules. According to dinoflagellate cyst zonation (REHÁKOVÁ, 2000) the presence of *Colomisphaera fibrata* (NAGY), *Cadosina parvula* (NAGY) determines the Oxfordian age of the sequence.

Nodular limestone sequence attributed to the Czorsztyn Formation by BORZA & MICHALÍK (1988) is formed by pink, red, reddish-brown and pink-grey microsparite. The Kimmeridgian part with abundant *Saccocoma* sp., *Stomiosphaera moluccana* WANNER and

Carpistomiosphaera borzai (NAGY) (9–11.5 m) contains thin crinoidal intercalations. The age of the upper, lithologically similar part (12–14 m) is dated by cyst association *Colomisphaera pulla* (BORZA), *Carpistomiosphaera tithonica* NOWAK, *Parastomiosphaera malmica* (BORZA), as well as by calpionellids *Longicollaria dobeni* (BORZA) and *Chitinoidella boneti* DOBEN as Early Tithonian. In the highermost part of the sequence pseudonodular and light-grey micritic limestones contain Late Tithonian crassicollarian association with *Crassicollaria intermedia* (DURAND-DELGA), *Cr. massutiniana* (COLOM) and *Cr. parvula* REMANE identifying the standard *Crassicollaria* Zone (REHÁKOVÁ & MICHALÍK, 1997).

Grey thick bedded micritic limestones with cherts (14,5–28 m) belong to the Padlá Voda Formation (BORZA & MICHALÍK, 1988). Microfossils *Calpionella alpina* LORENZ, *C. elliptica* CADISCH, *Tintinnopsella carpathica* MURGEANU & FILIPESCU indicate Early Berriasian age. *Calpionellopsis simplex* has been found in the uppermost layer. The Padlá Voda Formation is followed by schistose limestones of the Hlboč Formation preserved above the rocky narrows.



Text-Fig. 2: Schematic cross section of the Upper Jurassic and Lower Cretaceous limestone formations in the Rohožnícka Valley, Tmavý Jarok section (BORZA & MICHALÍK, 1988).

Stop 3. Hrušové (facultative)

Coordinates: E 17°45'50.30", N 48°46'22.51".
Location: Small valley in the N slope of Mestská Hora Hill by town of Nové Mesto nad Váhom.
Tectonic unit: Hronic Superunit, Nedze Nappe.

The section exposed by small quarry and by shallow roadcut consists of Upper Jurassic and Lower Cretaceous rocks of the Nedze Nappe belonging to the highest parts of the superficial nappe pile in the area. Detailed biostratigraphy has been described by ONDREJÍČKOVÁ et al. (1993). The lower part consists of nodular pale rose limestones of Tithonian age. They are covered by pale chalky Biancone limestones with rich content of well-preserved calpionellids, nannoplankton and radiolaria of Berriasian age.
Trenčin-Zamarovce: a short coffee stop in a rest station on the motorway.

Stop 4. Vršatec (R. Aubrecht)
Coordinates: E 18°09'35.6", N 49°04'16.7".
Location: Top of the Javornik hill above the Vršatecké Podhradie village near Pruské.
Tectonic unit: Pieniny Klippen Belt, Czorsztyn- and Orava Units.

The Vršatec Klippen group is the largest one in the entire Pieniny Klippen Belt. They crop out above the Vršatecké Podhradie village, NW of the Ilava town. Two largest tectonic blocks belong to the Czorsztyn Unit: The Vršatec Castle- and the Javornik klippe. They are formed by Middle Jurassic–Lower Cretaceous carbonates (including relatively thick, coral-dominated biohermal limestones) capped by Upper Cretaceous marls. MIŠÍK (1979) dealt in detail with sedimentology of two blocks in an E–W oriented transect based on seven stratigraphic sections. He suggested that the blocks consist of two tectonic slices with different stratigraphic successions.

According to this hypothesis, Middle Jurassic Smolegowa and Krupianka crinoidal limestone in the first slice is overlain by Upper Jurassic biohermal limestones (the Vršatec Limestone). In contrary, in the second slice, Middle Jurassic crinoidal limestone is overlain by the Czorsztyn Limestone Formation. However, SCHLÖGL et al. (2009) have found that both blocks are built of only one succession, probably with variable facies composition. Geopetal infillings within brachiopod shells indicate that crinoidal limestones are *overlying* the biohermal limestones. Moreover, biostratigraphic data prove that the biohermal limestone is older than thought before, probably of Middle Jurassic age.

The Vršatec Limestone is formed by white to pinkish biohermal limestone with corals, calcareous sponges, and locally with bivalves and brachiopods. They are laterally replaced or overlain by both pink and grey peri-biohermal limestone and breccia.

Based on bivalves, the biohermal limestones were assigned to the Oxfordian (MIŠÍK, 1979). However, these bivalves are stratigraphically inconclusive (GOLEJ, pers. comm.). One neptunian dyke cutting the limestone yielded uppermost Bajocian/lowermost Bathonian ammonite *Nannolytoceras tripartitum* RASPAIL. Moreover, most of the dykes are filled by filamentous microfacies (*Bositra* Limestone), which is restricted mainly to the Bathonian–Callovian in the Czorsztyn Unit. Oxfordian deposits are already characterized by the *Protoglobigerina* microfacies. Thus, based on the infillings of the neptunian dykes, the age of the biohermal and peribiohermal limestones is probably Early Bajocian. The exposed part of the limestones is at least 15 metres thick.

The Smolegowa- and Krupianka Limestone Formations are formed by grey to reddish crinoidal grainstone overlying the biohermal Vršatec Limestone. The top of the biohermal facies is marked by thin Fe-/Mn-crusts and impregnations. In contrast, the boundary between the peribiohermal facies and crinoidal limestone seems to be gradual in most sections. Because of lack of stratigraphically more valuable fauna, the age of crinoidal limestones is based on the dating of equal crinoidal deposits in the area as the Bajocian. The thickness is around 35 metres.

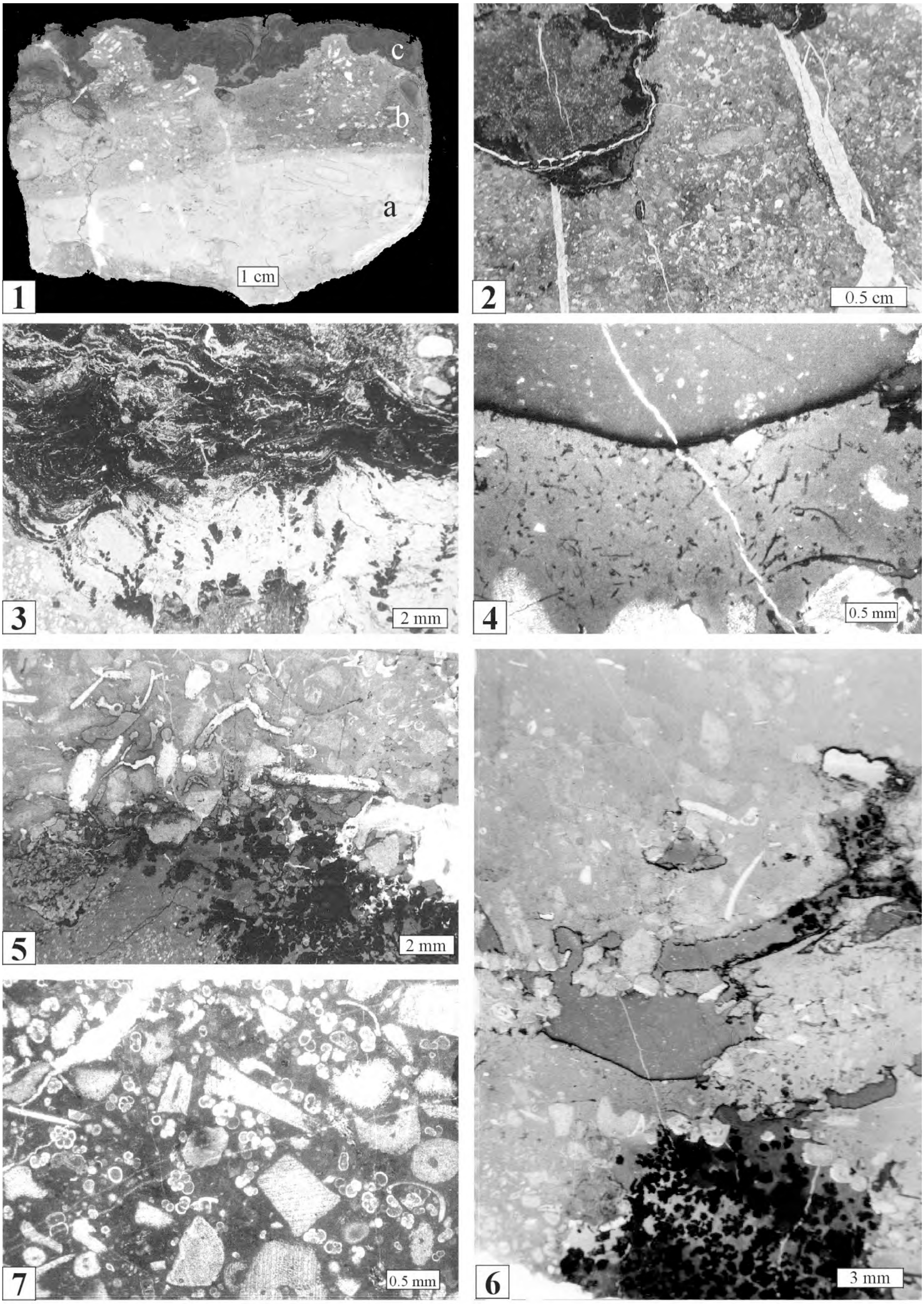
The Czorsztyn Limestone Formation consists of red micritic, locally nodular limestones. Based on ten detailed stratigraphic sections along both blocks, the thickness of this formation vary between 0.2 to more than 15 metres. There is invariably a 0.5–2 cm-thick Mn-crust at the base of the formation, marking the hiatus between the crinoidal and red micritic limestones. Based on ammonites and on data from other sections, the age of the whole formation is Bathonian to Early Tithonian. The thickness of the Bathonian–?Callovian deposits, which are separated from the overlying red micritic limestones by another Mn-/Fe-hardground, attains few cm up to 3.5 metres. The deposits contain mainly filaments (filamentous packstones), juvenile gastropods, benthic foraminifers and crinoidal ossicles. The *Protoglobigerina* microfacies characterizing overlying massive limestones suggests their Oxfordian age. The massive limestones pass gradually into massive red micritic limestones with the *Saccocoma* microfacies. Ammonite fauna including *Orthaspidoceras uhlandi* (OPPEL) and *Hybonoticeras hybonotum* (OPPEL) indicates a Kimmeridgian and Early Tithonian age.

The Dursztyn Limestone Formation consists of massive, red, pinkish or yellowish micritic limestones. Locally, they can be rich in crinoidal ossicles (forming lenses of crinoidal packstones) and fine shelly debris. The *Saccocoma* microfacies pass gradually into the *Crassicollaria* and *Calpionella* microfacies. The Middle Tithonian to Early Berriasian age of the formation is based on calcareous dinoflagellates and calpionellids.

Cretaceous deposits are represented by red marls and marlstones. A tectonic contact of the Upper Tithonian to Berriasian white to pinkish *Calpionella* limestones with red marls and marlstones is exposed in the road cut in the saddle above the Vršatské Podhradie village. Limestone and marl sequence is in a reverse position. Normal sedimentological contact between Dursztyn Limestone Formation and red Púchov marls is visible on the foot of the Vršatec Castle Klippe, where the signs of karstification of the Lower Cretaceous limestones can be observed. The marls are of Late Cenomanian to Campanian age.

As the sections in the Pieniny Klippen Belt represent isolated blocks and tectonic lenses which were rotated along several axes, paleomagnetic analyses are necessary for the reconstruction of their original palaeogeographic position. AUBRECHT & TÚNYI (2001) analysed neptunian dyke orientations in four sections in the Pieniny Klippen Belt. They include the Vršatec Castle Klippe (Text-Fig. 3-1), Babiná quarry, Mestečská skala and Bolešovská dolina. In majority, neptunian dykes are cut in Bajocian–Bathonian crinoidal limestones (Smolegowa- and Krupianka Limestone Formations) and consist of red micrites or biomicrites. They contain mainly juvenile bivalves or rarely the *Globuligerina* microfacies. These microfacies indicate that the dykes range from the Bathonian to Oxfordian. Exceptionally, neptunian dykes of Tithonian and Albian age were found in the Vršatec klippe. They represent rejuvenation of older dykes (MIŠÍK, 1979).

Text-Fig. 3-1 (page 71): Slabs and microphotos of microfacies from the Vršatec area. A: Slab showing Lower Cretaceous limestone (a), covered by Upper Albian organodetrital limestone (b) and by P-Fe stromatolite (c) which forms the base of pelagic Albian deposit. Note uneven surface between the Upper Albian limestone and the stromatolite cover. The surface has been most likely shaped by karstic dissolution. It provides an evidence of repeated emersion of the sedimentary area still after the first phase of Late Aptian flooding. B: Two veinlets filled by blocky calcite, cutting Lower Cretaceous organodetritic limestone but not continuing to the Albian stromatolitic hardground above. Their age is then pre-Albian and their filling could be of fresh-water origin. C: Albian stromatolite (with ptygmatitically folded calcite veinlets – the upper part of the photo) and bush-like (*Frutexites*-type) stromatolites growing in the Albian sediment towards the stromatolite. The latter means that the sediment represents a filling of larger cavity and the stromatolite above it grew on the roof of the cavity. D: Network of boring organism traces, most likely fungi (note local branching) filled by Mn-oxides in the Lower Cretaceous limestone below the base of the Albian sediments. E: Geopetal filling of leached bivalve shells in Lower Cretaceous limestone (above) contradicts with the location of Albian sediment (below). It indicates that the Albian sediment has been deposited in a (most likely karstic) cavity. F: Bizarre cavities in the Lower Cretaceous limestone filled by Albian micrite. Their geopetal filling enables proper orientation of the photo, in spite of position of the Albian stromatolite and sediment (below). They most probably represent filling of a larger karstic cavity. G: Upper Aptian–Lower Albian crinoidal-foraminiferal wackestone to packstone, recording the first flooding phase after hiatus.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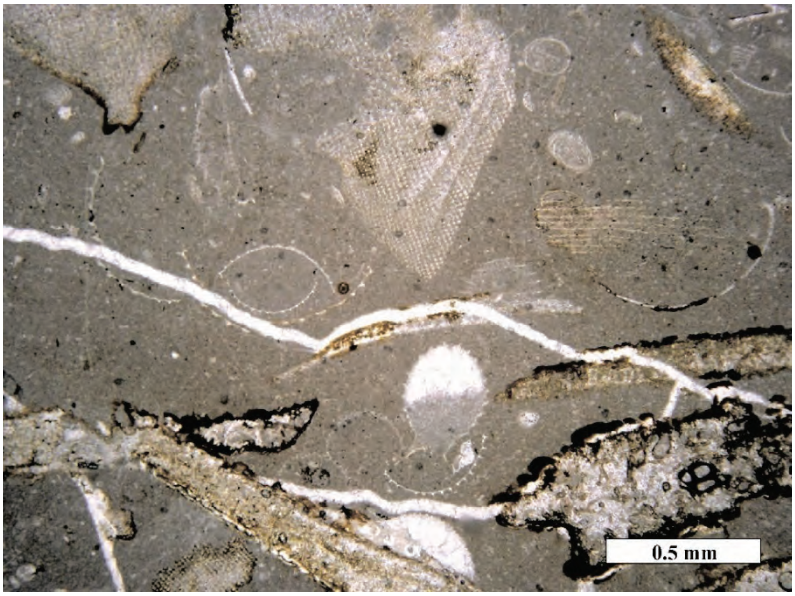


Text-Fig. 3-2: Cross-sections of cave-dwelling ostracods *Pokornyopsis feifeli* (TRIEBEL) in a neptunian dyke filling from the Vršatec Castle klippe.

The neptunian dykes (but also crevices in the breccias and even cavities in the stromatactis mud-mounds at Babiná and Slavnické Podhorie) show presence of *Pokornyopsis feifeli* (TRIEBEL) (Text-Fig. 3-2), ancestors of recent ostracod *Danielopolina* which is a common cave dweller in the so-called anchialine caves (AUBRECHT & KOZUR 1995). The measurements of the neptunian dykes and their evaluation, with utilizing of paleomagnetic correction, enable estimating the paleogeographic orientation of the Czorsztyn Ridge as NE–SW (with N–S to ENE–WSW variations). This direction points to the NW-SE oriented Jurassic extension in that area. Paleomagnetic inclination ranging between 21º and 46º, with mean point of about 33º, indicates that the Czorsztyn Ridge was located approximately at 10–30º paleolatitudes in the Middle Jurassic.

The Czorsztyn Unit is the shallowest Pienidic Unit of the West Carpathian Pieniny Klippen Belt. After the Hauterivian, a hiatus encompassing almost the whole Barremian and Aptian occurred in this unit. Tithonian–Lower Cretaceous limestones are overlain by pelagic Albian marlstones and marly limestones. The nature of this hiatus was frequently discussed in the literature: some authors favoured submarine non-deposition and erosion (BIRKENMAJER, 1958, 1975), whereas others proposed emersion of the ridge (MIŠÍK 1994).

Recently, most of the formerly known sites were re-examined and new sites with preserved contact between the Albian and the underlying formations of the Czorsztyn Unit were found. At two sites, Albian marlstones and limestones are in contact with Lower Cretaceous, Tithonian or older rocks. In Jarabiná, Barremian–Aptian erosion reached Kimmeridgian red micritic limestones but clasts of limestones with “filamentous” microfacies indicate that Bathonian–Callovian limestones had to be uncovered too. At Horné Sŕnie, where the deepest erosion level was stated, Albian deposits overlay Bajocian–Bathonian crinoidal limestones. Except of deep erosion, unequivocal signs of subaerial exposure and karstification (karren)-landform with vertical drainage grooves, small cavities in the bottom rock filled with later sediment, bizarre fractures and veinlets filled with calcite, were revealed, mainly in the Horné Sŕnie and Lednica sites. Erosion was followed by pelagic deposition, documented by Albian marlstones and limestones with pelagic fauna. In this time, the paleokarst surface was bored by boring bivalves and overgrown by deep-water Fe-Mn to phosphatic stromatolites. This suggests a very rapid relative sea-level rise, most likely due to platform collapse and drowning.

Several relics of the Albian marlstones overlying Lower Cretaceous limestones, together with some Albian neptunian dykes cutting the underlying rocks, were found in the Vršatec klippen. Most of them were summarized by MIŠÍK (1979); two localities were revealed recently. The basement below the Albian sediments is commonly irregular due to karstification and animals boring activity. Small caverns in Lower Cretaceous limestones filled by Albian sediments are common too. Albian pelagic marlstones contain belemnites (*Neohibolites minimus* LISTER), bivalves *Aucellina* sp. and numerous planktonic foraminifers *Ticinella roberti* (GANDOLFI), *Thalmanninella ticinensis* (GANDOLFI), *Hedbergella infracretacea* (GLAESSNER), *Thalmanninella apenninica* (RENZ), *Planomalina buxtorfi* (GANDOLFI) and many agglutinated foraminifers. The foraminifer assemblage indicates Albian to Cenomanian age of the overlying beds. Deep-water bacterial Fe-Mn-P stromatolites, oncoids and frutexites are common in the basal parts, sometimes directly overgrowing the underlying limestone. Higher up, radiolarian cherts were found in Cenomanian–Turonian marlstones at the southernmost Vršatec klippe (SÝKORA et al., 1997) which testifies rapid sea-level rise after drowning of the swell.

In the Albian sediments on six localities (two from Vršatec), detrital admixture including chrome spinels was found (JABLONSKÝ et al., 2001). Such minerals, derived from an unknown ophiolitic source area are common in the Albian deposits of the Klape Unit, the Tatric and Fatric units, but they were not found in the Czorsztyn Unit so far. The presence of Albian ophiolite debris in the Czorsztyn Unit is very surprising and contradicts to the classical paleogeographic schemes where the Czorsztyn Swell formed an isolated ridge, surrounded by deep troughs during Albian, still.

Stop 5. Butkov Quarry (J. Michalík)
Coordinates: E 18°19’21.23”, N 49°01’28.58”.
Location: Large quarry on the N slope of the Butkov Hill, Ladce BERGER Cement factory.
Tectonic unit: Manín Unit.

Jurassic to Lower Cretaceous sequence of the Manín Unit is exposed on fifteen-levels quarry (Text-Fig. 4). Lower Jurassic strata are built of sandy limestones, followed by Mid-Jurassic shaly siliceous rocks and Callovian/Tithonian Ammonitico Rosso nodular limestone complex. After a Berriasian gap, the Cretaceous sequence starts with hemipelagic carbonate deposition. Until now, hundreds of ammonite specimens were collected in it and put in the orthostratigraphic scale. Vertical distribution of ammonites and aptychi was laterally correlated with the distribution of calcareous microplankton (calpionellids, calcareous and non-calcareous dinoflagellates and nannoplankton).

Early Valanginian age of deposition of thin bedded pale marly Ladce Formation limestone has been proved by ammonite fauna of the *Campylotoxus* Zone. Sedimentation of this formation terminated during Late Valanginian (between *Peregrinus*- and *Furcillata* Zones). Ammonite findings were correlated with the aptychi distribution. The Valanginian age has been proved by calpionellids of the Calpionellites standard zone (the Darderi- and the Major subzones) and calcareous dinoflagellates. Moderately to poorly preserved *Nannoconus* spp. and *Watznaueria barnesae* constitutes 40–90 % of low-diversified calcareous nannofossil assemblage which allowed distinguishing of the Calcicalathina oblongata NK-3 Zone (the *Rucinolithus wissei* NK-3A Subzone). Seldom, poorly preserved non-calcareous dinoflagellate association belongs to the Spiniferites Zone.

The boundary between the Ladce Formation and overlying Mráznica Formation is not sharp (somethimes it is stressed by a calciturbidite layer). The *Verrucosum* and *Peregrinus* Zones were identified due to presence of subzonal ammonite species only. Ammonite remnants are abundant in Upper Valanginian part of the Mráznica Formation. They belong to the *Furcillata* Zone. Late Hauterivian age of the Mráznica Formation has been identified by the ammonite association of the *Balearis* Zone.

Text-Fig. 4: Jurassic to Lower Cretaceous sequences of the Manín Unit in the Butkov Quarry.

Sequence of marly limestones contains very rare microfossils of the *Tintinnopsella* Zone, rare remaniellids show rather the erosion of older deposits. Calcareous nannofossils belong to the Late Valanginian *Tubodiscus verenae* Subzone (NK–3). Cosmopolitan representatives (*Watznaueria barnesae, Cyclagelosphaera margerelii, Rhagodiscus asper, Zeugrhabdotus embergeri, Cretarhabdus* spp., *Micrantholithu*s spp.) together with Tethyan taxa (*Conusphaera mexicana, Cyclagelosphaera deflandrei, Cruciellipsis cuvillieri* and *Nannoconus* spp.) created nannofossils assemblages. In the Upper Valanginian and Lower Hauterivian rare boreal taxa has been noticed (*Micrantholithus speetonensis, Crucibiscutum salebrosum, Nannoconus pseudoseptentrionalis*). Palynological study shown rather the rich association of Late Valanginian to Lower Hauterivian non-calcareous dinoflagellates belonging to *Cymososphaeridium validum* (Cva) Zone determined by LEEREVELD (1997a, b).

Hauterivian age of pelagic cherty Kališčo Formation limestones has been proved by ammonites of the *Radiatus*- and *Ligatus* Zones. *Tintinnopsella carpathica* is very seldom in Kališčo Formation. Calcareous nannofossils allowed to determine NC-4A and NC-4B Subzones equivalent to the lowermost ammonite *Nodosoplicatum* Zone. Low content of nannoconids and abundance of *Micrantolithus hoschulzii* is a characteristic feature of Early Hauterivian nannofossil associations. Association of non-calcareous dinoflagellates belongs to the *Muderongia staurota* (Mst) Zone, which is correlated with ammonite *Radiatus*- and *Nodosoplicatum* zones. The *Nodosoplicatum* Zone is proved also by the first appearence of *Coronifera oceanica* and by presence of coeval nannofossils.

The basal part of grey bedded micritic limestones of the Lúčkovská Formation contains ammonites of Late Hauterivian *Balearis* Zone. Ammonites collected proved the Pulchella and *Compressissima* zones, and the basal part of Late Barremian *Vandenheckii* Zone. Sporadic *Tintinnopsella carpathica* was continuously observed in lower part of formation. The calcareous nannofossil assemblage belongs to the *Litraphidites bollii* Zone (NC-5B Subzone). If compared with the Kališčo Formation, nannoconids abundance increased. A block from the eastern part of the 7th etage (BK-7/V) belongs to the Early Barremian *Micratholithus hoschulzii* Zone, NC-5D Subzone. The Lúčkovská Formation yielded rich palynomorphs. Lower Barremian *Subtilisphaera scabrata* (Sca) and Upper Barremian *Odontochitina operculata* (Oop) dinozones were identified in the uppermost part of formation.

Dark grey bituminous limestones of the Podhorie Formation contain bad preserved, corroded dinoflagellates similar to Upper Barremian or younger types.

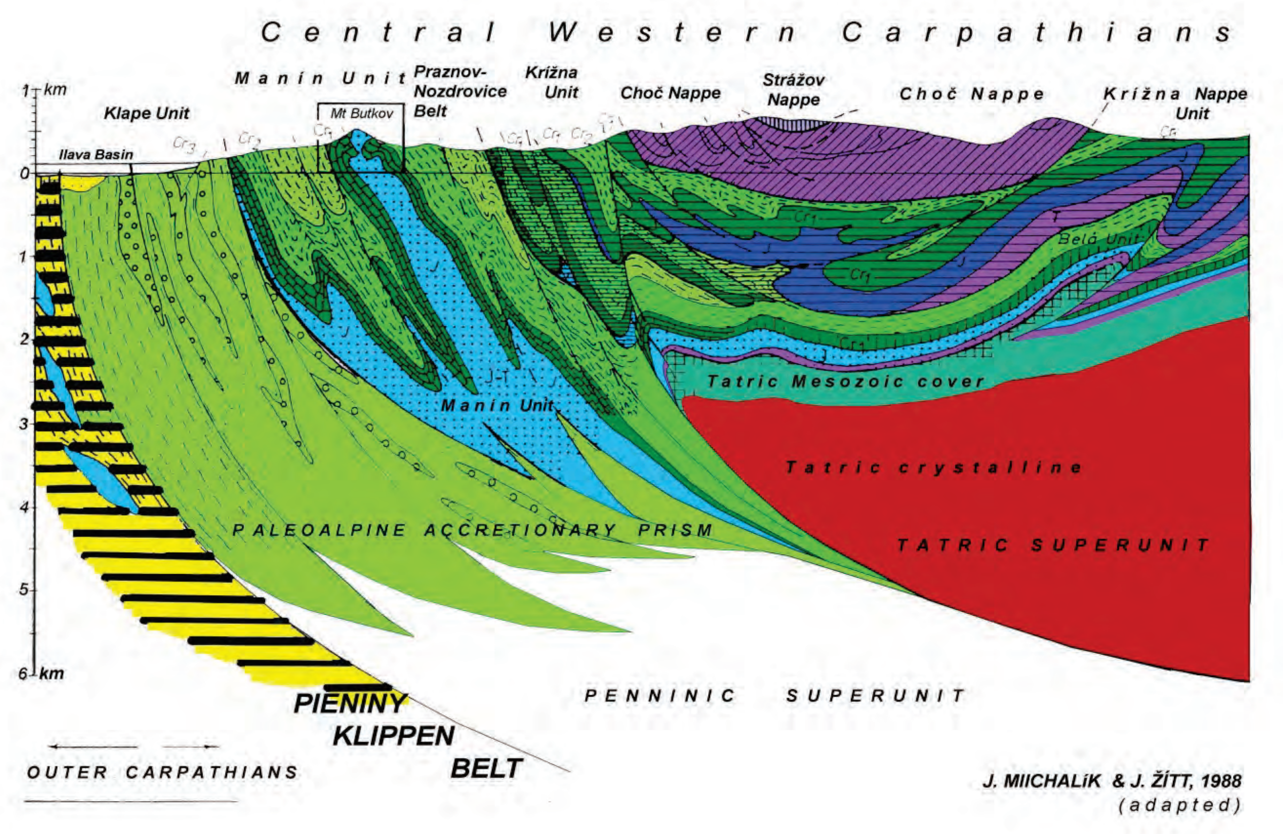
Dark grey marlstones of the Butkov Formation contain rich dinoflagellate association. On the base of their spectra it is possible to correlate it with the Late Albian ammonite *inflatum*- and *dispar* Zones. Very rare findings of the species *Eiffelithus turriseiffelii* in the Butkov Formation allow to set the Albian age of formation or assign the base of the *Eiffelithus turriseiffelii* Zone (CC9) sensu Perch-Nielsen (1985).

On the base of sequence stratigraphy study of the Lower Cretaceous formations mentioned above it was possible to recognize nine sequence boundaries. Comparison of non-calcareous dinoflagellates with sea-level fluctuation has shown the dominance of brackish species (*Muderongia*) during the lowstand conditions, and on the other hand, prevalence of neritic (*Oligosphaeridium, Spiniferites*) and oceanic (*Pterodinium*) species during transgressive and highstand intervals.

Stop 6. Mojtin Valley (J. Michalík)

Coordinates: E 18°21'23.25", N 49°01'06.53".
Location: Road cuts Beluša–Belušské Slatiny–Mojtín.
Tectonic unit: Klape Unit, Manín Unit, Krížna Nappe.

The roadcut between Beluša, Belušské Slatiny and Mojtín villages cuts frontal parts of the superficial nappe system in the Strážovské Vrchy Mts. It starts in slices of the Klape Unit covered by remnants of Neogene infilling of the Váh River depression. The road passes a well of mineral (sulphur) water penetrating along marginal faults of the basin. The Manín Unit forms an anticlinal fold with a core of Jurassic and Lower Cretaceous formations rimmed by mid- and Upper Cretaceous complexes (Text-Fig. 5). The unit is thrust westward onto the Klape Unit. From the eastern side, it is overthrust by a transitional unit, built of Cretaceous limestones and shales. The higher unit belongs to the frontal part of the Krížna Nappe, formed by Lower Cretaceous marly limestones of the Mráznica Formation, of the Aptian volcanic and shaly complex and of the Albian shaly Poruba Formation. The following Choč Nappe forms the second rocky narrows, built of Jurassic crinoidal and nodular limestones, Lower Cretaceous Biancone limestones, and the youngest member of sequence in this unit – Barremian shales with detritus of chromspinel grains. The highest part of the pile consists of Triassic limestones of the Strážov Nappe. The plateau where the Mojtín village is situated, is covered by bauxite weathering products below the base of Paleogene sedimentary infilling of a younger intra-Carpathian basin.



Text-Fig. 5: Cross-section through the front of the Central Carpathian nappe units.

Stop 7. Skalica Rock (J. Michalík & D. Reháková)

Coordinates: E 18°26'02.80", N 49°04'41.82".
Location: Rocks above meadows by the Dolný Moštenec village.
Tectonic unit: A "klippe" of the Manín Unit.

Prominent rock cliff exposes Upper Aptian–Lower Albian part of the sequence similar to the Manín Unit (Text-Fig. 6, 7). It consists of organodetrital limestones. The locality has been studied by ANDRUSOV & KOLLÁROVÁ-ANDRUSOVOVÁ (1971); RAKÚS (1977); BORZA et al. (1979); MARSCHALKO & KYSELA (1980); MICHALÍK & VAŠÍČEK (1984). In detail, the sequence consists of two different parts.

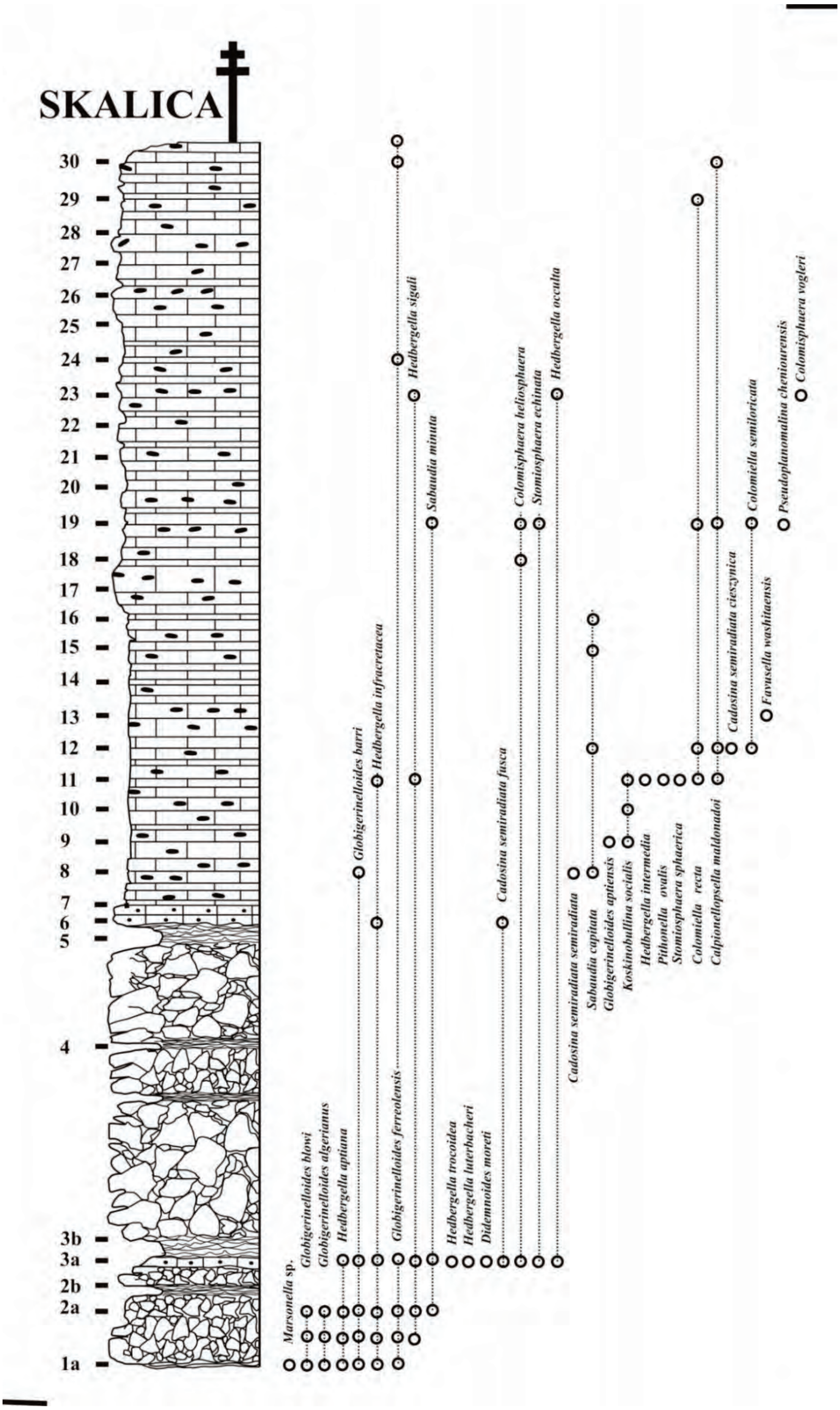
Six thick layers formed by breccia of "Urgonian-type" limestones crops out in the lower part of the rock wall. The clasts are 4 to 70 cm in diameter (some of them attain several meters), they consist of pelbiointrasparite (grainstone to rudstone). Clasts are cemented by glauconitic biodetrital wackestone with fragments of belemnite rostra.

Text-Fig. 6: The outcrop of the Skalica Rock succession above the meadows close to Dolný Moštenec.

Foraminifers are represented by *Globigerinoidelloides blowi*, *G. algerianus*, *G. ferreolensis*, *G. barri*, *Hedbergella aptiana*, *H. sigali*, *H. trocoidea*, *H. luterbacheri*, *H. infracretacea*, occurring along with *Cadosina semiradiata fusca*, *Sabaudia minuta*, *Colomisphaera heliosphaera*. Each of the layers is topped by greenish grey marl containing numerous (mostly fragmented) fossils, mainly belemnites (*Mesohibolites fallauxi* and *Neohibolites inflexus* cf. *angelanicus*), brachiopods, echinoids and ammonites. ANDRUSOV & KOLLÁROVÁ-ANDRUSOVOVÁ (1971) and VAŠÍČEK (in MICHALÍK & VAŠÍČEK, 1984) reported findings of *Melchiorites* cf. *melchioris* (TIETZE), *Acanthohoplites* ex gr. *bigoureti* and *Phylloceras* (*Hypophylloceras*) *moreti* (MAHMOUD) indicating the *Melchioris* Zone of Late Aptian.

The highest marlstone bed is covered by thick (90–120 cm) layer of glauconitic biodetrital packstone. It contains echinoids, seldom planktonic foraminifers (Hedbergella and Globiogerinelloides) and cysts (*Cadosina semiradiata semiradiata*). Framboidal pyrite occurs frequently.

The upper part of the sequence is built of thick bedded blackish grey biomicrite packstone-to wackestone of spongolitic facies with large loaf cherts. They contain *Koskinobullina socialis*, *Pithonella ovalis*, *Colomiella recta*, *C. semiloricata*, *Calpionellopsella maldonadoi*. Their age has been estimated as Early Albian by BORZA et al. (1979). The sequence represents a peri-basinal development of the Manín sequence.



Text-Fig. 7: Skalica Rock succession.

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Field Trip PRE-3
Cretaceous Building Stones of Vienna

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Text and text-figures are taken/translated from SUMMESBERGER & SEEMANN (2008).
All photographs by: Alice Schumacher (NHM Wien)

naturhistorisches museum wien

Stop 1. Maria Theresia Monument
(SUMMESBERGER & SEEMANN, 2008: p. 8, No. 1)
Opening ceremony: 13. Mai 1888 (birthday of Empress Maria Theresia, 1717–1780).
Bronze figures: Caspar von Zumbusch (1830–1915).
Architect: Carl von Hasenauer (1833–1894).
Foundation: bricks.
Base: Granite, Bohemian Massif.
Age: Variscan (300–350 Ma).
Origin: Mauthausen, Upper Austria.
Pedestal: Cistec "Granite" (granodiorite) from Pilsen area (Czech Republic).
Age: Variscan (300–350 Ma).
Pillars: Alpine serpentinite "Sterzinger Serpentin" from Vipiteno, Alto Adige, Italia.
Age: 160 Ma.

Stop 2. Natural History Museum
(SUMMESBERGER & SEEMANN, 2008: p. 11, No. 3)
1898 opened by Emperor Franz Joseph I. (1830–1916; see the monograms "F.J.").
Architects: Gottfried Semper (1803–1879), Carl von Hasenauer.
Neorenaissance style.
Building stone: Sandstone (Facade) and bricks.
Age: Neogene.
Origin: Eggenburg – North of Vienna (Lower Austria); Slovenia, Croatia.
First general director: Ferdinand von Hochstetter, geologist (1829–1884).

IMPERIAL PALACE

Stop 3. Äußeres Burgtor
(SUMMESBERGER & SEEMANN, 2008: p. 15, No. 6)
(Outer Gate of the Imperial Palace), 1821–1824.
Architects: Luigi Cagnola (1762–1833), Peter von Nobile (1774–1854).
Building stone: Conglomerate.
Age: Neogene.
Origin: Wöllersdorf, South of Vienna.

Ringstraße Constuction period since 1855.
The area between the former city walls and the surrounding villages – the "Glacis" – was sold by the government to wealthy private people who built several hundreds of Palais along the Ringstraße. From the incoming money the Opera House, the Burgtheater, the House of Parliament, the Museum of Fine Arts and Natural History Museum were founded. The monumental buildings consist mainly of brick constructions, mostly covered by natural stone, which was often integrated into in the structure itself.

Stop 4. Heldenplatz (Place of Heroes)
(SUMMESBERGER & SEEMANN, 2008: p. 16, No. 7)
Two equestrian monuments: Prince Eugene of Savoy (1663–1736) and Archduke Carl
Pedestal: Untersberg conglomerate with rudists and pebbles bored by Lithophaga mussels.
Age: Cretaceous, about 90 Ma.
Origin: Untersberg/Salzburg, Austria.

Stop 5. Neue Hofburg (Imperial Castle)
(SUMMESBERGER & SEEMANN, 2008: p. 20, No. 9)
Building stone: Marzana limestone.
Age: Cretaceous.
Origin: Marzana (today: Marčana), Croatia.

Stop 6. Innerer Burghof (Inner Courtyard)
(SUMMESBERGER & SEEMANN, 2008: p. 20, No. 10)
Floor: Granite from Upper Austria.

Monument Emperor Franz I. (1768–1835)
Pedestal: Granite; Bohemian Massif.
Age: Variscian (300–350 Ma).
Origin: Mauthausen, Upper Austria.

Stop 7. Schweizertor (Suisse Gate)
Surviving renaissance element in the Imperial Palace.
Inside: The oldest known (1552) relief with the "Habsburg Eagle" as the heraldic animal of the Austro-Hungarian coat of arms on the fountain basin made of "Kaiserstein" limestone.
Age: Neogene.
Origin: Kaisersteinbruch quarry, Lower Austria.

Stop 8. Entrance to the former Burgtheater (Imperial Court Theater)
Passing through the “Inneres Burgtor”, on the right hand side the preserved entrance to the former “Burgtheater” can be seen, which was demolished when the “Inneres Burgtor” was built.

Stop 9. Inneres Burgtor, Michaelertrakt (Inner Gate of the Imperial Palace)
(SUMMESBERGER & SEEMANN, 2008: p. 23, No. 11)
This part of the Imperial Palace was built (1889–1893) after original baroque plans of the famous architects Lucas von Hildebrandt (1668–1745) and Fischer von Erlach (1656–1723) during the “Ringstraßen” building period.

Monolithic Hercules statues:
Bryozoan limestone.
Age: Neogene.
Origin: Zogelsdorf, North of Vienna.

MICHAELERPLATZ AND KOHLMARKT

Stop 10. Michaelerplatz (St. Michael’s place, pedestrian area)
(SUMMESBERGER & SEEMANN, 2008: p. 23, No. 12)
Excavations of Roman and medieval foundations.

Stop 11. Loos Haus (Loos House)
(SUMMESBERGER & SEEMANN, 2008: p. 24, No. 13)
Cultural monument.
Architect: Adolf Loos (1870–1933), pioneer of modern architecture in Vienna.
Built after Loos’ then futuristic ideas without decoration of the Facade (“Haus ohne Augenbrauen” → “House without eye-brows” nicknamed by the Viennese).

Decoration stone: “Cipollino”, greenschist interbedded with white marble layers
Origin: Greece, island of Evvia. This stone was used since Roman times all over the Roman Empire.

Stop 12. Michaelerkirche
(St. Michael’s Church, 1220)
Romanesque style with early gothic architectural elements. 1276 rebuilt after a big fire.
Bell: damaged by the earthquake of Neulengbach 1590.
Mozart Requiem: premiere 1791.
Famous organ by Johann David Sieber (1670–1723) built in 1714, recently restored.

Stop 13. Großes Michaeler Haus
(SUMMESBERGER & SEEMANN, 2008: p. 27, No. 14)
1750 lived Joseph Haydn (1732–1809) here contemporaneously with Princess Esterhazy and the Librettist Pietro Metastasio, the Imperial Court poet (poeta Caesareus) during Emperor Karl's VI reign, buried at St. Michael's church.

Inside: yard with sculptures by Ben Siegel in Untersberger "marble".

Stop 14. Buchhandlung Manz
(bookshop, designed by Adolf Loos, 1870–1933, in 1912)
(SUMMESBERGER & SEEMANN, 2008: p. 28, No. 16)

Cultural monument.
Facade: Black Devonian decoration stone from Germany.

Stop 15. Artariahaus
(SUMMESBERGER & SEEMANN, 2008: p. 28, No. 17)

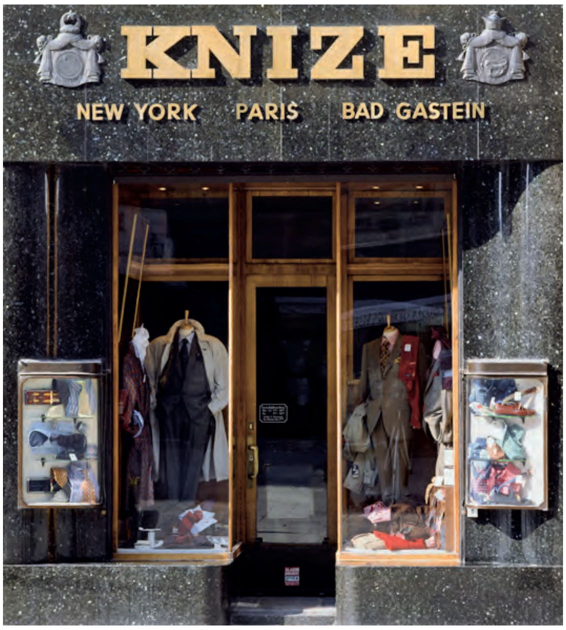
Architect: Max Fabiani (1865–1962) in 1912, student of Otto Wagner (1841–1918), Art Nouveau.
Facade: White Carrara marble, Italy and reddish Jurassic limestone, Hungary.

GRABEN (pedestrian area)
pavement: Granites from the Bohemian Massif (Variscan orogeny).

Stop 16. Kornmesser, jewelry shop (abandoned in 2014)
(SUMMESBERGER & SEEMANN, 2008: p. 40, No. 31)
Decoration stone: Rapakiwi granite.
Age: 1,500 Ma.
Origin: Finland.

Stop 17. Dreifaltigkeitssäule
(Pestsäule)
(SUMMESBERGER & SEEMANN, 2008: p. 43, No. 32)

Built 1682–1693, fulfilling a vow of emperor Leopold I (1640–1705) after the Big Plague (Pest). Building stone: Untersberg "marble" (arenitic limestone).
Age: Upper Cretaceous.
Origin: Salzburg, Austria.



Stop 18. La Rose (shop, ladies' dresses)
(SUMMESBERGER & SEEMANN, 2008: p. 43, No. 33)
Facade: Sodalithsyenite.
Origin: Brazil.

Stop 19. Knize (taylorshop designed by Adolf Loos, 1910–1913)
(SUMMESBERGER & SEEMANN, 2008: p. 44, No. 34)
Cultural monument.
Facade: Larvikite.
Age: Permian.
Origin: Norway.

Stop 20. H & M (shop, formerly "Braun")
(SUMMESBERGER & SEEMANN, 2008: p. 47, No. 37)
Facade: Serpentinite.
Pedestal: Paleozoic crinoidal limestone.

ST. STEPHEN'S PLACE
(Pedestrian area)

Stop 21. Haas Haus
(SUMMESBERGER & SEEMANN, 2008: p. 48, No. 39)

Architect: Hans Hollein (1934–2014, Vienna) 1990; (preceding "Haas Haus" demolished).
Facade: Decorated with greenish quartzite until the first floor.
Origin: Switzerland, "Verde Spluga" from Splügen Pass and greenish gneiss "Verde Andeer".

Stop 22. Palais Equitable (American Insurance Company)
(SUMMESBERGER & SEEMANN, 2008: p. 48, No. 40)
Building stone: Čistec granite – granodiorite, Bohemian Massif.
Age: 300–350 Ma.
Origin: Czech Republic and granite from Maissau.

Stop 23. Bank Austria
(SUMMESBERGER & SEEMANN, 2008: p. 51, No. 41)
Facade: Red granite “Koral” with dark red feldspar crystals, garnet and biotite.
Age: Carboniferous, 300 Ma.
Origin: Ukraine.

Stop 24. Dom St. Stephan (St. Stephen’s Cathedral)
(SUMMESBERGER & SEEMANN, 2008: p. 52, No. 43)
Architect: the legendary “Meister Pilgram” (Anton Pilgram, around 1460–1515).
Begun in romanesque, finished in gothic style.
Facade: Different stones from quarries around the greater Vienna region.
Age: Neogene, 16 Ma.

Inside St. Stephens: two masterpieces of gothic sculptures:

Gothic pulpit, late 15th century; carved from 7 blocks of fine grained sandstone, by an unknown artist, possibly from the working group around Gerhaert van Leyden. The sculptor may have portrayed himself looking out of the window in the socle.
The monument is made from of Neogene Breitenbrunn sandstone (Burgenland, Austria).

Sarcophage of emperor Friedrich III made of Adnet limestone by Niclaes Gerhaert van Leyden (1467–1473), after initial mason treatment transport on the Danube to Vienna and then to van Leyden’s atelier 40 km south of Vienna at Wiener Neustadt.

After Gerhaert van Leyden’s death the work was continued by Max Valmet and finished by Michel Trichter until 1513. The monument is made from of Jurassic limestone from Adnet near Salzburg.

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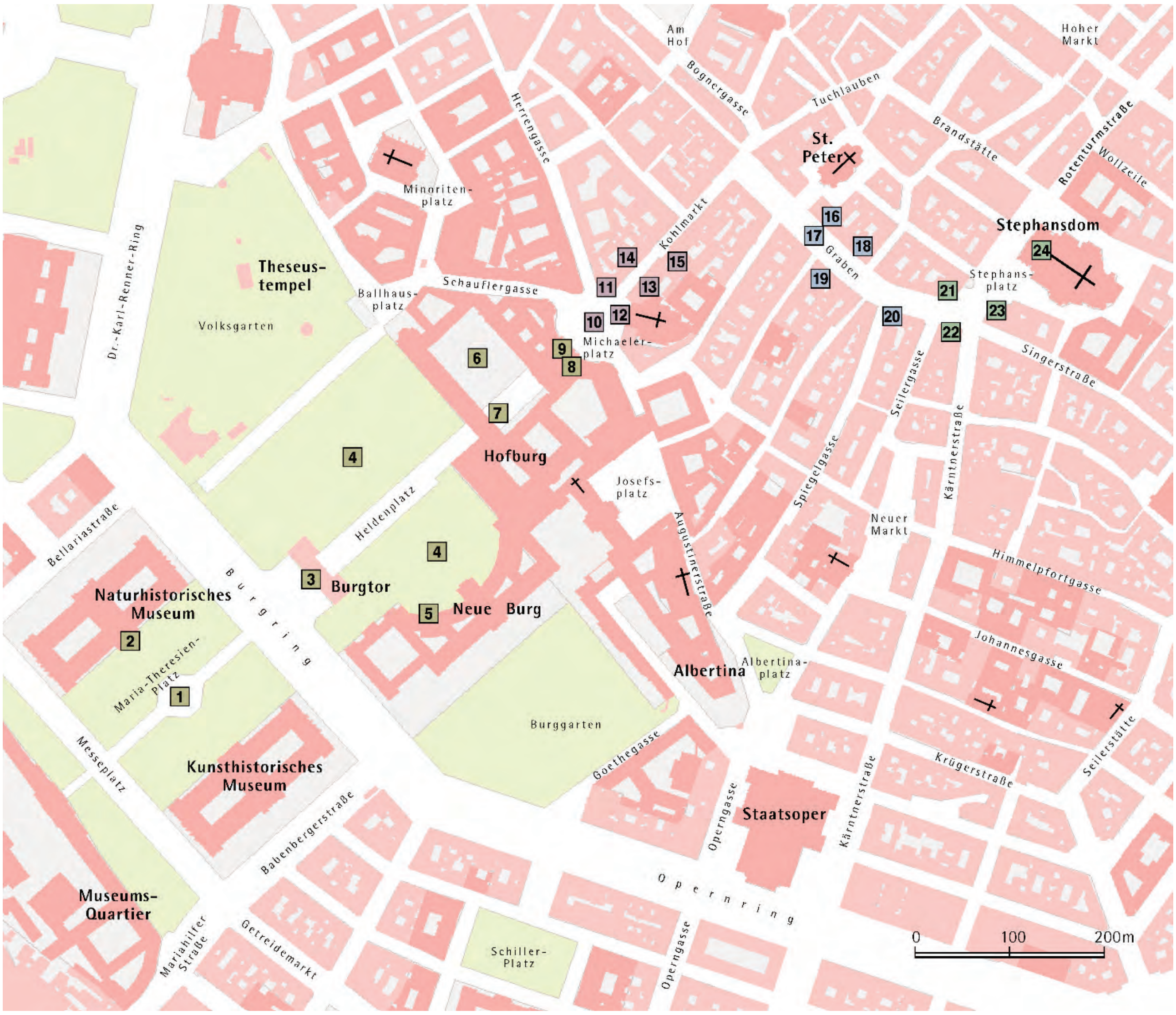

Locations of Stop 1 to 23 in the city of Vienna (adapted from SUMMESBERGER & SEEMANN (2008: Cover inside).

Field Trip POST-3
Eustasy and sea-level changes in the footsteps of Eduard Suess

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Introduction

Eduard Carl Adolph Suess (Text-Fig. 1) was born on 20th August 1831 in London and died on 26th April 1914 in Vienna. He was one of the most significant geologists in the history of this science of the second half of the 19th and the early 20th century. He published famous works such as "Das Antlitz der Erde" (The Face of the Earth; SUESS, 1883, 1888, 1901, 1909) and gave distinction to terms like Tethys or Gondwana. Eduard Suess was the inventor of the theory of "eustatic movements" (or sea level changes). He may therefore be called the "father of sequence stratigraphy".

Text-Fig. 1: Eduard Suess 1869 at the age of 38 years. Portrait by Josef Kriehuber, from the archive of the Geological Survey of Austria.

The idea of changing sea levels was based on Miocene marine sediments in the area of Eggenburg. Here, Suess went to field trips with interested people such as Johann Krahuletz, but also with his students. For this purpose, he drew the 4.2 km long section from Vitusberg to Kühnring (Text-Fig. 2).

Within the scope of his theory on "eustatic movements", Suess distinguished between positive eustatic movements which we call today a sea-level rise (transgression) and a negative eustatic movement (sea-level fall or regression). According to his theory, a gradually sedimentary fill-up of marine basins leads to a positive eustatic movement (transgression) or a landward shift of the coastline. The deepening of a marine basin results in a negative eustatic movement (regression) or retreat of the coastline towards the sea.

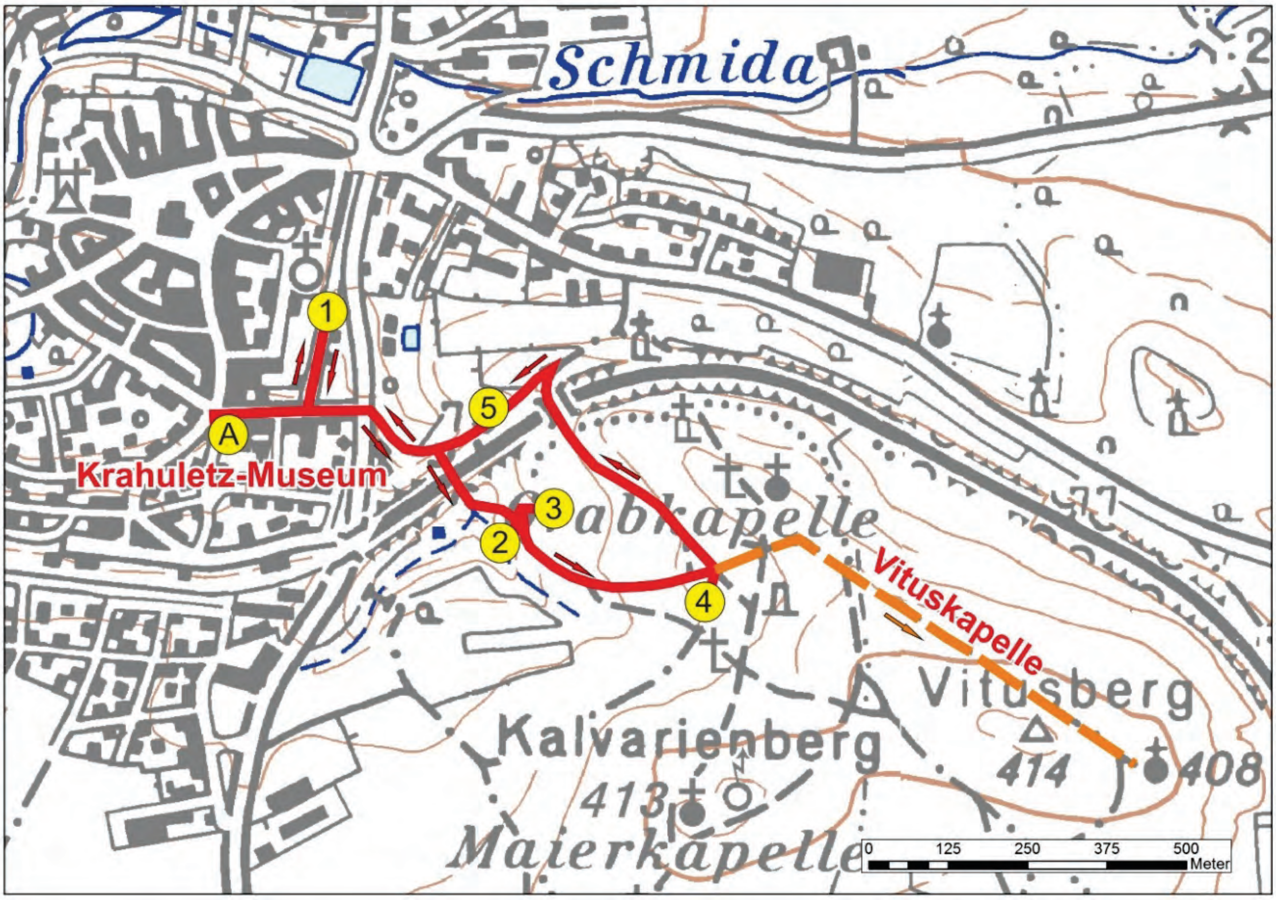
The City of Eggenburg honored the merits of Suess by naming the path in the Zwingergraben "Eduard Suess Weg" and created the "Window into Earth History" which exposes the transgression of calcareous sandstones (Zogelsdorf Formation) on sandstones (Gauderndorf Formation).

Text-Fig. 2: Eduard Suess (around 1865), section from the western slope of the Vitusberg via Eggenburg until the area northwest of Kühnring. (STEININGER et al., 2015: Fig. 25)

Field Trip

Within the Eggenburg city area: Stop 1 to 5
(text translated from Steininger et al., 2015)

From the Krahuletz-Museum (A) we follow the Luegerring (ring road) towards the east and enter the Zwingergraben (trench) at Eduard Suess Weg (path) (Text-Fig. 3).



Text-Fig. 3: Fieldtrip and locations of Stop 1 to 5 (Steininger et al., 2015: Fig. 11).

Stop 1. Zwingergraben Eggenburg

Coordinates: E 15°49'12.5", N 48°38'29.4".
Altitude: 322 m.

In the Zwingergraben (Text-Figs. 4, 5), we face the mighty, eastern, medieval defensive fortification of Eggenburg, build around 1300, with Hohlturm or Schwedenturm (tower), the inner wall with "Vorwerk" (front construction), the Zwingergraben, and the outer wall. Near the Hohlturm, in its southern section, the Zwingergraben was cut into the Gauderndorf Formation and quarried out of the Zogelsdorf Formation in the northern section. During construction works or on molehills one may find characteristic chips of fossil gastropods and bivalves of the Gauderndorf Formation at the beginning of the Zwingergraben near the Hohlturm. The outer wall of the bailey is completely made of calcareous sandstone of the Zogelsdorf Formation.
At the outcrop "Fenster in die Erdgeschichte (window into Earth history)" the base of the Gauderndorf Formation is exposed, with fossil remains and the bedded calcareous sandstones and interbedded sands of the Zogelsdorf Formation that crosscut the Gauderndorf Formation erosively (Text-Figs. 4, 5).

Text-Fig. 4: Outcrop at Eduard Suess Weg in the Zwingergraben in October 1978. Northward dipping sandstone beds with intercalated sand layers of the Zogelsdorf-Formation overlay fine sands and silts of the Gauderndorf-Formation. Photograph: Fritz F. Steininger, Eggenburg (STEININGER et al., 2015: Fig. 12).

Text-Fig. 5: Outcrop at Eduard Suess Weg in the Zwingergraben in October 1978. Werner Vasicek points to the fine sands and silts of the Gauderndorf Formation below the Zogelsdorf Formation. Photograph: Fritz F. Steininger, Eggenburg (STEININGER et al., 2015: Fig. 13).

We leave the Zwingergraben, ascend to the Luegerring, cross the Schubert Park with the art nouveau fountain which was built in 1908 by sculptor Wilhelm Hejda (1868–1942) on the occasion of the 60th anniversary celebration of the government of emperor Franz Josef I. (1830–1916), cross the Wienerstraße, the perimeter road and walk down towards the passages of the Franz Josefs railway and follow the passage towards Krahuletz-Ruhe (Krahuletz' rest, Text-Fig. 11).

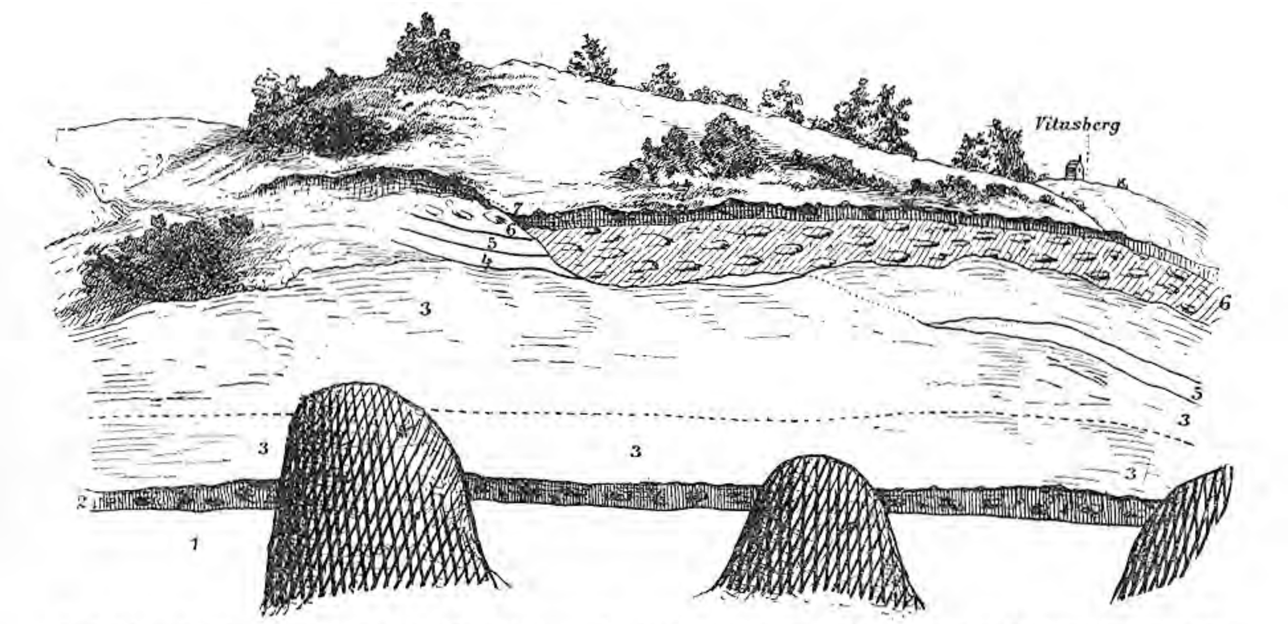
Stop 2. Krahuletz-Ruhe in the Schindergraben
Coordinates: E 15°49'26.5", N 48°38'19.1".
Altitude at base: 337 m.

Krahuletz-Ruhe is within the so-called Schindergraben (flayers trench, Text-Fig. 6). During the railroad construction, several thousand cubic meters of sediments where excavated for the large railway dam (Text-Figs. 7, 8).
Descriptions and sketches (FUCHS, 1868, 1900; SCHAFFER, 1914; TOULA & KAIL, 1885; see Text-Figs. 8, 9, 10) show, that coarse sands of the Burgschleinitz Formation were deposited below the Guderndorf Formation. These contain a transgressive layer of gravel with bones of the sea cow *Metaxytherium*, dolphins, *Brachiodus* and turtles that was deposited on the Eggenburg granite. Also the famous crocodile skull (Text-Fig. 11) came from one of the mine galleries figured on Text-Figure 9 of TOULA & KAIL (1885). The crocodile skull is exposed together with an also remarkable skull of a dolphin (Text-Fig. 12) at the Krahuletz-Museum. Text-Figure 13 shows the minister of railways Zdenko Ritter von Forster with his spouse, Johann Krahuletz, and Franz Gamerith at the place of discovery of the crocodile skull in 1916.

Text-Fig. 6: The Krahuletz-Ruhe, todays outcrop situation. Photograph: Fritz F. Steininger, Eggenburg (STEIN INGER et al., 2015: Fig. 14).

Text-Fig. 7: View from northeast towards the northern side of the railway dam before 1870. Historical photograph: Krahuletz-Museum (STEININGER et al., 2015: Fig. 15).

Text-Fig. 8: View from the railway dam towards northeast near Krahuletz-Ruhe (middle-right) and the quarry northwest of the Apfelthaler Weg (upper-left). The upper limit of the quarry is at c. 356 m. Granite occurrences are visible in the lower-left corner (from SCHAFFER, 1914: Plate II). Photograph: Georg Hiesberger, Eggenburg (STEININGER et al., 2015: Fig. 16).



Aufschluss bei den Sandgruben am Westabhange des Calvarienberges bei Eggenburg („im Schindergraben").

Text-Fig. 9: Outcrop near the sand pits in the Schindergraben at the western slope of the Kalvarienberg (Calvary) near Eggenburg (TOULA & KAIL, 1885) (STEININGER et al., 2015: Fig. 17).
Explanation of the section at Krahuletz-Ruhe:
1 – "at the very bottom occurs, more than 1 m thick, grey quartz sand (without fossil remains)."
2 – "Above this is laying an about 1 m thick layer of granite gravel with larger boulders and pebbles."
3 – "Up to the roof of the mine galleries continues a grey quartz sand, ferruginous in places.
Yonder contains many larger bivalves: *Venus* sp., *Mytilus Haidingeri, Perna, Ostrea*. (*Turritella* sp., *Natica* sp., *Fusus* sp. were found in the roof of this layer). The total thickness of this horizon is more than 3 m. At the height of the roof resides a well-marked sand layer with concretions."
4 – "Above this, an about 3 cm thick layer of a fine, yellow sand is lying, strongly deformed, then follows"
5 – "a white, limy-clayey layer, about 8 cm thick and then above"
6 – "a layer with sandy calcareous concretions, which are then covered by humus (7)."

At the bottom of this section, the coarse quartz sands of the Burgschleinitz Formation (beds 1 to 3) were exposed and were apparently mined in galleries. In Text-Figure 9, three of such mine galleries were plotted within these quartz sands, at which the crocodile skull was found at the base of bed 2 in the background of one of the mine galleries. Beds 4 and 5 correspond to the Gauderndorf Formation and bed 6 to the Zogelsdorf Formation. The Quaternary cover is not shown in this figure.

In Text-Figure 10, the beds p and p' can be interpreted as Burgschleinitz Formation, above these, Gauderndorf Formation (g) and Zogelsdorf Formation (m, n) follow. The layers g', l, l' belong to the Quaternary cover.

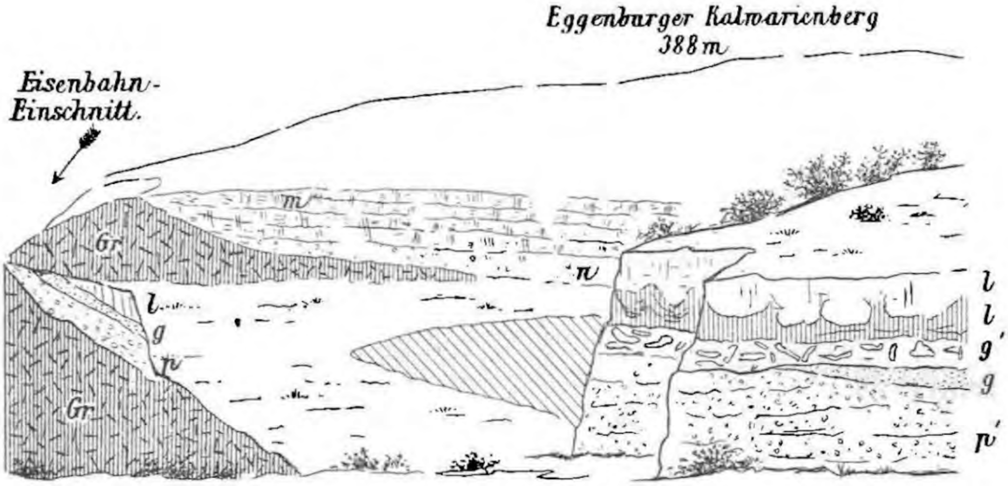


Fig. 5. Aufschlüsse im Schindergraben am Fuße des Calvarienberges.

Gr Granit.
p Pernabank mit Rippen von *Metaxitherium*.
p' Sandsteinbänke mit dem Knochenlager (Crocodil, *Brachyodon*, *Metaxitherium*).
g Gauderndorfer Tellinensande.
g' Umgeschwemmte Muggeln der Gauderndorfer Schichten.
l Löss.
l' Grauer quaternärer Letten.
m Harte Sandsteinbänke mit *Perna*.
n Grobe lose Sande mit Muscheltrümmern.

Text-Fig. 10: Outcrops in the Schindergraben at the foot of the Kalvarienberg (FUCHS, 1900: Fig. 5). Exploitation near the "Krahuletz-Ruhe" and extraction west of the Apfelthaler Weg in the Schindergraben (STEININGER et al., 2015: Fig. 18).

Text-Fig. 11: Skull of the gavial-like crocodile from the Schindergraben in Eggenburg: *Tomistoma eggenburgensis* (TOULA & KAIL, 1885). Photograph: Peter Ableidinger, Obernalb near Retz (STEININGER et al., 2015: Fig. 21).

Text-Fig. 12: Skull of a dolphin: *Schizodelphis sulcatus incurvata* (ABEL) from the pit "Bauernhanselgrube" in Eggenburg. Photograph: Peter Ableidinger, Obernalb near Retz (STEININGER et al., 2015: Fig. 20).

We walk along the overgrown wall towards northeast, cross the Josef-Wimmer-Weg and follow the cleared path continuously towards northeast (Text-Fig. 3).

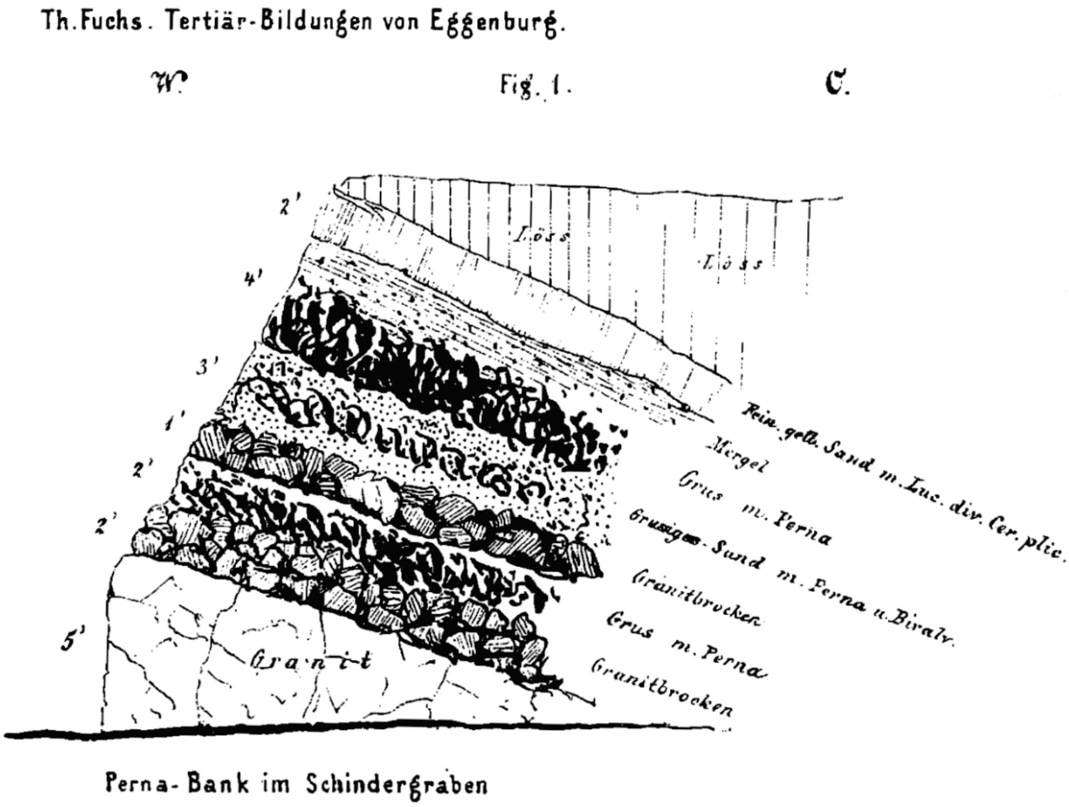
Stop 3. Material pit in the Schindergraben
Coordinates: E 15°49'29.5", N 48°38'20.0".
Altitude at base: 344 m.
Altitude at upper level: 356 m.

In a large former exploitation for the dam fill, the Zogelsdorf Formation with thick calcareous sandstone beds and intercalated sands and large down slid blocks can be found as the uppermost stratigraphic member that is still visible today (Text-Fig. 14). The following fossils were found: calcareous red algae, bryozoans, moulds of large bivalves, oysters and pectinid shells. Northwest of the pit, near the so-called *Perna*-bed (FUCHS, 1868; Text-Fig. 15), a layer of beach pebbles(?) of the Zogelsdorf Formation is transgressing directly on the granite that forms the bedrock at this position.

Starting from the material pit, the Zogelsdorf Formation continues upslope towards southeast into a narrow depression. Southwards, a planation plane extends on the granite, which can be interpreted as a wave-build platform. Again south of this granite eminence, another narrow valley in the granite is filled up with sediments of the Zogelsdorf Formation. To the east, this small basin reaches until shortly before the children playground where it merges with the depression southeast of the material pit.

Text-Fig. 13: Krahuletz-Ruhe. The minister for railways, Zdenko Ritter von Forster, and his spouse, Marianne Freiin von Ferstel, visit the place of discovery of the crocodile skull in 1916, together with Johann Krahuletz (with topper, apparently holding the coat of the spouse of the minister for railways) and Franz Gamerith (left). Photograph: Archive Krahuletz-Museum (Steininger et al., 2015: Fig. 19).

Text-Fig. 14: Former exploitation in the Schindergraben west of Apfelthaler Weg, todays view of part of the pit. Photograph: Fritz F. Steininger, Eggenburg (STEININGER et al., 2015: Fig. 22).



Text-Fig. 15: *Perna*-bed in the Schindergraben (FUCHS, 1868) (STEININGER et al., 2015: Fig. 23).

We return to the Apfelthaler Weg and follow it uphill, change to the path of the Alten Rodelbahn (old sledge run) and follow it until the playground. Here we turn right sharply and follow the cleared path to the geographically highest occurrence of the Zogelsdorf Formation in an abandoned quarry below the playground.

Stop 4. Vitusberg – pits south of Grabkapelle
Coordinates pebble layer: E 15°49’41.6”, N 48°38’15.4”.
Altitude: 371 m.
Coordinates material pit: E 15°49’41.9”, N 48°38’15.3”.
Altitude: Upper rim 374 m.
Coordinates playground centre: E 15°49’42.9”, N 48°38’16.9”.
Altitude: 376 m.

Within the forest, towards the southwest, several overgrown stone pits with blocks of Zogelsdorf Formation occur below the playground. In a trench southwest of it, a pebble layer of the Zogelsdorf Formation is outcropping. Attempts were made to excavate smaller walls of the stone pit and to uncover the pebble layer (Text-Fig. 16).

Text-Fig. 16: Nearby abandoned stone pit southwest of the playground at Vitusberg. Photograph: Fritz F. Steininger, Eggenburg (STEININGER et al., 2015: Fig. 24).

The sediments of the Zogelsdorf Formation reach about until the southern end of the playground. The eastern part of the playground and the following path to the “Vituskapelle” are already above granite (Text-Fig. 3).
The Zwingergraben has an altitude of c. 322 m, the highest layer of the Zogelsdorf Formation at the Vitusberg is at c. 374 m. The onlap of the Zogelsdorf Formation on the granite of the Vitusberg and the outreach up to the playground would correspond to a sea-level rise of c. 52 m. This amount is, however, probably too high, since tectonic movements shifted the position of the Zogelsdorf Formation in the Zwingergraben to higher altitudes after its deposition, as it can be seen from a mapped E–W striking fault in the southern areas of Eggenburg.

From the playground we can continue the path to the Vituskapelle (chapel), now always on granite bedrock (Text-Fig. 3). The view from the Vituskapelle offers a gorgeous outlook over the last granite heads standing out of Molasse sediments (so-called Kogelsteine, Kirchenberg of Wartberg) and further to the east into the Alpine-Carpathian Foreland Basin.

From the playground we can follow the Josef-Wimmer-Weg to the northwest, have a splendiferous view on the city of Eggenburg before the railway bridge, passing the bridge, turn left to the southwest immediately and walk down alongside the railway towards the railway passages (Text-Fig. 3).

Stop 5. Urtlbachtal – Pit north of the railway dam
Coordinates: E 15°49'24.8", N 48°38'24.9".
Altitude: 337 m.

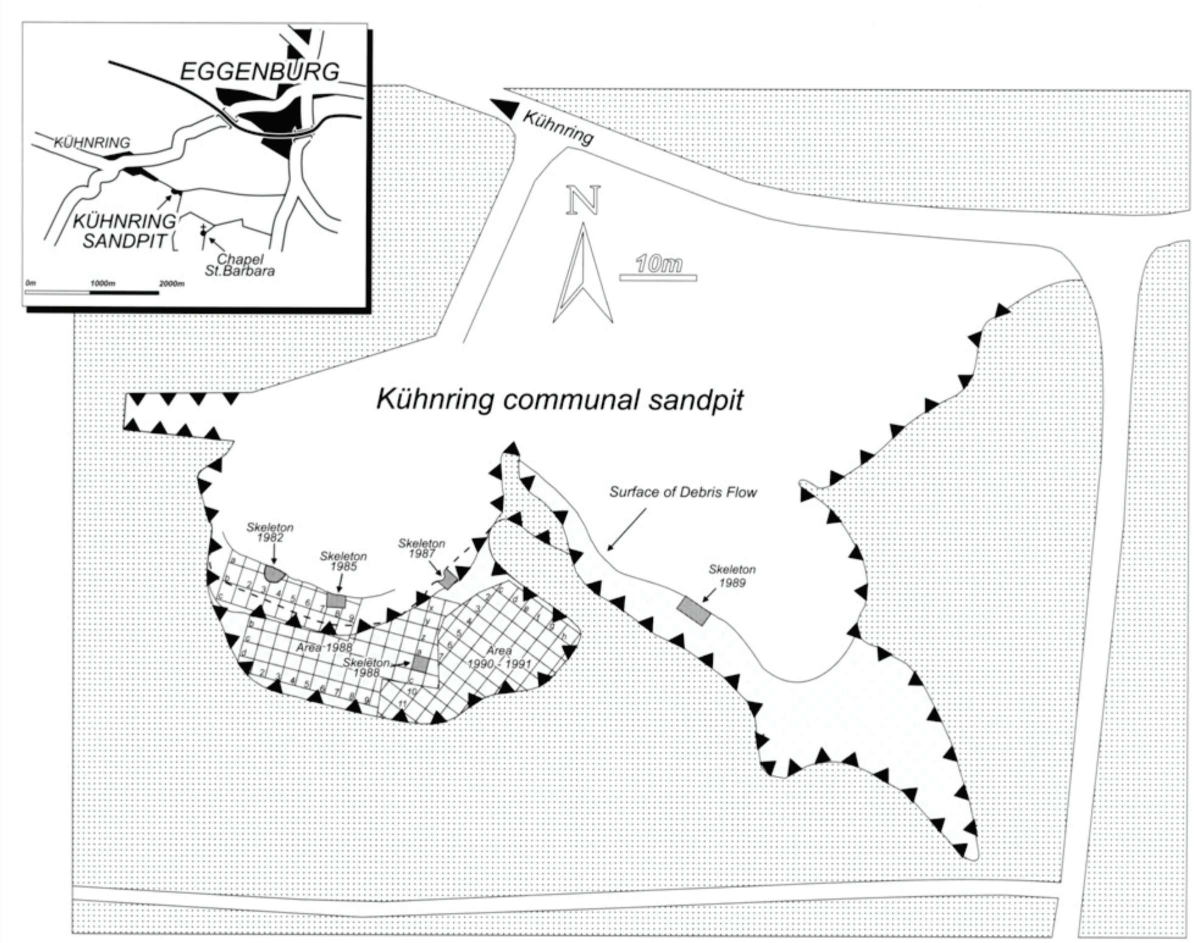
North of the big railway dam, along the path that leads to the railway passages, an overgrown material pit attracts attention. Its collapsed walls are probably mainly build of loess. A granite crops out at the south-western end of the pit and coarse, fossil-rich sands can be found on the granite and the along the path which probably belong to the Burgschleinitz Formation.

We now follow the path to the railway passages and walk back to the Krahuletz-Museum (Text-Fig. 3).

The vicinity of Eggenburg: Stops 6 to 8

Stop 6. Kühnring Gemeindesandgrube (municipal sandpit)
(text and text-figures from MANDIC et al., 2005)
Coordinates: E 15°47'34.6", N 48°37'47.3".
Location: The municipal sandpit of Kühnring is located about 2 km SW of Eggenburg and about 800 m SE of Kühnring (Text-Fig. 17), southwards of the path to the Armenseelenkreuz, on the northern slope of the Scheibenberg. The Miocene marine sediments fill a narrow W–E striking prae-Eggenburgian crystalline erosive depression, having the northern and southern boundaries defined by basement rocks. The best insight into the succession crops out in the western part of the pit to date.
Lithostratigraphic units: Burgschleinitz Formation, Gauderndorf Formation, Zogelsdorf Formation.
Age: Early Miocene (Late Eggenburgian), ~ 20 Ma.
Facies: Deepening and fining upward succession of shallow sublittoral sands and gravels including one mass flow horizon passing upsection into deeper sublittoral pelite sediments. On top the significant erosional contact is overlaid by detritic, biogenic, shallow water limestones.
References: STEININGER et al. (1991a, b), DOMNING & PERVESLER (2001), PERVESLER & ROETZEL (1991), PERVESLER et al. (1995, 1998), JENKE (1993).

Section (Text-Figs. 18, 19): The base of the Eggenburgian marine onlap is not cropping out at the site, yet according to the regional geological setting the succession must directly overlay the crystalline basement. Hence, up to 15 m of badly sorted pelitic and sandy siliciclastics termed Kühnring Member and bearing conspicuous giant *Crassostrea* reefs occupy basal parts of the marine succession in the region. The Member´s stratotype – *Judenfriedhof* – at the moment unexposed – is located about 1.5 km WNW from the site. In contrast, the crystalline basement rocks are exposed on the opposite side of the sandpit entrance. These hornfels penetrating aplite dikes represent a footwall contact of the Precambrian Thaya Batholith. The low-grade metamorphism of the formation has Variscan origin.



Text-Fig. 17: The geographic position and situation in the sandpit. The positions of the sea cow skeletons are marked by grey fields (from DOMNING & PERVESLER, 2001) (MANDIC et al., 2005: p. 28).

Burgschleinitz Formation (more than 8.5 m): The succession can be subdivided into four lithologic units. The basal part of the Unit 1 was originally studied in an artificial pit and is not exposed any more.

Unit 1 (6 m): The unit comprises yellowish brown to yellowish grey middle sands, fine sands and silty finesands. The sediments are strongly bioturbated and bear several fine gravel and mollusc coquina interlayers. The succession shows a slight fining upward trend. Hence, the lowermost 2.5 m are made of two coarse to fine sand normally graded packages, rich in mollusc fragments. In contrast, the upper part is characterized by a well preserved bivalve assemblage with representatives commonly found in life position. The following species can be find therein: *Macrochlamis holgeri, Pecten pseudobeudanti, Cardium hoernesianum, Acanthocardium moeschanum, Megaxinus transversus, Divalinga ornata, Dosinia exoleta, Pitar raulini, Cordiopsis schafferi, Cordiopsis incrassatus, Venerupis basteroti, Paphia benoisti praecedens, Peronea planata, Gari (Gobraeus) labordei, Panopea menardi, Thracia eggenburgensis*. The foraminifera are dominated by benthic species of the *Ammonia parkinsonia-tepida* group. Additionally, common are *Aubignyna simplex*, *Bucella propingua*, *Elphidium* div. sp. *Nonion commune*, *Hanzawaia boueana* and *Cibicidoides pseudoungerianus*. The scattered plankton includes *Cassigerinella globulosa* and *C. boudecensis*.

Unit 2 (massflow; 1.5 to 3 m): A mollusc coquina dominated by disarticulated, concave up oriented bivalve shells embedded in medium sand to fine gravel matrix overlays directly a low erosional relief on top of the previous unit. The horizon comprises among others

Anadara fichteli, *Glycymeris fichteli*, *Ostrea lamellosa* and *Panopea menardi*. Without a sharp boundary follows an inverse graded medium to coarse gravel sized crystalline debris horizon. The crystalline lithoclasts are badly sorted, matrix supported and chaotically, in part uprightly oriented. They comprise platy, angular aplitic schist-gneiss and quartzite although scattered rounded quartz pebbles are also present. On top the 10 to 80 cm large, preferably WNW–ENE oriented crystalline plates occur, getting more frequent and larger southeastward. Eastward, however, the inverse graded bed becomes more homogenous and thicker (up to 2 m), the basal coquina disappears and the large, chaotically embedded, disarticulated mollusc remains with *Glycymeris fichteli*, *Macrochlamis holgeri*, *Cordiopsis schaferri* and *Protoma cathedralis* become frequent. The coarse platy debris is topped by about 20 cm thick horizon of well rounded, medium to coarse quartz pebble bearing silty coarse sands. This horizon is as well variably present in different positions of the site. Hence being still thicker in the east it wedges almost completely out in the southeast.

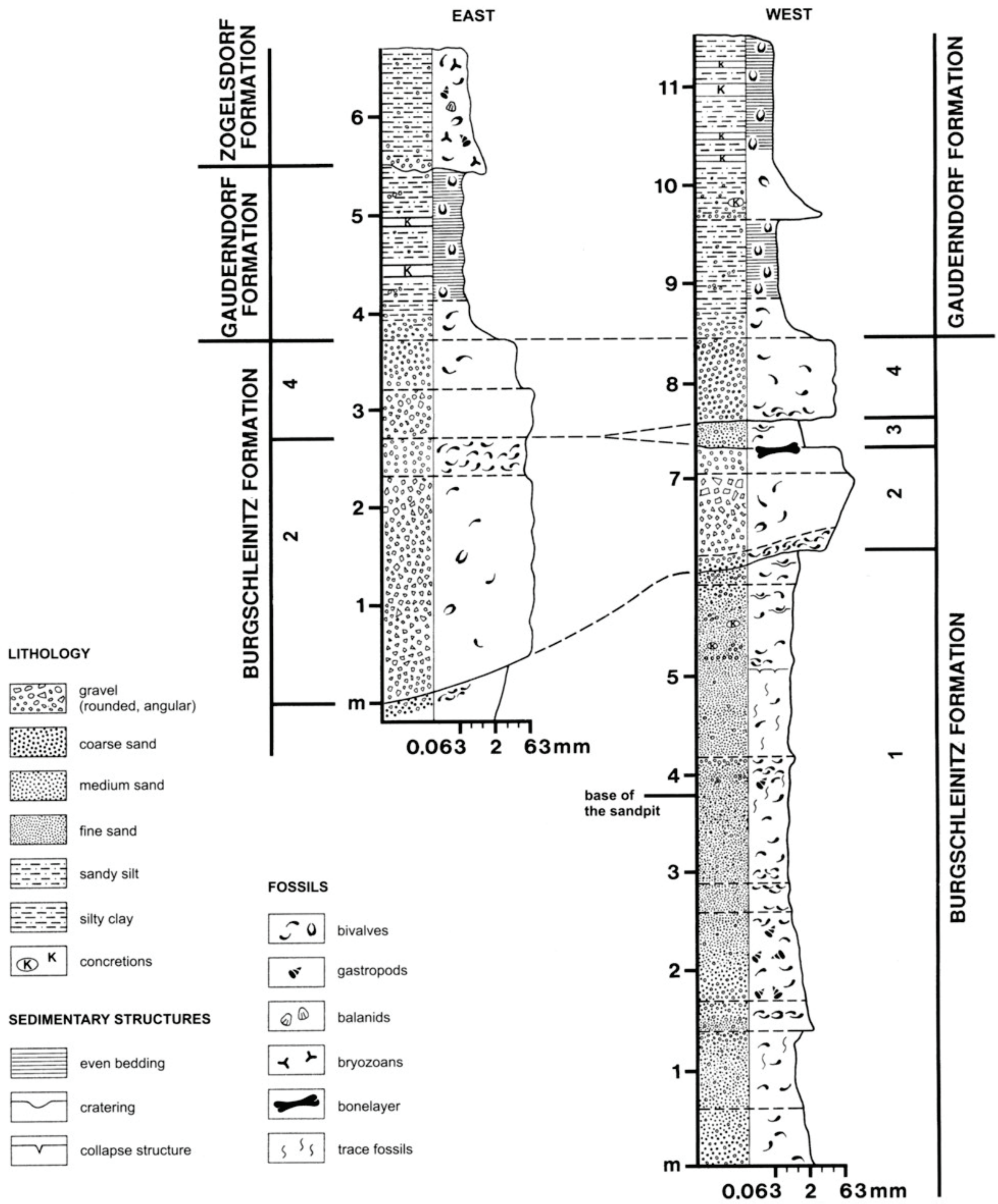
Unit 3 (0 to 30 cm): This is a grey-yellowish silty to gravel comprising fine to medium sand horizon outwedging completely in the eastern part of the pit. In the same direction the gravel components characterized by a very well rounding grade get more frequent. The base of those sands bear the sea cow *Metaxytherium krahuletzi* fossil Lagerstätte with at least six more or less articulated skeletons and many accompanied isolated bones. The bones belong to adult as well as juvenile individuals. Additionally, at the same position a skull and mandible of the dolphin *Schizodelphis sulcatus* has been found. In places where Unit 3 is outwedging the sea cow Lagerstätte comprises the base of Unit 4.

Unit 4 (max. 1 m): This horizon has, in contrast to previous units, more continuous lateral distribution within the site. It comprises fine to medium gravels embedded in a medium to coarse grained sandy matrix. The gravel components are generally very well rounded. Disarticulated, large-sized, convex up oriented bivalve shells are particularly frequent in the lower part of the horizon. Following mollusc are present therein: *Turitella gradata*, *T*. *vermicularis*, *Protoma cathedralis*, *Glycymeris fichteli*, *Ostrea* div. sp., *Macrochlamis holgeri*, *Pecten pseudobeudanti*, *Anomia ephippium*, *Pitar raulini*, *Cordiopsis islandicoides*, *Dosinia exoleta*, *Divalinga ornata*, *Florimetis lacunosa*, *Panopea menardi*.

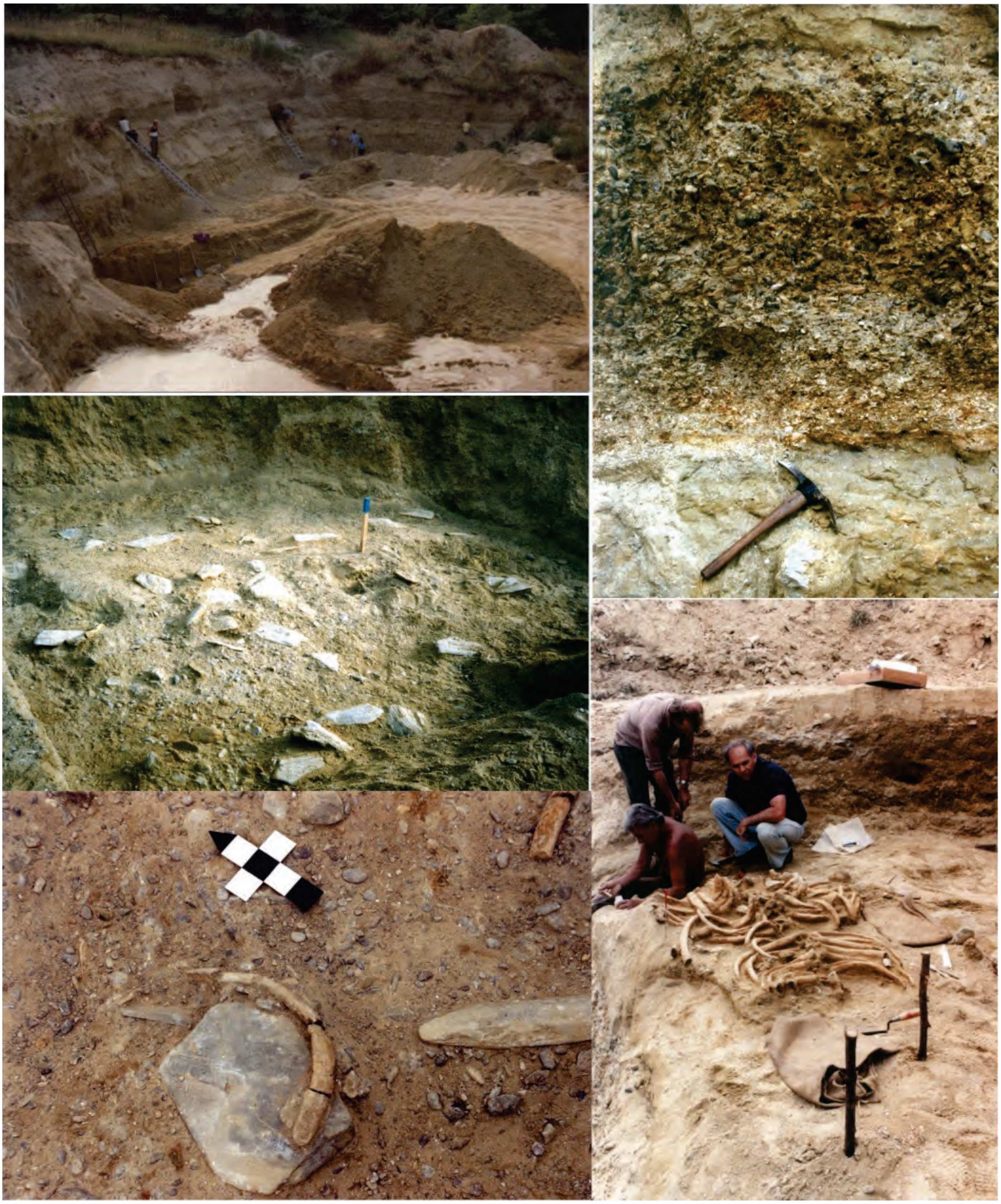
Gauderndorf Formation (max. 3 m): It comprises the green-greyish to yellow-brownish plane to light wavy, clearly cm-thick bedded clayey silt to claysilt. At the base, a gravel component is added, elsewhere fine gravel can occur scattered in form of small-scale clusters. Additionally, the middle part of the succession is interlayered by one normally graded gravel bed topping the sharp erosive contact. Additionally, the pelites bear several concrete horizons. The rich macrofossil assemblage is characterised by thin shelled, infaunal bivalves found commonly articulated and in life position.
The following mollusc species are represented therein: *Haliotis* sp., *Diloma amedei*, *Turritella* div. sp., *Ficopsis* (*Fulguroficus*) *burdigalensis*, *Euthriofusus burdigalensis*, *Cerastoderma edule*, *Acanthocardium* sp., *Cordiopsis* sp., *Paphia* sp., *Peronea planata* and *Solen marginatus.* The microfossil assemblage is strongly dominated by small-sized planktonic foraminifera, particularly *Cassigerinella globulosa* and *C. boudecensis* accompanied by *Globigerina ciperoensis ottnangensis*, *G. angustiumbilicata* and *G. brevispira*. The benthic foraminifera include particularly *Ammonia parkinsonia-tepida* gr., *Hanzawaia boueana* and *Cibicidoides pseudoungerianus* accompanied by *Lenticulina inornata*, *Caucasina cylindica*, *Elphidium granosum, Nonion commune*, *Epistominella* cf. *molassica* and *Globocassidulina oblonga*. Upsection planoconvex species (*Cibicidoides*, *Hanzawaia*) become even more frequent.

Zogelsdorf Formation (1.5 m): It is restricted to the eastern part of the sand pit, where it transgrades a well-developed, distinct erosional boundary. These quartz-gravel rich, weakly stratified, partly nodularly cemented, detritic biogenic limestones are typically white greyish to brown yellowish in color. Included gravel components are medium to fine grained, well-rounded and matrix-supported. The scattered angular crystalline lithoclasts are additionally present therein. The originally rich mollusc assemblage is secondarily diminished by means of the diagenetic leaching of aragonite shells. Hence the presence of turritellid gastropods, for example, is signalized only by typical turriform molds and shell exterior imprints. Otherwise the calcite mineralizing pteriomorph species like *Hyotissa hyotis*, *Ostrea lamellosa*, *Pecten hornensis* and *P. pseudobeudanty* are rather well preserved. In addition to the latter taxa, well-preserved balanid remains and celeporid bryozoan colonies contribute likewise abundantly to the biogenic content of the limestones. *Cibicidoides pseudoungerianus* dominates the moderately preserved foraminifera assemblage. The planktonic foramininfera are with only 6.6 % content underrepresented.

Interpretation: According to molluscs and foraminifera and along with the sedimentological character of Unit 1 the package can be at best interpreted as a typical deposit of a shallow marine subtidal environment. It represents the continuous sedimentation of a shallow marine embayment, interrupted by the deposition of Unit 2. The inverse grading, bad sorting and chaotical character of the latter sediment, comprising the large crystalline plates floating on top of the package, all point to its deposition within a single high-energy event. Hence, a sudden sea level rise of several meters, followed by its immediate retreat, ripped the blocky material from the shore and transferred it by one single debris flow onto the shallow sea bottom. The quantity of material deposited in that partly 3 m thick package indicates that the event can hardly be explained by a single heavy storm. Moreover, the storm beds are characterized usually by normally graded deposit packages. Therefor, a much better explanation would be the action of a submarine earthquake producing the tsunami wave triggering the spectacular devastation of the Eggenburg Bay within a very short period of time. The presence of occasional tsunamis in the Molasse Sea appears quite reliable. Hence the Austroalpine subduction front comprising the southern margin of the Alpine-Carpathian Foredeep represented in the Early Miocene a highly active tectonic zone under a transpressional regime. The argument that the event had to be of larger scale is provided also by the sea cow Lagerstätte, where apparently the whole herd starved to death shortly after the debris deposition finished. Apparently due to devastated marine bottom and especially due to total loss of the submarine sea grass meadows, the herd did not have enough food for living. However, if the meadows would have been destroyed only locally the herd would not have been able to find enough resources in other protected parts of the bay. Therefore, the only reliable explanation – the complete loss of all regional resources – correlate at best with the effect of a single tsunami wave.
The Gauderndorf Formation represents the end of the first siliciclastic sedimentation cycle and the maximal flooding of the environment. The enhanced content of planktonic foraminifera points therein to the improved contact to open sea. The sea level fall followed by its rise is indicated by the erosive contact and the transgression of the Zogelsdorf Formation. The mollusc fauna with the thick shelled shallow subtidal ostreids as well as common barnacle colonies and well-rounded pebble grains point to its sedimentation in a wave-agitated shallow water depositional environment.
Stratigraphically important is the occurrence of *Macrochlamis holgeri* in the Burgschleinitz Formation pointing to its Upper Eggenburgian stratigraphic position. Additionally, *Pecten hornensis* is restricted to the Zogelsdorf Formation pointing to its still younger stratigraphic position within the uppermost Eggenburgian.



Text-Fig. 18: The sections from the eastern and western parts of the sand pit in Kühnring (modified after DOMNING & PERVESLER, 2001) (MANDIC et al., 2005: p. 29).



Text-Fig. 19: The overview of the western sand pit wall (upper-left), the vertical section of the Unit 2 mud flow (upper-right), top of the Unit 2 with crystalline plates and sea cows remains hanging on them (down-left), and finally one of the articulated skeletons in original position (down-right) (MANDIC et al., 2005: p. 31).

Stop 7. Zogelsdorf Johannessteinbruch

(text and text-figures from Mandic et al., 2005)

Coordinates: E 15°48’38.2”, N 48°37’12.7”.

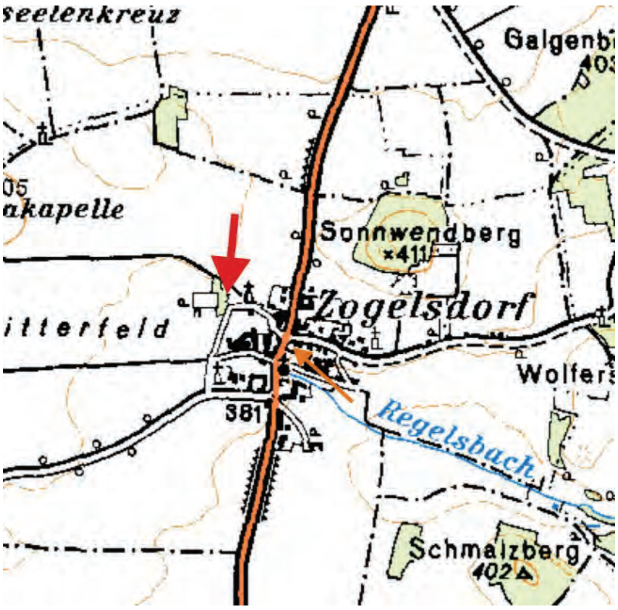
Location: The quarry is positioned on the northwestern margin of Zogelsdorf, about 2.5 km southwards of Eggenburg (Text-Fig. 20). The stone production began here around 1870 when the large-scale reconstructions around the capital´s old city, initiated by the Austro-Hungarian Emperor, triggered an outstanding demand for building materials. Among others also blocks for the four Hercules statues at the Michaelertor in the city of Vienna originate from here. The quarry was at that time the property of the famous female writer, pacifist and 1905 Nobel Peace Prize laureate, Bertha von Suttner (1843–1914), with the domicile in the neighbouring Hermannsdorf am Manhartsberg. Today the quarry represents a natural and industrial monument and contributes to the exhibition of the stonemason museum “Steinmetzhaus” on the main road of Zogelsdorf. The original traces of old production methods together with the typical ancient tools can be checked up already at the site.

Lithostratigraphic unit: Zogelsdorf Formation (on its type locality), uppermost Eggenburgian.

Age: Early Miocene (Late Eggenburgian), ~ 19 Ma.

Facies: Shallow water biogenic detritic limestone.

References: Nebelsick et al. (1991a, b), Nebelsick (1989a, b), Vavra (1979, 1981), Schaffer (1914, 1927).



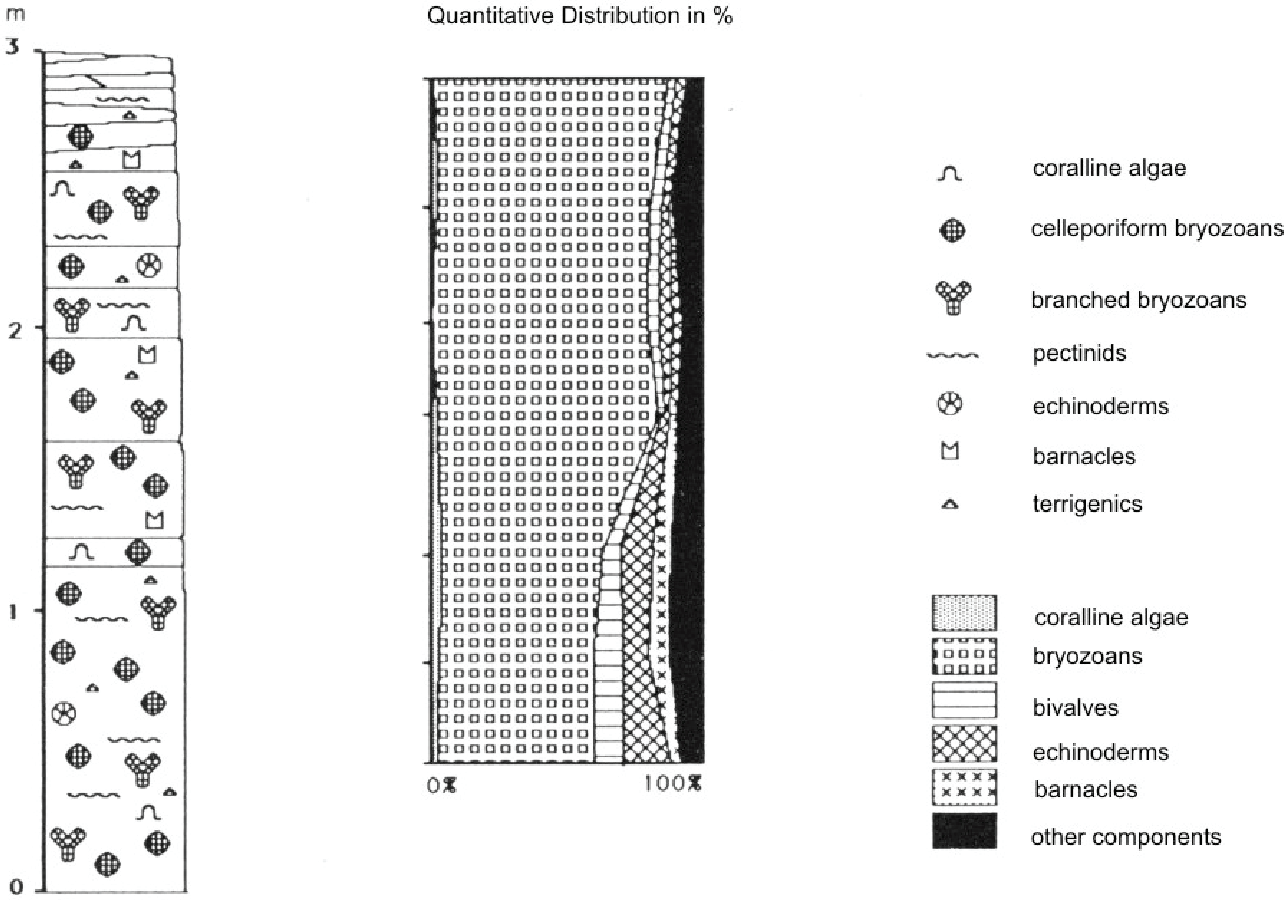
Text-Fig. 20: The position of the Johannes quarry is indicated by the red arrow. The smaller, orange arrow indicates the position of the stonemason museum (the picture length = 2 km) (Mandic et al., 2005: p. 33).

Section (Text-Figs. 21, 22): It represents the type section of the Zogelsdorf Formation showing it in the bryozoan dominated facies. This detritic, muddy biogene limestone succession with about 3 m thickness reflects a fining and thinning upward trend upsection. The position and the character of the foot wall is unknown. The basal part of the succession shows one single 1 m thick homogenous bed. It is overlain by a well-bedded part consisting of 10 to 30 cm thick packages. Finally, the topmost 50 cm are intensively bedded comprising 5 to 10 cm thick sediment packages. These rudstones are throughout dominated by bryozoan remains and characterized likewise by a high mud content. This significant content, with up to 30 % of additional biogene material in the lower half of the succession – dominated by bivalves, barnacles, echinoid and coral algal remains – diminishes definitely upsection with values going down to only 10 %. The bryozoan colonies are mostly celleporiform. Hence, they commonly form macroids built by several, interchanging bryozoan taxa as well as other incrusting organism groups like serpulids or coral algae. Accompanied by dominant Celeporidae the following bryozoan genera are additionally present in the type section: *Cellaria, Sertella, Porella, Schizoporella, Myriapora,* *Crisia, Entalopora, Lichenopora, Frondipor, Mesenteriopora, Tetrocycloecia, Tervia, and Hornera*. Moreover, characteristic are monospecific pectinid layers bearing disarticulated and articulated, horizontally oriented shells of *Pecten hornensis*. Regarding echinoderms, remains of Echinoidea, Asterozoa, Ophiuroidea as well as Crinoidea can be found.

Interpretation: The site is located in the southern part of the Eggenburg Bay which was originally sheltered from the influence of the open sea by roughly north-south striking submarine, crystalline swells as well as islands and peninsulas. Thus, the Zogelsdorf Formation, topping the basal Late Eggenburgian siliciclastics is developed in a typical terrigenous poor/bryozoan rich facies.
However, the absence of the bryozoan genus *Crisia*, being otherwise common in many other sites of the Eggenburg Bay, appears indicative for the succession. This could point to the absence of submarine vegetation at the depositional site. Indeed, the common incrusting bryozoans as well as other incrusting organisms dominating the biogene composition indicate the lowered sedimentation rate resulting possibly from the missing vegetational sedimentary trap at the sea bottom. Moreover, the high mud content of limestones points to a less agitated hydrodynamic regime certainly below the fair weather wave base at the depositional site. The fining upward along with the thinning upsection reflects the deepening of the depositional environment. This involves the diminishing upsection of shallow subtidal depth indicators like barnacles or common echinoid remains. The pectinid shell beds are remains of their original colonies typically inhabiting detritic, shelly bottoms at medium subtidal depths around the storm weather wave base.

The mass occurrence of *Pecten hornensis* in the Zogelsdorf Formation represents an important regional biostratigraphic signal. Along with the remarkable facies change during the latest Eggenburgian (basal marine siliciclastic sequence in the base vs. detritic carbonate sequence on top), the FAD of that pectinid species in the carbonates enables their clear stratigraphic distinction.

Text-Fig. 21: The Johannes quarry's overview (MANDIC et al., 2005: p. 34).

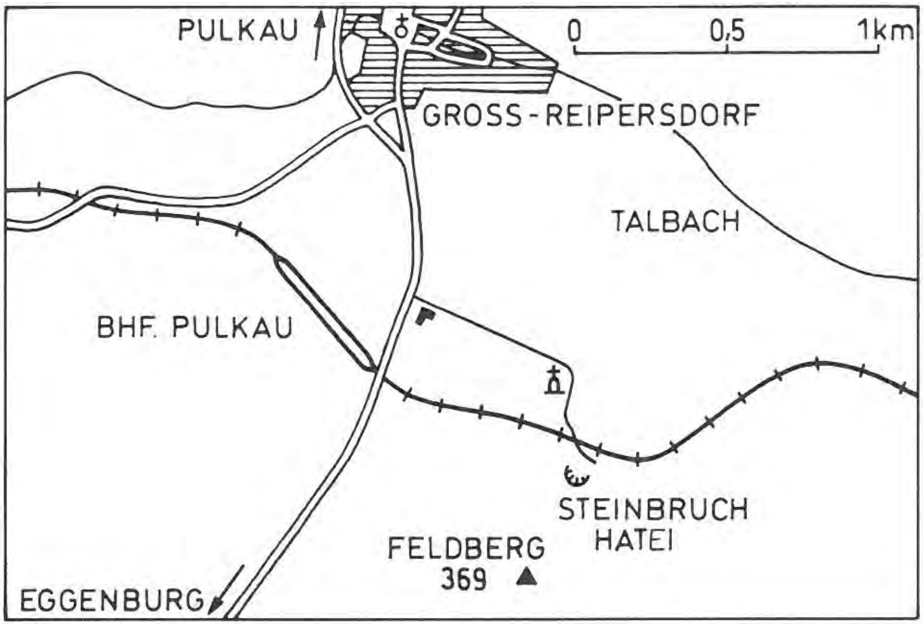


Text-Fig. 22: The section of the Johannes quarry. The diagram shows the vertical distribution of the biogene. Note the increase of the bryozoan contribution upsection (MANDIC et al., 2005: p. 35).

Stop 8. Groß-Reipersdorf – abandoned Quarry Hatei
(from the Molasse Tagung 2012, 27.–28. April, Vienna, Excursion Guide (ROETZEL et al., 2012); translation of description and interpretation by HOLGER GEBHARDT)
Coordinates: E 15°51'14.7", N 48°41'14.1".
Location: Groß-Reipersdorf, south of Pulkau.
Topic: Lower Miocene sediments of the Ottnangian. Corralinacean limestone of the Zogelsdorf Formation overlain by pelites of the Zellerndorf Formation.

The point known as abandoned Hatei Quarry or Pracht Quarry (after its owner) is located in Groß-Reipersdorf, south of Pulkau. There, corralinacean limestone (Zogelsdorf Formation) is overlain on top by deeper marine clay and marl of the Zellerndorf Formation. The succession represents a single transgressive sequence of the Early Ottnangian. The description below is from NEBELSICK (1989a, b) and NEBELSICK et al. (1991).

Description: The abandoned stone pit is situated at the northern slope of the Feldberg, c. 1,6 km SSE of Groß-Reipersdorf, c. 350 m NNE of the Feldberg, or c. 50 m south of the railway Zellerndorf–Sigmundsherberg, directly at the crossing of the path to Groß-Reipersdorf (Text-Fig. 23).



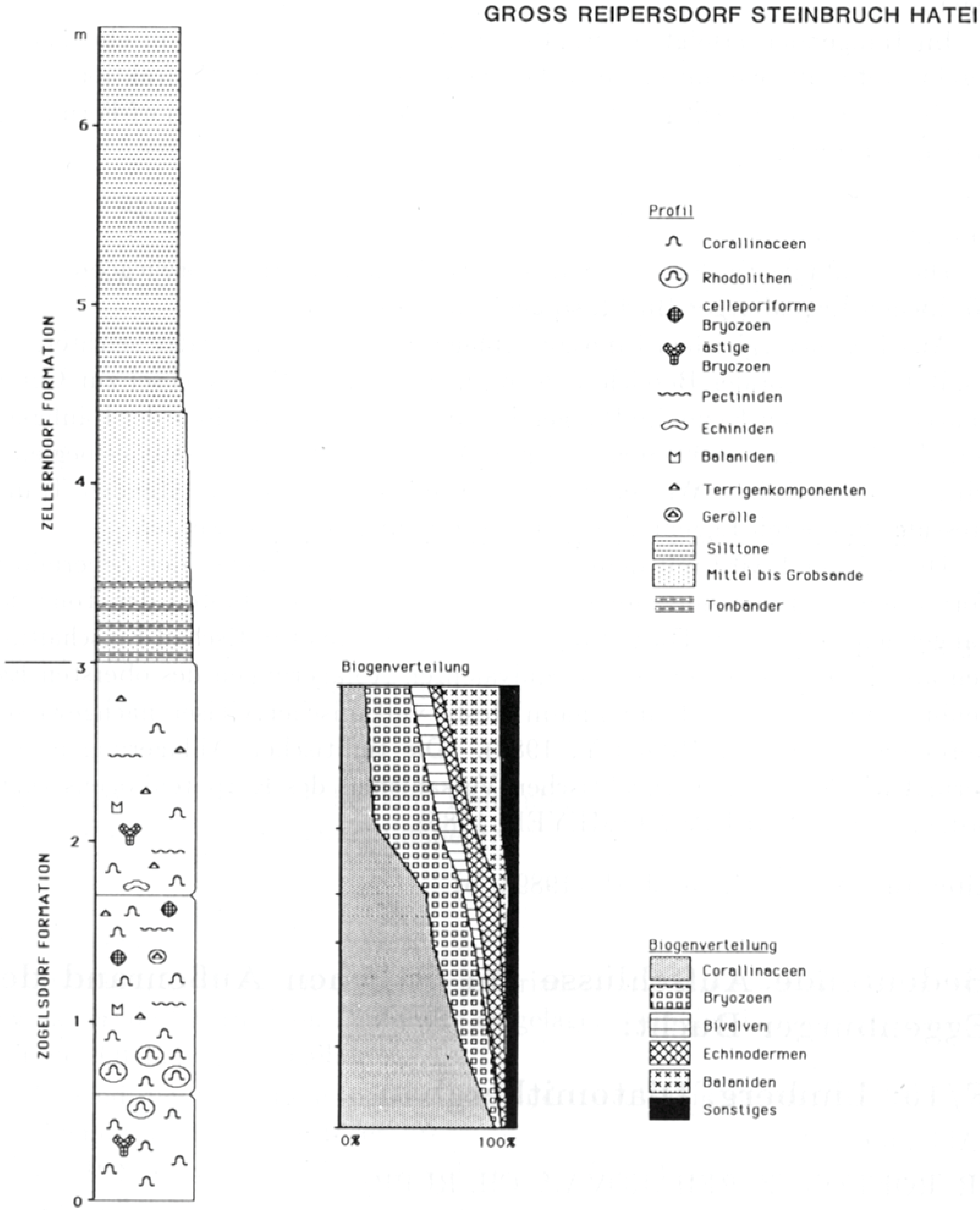
Text-Fig. 23: Location of the abandoned Quarry Hatei.

The Hatei Quarry near Groß-Reipersdorf (Text-Fig. 24) is one of the few outcrops, which shows the transition from the Zogelsdorf Formation to the Zellerndorf Formation (Upper Eggenburgian to Ottnangian). The c. 3 m thick outcropping Zogelsdorf Formation consists of largely massive, biogene-rich limestones showing a fining upward trend. The biogenic components are composed of bryozoans, bivalves (pectinids), echinoderms, balanids, and particularly frequent corallinaceans. The latter are dominant in the lower part of the outcrop and occur also as rhodoliths. They are densely branched, show ellipsoidal to spherical shapes and reach up to 10 cm in size. Towards the upper part, the frequency of the corallinaceans decreases continuously. Here they occur increasingly as fragments or encrusted particles. Also the size of the rhodoliths decreases. Other components such as bryozoans, balanids or terrigenous particles increase towards the top. Accordingly, the facies changes from a corallinacean-facies at the bottom to a corallinacean-bryozoan facies at the top (NEBELSICK, 1989a, b). The flora of the non-corallinaceans is relatively diverse but poorly preserved and contains, among others, the genera *Sporolithon*, *Lithothamnion*, ?*Palaeothamnium*, *Spongites*, *Lithophyllum* and *Titanoderma*. The foraminiferal assemblages contain smaller benthic types such as textulariids, cibicidids, *Asterigerinata*, *Ammonia*, elphidiids, buliminids, bolivinids and, with better preservational conditions, Miliolidae, also *Amphistegina* and in some samples planktic foraminifera. The transition of the clay-rich Zellerndorf Formation appears relatively abrupt. Above of a wavy surface, 140 cm of very poorly sorted, clay-rich, gravelly medium to coarse sands of quartz-rich crystalline grit follows. Intercalations of cm-thick layers of sandy to silty clay show a horizontal stratification. Prominent in these deposits are large amounts of inarticulate brachiopods (*Discinisca* sp.). Above this, the transition to horizontally bedded silty clays with high smectite content occurs within 20 cm. Above the 2 m thick pelites of the Zellerndorf Formation lays quaternary loess.

Interpretation: The coralline facies of the Zogelsdorf Formation occurs mainly in the northern Eggenburg Bay, thus also in the area of Pulkau. From comparison with modern analogues, a relatively shallow, protected, sub-littoral palaeoenvironment is assumed. The change to the corallinacean-bryozoan-facies in the overlying stratum is accompanied by a decrease of the corallinacean content and a slight increase of mud and is interpreted as a deepening during the progressing transgression of the late Eggenburgian (Text-Fig. 26). This trend continues with the transition to a basinal facies of the Zellerndorf Formation later on. The high smectite content of the Zellerndorf Formation can most likely be derived from tuffitic intercalations, particularly because volcanic gases were found in equivalent deposits of latest Eggenburgian age from the Znojmo area. The tuffitic deposits have probably to be assigned to the acidic, rhyolitic volcanism of the Carpathian Arc.

Text-Fig. 24: Groß-Reipersdorf – abandoned Quarry Hatei.

Text-Fig. 25: Groß-Reipersdorf – abandoned Quarry Hatei. Zogelsdorf Formation overlain by Zellerndorf Formation and Löss.



Text-Fig. 26: Section of the Hatei Quarry showing results of microfacies analysis of the Zogelsdorf Formation (from NEBELSICK et al., 1991).

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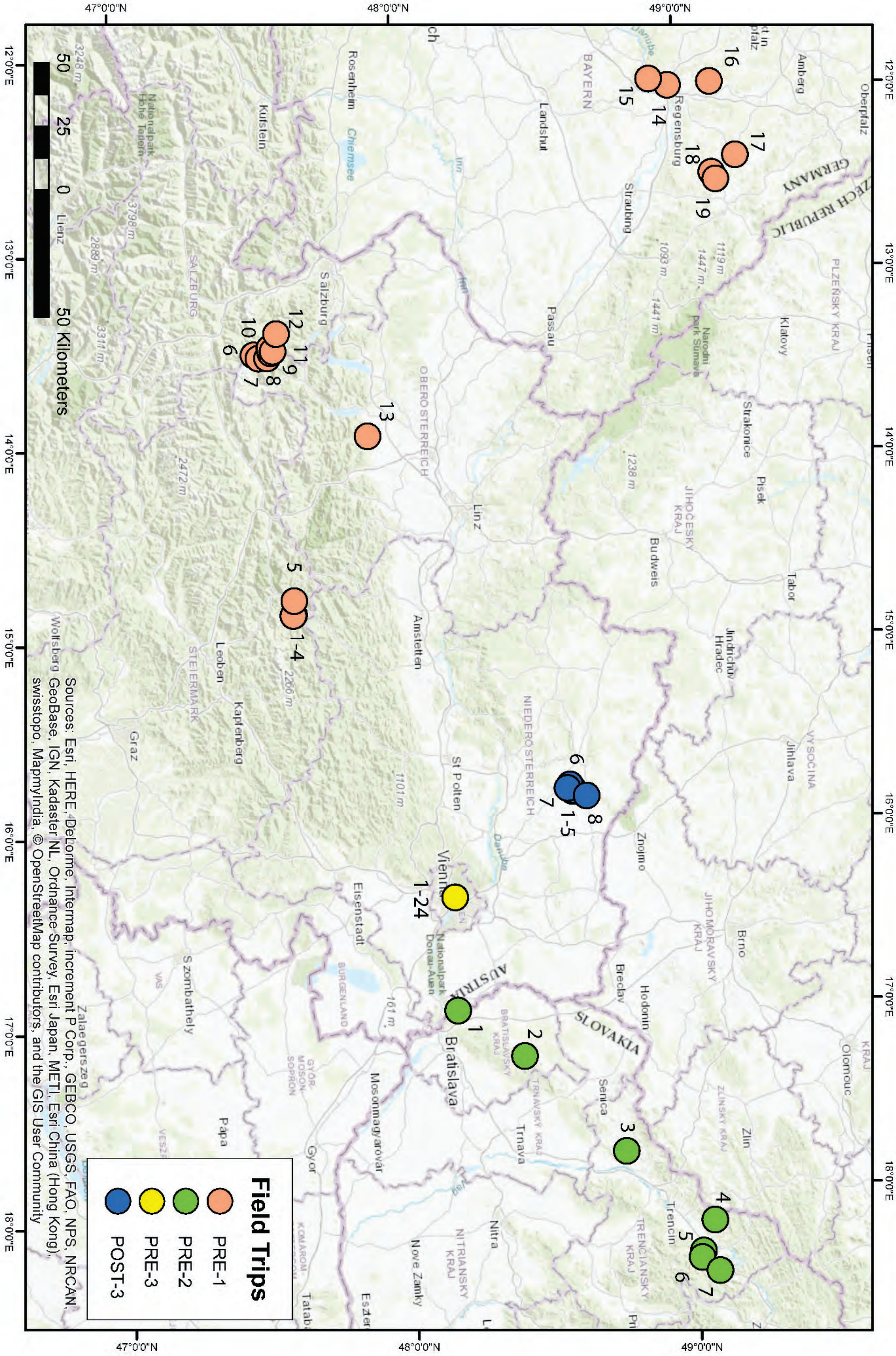
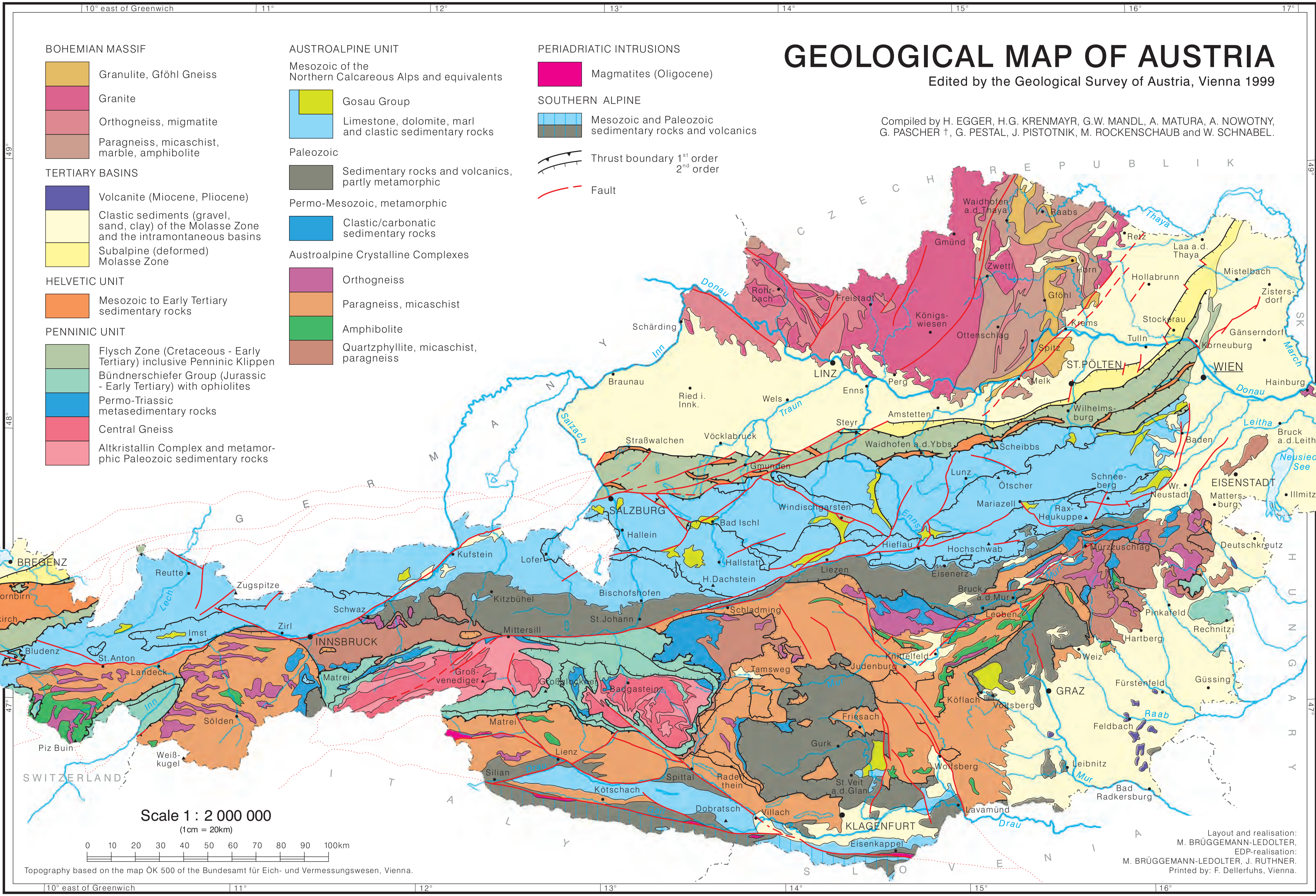


Location of Stops of all Field Trips.


GEOLOGICAL MAP OF AUSTRIA
Edited by the Geological Survey of Austria, Vienna 1999
Compiled by H. EGGER, H.G. KRENMAYR, G.W. MANDL, A. MATURA, A. NOWOTNY, G. PASCHER †, G. PESTAL, J. PISTOTNIK, M. ROCKENSCHAUB and W. SCHNABEL.
BOHEMIAN MASSIF
Granulite, Gföhl Gneiss
Granite
Orthogneiss, migmatite
Paragneiss, micaschist, marble, amphibolite
TERTIARY BASINS
Volcanite (Miocene, Pliocene)
Clastic sediments (gravel, sand, clay) of the Molasse Zone and the intramontanous basins
Subalpine (deformed) Molasse Zone
HELVETIC UNIT
Mesozoic to Early Tertiary sedimentary rocks
PENNINIC UNIT
Flysch Zone (Cretaceous - Early Tertiary) inclusive Penninic Klippen
Bündnerschiefer Group (Jurassic - Early Tertiary) with ophiolites
Permo-Triassic metasedimentary rocks
Central Gneiss
Altkristallin Complex and metamorphic Paleozoic sedimentary rocks
AUSTROALPINE UNIT
Mesozoic of the Northern Calcareous Alps and equivalents
Gosau Group
Limestone, dolomite, marl and clastic sedimentary rocks
Paleozoic
Sedimentary rocks and volcanics, partly metamorphic
Permo-Mesozoic, metamorphic
Clastic/carbonatic sedimentary rocks
Austroalpine Crystalline Complexes
Orthogneiss
Paragneiss, micaschist
Amphibolite
Quartzphyllite, micaschist, paragneiss
PERIADRIATIC INTRUSIONS
Magmatites (Oligocene)
SOUTHERN ALPINE
Mesozoic and Paleozoic sedimentary rocks and volcanics
Thrust boundary 1st order
2nd order
Fault
Scale 1 : 2 000 000
(1cm = 20km)
0 10 20 30 40 50 60 70 80 90 100km
Topography based on the map ÖK 500 of the Bundesamt für Eich- und Vermessungswesen, Vienna.
10° east of Greenwich
11°
12°
13°
14°
15°
16°
17°
47°
48°
49°
CZECH REPUBLIK
GERMANY
SWITZERLAND
ITALY
SLOVENIA
HUNGARY
SK
WIEN
LINZ
SALZBURG
INNSBRUCK
GRAZ
KLAGENFURT
ST.PÖLTEN
EISENSTADT
BREGENZ
Donau
Inn
Salzach
Traun
Enns
Mur
Drau
Raab
Thaya
March
Leitha
Rhein
Lech
Bodensee
Neusiedler See
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