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Field Trip Post-Ex-2

Latest Jurassic to Early Cretaceous evolution in the central Northern Calcareous Alps

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Abstract

This field trip will provide new insights in the latest Jurassic to Early Cretaceous depositional history of the central Northern Calcareous Alps based on new data from: biostratigraphy, sedimentology (e.g., facies, component analysis), biogeography, geophysics (e.g., magnetic stratigraphy, magnetic susceptibility, gamma ray spectrometry), and geochemistry from a basinal perspective. Starting in the latest Jurassic we will see deep-water *Calpionella* limestones with intercalated mass transport deposits and turbidites made of shallow-water material from a contemporaneously growing carbonate platform, in parts mixed with older components derived from the Late Permian to earliest Early Triassic Alpine Haselgebirge (Alpine Haselgebirge Mélange). Backstepping of this platform is manifested by a fining upward-trend in the sedimentological record of the age-equivalent basinal sedimentary rocks. The drowning of this platform started in the Middle Berriasian and the final drowning is dated as Late Berriasian. Onset of platform drowning in the Middle Berriasian resulted in the basin in starvation, increasing siliciclastic input, and an isotope excursion. Late Berriasian to Late Valanginian deposition is characterized by marly deposition with intercalated turbidites containing contemporaneous calcareous litho- and bioclasts and siliciclastic material. Still in the Late Valanginian intense redeposition from the hinterland started and mass transport deposits with e.g., components from the obducted Triassic-Jurassic Neotethys-Ocean floor were deposited. Sea-level changes triggered in the timespan Middle/Late Berriasian to Middle Aptian (basin is filled) the depositional history, mass transport deposits occur during lowstand phases. We will present this history on base of a multi-method approach with a lot of additional results regarding e.g., the Jurassic/Cretaceous-boundary, the Early Cretaceous geodynamic history of the Eastern Alps in one of the most prominent areas of the Northern Calcareous Alps: the Salzburg Calcareous Alps.

1 Introduction

During this field trip in one of the geologically most classical areas of the world, the central Northern Calcareous Alps as part of the Eastern Alps (Fig. 1) we will visit locations documenting the whole latest Jurassic (Late Tithonian) to Early Cretaceous (Middle Aptian) depositional history in basinal sequences.

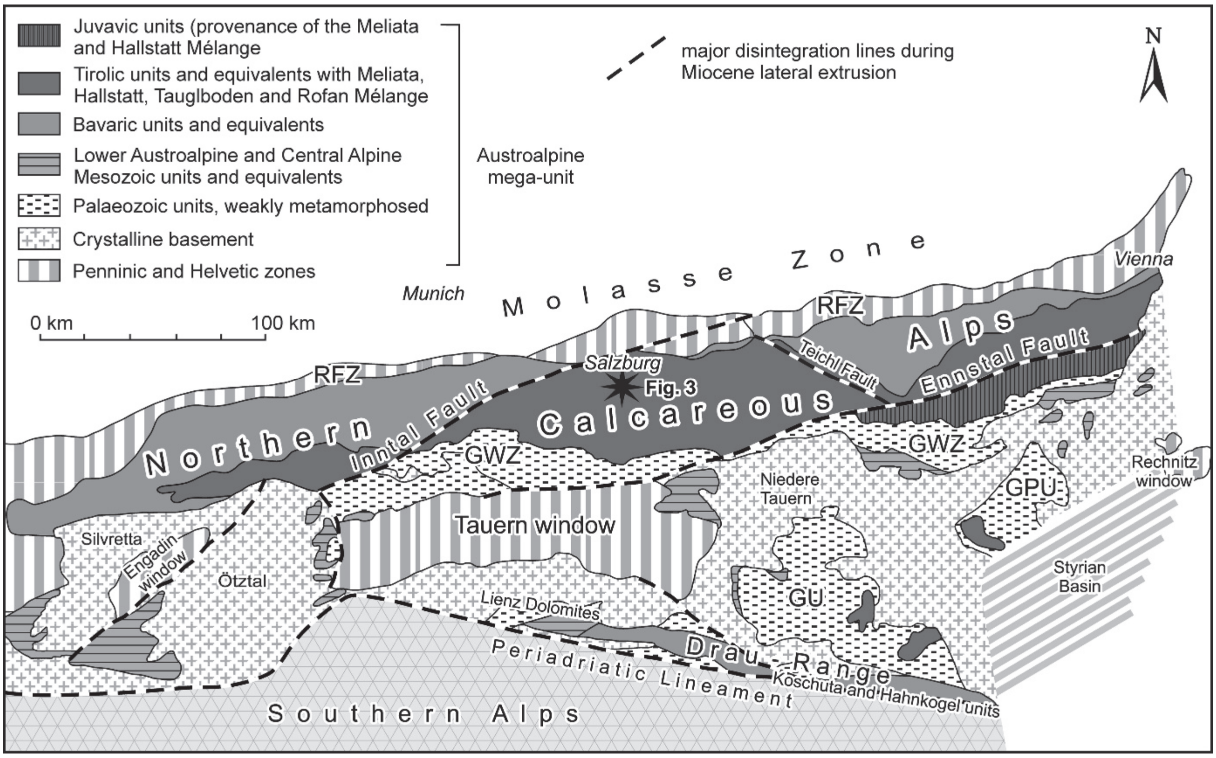

Fig. 1: Tectonic sketch map of the Eastern Alps and field trip area, indicated by an asterisk (compare Fig. 2). After Tollmann (1977) and Frisch & Gawlick (2003). GPU Graz Palaeozoic Unit; GU Gurktal Unit; GWZ Greywacke Zone; RFZ Rhenodanubian Flysch Zone.

Until today there is little consensus on the Late Jurassic to Early Cretaceous geodynamic history of the Northern Calcareous Alps. One crucial problem is the still in cases poorly known stratigraphic and facies evolution of the sedimentary sequences, very often only preserved as pebbles in mass transport deposits. However, in the last few years and still ongoing is progress in e.g.,

1. age dating, lithology, microfacies, geochemical and petrophysical characteristics, and magnetic stratigraphy of the latest Jurassic to Early Cretaceous sedimentary sequences,
2. understanding the history of lost oceanic domains, mainly based on pebble and clast analysis,
3. understanding the geodynamic processes in the Western Tethyan realm and timing of the polyphase thrusting processes in the Northern Calcareous Alps.

It is out of our scope to give in this field trip guide a historical overview about the different views and interpretations during the history of investigations. Therefore only a brief review is given in the description of the formations will be visited and, in addition, several remarks to the discussed topics described in the different chapters. For the wealth of literature about the Northern Calcareous Alps until 1995 see Tollmann (1976a, b, 1985) and Plöchinger (1980, 1995). A summary about the different nappe concepts is given in Frisch & Gawlick (2003), and Missoni & Gawlick (2011a, b). Crucial for the understanding of the Mesozoic geodynamic history of the Northern Calcareous Alps is a restoration of the palaeogeography before the tectonic motions in the frame of the Neogene lateral tectonic extrusion of the Eastern Alps (Ratschbacher et al., 1991; Linzer et al., 1995; Pueyo et al., 2007).

2 Latest Jurassic to Early Cretaceous stratigraphy and formations

For definition and detailed description of the Jurassic formations (Fig. 2) see GAWLICK et al. (2009). The formations which will be visited during this field trip were deposited in the Tauglboden Basin (e.g. SCHLAGER & SCHLAGER, 1969, 1973; compare KRISCHE, 2012 who discussed for the Leube quarry a provenance from the southern part of Trattberg Rise) or Tauglboden-Rossfeld Basin, even the Rossfeld Basin has a larger extension to the south. The Tauglboden Basin was formed in Early Oxfordian times as a trench-like basin in front of the Trattberg Rise representing the frontal part of the advancing upper Tirolic nappe (FRISCH & GAWLICK, 2003). Later, in the Late Oxfordian compression moved to the north forming the Brunnwinkl Rise (Fig. 2). From this time onwards the Tauglboden Basin became an isolated basin between two topographic highs on which a shallow-water carbonate platform start to grow from Early Kimmeridgian onwards (Plassen Carbonate Platform; Fig. 2). During the Kimmeridgian to Early Tithonian sediment supply from the platforms into the Tauglboden Basin was rather low. The situation changed with the extensional collapse of the Trattberg Rise from the Early Tithonian onwards which gave way for the Plassen Carbonate Platform in the south to shed carbonate into the Tauglboden Basin to the north. Latest Jurassic (Late Tithonian) to earliest Cretaceous (Middle Berriasian) deposition in the Tauglboden Basin was controlled by this carbonate platform evolution in a highly tectonically active regime. These Tithonian tectonic motions are interpreted by MISSONI & GAWLICK (2011a) as expression of mountain uplift and unroofing. This led in the field trip area, situated to the north, to extension, e.g. expressed in the collapse of the Trattberg Rise and the advancing Haselgebirge Mélange from a more southern palaeogeographic position (Fig. 2). The final drowning of the Plassen Carbonate Platform in the Late Berriasian gave way for an increasing siliciclastic influx from the south from Middle/Late Berriasian times onwards. This siliciclastic influx was mainly controlled by sea-level changes and decreasing tectonic activity during the more or less whole Early Cretaceous. In the Late Berriasian resedimented arenitic beds with calcareous shallow-water clasts within the basinal sequence show the influence of a newly evolving carbonate producing area in the south in a very narrow time span. Successively the Tauglboden Basin (now the Tauglboden-Rossfeld Basin or Rossfeld Basin) became filled, mainly with marls and mixed carbonatic-siliciclastic material, but still a Late Berriasian to Late Valanginian shallow-water area (carbonate-ramp) to the south influenced parts of the basin with resedimented calcareous material. Deposition ended in the Middle Aptian. “Mid-Cretaceous” tectonic motions started slightly later and became sealed by the Late Cretaceous Gosau sedimentary cycle.

In former interpretations the Rossfeld Basin as continuation of the Late Jurassic Tauglboden Basin should be a newly formed Early Cretaceous flysch basin in a migrating foredeep in front of advancing Juvavic nappes (FAUPL & TOLLMANN, 1979; TOLLMANN, 1985; FAUPL & WAGREICH, 2000; NEUBAUER et al., 2000; FRANK & SCHLAGER, 2006). The sedimentation in the basin should have been terminated by the overthrust of these nappes, documented e.g. by the Hallstatt outliers on top of the Rossfeld Formation type-locality. By this interpretation mass-flow deposits, intercalated in calcareous sandstones and cherty limestones of the upper Rossfeld Formation should contain the complete component spectrum of the arriving Juvavic nappes (e.g., PESTAL et al., 2009) as documented in the different Jurassic basins. However, new results on the uninvestigated carbonate components in these mass flows of the type locality and elsewhere (e.g., MISSONI & GAWLICK, 2011b; KRISCHE, 2012, KRISCHE et al., 2014; KRISCHE & GAWLICK, 2015) show only different Late Jurassic to Early Cretaceous shallow-water clasts from the Plassen Carbonate Platform sensu stricto, their drowning sequence, the following Early Cretaceous basinal sediments, and contemporaneous shallow-water clasts derived from an unexplored source in the hinterland beside the already known siliciclastic, volcanic, ophiolitic components (POBER & FAUPL,

1988; FAUPL & POBER, 1991; SCHWEIGL & NEUBAUER, 1997a, b; von EYNATTEN et al., 1996; von EYNATTEN & GAUPP, 1999; FAUPL & WAGREICH 2000), and radiolarite clasts from the Neo-Tethys ocean floor and matrix radiolarites from the ophiolitic mélange (KRISCHE et al., 2014). Triassic-Jurassic components from the Hallstatt Zone (Hallstatt and Pötschen Limestones) or Triassic shallow-water carbonate components of the Upper Tirolic Berchtesgaden (formerly a Juvavic) unit as well as components of the Alpine Haselgebirge are completely absent. Only in few cases not facies indicative clast of the uppermost Werfen to lowermost Gutenstein Formations may occur.

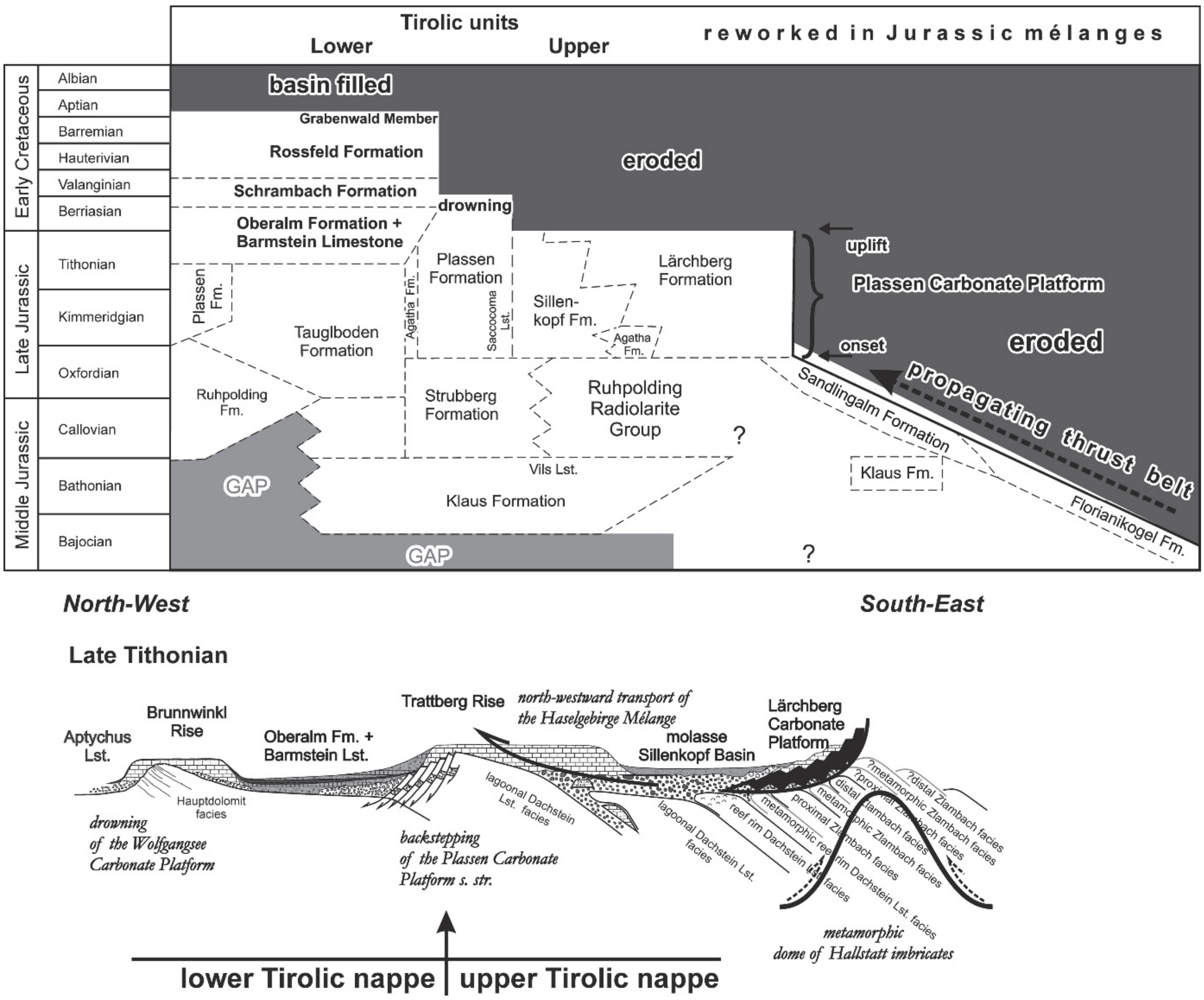

*Fig. 2: **A**) Middle Jurassic to Early Cretaceous stratigraphy of the central Northern Calcareous Alps with an overview of the common formation names, simplified after MISSONI & GAWLICK (2011a). Late Jurassic and Early Cretaceous formation names which will be visited during the field trip are written in bold letters. **B**) Simplified Late Tithonian basin and rise configuration (after MISSONI & GAWLICK 2011a). The boundary between the lower and the upper Tirolic nappe is the Trattberg Rise, formed in Early Oxfordian times.*

Oberalm Formation + Barmstein Limestone: In the Late Jurassic (Middle-Late Tithonian) to Early Cretaceous (Middle Berriasian) Oberalm Formation (LIPOLD, 1854; for complete history and definition see GAWLICK et al., 2009) occur intercalated coarse-grained resediments (mass transport deposits and turbidites) from the Plassen Carbonate Platform, named Barmstein Limestones (GÜMBEL, 1861). The overall depositional trend of the Oberalm Formation is fining upward (MISSONI & GAWLICK, 2011a, b). A special type of Barmstein Limestones was deposited in the latest Tithonian: beside reworked material from the shallow-water area of the Plassen Carbonate Platform components of the Late Permian Haselgebirge appear (Fig. 2 for explanation). This type of mass transport deposit was named by PLÖCHINGER (1974) as "Tonflatschenbreccia" with its type area in the Leube quarry (see below).

In the upper Oberalm Formation widespread a microfacies and lithological change can be observed between the late Early Berriasian and the Middle Berriasian. Deposition of the more or less variegated, purple to reddish, siliceous to slaty marly limestones of roughly Middle Berriasian age (or late Early Berriasian age; Gutratberg Member of the Oberalm Formation: KRISCHE et al., 2013) is the basinal expression of the stepwise demise of the Plassen Carbonate Platform due to the increasing siliciclastic input. Carbonate production of the Plassen Carbonate Platform decreased since the late Early Berriasian and resulted in its final drowning in the Late Berriasian (GAWLICK & SCHLAGINTWEIT, 2006).

Schrambach Formation: After the final drowning of the Plassen Carbonate Platform in the Late Berriasian (GAWLICK & SCHLAGINTWEIT, 2006) and the rapid decrease of shallow-water carbonate production in basinal areas condensed red marls were deposited (Gutratberg Member as topmost part of the Oberalm Formation: KRISCHE et al., 2013). Above the Gutratberg Member and intercalated in the marls of the typical Schrambach Formation (Late Berriasian to Late Valanginian) first coarse-grained arenitic turbidites were deposited (KRISCHE & GAWLICK, 2010). The Schrambach Formation is mostly developed as a marl and calcareous marl succession, but also resedimented limestone beds consisting of shallow-water material within the marly sequence can be observed.

The age range of the Schrambach Formation (LILL v. LILIENBACH, 1830) is different in different areas of the Northern Calcareous Alps (TOLLMANN, 1976a, 1985 with references therein). A former estimated onset of the Schrambach Formation in the lower Early Berriasian in the type area cannot be confirmed. At the type locality, the Schrambachgraben northwest of the village Kuchl the age range of the Schrambach Formation is Late Berriasian to Early Valanginian (BOOROVÁ et al., 2015 with references therein). In the Leube quarry reference section the Schrambach Formation has an age range of latest Early Berriasian to Late Valanginian (KRISCHE et al., 2013 and herein). The transition between the underlying Oberalm Formation and the Schrambach Formation should be gradual in the type section and no distinct and/or essential lithological changes are observed in the lower horizons of the Schrambach Formation compared with those of the topmost part of the Oberalm Formation except a change in the occurrence and quantity of calcareous dinoflagellates (BOOROVÁ et al., 2015). Therefore also in the youngest study of BOOROVÁ et al. (2015) the change from the Oberalm Formation to the Schrambach Formation is placed at the Middle/Late Berriasian boundary (compare RASSER et al., 2003).

In contrast to the type-locality Schrambachgraben in the Leube quarry to the north or the Weitenau area to the east a significant lithological change between the Oberalm and the Schrambach Formations is observed: A microfacies and lithological change is between Middle and Late Berriasian. In this time interval the carbonate content decreases and the fine-grained siliciclastic content increases permanently with detrital quartz, apatite and garnet becoming more frequent (KRISCHE et al., 2013). Coarse-grained limestone beds above the Gutratberg Member and below the Late Berriasian marly limestone succession (BUJTOR et al., 2013) belong to the basal Schrambach Formation. These turbidite beds in the Leube succession may correspond to the sandy limestones layers in the type section Schrambachgraben slightly above the boundary between the Oberalm and the Schrambach Formation (BOOROVÁ et al., 2015), even such sandy limestones layers with resediments occur in different horizons in the Schrambach Formation (KRISCHE et al., 2013).

However, a characteristic change in the lithology or a direct biostratigraphic proof for the onset of the Schrambach Formation in the Late Berriasian is still missing in the type section. In addition, MISSONI & GAWLICK (2011b) dated the lower part of the Schrambachgraben section by coccolithophorid taxa as Late Berriasian (Middle Berriasian in BOOROVÁ et al., 2015) and attributed also this part of the section to the Schrambach Formation, meaning that the Gutratberg Member and the coarse-grained turbidites are situated below the Schrambachgraben section and covered by dense vegetation or the road. Only magnetostratigraphy of the type section may clarify this open problem.

Rossfeld Formation: In the Early Cretaceous (Valanginian to Aptian: TOLLMANN, 1976a; OBERHAUSER, 1980; PLÖCHINGER, 1990; KRISCHE et al., 2014) Roßfeld Formation (LILL v. LILIENBACH, 1830) and equivalents (Lackbach beds: DARGA & WEIDICH, 1986) several levels of oligo- to polymictic conglomerates, coarse-grained breccias and arenitic turbidites occur. The until recent times commonly accepted interpretation of the Early Cretaceous geodynamic evolution of the Northern Calcareous Alps is a convergent regime mirrored by the coarsening-upward depositional trend in the Late Valanginian to Early Aptian Rossfeld Formation (FAUPL & TOLLMANN, 1979, DECKER et al., 1987; LEISS, 1992). In this scenario the Rossfeld cycle ended with the overthrust of the Tirolic nappe by the Juvavic nappes (e.g., PLÖCHINGER, 1968; TOLLMANN, 1976a, b; SCHWEIGL & NEUBAUER, 1997a, b; SCHORN & NEUBAUER, 2011). The main argument for the overthrust of the Juvavic nappes over the Tirolic nappe are the huge Hallstatt Limestone blocks in the Rossfeld Formation type area, which should rest in the Rossfeld Formation (TOLLMANN, 1976a with reference therein). This view could not be confirmed by reinvestigation of the mass transport deposits and blocks in the type area by MISSONI & GAWLICK (2011b). The Hallstatt Limestone blocks rest tectonically transported (younger than "Mid-Cretaceous") on top of the Rossfeld Formation. Furthermore, the highest part of the Rossfeld Formation at the type section is Barremian and not Aptian, meaning that parts of the Rossfeld Formation were eroded before the emplacement of the Hallstatt Limestones. In addition, components of Hallstatt Limestones (or other Middle - Late Triassic pebbles) in the various breccia layers of the Rossfeld Formation indicating an arrival of "Juvavic nappes" do not occur.

However, a detailed and systematic description of the very heterogeneous component spectrum in the Rossfeld Formation in a wider scale was until recent times (KRISCHE, 2012) not carried out. Earlier investigations focused on the biostratigraphic age dating of the Rossfeld Formation or the description of some specific components (e.g., KÜHNEL, 1929; WEBER, 1942; DEL-NEGRO, 1949; 1983; PICHLER, 1963; DARGA & WEIDICH, 1986; IMMEL, 1987; SCHWEIGL & NEUBAUER, 1997a). In contrast to the un-investigated radiolarite and carbonate pebbles in the mass-transport deposits, the other components from the ophiolite suite like dolerites, mafic volcanites, intermediate/basic magmatites, ultrabasic rocks and serpentinites were well investigated (e.g. von EYNATTEN & GAUPP, 1999). In addition, the typical heavy minerals like chromium spinel, hornblende, green calcium-rich amphiboles, and brown amphiboles indicating an ophiolitic source area were well described (e.g. WOLETZ, 1963; FAUPL & POBER, 1991; SCHWEIGL & NEUBAUER, 1997a; VON EYNATTEN & GAUPP, 1999). First microfacies studies and biostratigraphic age dating of the radiolarite and carbonate components in the different mass transport deposits in the Rossfeld Formation were carried out by MISSONI & GAWLICK (2011a, b) in the type area of the Rossfeld Formation. A detailed component analysis of the mass transport deposits from all different stratigraphic levels of the Rossfeld Formation in a wider scale was carried out by KRISCHE (2012), KRISCHE et al. (2013, 2014), and KRISCHE & GAWLICK (2015).

The different fining- and coarsening-upward trends in the Rossfeld Basin fill can be best explained by sea-level fluctuations and decreasing tectonic activity in the Jurassic orogen in an underfilled foreland basin.

3 The Field Trip

In Figure 3 the localities which will be visited during this field are shown. In the Leube quarry near the village Gartenau south of Salzburg we will study the latest Jurassic to Late Valanginian sedimentary succession: Oberalm Formation + Barmstein Limestone, Schrambach Formation, and lower part of the Rossfeld Formation. In the Rossfeld area (Germany), type-locality of the Rossfeld Formation, we will study the Late Valanginian to Barremian part of the Rossfeld Formation. In the central Weitenau area we will visit the latest Barremian to Middle Aptian Grabenwald Member of the Rossfeld Formation. The Grabenwald Member is the youngest part of the Rossfeld Basin fill.

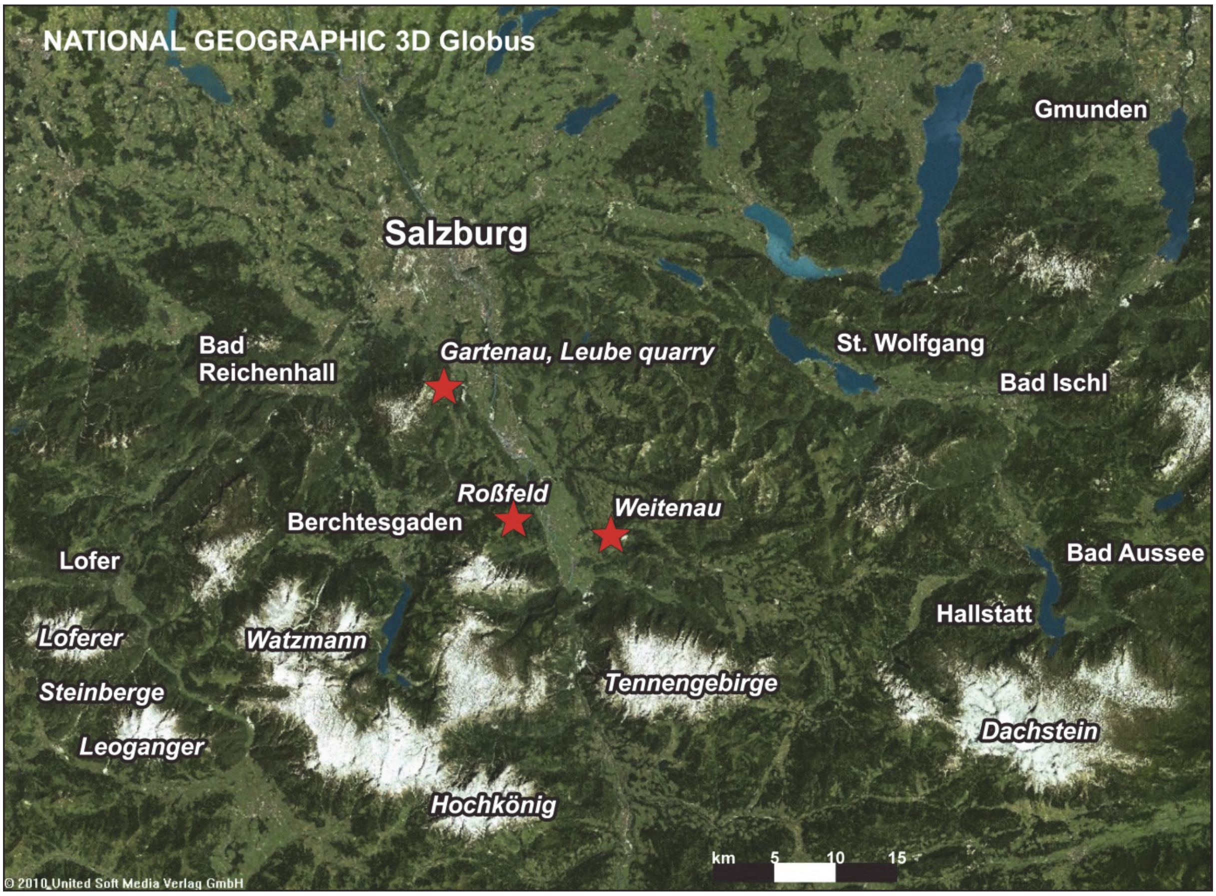

Fig. 3: Satellite image of the central Northern Calcareous Alps, showing the localities which will be visited during this field trip (red stars).

3.1 Gartenau: Leube quarry

The Leube quarry (Fig. 4, 6), where the latest Jurassic to Early Cretaceous sedimentary rocks are exploited for cement production, is located in the central Northern Calcareous Alps south of Salzburg, near to the villages of Gartenau and St. Leonhard. In this quarry, a complete and only slightly disturbed sedimentary succession from the higher Oberalm Formation + Barmstein Limestone to the Roßfeld Formation is well preserved (Fig. 5).

The Leube quarry provides one of the best preserved and exposed uppermost Jurassic to Early Cretaceous sedimentary successions in the central Northern Calcareous Alps. The new calpionellid data, in combination with ammonite, microfacies and lithology analyses, form the basis for a detailed, revised biostratigraphy of this time interval (KRISCHE et al., 2013) and gave rise for further very detailed investigations. Additionally, the investigation of hemipelagic basinal sedimentary sequences is very important for a better understanding of the Late Jurassic to Early Cretaceous evolution of the central Northern Calcareous Alps and also allows new insights into the development of the Late Jurassic to Early Cretaceous shallow-water carbonate platform at the southern rim of the basin (Plassen Carbonate Platform *sensu stricto*). The remarkably rich Late Berriasian ammonite fauna (BUJTOR et al., 2013) reveals strong biogeographic connections toward the Tethyan faunas along the northern margin of the Tethys; many are reported for the first time from Austria (Fig. 11). The presented results contribute to an improvement of the palaeogeographical and geodynamical model of the Northern Calcareous Alps for this time span.

Former and recent investigations at the Leube quarry section

The history of investigations until 2013 is described in detail in KRISCHE et al. (2013). Therefore we see no need to write a new historical overview. We take in general the text from KRISCHE et al. (2013), slightly modified and added: In the last hundred years the classic profile in the northern active Leube quarry was studied several times. The first indication for the presence of ammonites was reported by FUGGER (1907) in "Schrammbach" and Rossfeld beds in the vicinity of the villages of St. Leonhard, Gartenau and Götschen. WEBER (1942) referred the first ammonites (*Pseudothurmannia (Parahoplites) spinigera*) in the Schrambach and the Lower Rossfeld beds nearby the village Gartenau. OEDL (in: PLÖCHINGER, 1955) reported the occurrence of *Fuhriella michaelis* from the marly limestones of the open pit mine. From the underground mine PLÖCHINGER (1961) described the first lithological profile with Oberalm, Schrambach and Rossfeld beds. Mapping of PICHLER (1963) gave information about the lithology, sedimentology and the fossil content of the Schrambach beds. Their age was considered as Berriasian to Early Valanginian, based on ammonite biostratigraphy. PLÖCHINGER (1968) reported *Bochianites neocomiensis* and *Kilianella roubaudiana* from greenish-grey marls, indicating a Valanginian to Early Hauterivian age. PLÖCHINGER (in: MATURA & SUMMESBERGER, 1980) also referred findings of *Olcostephanus*, *Berriasella* and *Neolissoceras* from the quarry. First lithological and microfacies analyses around the Schneiderwald (Fig. 4) and the eastern part of the open pit were carried out by PLÖCHINGER (1974, 1976, 1977) who included calpionellid biostratigraphy in his investigations. IMMEL (1987) described a Late Hauterivian ammonite assemblage with *Oosterella kittli*, *Crioceratites (Crioceratites) nolani* and *Moutoniceras annulare* from sandy limestones (Rossfeld Formation) of the Köppelschneid (Fig. 4).

Starting from the 1990s, WEIDICH (1990), STEIGER (1992), BODROGI et al. (1996), REHÁKOVÁ et al. (1996), BOOROVÁ et al. (1999) and HRADECKÁ (2003) investigated profiles in the open pit mine and delivered litho- and biostratigraphical descriptions of the quarry, based on foraminifers, radiolarians, shallow-water organisms, calpionellids, dinoflagellates and aptychi. BOOROVÁ et al. (1999) and DORNER et al. (2009) mentioned very scarce occurrences of ammonites in their profiles.

Recent investigations were carried out by GAWLICK et al. (2005) in the area of the old, recultivated quarry south of today´s open pit and by WAGREICH (2009) in the active Leube quarry. BUJTOR et al. (2013) investigated the ammonite assemblage of the active Leube quarry and described the occurring species palaeontological and biostratigraphically. KRISCHE et al. (2013) presented a modern analysis of the Late

Tithonian to Valanginian Oberalm Formation + Barmstein Limestones and the Schrambach Formation with exact biostratigraphic ages. KRISCHE et al. (2014) analyzed and dated the exotic components from the mass transport deposits of the lowermost Rossfeld Formation. Ongoing studies deal with isotope stratigraphy (MAIER et al., 2013), magnetostratigraphy, gamma ray spectrometry, AMS studies, and geochemical analysis (GRABOWSKI et al., 2016a, 2017a, b) to enlighten the Early Cretaceous depositional history of the Western Tethyan realm.

During this field trip published results are combined with the recently obtained and still unpublished and here for the first time presented results.

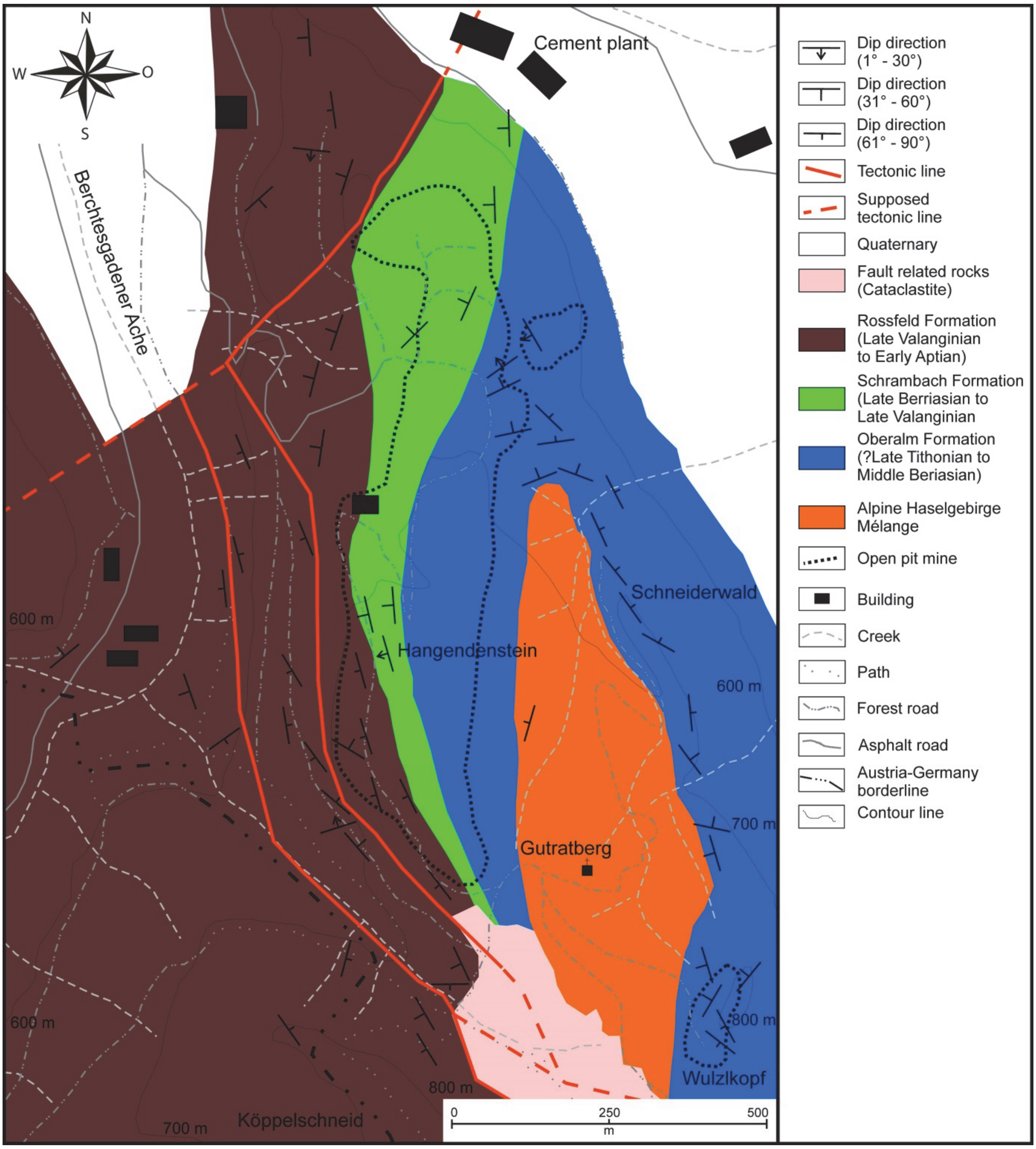

Fig. 4: Geological map of the Leube quarry and the surrounding area, after KRISCHE et al. (2013).

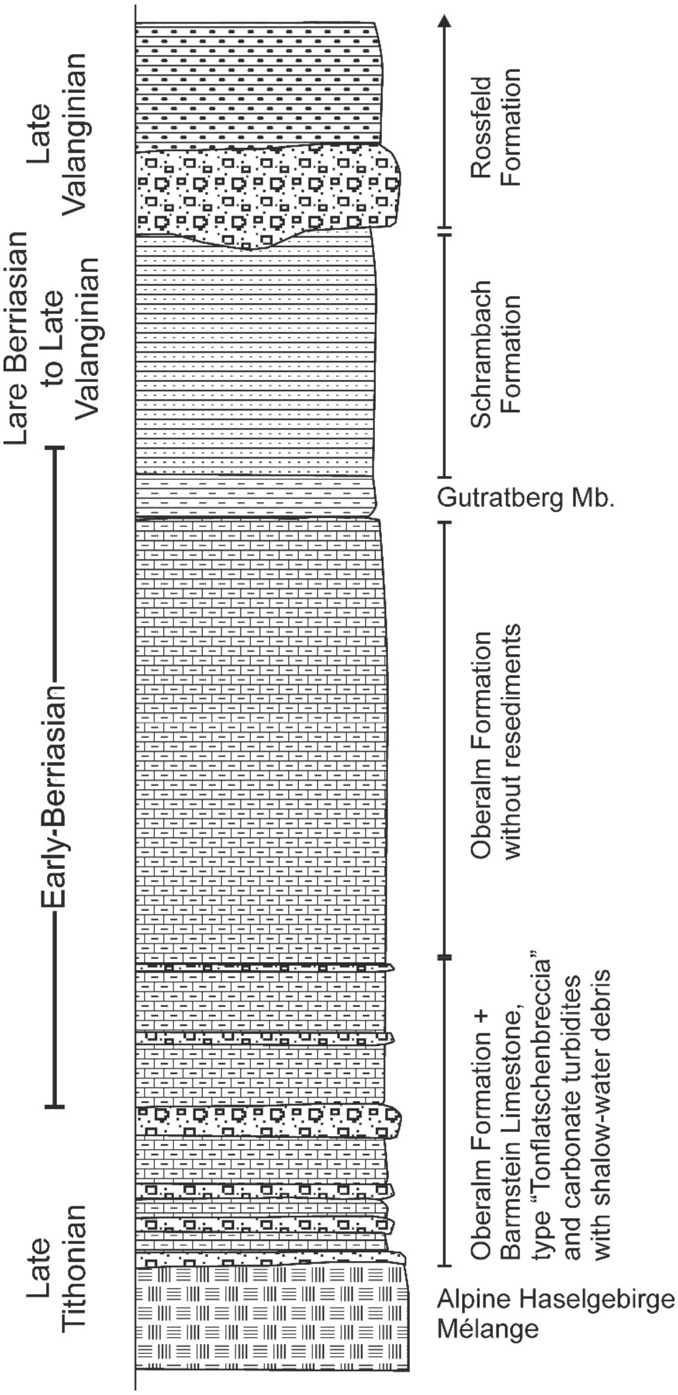

Fig. 5: Overall composite Leube quarry section with the standard lithostratigraphy modified after Krische *et al. (2013). Ages adapted according to the new definition of the Jurassic/Cretaceous boundary.*

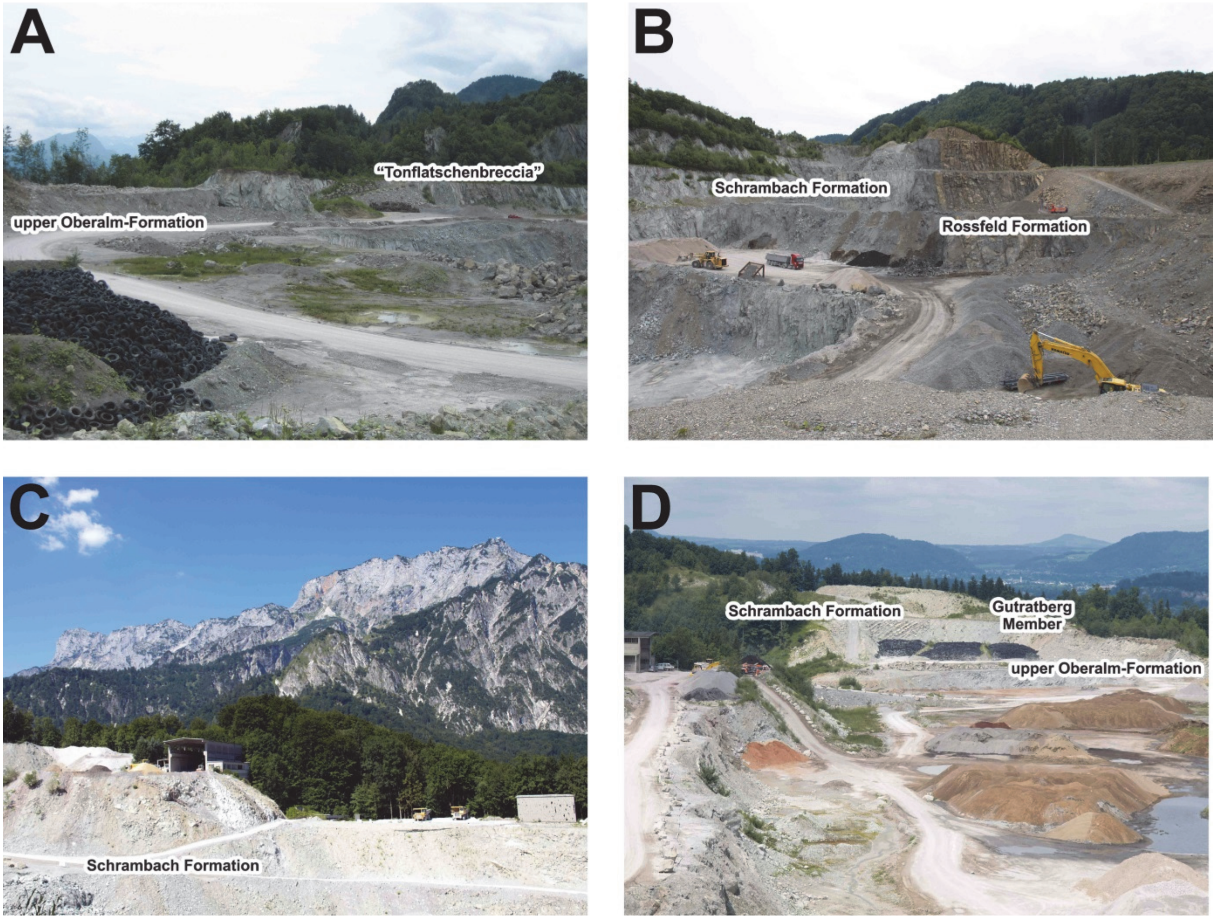

Fig. 6: Different views of the Leube quarry and formations which will be visited. Due to the fact of ongoing exploitation in the quarry the outcrop situation and available parts of the succession may change. ***A****) Northwestern part of the quarry with the Early Berriasian part of the succession.* ***B****) Northern part of the quarry with the Early Berriasian (upper Oberalm Formation), the Middle Berriasian (Gutratberg Member of the Oberalm-Formation), and the Late Berriasian (Schrambach Formation).* ***C****) Eastern side of the quarry with the in details presented part of the succession for magnetostratigraphy, gamma ray spectrometry, AMS studies, and geochemical analysis.* ***D****) Southern part of the quarry with the transition from the Schrambach Formation to the Rossfeld Formation.*

Oberalm Formation + Barmstein Limestone

Basal part: Barmstein Limestone: "Tonflatschenbreccia" (PLÖCHINGER, 1974)

A contact between the Alpine Haselgebirge Mélange or a huge Alpine Haselgebirge Mélange block with the overlying Barmstein Limestone with Haselgebirge components and *Calpionella*-limestones of the Oberalm Formation is outcropping in the Ottobau. Here the Oberalm Formation contains *Calpionella alpina* and *Crassicollaria* sp. (KRISCHE et al., 2013) and is Late Tithonian in age.

This is in accordance with the biostratigraphic results of a section to the south, in the so-called Schneiderwald-anticline (PLÖCHINGER, 1974, 1976). Here a roughly 50 m thick succession of the Oberalm Formation + Barmstein Limestone, type "Tonflatschenbreccia" is preserved (Fig. 7). According to GAWLICK et al. (2005) the age of practically the whole part of the succession is early Early Berriasian. A latest Tithonian age for the basal part of the succession cannot be excluded (compare PLÖCHINGER, 1976).

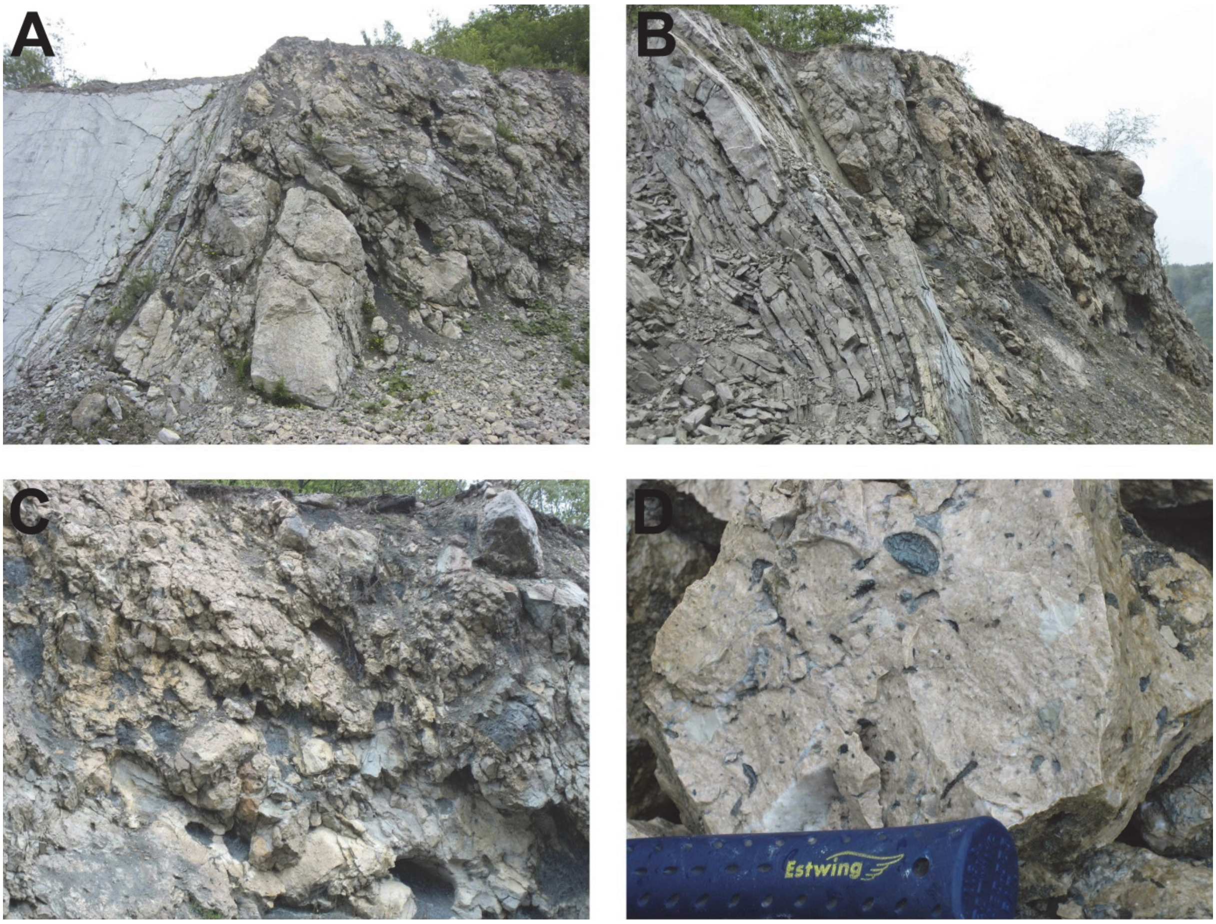

Fig. 7: "Tonflatschenbreccia" in the Leube quarry: mass transport deposit with shallow-water clasts from the Plassen Carbonate Platform s. str. and the Late Permian Alpine Haselgebirge Mélange. **A**) and **B**) Outcrop situation. **C**) and **D**) Details from the "Tonflatschenbreccia".

In this part of the succession KRISCHE et al. (2013) described several depositional cycles starting with coarse-grained breccia layers at its base overlain by wacke- and packstones with fine-grained biodetritus. The top of each cycle is represented by marly wackestones with radiolarians, "filaments" and calpionellids. Aside the different clasts which derive from the Alpine Haselgebirge Mélange several limestone lithoclasts occur: A) Radiolarian-spicula wackestones, B) Calpionellid-radiolarian wackestones, C) slope derived bio- und lithoclastic wacke- to floatstones, D) grainstones with pellets, D) bioclastic lagoonal wackestones. A heterogeneous Triassic clast spectrum as described by GAWLICK et al (2005) from other occurrences of the Barmstein Limestones was not detected in the Leube quarry.

More in the eastern part of the quarry, near the biotope the Jurassic/Cretaceous boundary is preserved in the Oberalm Formation. In the lower part of this section a poorly preserved and re-deposited *Micracanthoceras microcanthum* was referred (FRAU et al., 2016), which was originally described as ?*Djurjuriceras* sp. from the "Tonflatschenbreccia" by BUJTOR et al. (2013) referring to the Late Tithonian Microcanthum Zone (Fig. 8). *Micracanthoceras microcanthum* occur together with *Calpionella alpina* and Crassicollarians, indicating the Late Tithonian age of this part of the succession. Ongoing studies will improve the age of this part of the section.

*Fig. 8: Re-deposited Micracanthoceras microcanthum from the "Tonflatschenbreccia" (*BUJTOR *et al., 2013).*

Upper part: Calpionellid-radiolarian wackestones with intercalated turbidites

Above the graded cycles follow a relative thick series of stratified greenish, marly limestones (radiolarian wackestones with rare calpionellids). They alternate with greenish-grey-brownish marls and contain intercalations of turbiditic radiolarian packstones. The occurrence of *Calpionella alpina* and Remaniellids prove the Early Berriasian age of the rocks.

Both the lithology and the microfacies change in the highest part of the Oberalm Formation (Fig. 9A). Red-green marls, marly limestones (wackestones with radiolarians, calpionellids and spicula) with coarser-grained turbiditic intercalations (packstones with shell fragments, sparite and micrite clasts) and radiolarian packstones occur. A conspicuous, stratified green marly limestone horizon of roughly one metre thickness is referred to as Portland cement bed (PLÖCHINGER, 1976: calpionellid-rich wackestone). In between thicker marl beds green-reddish fine-grained marly limestones (very fine-grained wackestones with some biodetritus) occur. The variegated limestone-marl sequence is a characteristic feature within the highest part of the Oberalm Formation, recently defined as Gutratberg Member of the Oberalm Formation (KRISCHE et al. 2013).

Aside the Calpionellid biostratigraphy for the upper part of the Oberalm Formation below the Gutratberg Member (KRISCHE et al., 2013) an Early Berriasian age is also confirmed by following nannofossil assemblage (det. M. Báldi-Beke): *Conusphaera mexicana, Cyclagelosphaera margerelii, Haqius circumradiatus, Polycostella senaria, Watznaueria barnesae, Watznaueria Britannica, Watznaueria fossacincta*, and *Watznaueria manivitiae*. *Polycostella senaria* has the shortest range (Late Tithonian to Early Berriasian). *Haqius circumradiatus* is a typical Cretaceous form (from the Berriasian to Campanian). The range of *Conusphaera mexicana* (Tithonian to Aptian) and the absence of the Nannoconids confirm the age.

Schrambach Formation

The Gutratberg Member is followed by green-brown marls with plant debris and ammonite fragments. These rocks are defined as Schrambach Formation based on the lithological and microfacies change. A coarser allodapic, cherty limestone bed (KRISCHE & GAWLICK, 2010) terminates the ammonite bearing beds. The marl beds on top are overlain by a well stratified limestone (pellets-sparite packstones with foraminifera) and marl (marly wackestones with sparite and micrite clasts, calpionellids, filaments, spicula) succession with occasional ammonite fragments. The stratified limestone-marl succession is erosionally truncated by a coarse-grained conglomerate bed of the basal Rossfeld Formation. In general the Schrambach Formation consists of silty or cherty marls and alternating marl-limestone successions (Fig. 9B).

*Fig. 9: **A**) Gutratberg Member of the Oberalm Formation and transition to the Schrambach Formation. **B**) Late Berriasian Schrambach Formation.*

Of special interest are the various ammonites found in the Late Berriasian part of the Schrambach Formation (BUJTOR et al., 2013), because Berriasian ammonite faunas are rarely reported from Austria (UHLIG, 1882; PLÖCHINGER in MATURA & SUMMESBERGER, 1980). From the marl and alternating marl-limestone part of the Schrambach Formation a Late Berriasian ammonite fauna was collected, which represents the Subthurmannia boissieri Zone. Subzonal division was impossible. The diverse ammonite fauna (Figs. 10, 11) has a Mediterranean character. Besides phylloceratid, lytoceratid and haploceratid ammonoids, a diverse olcostephanid, berriasellid and neocomitid ammonite assemblage was determined including *Spiticeras* cf. *bulliforme*, *Spiticeras* div. sp., *Negreliceras* cf. *negreli*, *Berriasella (Berriasella) calisto*, *Berriasella (Berriasella)* sp. aff. *picteti*, *Pomeliceras (Mazenoticeras)* sp. aff. *iovkovciense*, *Erdenella* cf. *isaris*, *Tirnovella* cf. *alpillensis*, *Fauriella boissieri*, *Fauriella donzei*, *Fauriella shipkovensis*, *Spiticeras* sp., and *Kilianella* ex gr. *chamalocensis*. Eight species are reported for the first time from Austria. This fauna provides a faunal link between the Mediterranean ammonite faunas from SE Spain, SE France, Bulgaria, and Crimea.

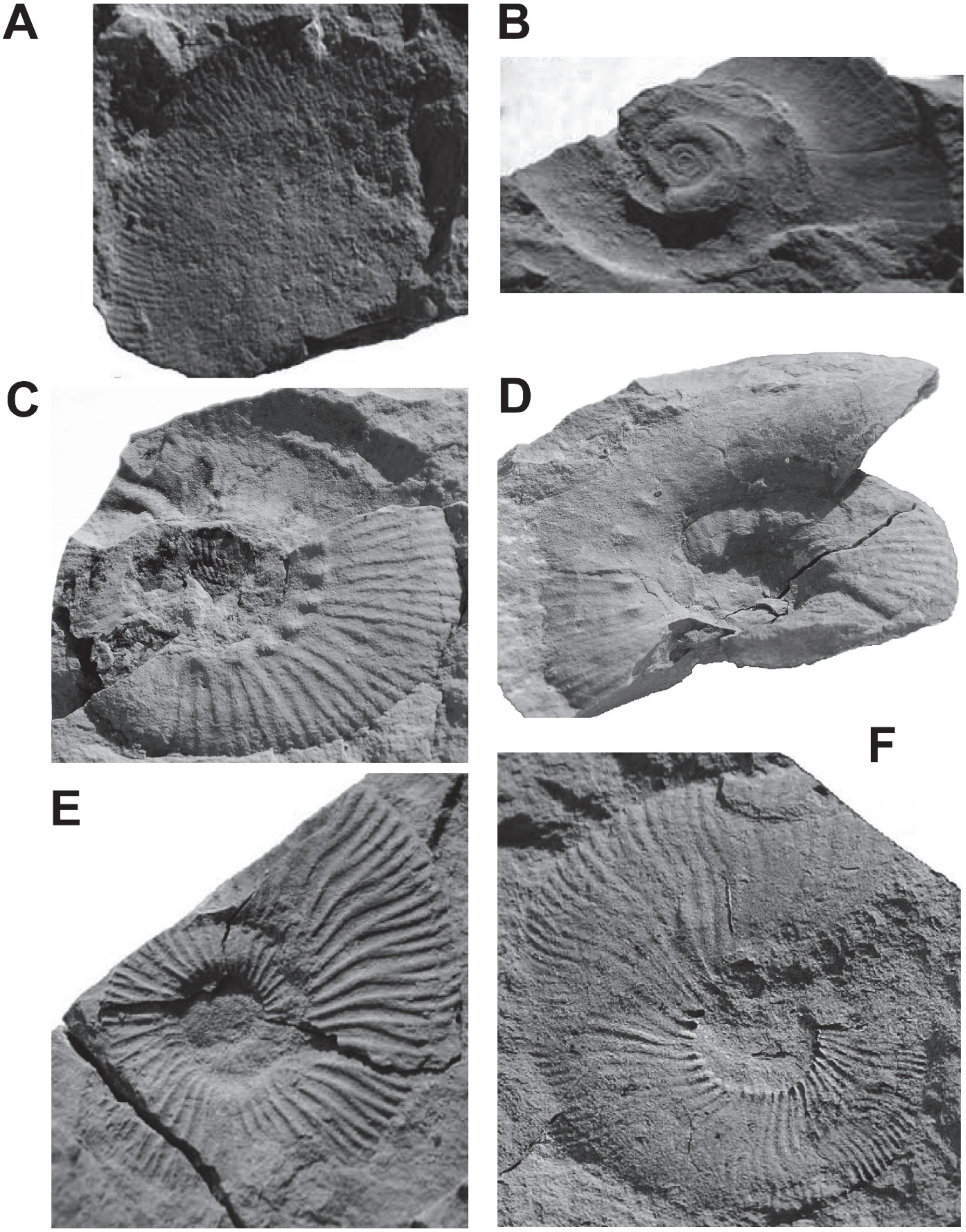

Fig. 10: Ammonites indicating a Tethyan fauna with lyto-, phyllo- and haploceratids, however the abundance of olcostephanid and neocomitid ammonites may refer shallower environments (after BUJTOR *et al., 2013).* ***A****) Euphylloceras cf. thetys,* ***B****) Lytoceras liebigi,* ***C****) Spiticeras bulliforme,* ***D****) Negreliceras sp. aff. negreli,* ***E****) Berriasella calisto,* ***F****) Fauriella boissieri. Not to scale - for dimensions see* BUJTOR *et al. (2013).*

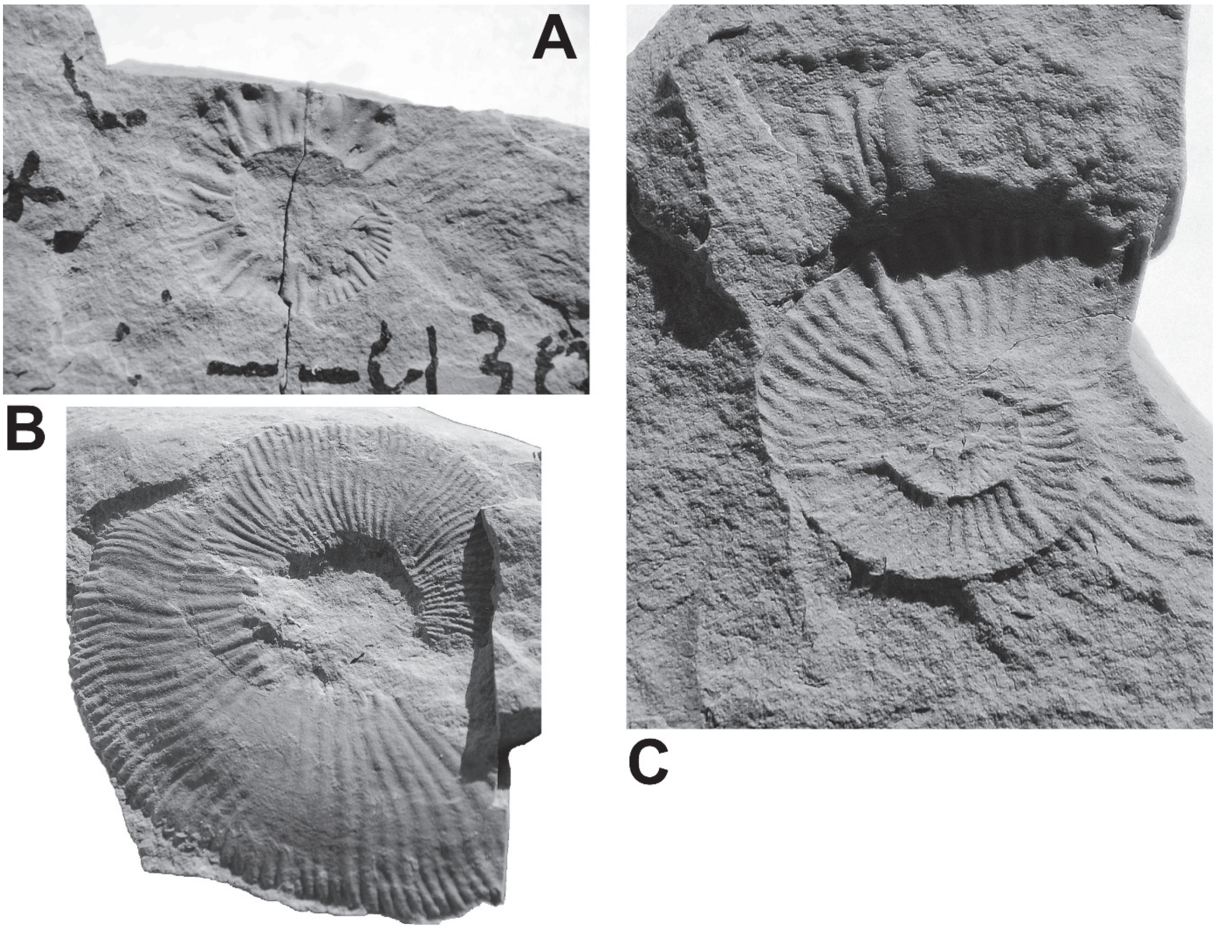

Fig. 11: Ammonites indicating important biogeographically connections toward westward (Micracanthoceras microcanthum (Fig. 8) and Kilianella chamalocensis) and eastward (Fauriella shipkovensis, and Pomeliceras (Mazenoticeras) iovkovciense) along the northern margin of the Tethys. ***A****) Pomeliceras (Mazenoticeras) iovkovciense,* ***B****) Fauriella shipkovensis,* ***C****) Kilianella chamalocensis.*

In contrast to the well dated lower part of the Schrambach Formation the upper part of the Schrambach Formation and its maximum age range below the Rossfeld Formation is rather poorly known. KRISCHE et al. (2013) dated in several sections the higher part of the Schrambach Formation as Early Valanginian based on Calpionellid associations. In several cases the mass transport deposits of the Rossfeld Formation overlie directly the limestone-marl succession of the Schrambach Formation with an erosional contact. In other cases the topmost part of the Schrambach Formation was not dateable with Calpionellids or ammonites. Under the circumstances that all ages directly obtained from the Schrambach Formation below the basal part of the Rossfeld Formation show Early Valanginian an Late Valanginian age for the topmost part of the Schrambach Formation could be only estimated for the type area. A Late Valanginian age for the mass transport deposits in the lower part of the Rossfeld Formation is proven in the Salzkammergut (Bad Ischl area; KRISCHE & GAWLICK, 2015) and the Rossfeld Formation type locality (see below).

Few samples from the Schrambach Formation directly below the mass transport deposits yielded poorly preserved and rare nannofossil assemblages. All samples were taken from sections in the western part of the quarry, today not anymore existing.

A Valanginian age could be determined by following nannofossil assemblage (det. M. Báldi-Beke): *Calcicalathina oblongata, Cyclagelosphaera argoensis, Cyclagelosphaera margerelii, Micrantholithus* *obtusus, Watznaueria barnesae, Watznaueria britannica, Watznaueria fossacincta, Zeugrhabdotus* cf. *cooperi*, and *Zeugrhabdotus embergeri*. *Calcicalathina oblongata* has the shortest range from the very early Valanginian (base of the petransiens ammonite zone) to the early Barremian. Other forms have longer age ranges but are in line: *Nannoconus steinmanni* (since Berriasian) and *Micrantholithus obtusus* (Berriasian to Aptian).

Another sampled yielded following Valanginian (to Hauterivian) nannoplankton assemblage (det. M. Báldi-Beke): *Biscutum constans, Calcicalathina oblongata, Cyclagelosphaera argoensis, Cyclagelosphaera margerelii, Nannoconus steinmanni, Nannoconus kamptner*i, ?*Rhagodiscus asper*, ?*Sollasites horticus,* and *Watznaueria barnesae*. This nannoplankton assemblage cannot be older than Valanginian, because of the FO of *Calcicalathina oblongata* is in the lowermost Valanginian, at the base of the petransiens Ammonite zone.

An third nannofossil assemblage provided an Late Valanginian (to Early Hauterivian) age (det. M. Báldi-Beke): *Calcicalathina oblongata, Cyclagelosphaera argoensis, Cyclagelosphaera margerelii, Diazomatholithus lehmanii, Eiffellithus (Rothia) windii, Micrantholithus obtusus, Percivalia fenestrate, Watznaueria barnesae, Watznaueria britannica, Watznaueria fossacincta*, and ?*Zeugrhabdotus* sp. *Eiffellithus (Rothia) windii* has a very short range in the Late Valanginian to Early Hauterivian and has its FO in the campylotoxus ammonite zone, and the LO is in the radiatus ammonite zone.

Based on this sample the open question of the maximum age range of the Schrambach Formation in the wider area is now solved. The Schrambach Formation has in the type region an age range from Late Berriasian to Late Valanginian.

Magnetostratigraphy, gamma ray spectrometry, AMS studies, and geochemical analysis

A total number of more than 150 oriented drill cores were collected from the roughly 130 m thick Berriasian interval of the Leube quarry section. Sampling covered the upper part of the Oberalm Formation (including Gutratberg Member) and the lower to middle(?) part of the Schrambach Formation (Fig. 12). The samples were demagnetized thermally in the Palaeomagnetic Laboratory of the Polish Geological Institute - National Research Institute. Magnetite was identified as principal magnetic mineral in grey limestones, while magnetization of red beds was related to hematite. Two components of natural remanent magnetization (NRM) were documented. The first component A with low unblocking temperatures (100-300^{o} C) of normal polarity was quite dispersed. The second component B, identified in a temperature range between 350-550^{o} C, is well clustered and revealed both normal and reversed polarities (Fig. 13). The component B is interpreted as primary. The palaeomagnetic vectors revealed NE-SW declination and moderate inclination (ca. 49^{o}), indicating Berriasian palaeolatitude of around 30^{o} N. Several normal and reversed magnetic intervals were correlated with magnetozones M17r (upper part of the Early Berriasian) to M14r (Berriasian/Valanginian-boundary). The lower part of the Schrambach Formation can be correlated with the magnetozones M17r to M16n (Fig. 14) which is consistent with biostratigraphic dating (KRISCHE et al., 2013; BUJTOR et al., 2013).

Our results show that remagnetization of Mesozoic rocks in the Northern Calcareous Alps (PUEYO et al., 2007) did not affect every sedimentary succession of the Tirolic units. Magnetic susceptibility indicates a long term increasing trend (Fig. 14) which is interpreted as manifestation of accelerating siliciclastic input from the hinterland in the south. This result is supported by gamma ray spectrometric measurements which show an increasing trend of K and Th content (Fig. 14). Definite increase of the siliciclastic input took place in the lower part of M16n. The onset of more marly sedimentation in the lower part of M16n (lower part of *oblonga* calpionellid Subzone) can be well correlated with other sections in the Central Carpathians and the Western Balkan region (GRABOWSKI et al., 2013; 2016b) pointing to a regional event related probably to tectonic uplift or more likely a regression with subsequent sea-level lowstand resulting in increasing erosion of the mountain range at the southern peripheries of the Carpathian-Alpine realm. This would correspond to the sea-level curve of HARDENBOL et al. (1998). Th/U ratio, widely used as redox proxy, show large variations between the beds which might sharp contrasts in oxygenation conditions. A gentle decrease of Th/U ratio towards the top of M16n point to slight deterioration of oxygen availability in the upper part of M16n. High resolution carbon isotope ($\delta^{13}C$) curve reveals a well-defined second order changes between 0.8 and 1.3 ‰ which is in very good agreement with other magnetostratigraphically calibrated $\delta^{13}C$ Berriasian trends (see GRABOWSKI et al., 2016b).

Fig. 12: Sampling campaign in the Leube quarry, beds 1-25, lower part of the Late Berriasian. Boundary between magnetozones M16r and M16n is situated between points 11 and 12.

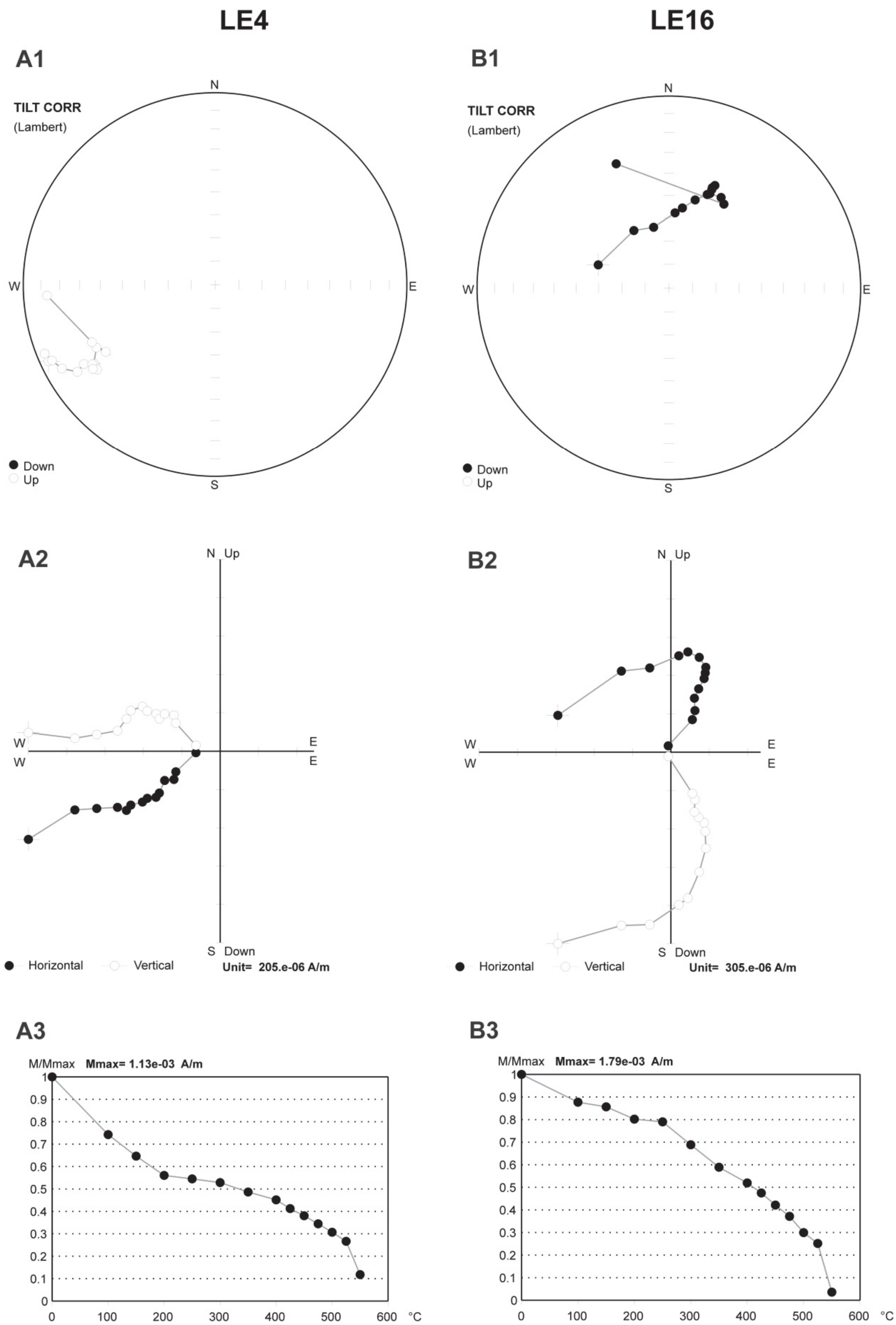

*Fig. 13: Thermal demagnetization of typical specimens with reversed (sample Le 4, left side) and normal polarity (sample Le 16, right side) of the component B. **A1 and B1**) stereographic projection of demagnetization path (after bedding correction). **A2 and B2**) orthogonal projection of demagnetization path (after bedding correction). **A3 and B**) natural remanent magnetization intensity decay during thermal treatment.*

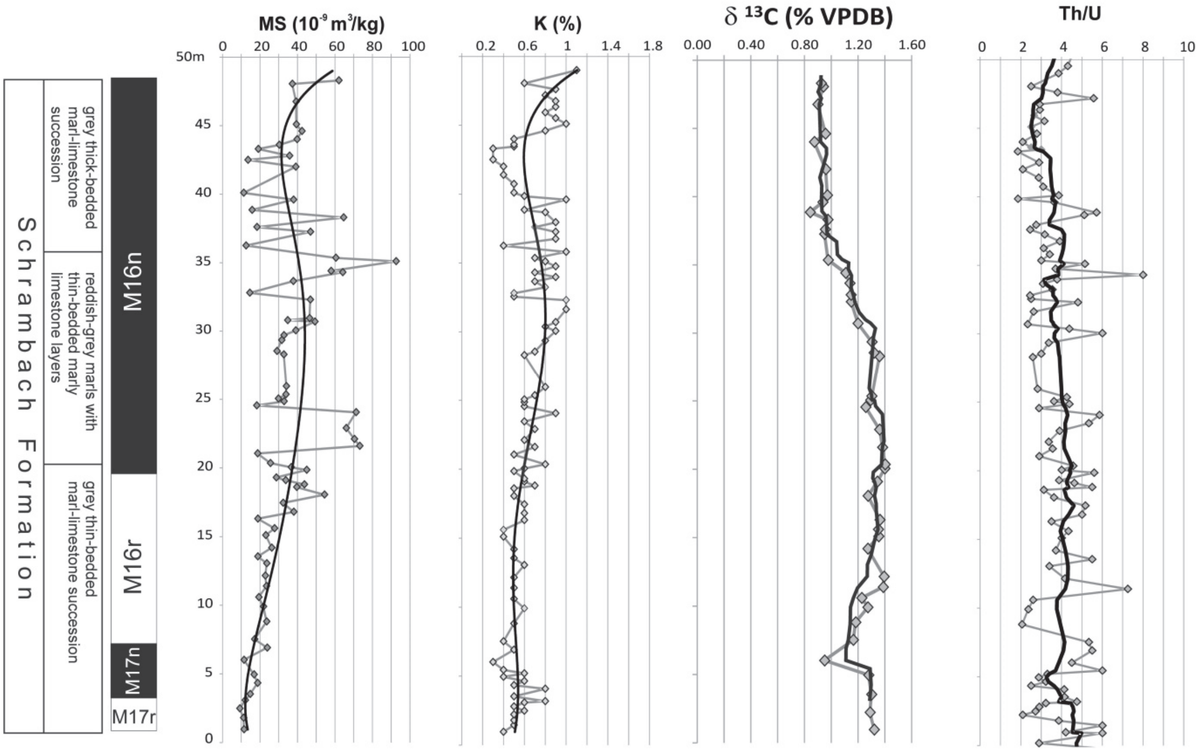

Fig. 14: Magnetic stratigraphy, magnetic susceptibility (MS), gamma ray spectrometry (K and Th/U) and $\delta^{13}C$ curve from the lower part of Schrambach Formation (Leube quarry). Black - normal polarity; white - reversed polarity.

Rossfeld Formation

The lowermost part of the Rossfeld Formation in the Leube quarry consists of a series of mud and debris flows (Fig. 15). These mass transport deposits overlie the Schrambach Formation with an erosional contact. Therefore the youngest part of the Schrambach Formation is in this part of the succession eroded. Of special interest in these mud flows is the occurrence of well-rounded exotic components, i.e. volcanites and different radiolarite pebbles (Fig. 16).

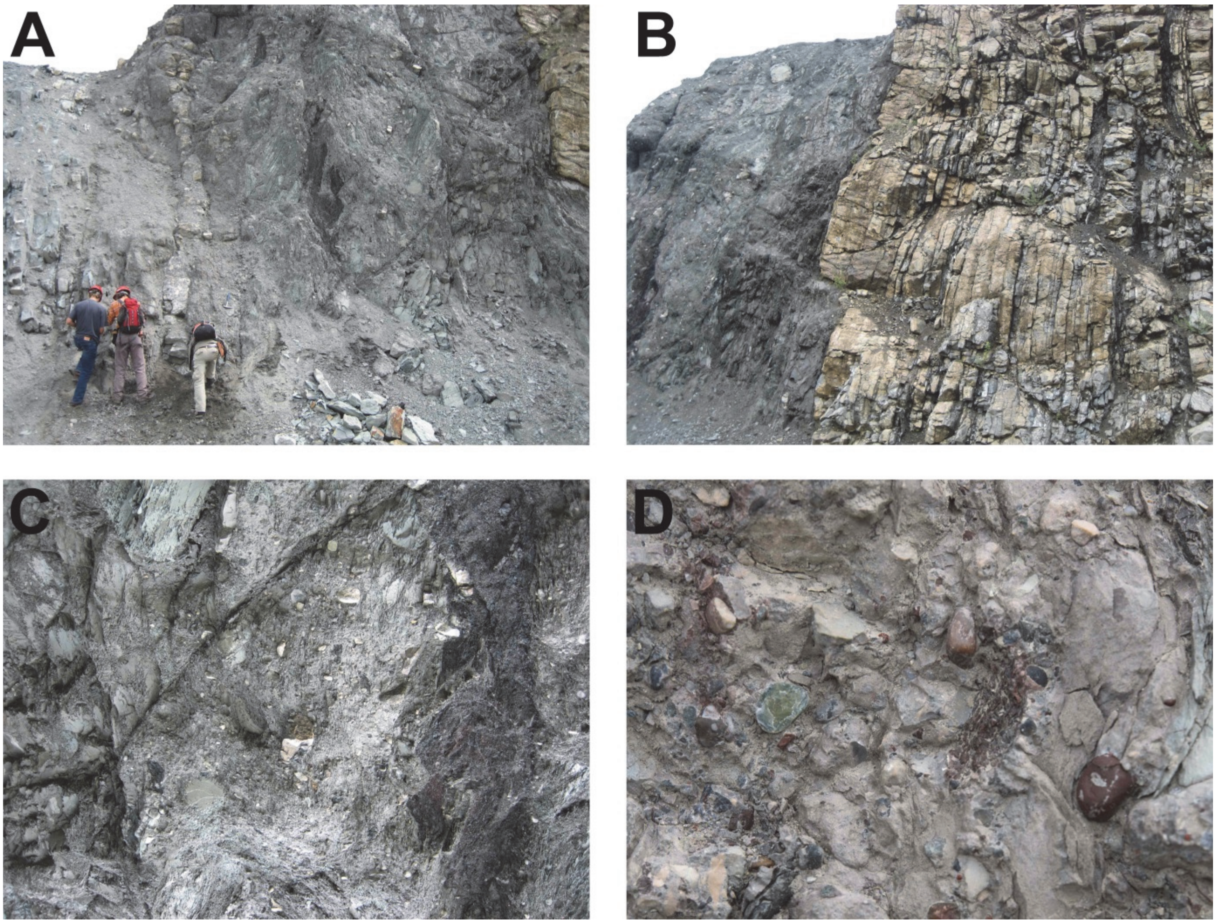

Fig. 15: Field view of the basal part of the Rossfeld Formation. ***A****) Transition from the Schrambach Formation (left side) to the different mass transport deposits of the lower Rossfeld Formation. The contact between the bedded marls succession of the Schrambach Formation and the first mud flow is erosional. This part of the series consists of at least 4 different mud flows and one debris flow (details in Krische et al. 2014).* ***B****) The mud flows are overlain by bedded, siliceous arenites.* ***C****) and* ***D****) Details from the mud-flow deposits with angular carbonate clasts and well-rounded radiolarite and volcanic clasts.*

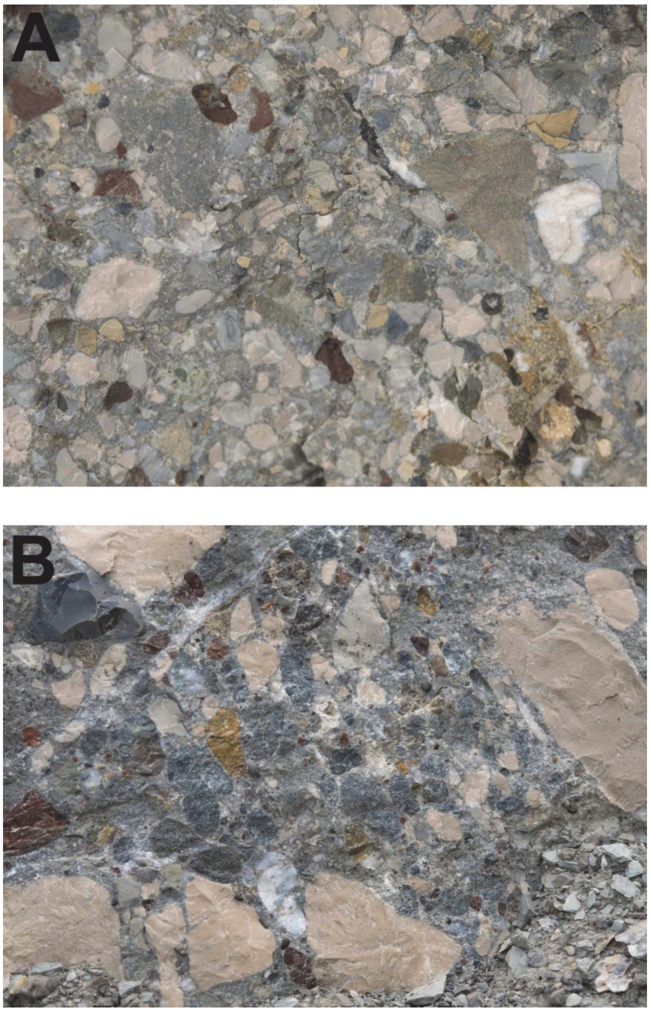

Fig. 16: ***A****) and* ***B****) Macroscopic view of the component spectrum of the debris-flow deposit. The predominantly build by different carbonate clast with angular to sub-angular shape debris flows contain rarely exotic clasts of volcanites and different radiolarites with sub-rounded to well-rounded shape.*

3.2 Rossfeld

The Rossfeld area (Germany) along the Rossfeld panorama road is the type area of the Early Cretaceous Rossfeld Formation and represents the westward continuation of the Tauglboden Basin north of the Trattberg Rise of Mount Kehlstein. Sedimentation of the Rossfeld Formation in the type area lasted according to TOLLMANN (1985) until the Barremian.

The first stop is located near the toll station of the Rossfeld Panorama road. Along the panorama road and adjacent forest roads the Late Valanginian part of the Rossfeld succession is outcropping: fine-grained siltstones to marls are intercalated with different mass transport deposits (Fig. 17). A Late Valanginian (Peregrinus and Furcillata Zones, HOEDEMAEKER et al. 2003) age is proven by the occurrence of *Himantoceras trinodosum* together with *Haploceras* (*Neolissoceras*) *grasianum* and *Phyllopachyceras* sp. (Fig. 18).

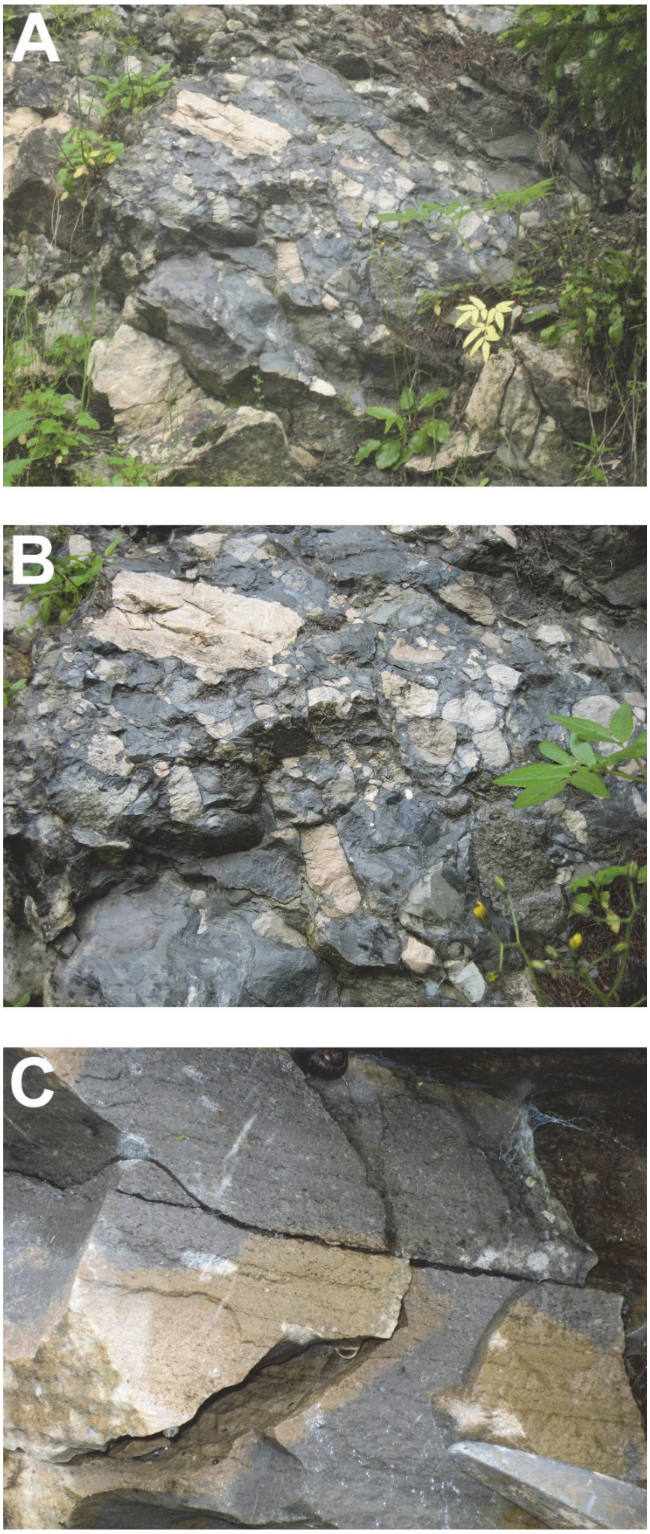

Fig. 17: Outcrop situation of the Rossfeld Formation near the toll station of the Rossfeld panorama road. ***A****) Part of the section with an intercalated coarse-grained mass transport deposit in sandy marls with turbiditic calcareous sandstones.* ***B****) Most components in the mass transport deposit are angular to subangular carbonate clasts. Exotic components occur only rarely.* ***C****) Graded calcareous sandstones; the component spectrum in the turbidites is identical to those of the coarse-grained mass transport deposits.*

Fig. 18: Late Valanginian ammonites from the Rossfeld Formation near the toll station of the Rossfeld panorama road. ***A****) Himantoceras trinodosum,* ***B****) Haploceras (Neolissoceras) grasianum,* ***C****) Phyllopachyceras sp.*

The second stop is the Hahnenkamm near the highest point of the Rossfeld panorama road. Here the Barremian part of the Rossfeld succession (TOLLMANN, 1985) is well preserved on an outcrop along the road (Fig. 19). Calcareous sandstones intercalated with several mass transport deposits which contain a similar component spectrum as in the Leube quarry except the Triassic radiolarites. The mass transport deposits show also a lack in components from both the Hallstatt Zone as well the Berchtesgaden unit. The Hallstatt outliers on top of the Rossfeld Formation are explained by MISSONI & GAWLICK (2011b) as southward-thrust elements during the Miocene tectonic extrusion, because they came to their present position after the youngest diagenetic overprint.

All (sub)angular carbonate components derive from a nearby source area and are of Late Jurassic to Early Cretaceous age, similar to the sedimentary succession of Mt. Plassen (Salzkammergut) and the overlying drowning sequence (GAWLICK & SCHLAGINTWEIT, 2006). These components are mixed with significant amounts of siliciclastic and ophiolitic material, indicating both local and distant source areas of continental and oceanic basement (DECKER et al., 1987; FAUPL & WAGREICH, 2000) beside volcanic material (SCHWEIGL & NEUBAUER, 1997b), and rounded Oxfordian radiolarite pebbles (MISSONI & GAWLICK, 2011a). Some radiolarite pebbles look like Triassic radiolarites, but their stratigraphic age is so far not proven.

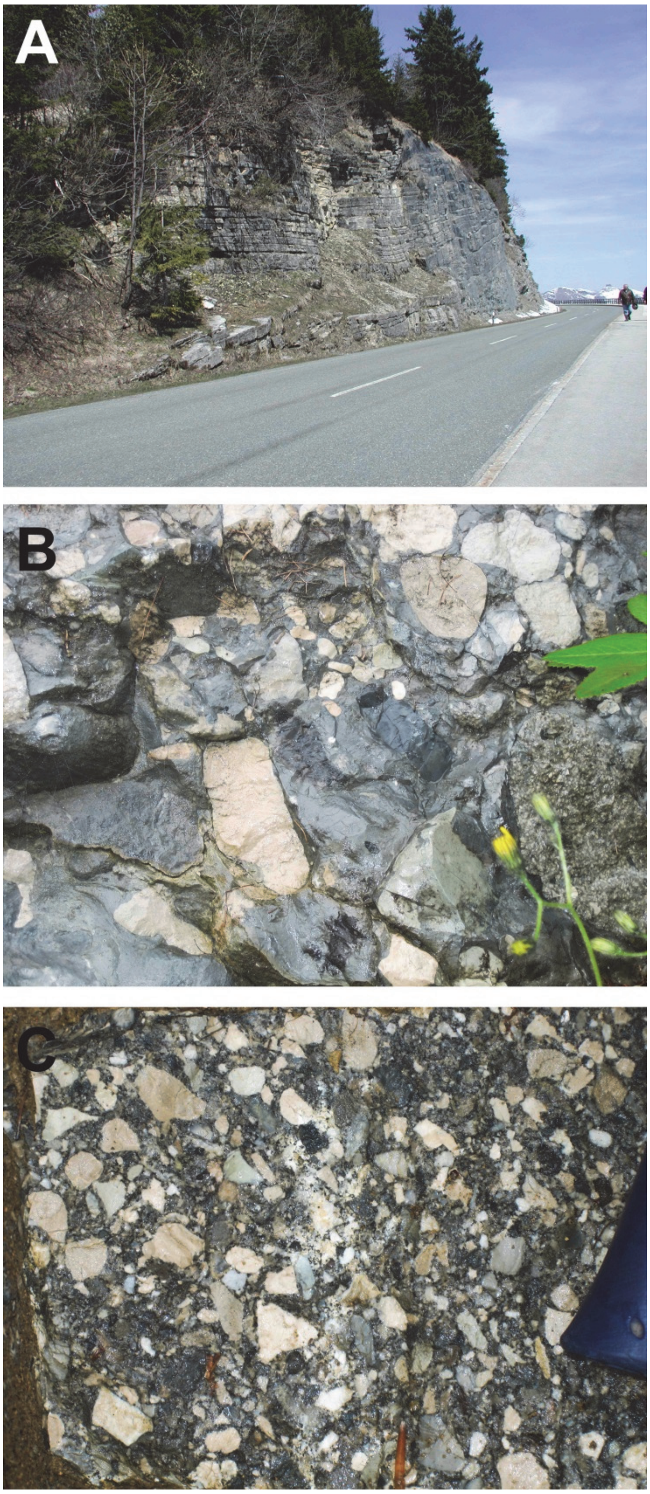

Fig. 19: ***A****) Rossfeld Formation at the Hahnenkamm locality on the Rossfeld Panorama road. Calcareous sandstones with intercalated mass transport deposits.* ***B****) Coarse-grained polymictic breccia. Besides the dominating carbonate clasts (Late Jurassic - Early Cretaceous) few radiolarite components (?Triassic and Jurassic radiolarites) occur.* ***C****) Finer-grained polymictic breccia. Beside the dominating carbonate clasts radiolarites and ophiolitic grains occur.*

Components in the mass transport deposits of the Rossfeld Formation

On base of microfacies analysis and biostratigraphy the components in the different mass transport deposits of the Rossfeld Formation are classified into six groups (KRISCHE, 2012; KRISCHE et al., 2014; KRISCHE & GAWLICK, 2015):

1. Triassic carbonates: uppermost Werfen to lowermost Gutenstein Formations,
2. Late Jurassic to earliest Cretaceous limestones: Oberalm Formation + Barmstein Limestone,
3. Carbonate bioclasts from a proximal Rossfeld basin shallow-water depositional realm,
4. Radiolarites, ophicalcites, siliceous deep-sea claystones, cherts,
5. Volcanic and ophiolite rock fragments
6. Siliciclastics: sand- and siltstones.

Biostratigraphic dating of the different radiolarite pebbles in the mass transport deposits with poor to moderate preserved radiolarians (KRISCHE et al., 2014) show three age clusters:

1. Ladinian to Early Carnian: these radiolarite pebbles are interpreted as derived from the Meliata facies zone (continental slope) or from the Neo-Tethys ocean floor.
2. Late Carnian/Norian: these radiolarite pebbles derive from the original sedimentary cover sequences of the Neo-Tethys ocean floor.
3. Late Bajocian to Callovian. These radiolarite pebbles are interpreted to derive from the matrix of the ophiolitic mélanges below the Neo-Tethys obducted ophiolites.
4. Oxfordian: These radiolarite pebbles are interpreted to derive from the matrix of the ophiolitic mélanges below the Neo-Tethys obducted ophiolites.

These radiolarite pebbles together with the volcanic and ophiolitic material were eroded in Early Cretaceous times from the ophiolitic nappe stack and transported by a fluvial system to the Rossfeld Basin (Fig. 20). On the way from the ophiolitic nappe stack the fluvial system crossed an area with exposed late Early to early Middle Triassic carbonates, latest Jurassic to earliest Cretaceous basinal sediments of the Plassen Carbonate Platform and the proximal depositional realm of the Rossfeld Basin.

Middle to Late Triassic shallow-water carbonate clasts from the Dachstein and/or Berchtesgaden nappes as commonly interpreted on the basis of the colour of the clasts and without microfacies analyses (KÜHNEL, 1929; WEBER, 1942; MEDWENITSCH, 1949, 1958; DEL-NEGRO, 1949, 1983; PLÖCHINGER, 1955, 1968, 1974, 1990; PICHLER, 1963) are missing, in all mass transport deposits of the Rossfeld Formation. No single grain deriving from the Triassic carbonate platforms or the Hallstatt zone was found in the mass-flows.

The Late Jurassic to earliest Cretaceous shallow-water carbonate clasts derive from the Plassen Carbonate Platform (e.g. Plassen Formation) or represent slope-to-basinal carbonate pebbles (Oberalm Formation and Barmstein Limestone).

Valanginian to Hauterivian carbonate clasts prove the existence of a contemporaneous shallow-water carbonate platform or ramp. Especially the existence of contemporaneous shallow-water carbonate areas, proved by carbonate litho- and bioclasts, was more or less unknown from the Rossfeld Formation.

The siliceous pebbles can be classified by their microfacies into different groups: radiolarites, ophicalcites, siliceous (deep-sea) clays, microcrystalline cherts and brown-black siliceous marlstones. Late Ladinian to Late Triassic ribbon radiolarites are of special interest because they indicate fragments of the Neotethys oceanic realm. Ophicalcites and colourful siliceous (deep-sea) clays complete the pebble spectrum derived from the Neo-Tethys ocean floor. Intra-oceanic subduction in the Neo-Tethys started around the Early/Middle Jurassic boundary, and ophiolite obduction started in the Bajocian. Ophiolitic mélanges in the Dinarides/Albanides/Hellenides yielded Bajocian to Oxfordian ages from matrix radiolarites (GAWLICK et al., 2016 with references therein). Therefore the proof of Middle and Late Triassic and Middle-Late Jurassic radiolarite pebbles together with ophiolitic and volcanic material is a strong argument for the erosion of an ophiolitic nappe-stack carrying an island arc similar to those of the Dinaridic-Hellenic belt south of the present day Northern Calcareous Alps at that time.

Siliciclastic rocks such as quartz-sandstones, siltstones and singular quartz-grains and specific heavy minerals indicate erosion of a crystalline hinterland and complete the mixed conglomerate and breccia component suite.

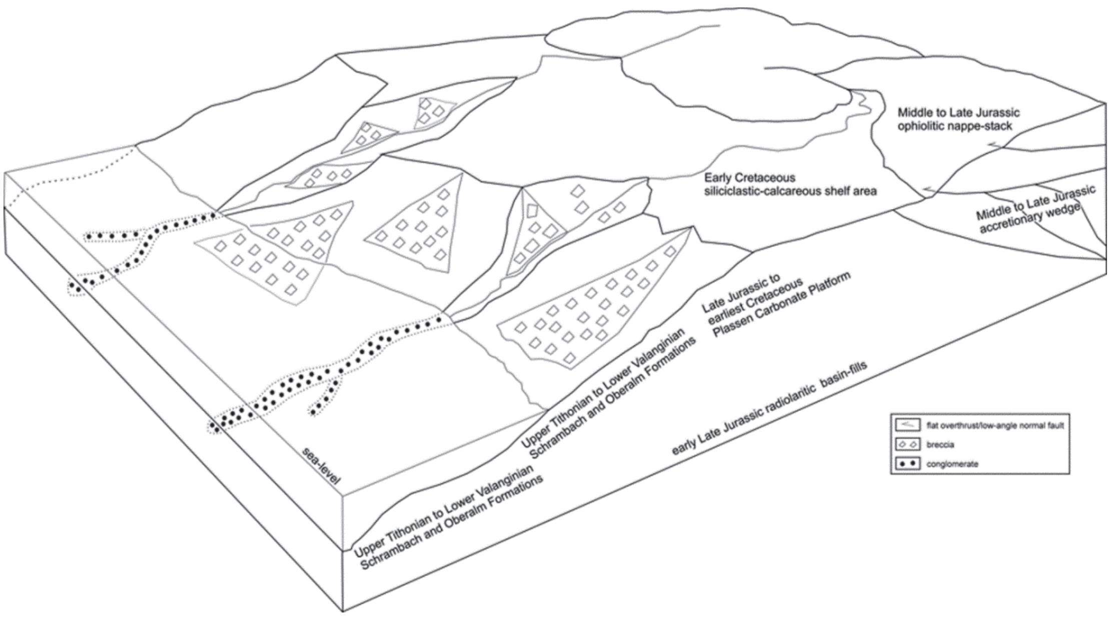

Fig. 20: Simplified sketch of the evolution of the basal conglomerates of the Rossfeld Formation. After the main sea-level lowstand after the late Early Valanginian/early Late Valanginian the rounded components in the mass transport deposits were brought by fluvial systems from the exposed hinterland and shelf area to the deeper parts of the basin. Local material from breccia fans was also incorporated in the mass transport deposits. During the sea-level rise in the Late Valanginian the typical fining-upward sequences of the Rossfeld Formation were deposited, today clearly visible at several outcrops in Bad Ischl, in Gartenau, in the Weitenau area and on the Rossfeld. From KRISCHE et al. (2014).

Panorama view from the Rossfeld road

To the east the Callovian to Oxfordian Lammer Basin fill on the northern side of the Tennengebirge Mt. is visible. The nearly 2000 m thick trench-like basin fill consists of olistostromes and huge slide blocks (Fig. 21) in a radiolaritic matrix. The reworked material derived from the Zlambach facies zone and the Dachstein reef rim. Hallstatt Limestones and material from the continental slope (Meliata facies zone) (Fig. 21) were transported in a piggy-back manner and were reworked in an earlier phase of northward propagating compression. In tectonic sense this basin fill corresponds to the Upper Tirolic nappe (Fig. 2). For a detailed description of the Lammer Basin fill see GAWLICK (1996), MISSONI & GAWLICK (2011b), and GAWLICK et al. (2012).

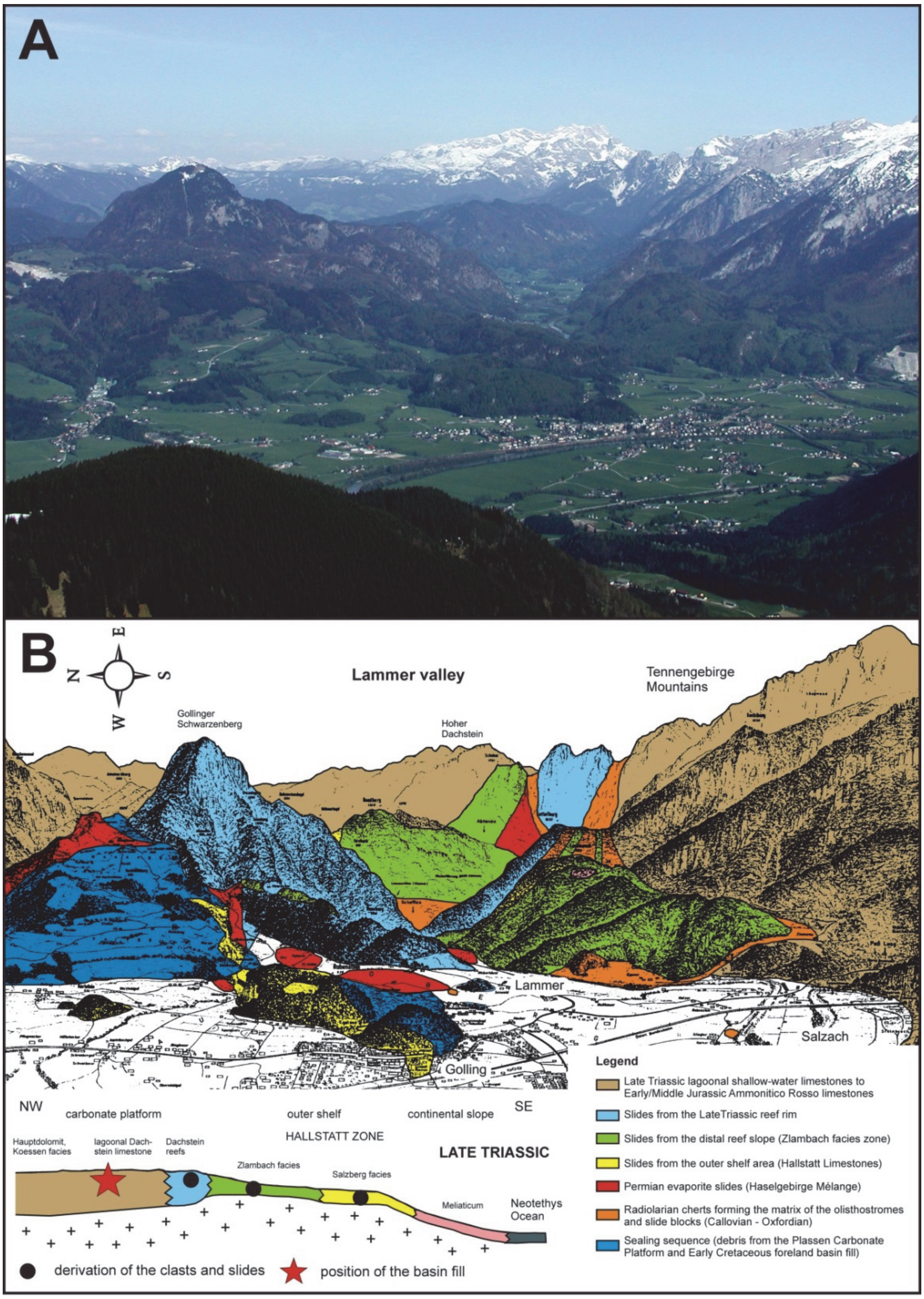

*Fig. 21: **A**) View from the west showing the type area of the Callovian-Oxfordian Lammer Basin fill. **B**) Geological interpretation of the landscape picture. The basin fill consists of allochthonous material of different age and facies provenance, which generally derives from the outer shelf area transitional to the Neo-Tethys Ocean.*

To the south of the Rossfeld Panorama road the Late Triassic sedimentary succession of Mt. Hohes Freieck as eastward continuation Mt. Hoher Göll is visible (Fig. 22). The exposed sedimentary succession represents the southern rim of the Rhaetian Kössen Basin and in tectonic sense the Trattberg Rise, i.e. the since the Early Oxfordian formed nappe front of the Upper Tirolic nappe (Fig. 2). From this nappe front Late Triassic to Middle Jurassic sedimentary rocks were eroded, mobilized as blocks and slides, and redeposited in the Tauglboden Basin. The Tauglboden Basin and the Rossfeld Basin fill are palaeogeographically situated north of the Trattberg Rise and correspond to the Lower Tirolic nappe (Fig. 2).

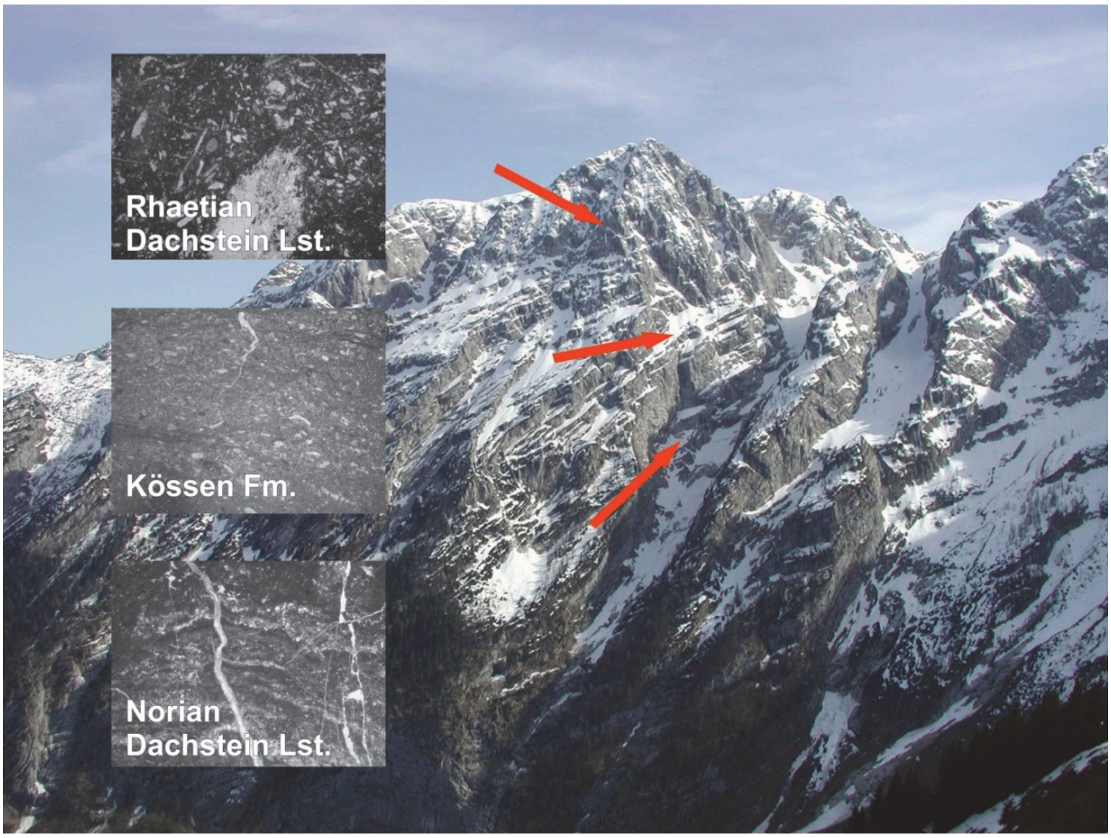

Fig. 22: Late Triassic sedimentary succession of the Trattberg Rise, Mt. Hohes Freieck east of Mt. Hoher Göll. Insets show typical microfacies of the Late Norian to Rhaetian succession. The Rhaetian reefs represent the southern margin of the Kössen Basin to the north. This clearly documents the palaeogeographic position of the area near the southern rim of the Kössen Basin and far away from the Dachstein Limestone reef zone to the south facing the open marine realm (Hallstatt Zone). For details MISSONI & GAWLICK (2011b).

3.3 Weitenau area

The Weitenau area is located between the township Golling to the west and the village Voglau to the east (Fig. 3). Geologically the Weitenau area is built of a different independent blocks of different palaeogeographic origin separated by faults with different character (KRISCHE, 2012; compare PLÖCHINGER 1968, 1990; Fig. 23). Of special interest in the Weitenau area is the preservation of the youngest part of the Rossfeld Formation, the Late Barremian to Middle Aptian shallowing cycle of the basin fill (Grabenwald Member: FUCHS, 1968; Plöchinger, 1968; WEIDICH, 1990; SCHLAGINTWEIT et al., 2012).

The Late Barremian to Middle Aptian Grabenwald Member is characterized by coarse-grained carbonatic sandstones (Fig. 24). Beside remains of corals and red algae also orbitolinids occur (*Montseciella arabica* and *Palorbitolina lenticularis*; SCHLAGINTWEIT et al., 2012) indicating a today eroded shallow-water evolution near the southern rim of the Northern Calcareous Alps. Planktonic foraminifera from the uppermost Grabenwald Member (FUCHS, 1968) were dated as Middle Aptian

(WEIDICH, 1990). However, within the Aptian the filling and shallowing of remaining deeper water areas in the Rossfeld Basin is documented by local remnants of coal and amber (PLÖCHINGER, 1968; WINKLER, 2004).

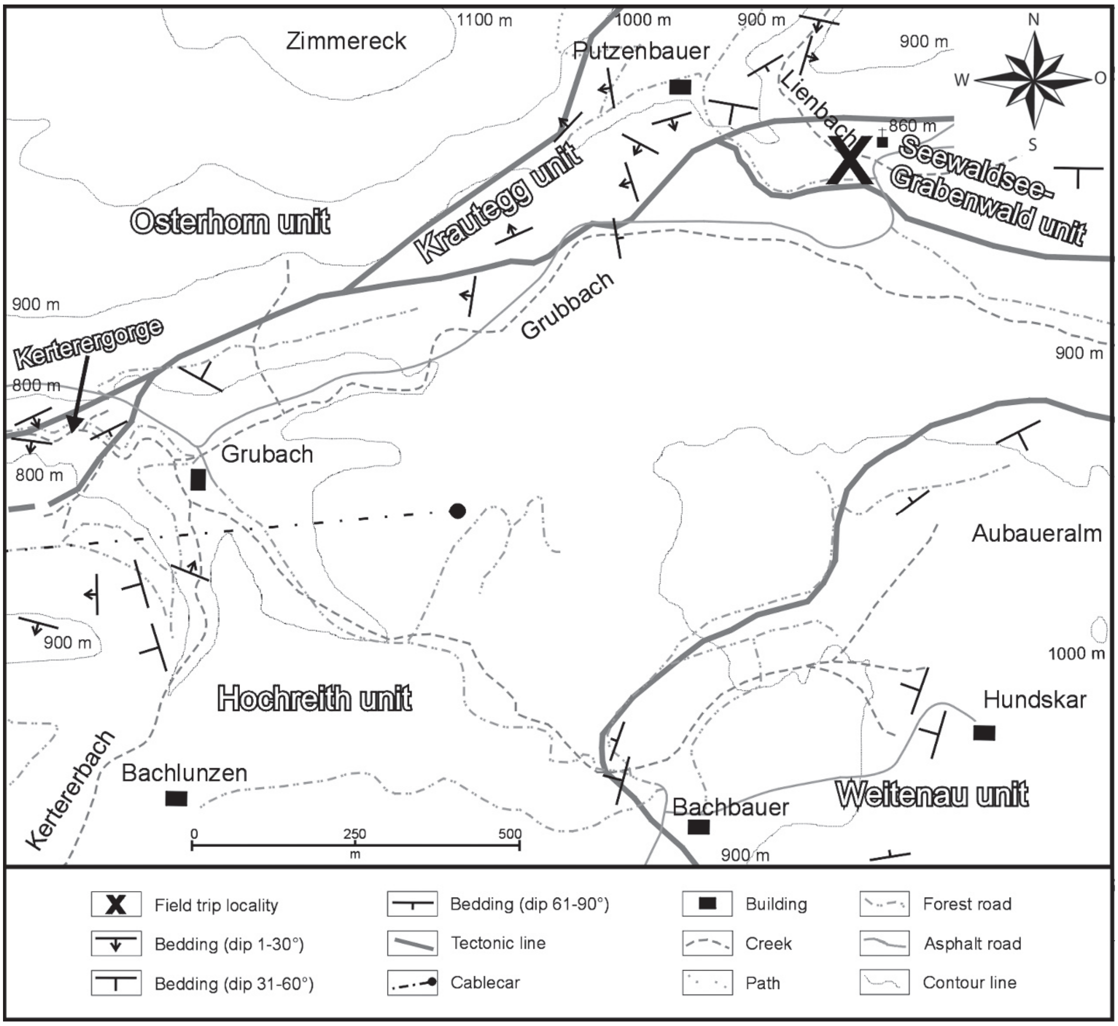

Fig. 23: Locality of the Aptian Orbitolina-bearing sedimentary rocks in the central Weitenau area, located in the Seewaldsee Grabenwald Block (after SCHLAGINTWEIT et al., 2012).

We will visit the Grabenwald outcrop in the central part of the Weitenau area situated in the Seewaldsee Grabenwald Block according to KRISCHE (2012) and SCHLAGINTWEIT et al. (2012). In the Lienbach valley up to 40 cm thick siliciclastic packstone beds are intercalated in turbiditic brownish marls (Fig. 24). Along the forest road to the cottage Putzenbauer the slightly older orbitolinid-bearing sandstones and fine-grained breccias can be studied (Fig. 24). The siliciclastic fraction of these sedimentary rocks consists of subangular quartz grains, quartzites, volcanites, reddish radiolarites, metasedimentary colourless silicified rocks, and yellowish silicified claystones (SCHLAGINTWEIT et al., 2012).

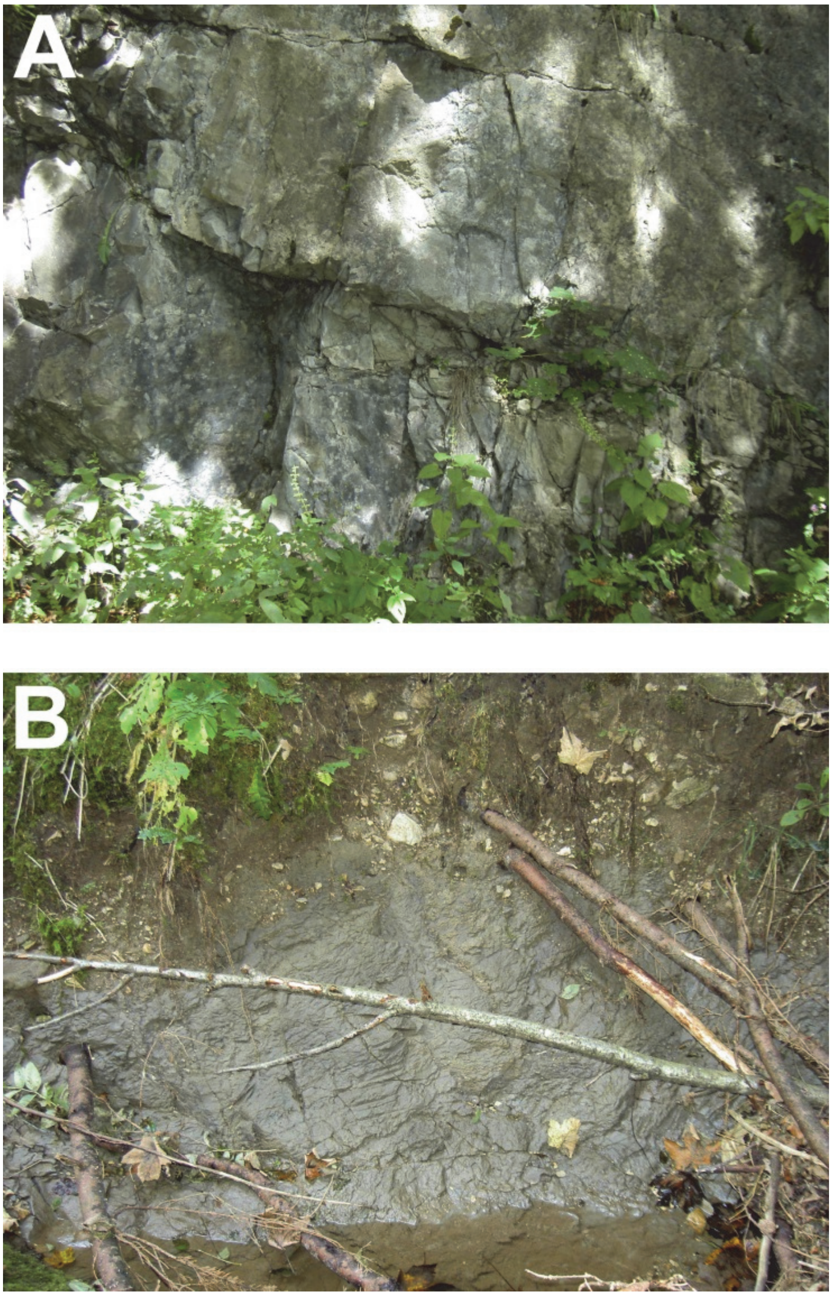

Fig. 24: Outcrop situation of the Aptian sedimentary sequence along the forest road to the cottage Putzenbauer and in the Lienbach valley. ***A****) Orbitolina-bearing calcareous coarse-grained turbiditic sandstones.* ***B****) Marly sequence in the Lienbach valley were up to 40 cm thick siliciclastic packstone beds are intercalated in turbiditic brownish marls of Middle Aptian age.*

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References

BODROGI, I., DRAXLER, I., FILACZ, E. & LOBITZER, H., mit Beiträgen von STRADNER, H., EGGER, H., SURENIAN, R., SACHSENHOFER, R. F., KNAUER, J. & KLEIN, P. (1996): Die Mikrofauna und -flora ausgewählter (hemi)pelagischer Oberjura/Unterkreide- Schichtfolgen der Salzburger Kalkalpen sowie ein Vergleich mit der Unterkreide des Gerecse-Gebirges in Ungarn. - Unveröffentliches Manuskript, 1-31, Wien.

BOOROVÁ, D., LOBITZER, H., SKUPIEN, P. & VAŠÍČEK, Z. (1999): Biostratigraphy and Facies of Upper Jurassic-Lower Cretaceous pelagic carbonate sediments (Oberalm-, Schrambach- and Roßfeld-Formation) in the Northern Calcareous Alps, South of Salzburg. - Abhandlungen der Geologischen Bundesanstalt, 56/2: 273-218, Wien

BOOROVÁ, D., SKUPIEN, P., VAŠÍČEK, Z. & LOBITZER, H. (2015): Biostratigraphy of the Lower Cretaceous Schrambach Formation of the classical locality of Schrambachgraben (Northern Calcareous Alps, Salzburg Area). - Bulletin of Geosciences, 90: 89-131, Prag.

BUJTOR L., KRISCHE O. & GAWLICK H.-J. (2013): Late Berriasian ammonite assemblage and biostratigraphy of the Leube quarry near Salzburg (Northern Calcareous Alps, Austria). - Neues Jahrbuch für Geologie und Paläontologie - Abhandlungen, 267: 273-295, Stuttgart.

DARGA, R. & WEIDICH, K.F. (1986): Die Lackbach-Schichten, eine klastische Unterkreide-Serie in der Unkener Mulde (Nördliche Kalkalpen, Tirolikum). - Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie, 26: 93-112, München.

DECKER, K., FAUPL, P. & MÜLLER, A. (1987): Synorogenic Sedimentation on the Northern Calcareous Alps during the Early Cretaceous. - In: FLÜGEL, H.W. & FAUPL, P. (Eds.): Geodynamics of the Eastern Alps, 126-141, (Deuticke) Wien.

DEL NEGRO, W. (1949): Geologie von Salzburg. - 1-348, (Wagner) Innsbruck.

DEL NEGRO, W. (1983): Geologie des Landes Salzburg. - Schriftenreihe des Landespressebüros: Serie Sonderpublikationen, 45: 1-152, Salzburg.

DORNER, R., HÖFLING, R. & LOBITZER, H. (2009): Nördliche Kalkalpen in der Umgebung Salzburgs (Exkursion H am 17. April 2009). - Jahresberichte Mitteilungen Oberrheinischer Geologischer Verein NF, 91: 317-366, Stuttgart.

FAUPL, P. & POBER, E. (1991): Zur Bedeutung detritischer Chromspinelle in den Ostalpen: Ophiolithischer Detritus aus der Vardarsutur. - Jubiläumsschrift 20 Jahre Geologische Zusammenarbeit Österreich - Ungarn, Teil 1: 133-143, Wien.

FAUPL, P. & TOLLMANN, A. (1979): Die Roßfeldschichten: Ein Beispiel für Sedimentation im Bereich einer tektonisch aktiven Tiefseerinne aus der kalkalpinen Unterkreide. - Geologische Rundschau, 68: 93-120, Stuttgart.

FAUPL, P. & WAGREICH, M. (2000): Late Jurassic to Eocene Palaeogeography and Geodynamic Evolution of the Eastern Alps. - Mitteilungen der Österreichischen Geologischen Gesellschaft, 92: 79-94, Wien.

FRANK, W. & SCHLAGER, W. (2006): Jurassic strike slip versus subduction in the Eastern Alps. - International Journal of Earth Sciences, 95: 431-450, Berlin Heidelberg.

FRAU, C., BULOT, L.-G., WIMBLEDON, W.A.P. & IFRIM, C. (2016): Upper Tithonian ammonites (Himalayitidae Spath, 1925 and Neocomitidae Salfeld, 1921) From Charens (Drôme, France). - Geologica Carpathica, 67(6): 543-559, Bratislava.

FRISCH, W. & GAWLICK, H.-J. (2003): The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion - a contribution to understanding the orogenic evolution of the Eastern Alps. - International Journal of Earth Sciences, 92/5: 712-727, Berlin Heidelberg.

FUCHS, W. (1968): Eine bemerkenswerte, tieferes Apt belegende Foraminiferenfauna aus den konglomeratreichen Oberen Roßfeldschichten von Grabenwald (Salzburg). - Verhandlungen der Geologischen Bundesanstalt, 1968: 87-89, Wien.

FUGGER, E. (1907): Erläuterungen zur Geologischen Karte der im Reichsrate vertretenen Königreiche und Länder der Österreichisch - Ungarischen Monarchie. SW-Gruppe Nr. 18 Hallein und Berchtesgaden. (Zone 13, Kol.

VIII der Spezialkarte der Österreichisch - Ungarischen Monarchie im Maßstab 1:75:000. - K.K. Geologische Reichsanstalt, 1-34, Wien.

GAWLICK, H.-J. (1996): Die früh-oberjurassischen Brekzien der Stubbergschichten im Lammertal - Analyse und tektonische Bedeutung (Nördliche Kalkalpen, Österreich). - Mitteilungen Gesellschaft Geologie Bergbaustudenten Österreichs, 39/40, 119-186, Wien.

GAWLICK, H.-J. & SCHLAGINTWEIT, F. (2006): Berriasian drowning of the Plassen carbonate platform at the type-locality and its bearing on the early Eoalpine orogenic dynamics in the Northern Calcareous Alps (Austria). - International Journal of Earth Sciences, 95, 451-462, Berlin Heidelberg.

GAWLICK, H.-J., SCHLAGINTWEIT, F. & MISSONI, S. (2005): Die Barmsteinkalke der Typlokalität nordwestlich Hallein (hohes Tithonium bis tieferes Berriasium; Salzburger Kalkalpen) - Sedimentologie, Mikrofazies, Stratigraphie und Mikropaläontologie: neue Aspekte zur Interpretation der Entwicklungsgeschichte der Ober-Jura-Karbonatplattform und der tektonischen Interpretation der Hallstätter Zone von Hallein - Bad Dürrnberg. - Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 236: 351-421, Stuttgart.

GAWLICK, H.-J., MISSONI, S., SCHLAGINTWEIT, F., SUZUKI, H., FRISCH, W., KRYSTYN, L., BLAU, J. & LEIN, R., (2009): Jurassic Tectonostratigraphy of the Austroalpine Domain. - Journal of Alpine Geology, 50, 1-152, Wien.

GAWLICK, H.-J., MISSONI, S., SCHLAGINTWEIT, F. & SUZUKI, H. (2012): Jurassic active continental margin deep-water basin and carbonate platform formation in the north-western Tethyan realm (Austria, Germany). - Journal of Alpine Geology, 54, 189-292, Wien.

GAWLICK, H.-J., MISSONI, S., SUZUKI, H., SUDAR, M., LEIN, R. & JOVANOVIC, D. (2016): Triassic radiolarite and carbonate components from a Jurassic ophiolitic mélange (Dinaridic Ophiolite Belt). - Swiss Journal Geoscience, 109: 473-494, Basel.

GRABOWSKI, J., SCHNEYDER, J., SOBIEN, K., KOPTIKOVA, L., KRZEMINSKI, A., PSZCZOLKOWSKI, A., HEJNAR, J. & SCHNABL, P. (2013): Magnetic susceptibility and spectral gamma logs in the Tithonian-Berriasian pelagic carbonates in the Tatra Mts (Western Carpathians, Poland): Palaeoenvironmental changes at the Jurassic/Cretaceous boundary. - Cretaceous Research, 43, 1-17.

GRABOWSKI, J., GAWLICK, H.-J., IWANCZUK, J., KRISCHE, O., REHAKOVA, D. & WOJCIK, K. (2016a): Tithonian-Berriasian magnetostratigraphy in the Northern Calcareous Alps (Leube quarry, Northern Calcareous Alps, Austria) - first results. - In: MICHALIK, J. & FEKETE, K. (Eds.): XIIth Jurassica Conference, Field Trip Guide and Abstract Book, 91-92, Earth Science Institute, Slovak Academy of Science, Bratislava.

GRABOWSKI, J., LAKOVA, I., PETROVA, S., STOYKOVA, K., IVANOVA, D., WOJCIK-TABOL, P., SOBIEN, K. & SCHNABL, P. (2016b): Paleomagnetism and integrated stratigraphy of the Upper Berriasian hemipelagic succession in the Barlya section Western Balkan, Bulgaria: Implications for lithogenic input and paleoredox variations. - Palaeogeography, Palaeoclimatology, Palaeoecology, 461, 156-177, Amsterdam.

GRABOWSKI, J., GAWLICK, H.-J., HIRSCHHUBER, H.-J., IWANCZUK, J., KRISCHE, O., REHAKOVA, D., ZIOLKOWSKI, P., TEODORSKI, A. & VRSIC, A. (2017a): Tithonian - Berriasian magnetic stratigraphy, gamma ray spectrometry, AMS studies, and geochemical analyses in the Northern Calcareous Alps (Leube quarry, Salzburg area, Austria) - first results. - Jurassica XIII: Jurassic Geology of Tatra Mts., Abstracts and Field Trip guidebook, 34-35, Koscielisko, Polish Geological Institute.

GRABOWSKI, J., GAWLICK, H.-J., HIRSCHHUBER, H.-J., IWANCZUK, J., KRISCHE, O., REHAKOVA, D., ZIOTKOWSKI, P., TEODORSKI, A. & VRSIC, A. (2017b): Primary magnetization in the Berriasian of the Northern Calcareous Alps (Salzburg area). - In: SARIC, K., PRELEVIC, D., SUDAR, M. & CVETKOVIC, V. (Eds.): Émile Argand Conference - 13th Workshop on Alpine Geological Studies - September 7th-18th 2017, Zlatibor Mts. (Serbia), 37, (University of Belgrade - Faculty of Mining and Geology) Beograd.

GÜMBEL, C.W. von (1861): Geognostische Beschreibung des Bayrischen Alpengebirges und seines Vorlandes. I-XX. - 1-950, (Justus Perthes) Gotha.

HARDENBOL, J., THIERRY, J., HARLEY, M.B., JACQUIN, T., DE GRACIANSKY, P.-C. & VAIL, P.R. (1998): Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of Europaean basins. - SEPM special Publications, 160: 763-786.

HOEDEMAEKER, PH., REBOULET, S., AGUIRRE-URRETA, M.B., ALSEN, P., AOUTEM, M., ATROPS, F., BARRAGAN, R., COMPANY, M., GONZÁLEZ-ARREOLA, C., KLEIN, J., LUKENEDER, A., PLOCH, I., RAISOSSADAT, N., RAWSON, P.F., ROPOLO, P., VASÍCEK, Z., VERMEULEN, J. & WIPPICH, M.G.E. (2003): Report on the 1st International Workshop of the IUGS Lower Cretaceous Ammonite Working Group, the 'Kilian Group' (Lyon, 11 July 2002). - Cretaceous Research, 24: 89-94.

HRADECKÁ, L. (2003): Srovnání spodnokřídového foraminiferového společenstva z výplní štramberských vápenců lomu Kotouč ve Štramberku na Moravě se společenstvem stejného stáří z lomu Gutrathsberg v Gartenau v Rakousku. - Sbor. věd. prací VŠBTech. univ. Ostrava, Ř. hornicko-geologická, mimoř. čís. ke 4. paleont. semináři, XLIX: 45-47, Ostrava.

IMMEL, H. (1987): Die Kreideammoniten der Nördlichen Kalkalpen. - Zitteliana, 15: 3-163, München.

KRISCHE, O. (2012): Die Platznahme der Alpinen Haselgebirge Mélange: Die geodynamische Entwicklung der zentralen Nördlichen Kalkalpen im höchsten Ober-Jura und in der Unter-Kreide. - Unpublished PhD Thesis, 1-340, Montanuniversität Leoben, Leoben.

KRISCHE, O. & GAWLICK, H.-J. (2010): Berriasian turbidites in the central Northern Calcareous Alps (Salzburg, Austria): palaeogeography and hinterland reconstructions. Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften, 72: 60, Hannover.

KRISCHE, O. & GAWLICK, H.-J. (2015): Age and significance of Lower Cretaceous mass flows: Ischler Breccia revisited (Rossfeld Formation, Northern Calcareous Alps, Austria). - Austrian Journal of Earth Sciences, 108: 128-150, Wien.

KRISCHE, O., BUJTOR, L. & GAWLICK, H.-J. (2013): Calpionellid and ammonite biostratigraphy of uppermost Jurassic to Lower Cretaceous sedimentary rocks from the Leube quarry (Northern Calcareous Alps, Salzburg, Austria). - Austrian Journal of Earth Sciences, 101: 26-45, Wien.

KRISCHE, O., GORIČAN, S. & GAWLICK, H.-J. (2014). Erosion of a Jurassic ophiolitic nappe-stack as indicated by exotic components in the Lower Cretaceous Rossfeld Formation of the Northern Calcareous Alps (Austria). - Geologica Carpathica, 65: 3-24, Bratislava.

KÜHNEL, J. (1929): Geologie des Berchtesgadener Salzberges. - Neues Jahrbuch für Mineralogie, Geologie und Paläontologie Beilagebände B, 61: 17-22, Stuttgart.

LEISS, O. (1992): Orogenically controlled sedimentation in the Lechtaler Kreideschiefer (Lechtal shale; Cretaceous) and geodynamics of the inner western NCA (Northern Calcareous Alps, Lechtal Alps). - Geologische Rundschau, 81: 603-634, Stuttgart.

LILL V. LILIENBACH, A. (1830): Ein Durchschnitt aus den Alpen mit Hindeutung auf die Karpathen. - Neues Jahrbuch Mineralogie, Geognosie, Geologie Petrefaktenkunde, **1**: 153-220, Heidelberg.

LINZER, H.G., RATSCHBACHER, L. & FRISCH, W. (1995): Transpressional collision structures in the upper crust: the fold-thrust belt of the Northern Calcareous Alps. - Tectonophysics, 242: 41-61, Amsterdam.

LIPOLD, M. v. (1854): Der Salzberg am Dürnberg nächst Hallein. - Jahrbuch der kaiserlich-königlichen Geologischen Reichsanstalt, 1854: 590-610, Wien.

MAIER, G., MLEKUSCH, T., KRISCHE, O. & GAWLICK, H.-J. (2013): Biostratigraphy, isotope stratigraphy ($\delta^{18}O$, $\delta^{13}C$) and geochemical characteristics (XRF) of Upper Tithonian to Lower Cretaceous deeper water sedimentary rocks (Northern Calcareous Alps, Salzburg) as a tool to prospect raw material for cement industry. - In: SCHUSTER, R. (Ed.): 11th Workshop on Alpine Geological Studies & 7th European Symposium on Fossil Algae. Abstract & Field Guides. 58, Schladming, Sept. 2013, Wien.

MATURA, A. & SUMMESBERGER, H. (1980): Geology of the Eastern Alps (An excursion guide). - Abhandlungen der Geologischen Bundesanstalt, 34: 103-170, Wien.

MEDWENITSCH, W. (1949): Die Geologie der Hallstätterzone von Ischl - Altaussee (mit einer Situationsskizze 1:50000, mit einem N-S- und einem W-E- Tektonogramm 1:25000 als Beilagen). - Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Wien, I./Heft 2: 1-27, Wien.

MEDWENTISCH, W. (1958): Die Geologie der Salzlagerstätten Bad Ischl und Alt-Aussee (Salzkammergut). - Mitteilungen der Geologischen Gesellschaft in Wien, 1957: 133-200, Wien.

MISSONI, S. & GAWLICK, H.-J. (2011a): Evidence for Jurassic subduction from the Northern Calcareous Alps (Berchtesgaden; Austroalpine, Germany). - International Journal of Earth Sciences, 100/7, 1605-1631, Berlin Heidelberg.

MISSONI, S. & GAWLICK, H.-J. (2011b): Jurassic mountain building and Mesozoic-Cenozoic geodynamic evolution of the Northern Calcareous Alps as proven in the Berchtesgaden Alps (Germany). - Facies, 57: 137-186, Berlin Heidelberg.

NEUBAUER, F., GENSER, J. & HANDLER, R. (2000): The Eastern Alps: result of a two-stage collision process. - In: Neubauer, F. & HÖCK, V. (Eds.): Aspects of geology in Austria. - Mitteilungen Österreichische Geologische Gesellschaft, 92:117-134, Wien.

OBERHAUSER, R. (1980): Der geologische Aufbau Österreichs. XIX. - 1-701 (Springer) Wien/New York.

PESTAL, G., HEJL, E., BRAUNSTINGL, R. & SCHUSTER, R. (Eds.) (2009): Erläuterungen Geologische Karte von Salzburg 1:200000. - Geologische Bundesanstalt, 1-162, Wien.

PICHLER, H. (1963): Geologische Untersuchungen im Gebiet zwischen Roßfeld und Markt Schellenberg im Berchtesgadener Land. - Beihefte zum Geologischen Jahrbuch, 48: 129-204, Hannover.

PLÖCHINGER, B. (1955): Zur Geologie des Kalkalpenabschnittes vom Torrener Joch zum Ostfuß des Untersberges; die Göllmasse und die Halleiner Hallstätter Zone. - Jahrbuch der Geologischen Bundesanstalt, 98: 93-144, Wien.

PLÖCHINGER, B. (1961): Bericht 1960 über Aufnahmen auf den Blättern Berchtesgaden (93) und St. Wolfgang (95/N1). - Verhandlungen der Geologischen Bundesanstalt, 1961: A48-A49, Wien.

PLÖCHINGER, B. (1968): Die Hallstätter Deckscholle östlich von Kuchl/Salzburg und ihre in das Aptium reichende Roßfeldschichten-Unterlage. - Verhandlungen der Geologischen Bundesanstalt, 1968: 80-86, Wien.

PLÖCHINGER, B. (1974): Gravitativ transportiertes permisches Haselgebirge in den Oberalmer Schichten (Tithonium, Salzburg). - Verhandlungen der Geologischen Bundesanstalt, 1974: 71-88, Wien.

PLÖCHINGER, B. (1976): Die Oberalmer Schichten und die Platznahme der Hallstätter Masse in der Zone Hallein-Berchtesgaden. - Neues Jahrbuch Geologie und Paläontologie Abhandlungen, 151: 304-324, Stuttgart.

PLÖCHINGER, B. (1977): Die Untersuchungsbohrung Gutrathsberg B I südlich St. Leonhard im Salzachtal (Salzburg). - Verhandlungen der Geologischen Bundesanstalt, 1977: 3-11, Wien.

PLÖCHINGER, B. (1990): Geologische Karte der Republik Österreich 1:50.000, Erläuterungen zu Blatt 94 Hallein. - Geologische Bundesanstalt, 1-76, Wien.

PLÖCHINGER, B. (1995): Tectonics of the Northern Calcareous Alps: a review. - Mem Sci Geol Padova, 47: 73-86, Padua.

POBER, E. & FAUPL, P. (1988): The chemistry of detrital chromian spinels and its implications for the geodynamic evolution of the Eastern Alps. - Geologische Rundschau, 77: 641-670, Stuttgart.

PUEYO, E.L., MAURITSCH, H.J., GAWLICK, H.-J., SCHOLGER, R. & FRISCH, W. (2007): New evidence for block and thrust sheet rotations in the central northern Calcareous Alps deduced from two pervasive remagnetization events. - Tectonics, 26: 1-25.

RASSER, M.W., VAŠÍČEK, Z., SKUPIEN, P., LOBITZER, H. & BOOROVÁ, D. (2003): Die Schrambach-Formation an ihrer Typlokalität (Unter-Kreide, Nördliche Kalkalpen, Salzburg): Lithostratigraphische Formalisierung und „historische“ Irrtümer. - In: PILLER, W.E. (Ed.): Stratigraphia Austriaca, Schriftenreihe der Erdwissenschaftlichen Kommissionen, 16: 193-216, Wien.

RATSCHBACHER, L., FRISCH, W., LINZER, H.G. & MERLE, O. (1991): Lateral extrusion in the Eastern Alps, Part 2: structural analysis. - Tectonics, 10: 257-271.

REHÁKOVÁ, D., MICHALIK, J. & OŽVOLDOVÁ, L. (1996): New microbiostratigraphical data from several Lower Cretaceous pelagic sequences of the Northern Calcareous Alps, Austria (preliminary results). - Geologisch-Paläontologische Mitteilungen Innsbruck, Sonderband 4: 57-81, Innsbruck.

SCHLAGER, M. & SCHLAGER, W. (1969): Über die Sedimentationsbedingungen der jurassischen Tauglbodenschichten (Osterhorngruppe, Salzburg). - Anzeiger der Österreichischen Akademie der Wissenschaften. Mathematisch-naturwissenschaftlichen Klasse, 106: 178-183, (Österreichische Akademie Wissenschaften) Wien.

SCHLAGER, W. & SCHLAGER, M. (1973): Clastic sediments associated with radiolarites (Tauglbodenschichten, Upper Jurassic, Eastern Alps). - Sedimentology, 20: 65-89, (Blackwell) Oxford.

SCHLAGINTWEIT, F., KRISCHE, O. & GAWLICK, H.-J. (2012): First findings of orbitolinids (larger benthic foraminifera) from the Early Cretaceous Rossfeld Formation (Northern Calcareous Alps, Austria). - Jahrbuch der Geologischen Bundesanstalt, 152: 145-158, Wien.

SCHORN, A. & NEUBAUER, F. (2011): Emplacement of an evaporitic mélange nappe in central Northern Calcareous Alps: evidence from the Moosegg klippe (Austria). - Austrian Journal of Earth Sciences, 104: 22-46, Wien.

SCHWEIGL, J. & NEUBAUER, F. (1997a): New structural, sedimentological and geochemical data on the Cretaceous geodynamics of the central Northern Calcareous Alps (Eastern Alps). – Zentralblatt Geologie und Paläontologie Teil 1, 1996: 329-343, Stuttgart.

SCHWEIGL, J. & NEUBAUER, F. (1997b): Structural evolution of the central Northern Calcareous Alps: Significance for the Jurassic to Tertiary geodynamics in the Alps. - Eclogae geol. Helvetiae, 90: 303-323, Basel.

STEIGER, T. (1992): Systematik, Stratigraphie und Palökologie der Radiolarien des Oberjura-Unterkreide-Grenzbereiches im Osterhorn-Tirolikum (Nördliche Kalkalpen, Salzburg und Bayern). – Zitteliana, 19: 1-188, München.

TOLLMANN A. (1976a): Monographie der Nördlichen Kalkalpen. Teil II. Analyse des klassischen nordalpinen Mesozoikums. Stratigraphie, Fauna und Fazies der Nördlichen Kalkalpen. - 1-580, (Deuticke) Wien.

TOLLMANN, A. (1976b): Der Bau der Nördlichen Kalkalpen. Orogene Stellung und regionale Tektonik. - 1-449, (Deuticke) Wien.

TOLLMANN, A. (1977): Geologie von Österreich, Band **1**: Die Zentralalpen. - 1-766, (Deuticke) Wien.

TOLLMANN, A. (1985): Geologie von Österreich, Band 2: Außerzentralalpiner Anteil. - 1-710, (Deuticke) Wien.

UHLIG, V. (1882): Zur Kenntnis der Cephalopoden der Rossfeldschichten. Jahrbuch der Kaiserlich - Königlichen Geologischen Reichsanstalt, 32/III: 346-396, Wien

VON EYNATTEN, H. & GAUPP, R. (1999): Provenance of Cretaceous synorogenic sandstones in the Eastern Alps: constraints from framework petrography, heavy mineral analysis and mineral chemistry. - Sedimentary Geology, 124: 81-111, Amsterdam.

VON EYNATTEN, H., GAUPP, R., WIJBRANS, J.R. (1996): ^{40}Ar/^{39}Ar laser-probe dating of detrital white micas from Cretaceous sedimentary rocks of the Eastern Alps: evidence for Variscan high-pressure metamorphism and implications for Alpine orogeny. - Geology, 24: 691-694, Boulder

WAGREICH, M. (2009): Stratigraphic constraints on climate control of Lower Cretaceous oceanic red beds in the Northern Calcareous Alps (Austria). - SEPM Special Publication 91: 91-98, Tulsa.

WEBER, E. (1942): Ein Beitrag zur Kenntnis der Roßfeldschichten und ihrer Fauna. - Neues Jahrbuch für Mineralogie, Geologie und Paläontologie Beilage-Bände Abteilung B: Geologie und Paläontologie, 86: 247-281, Stuttgart

WEIDICH, K. F. (1990): Die kalkalpine Unterkreide und ihre Foraminiferenfauna. - Zitteliana, 17: 1-312, München.

WINKLER, W. (2004): Eine mineralogische Besonderheit aus dem Lammertal, Salzburg, Österreich - fossile Harze aus der Unterkreide. - Gmundner Geostudien, 2: 337-342, Gmunden.

WOLETZ, G. 1963): Charakteristische Abfolgen der Schwermineralgehalte in Kreide- und Alttertiär-Schichten der nördlichen Ostalpen. - Jahrbuch der Geologischen Bundesanstalt, 106: 89-119, Wien.