Austrian Journal of Earth Sciences | Volume 106/1 | 26 - 45 | Vienna | 2013

Calpionellid and ammonite biostratigraphy of uppermost Jurassic to Lower Cretaceous sedimentary rocks from the Leube quarry (Northern Calcareous Alps, Salzburg, Austria)

Oliver KRISCHE[1)*)], László BUJTOR[2)] & Hans-Jürgen GAWLICK[1)]

[1)] Department of Applied Geosciences and Geophysics, Chair of Petroleum Geology, Peter-Tunner-Straße 5, 8700 Leoben, Austria;

[2)] Department of Geology, University of Pécs, 6 Ifjúság útja, H-7624 Pécs, Hungary;

[*)] Corresponding author, oliver_krische@gmx.at

KEYWORDS

Northern Calcareous Alps
biostratigraphy
calpionellids
ammonites
Valanginian
Berriasian
Tithonian

Abstract

New calpionellid and ammonite data from the Leube quarry in combination with microfacies and lithology analyses allow a new and precise biostratigraphy in Upper Tithonian and Lower Cretaceous hemipelagic sedimentary rocks of the Northern Calcareous Alps south of Salzburg (Austria). The Upper Tithonian Oberalm Formation is dated by the first occurrence of *Calpionella alpina* (Lorenz, 1902), *Crassicollaria massutiniana* (Colom, 1948) and *Crassicollaria intermedia* (Durand-Delga, 1957) (*Crassicollaria intermedia* Subzone). In the Upper Tithonian hemipelagic radiolarian wackestones several clastic cycles are intercalated, consisting of breccia beds (mass-flow deposits) and turbidites with resedimented litho- and bioclastic material from nearby carbonate platforms (Barmstein Limestone). The change from white, hemipelagic limestones to greenish, marly limestones with marl intercalations takes place in between the Upper Tithonian and Lower Berriasian part of the Oberalm Formation and is dated by the first common occurrence of *Calpionella alpina* (Lorenz, 1902) together with *Remaniella* sp. (*Calpionella alpina* and *Remaniella* Subzones). The next lithological change follows in the upper Lower Berriasian to Middle Berriasian, constrained by the first occurrences of *Calpionella elliptica* (Cadisch, 1932) and *Remaniella cadischiana* (Colom, 1948) (*Calpionella elliptica* and *Remaniella cadischiana* Subzones). Green-red marly limestones (Gutratberg beds of the Oberalm Formation with the economically important Portland cement layer) and marls with an increasing amount of sponge spicula, turbiditic layers with echinoderm remnants and detrital minerals are characteristic. The variegated marls and limestones are overlain by silty brownish to greenish marls with plant remnants and ammonites of the Schrambach Formation (Middle Berriasian). The first occurrence of *Calpionellopsis* sp. within calcareous turbidites defines the basis of the Upper Berriasian (*Calpionellopsis* Zone). These turbidites are overlain again by plant remnant bearing marls and a well bedded limestone-marl succession. *Fauriella boissieri* (Pictet, 1867) within the marls below the well bedded rocks indicates a Late Berriasian age (*Subthurmannia boissieri* Zone). The first occurrence of *Calpionellites* sp. together with *Remaniella filipescui* (Pop, 1994) in the bedded limestone-marl succession marks the beginning of the Lower Valanginian.

Neue biostratigraphische Ergebnisse aus Calpionellen- und Ammonitendatierungen aus dem Leube Steinbruch, Salzburg, in Kombination mit mikrofaziellen und lithologischen Untersuchungen erlauben eine präzise, verbesserte Biostratigraphie in obertithonen und unterkretazischen hemipelagischen Sedimentgesteinen der Nördlichen Kalkalpen von Österreich. Die obertithone Oberalm-Formation wird durch das Erstauftreten von *Calpionella alpina* (Lorenz, 1902), *Crassicollaria massutiniana* (Colom, 1948) und *Crassicollaria intermedia* (Durand-Delga, 1957) (*Crassicollaria intermedia* Subzone) datiert. In den obertithonen hemipelagischen Radiolarien-Wackestones sind mehrere gradierte Zyklen mit Brekzienbänken (Mass-flow Ablagerungen) und Turbiditen mit resedimentiertem, bioklastischem Material (Barmsteinkalk) einer Flachwasserkarbonatplattform eingelagert. Die lithologische Änderung von weißen, hemipelagischen Kalken hin zu grünen, mergeligen Kalken mit Mergelzwischenlagen erfolgt innerhalb der Oberalm-Formation zwischen Ober-Tithonium und Unter-Berriasium. Durch das gemeinsame Auftreten von *Calpionella alpina* (Lorenz, 1902) mit *Remaniella* sp. (*Calpionella alpina* und *Remaniella* Subzonen) kann diese lithologische Änderung biostratigraphisch eingeordnet werden. Der nächste lithologische Wechsel folgt im höheren Unter-Berriasium bis zum Mittel-Berriasium, gemeinsam mit dem Erstauftreten von *Calpionella elliptica* (Cadisch, 1932) bzw. *Remaniella cadischiana* (Colom, 1948) (*Calpionella elliptica* und *Remaniella cadischiana* Subzonen). Grün-rote mergelige Kalke (Gutratberg-Schichten der Oberalm-Formation, mit der ökonomisch wichtigen Portlandzementbank) und Mergel mit einem zunehmendem Anteil an Schwammnadeln, Turbidite mit Echinodermenresten und detritären Komponenten sind charakteristisch. Diese gefleckten Mergel und Kalke werden von siltigen, braunen bis grünlichen Mergeln mit Pflanzenresten und Ammoniten der Schrambach-Formation (Mittel-Berriasium) überlagert. Das Erstauftreten von *Calpionellopsis* sp. innerhalb von kalkigen gebankten Resedimenten der Schrambach-Formation zeigt den Beginn des Ober-Berriasium (*Calpionellopsis* Zone) an. Über den Turbiditen liegen Pflanzenreste-führende, siltige Mergel, und darüber schließt eine gut gebankte Kalk-Mergel-Abfolge an. *Fauriella boissieri* (Pictet, 1867) konnte aus den Mergeln unterhalb dieser gut gebankten Abfolge nachgewiesen werden, ebenfalls das Ober-Berriasium (*Subthurmannia boissieri* Zone) anzeigend. Das Erstauftreten von *Calpionellites* sp. gemein-

sam mit *Remaniella filipescui* (Pop, 1994) innerhalb der Kalk-Mergel-Abfolge markiert den Beginn des Unter-Valanginium.

1. Introduction

1.1 Aim of research

In the central Northern Calcareous Alps the Late Jurassic to earliest Cretaceous time span is characterized by a significant change in both geodynamic and environmental setting. In latest Jurassic time the step-by-step demise of a huge carbonate platform with deep-water basins between the different shallow-water areas started. Parts of this platform drowned in the Tithonian (Gawlick and Schlagintweit, 2010) whereas in other places the increased subsidence was counterbalanced by carbonate production. Overall platform drowning occurred later in the Berriasian (Gawlick and Schlagintweit, 2006). During that time a complex basin and platform pattern established. We try to reconstruct this evolution by means of a detailed analysis of the basin sediments between these platforms with their more continuous, more complete depositional record.

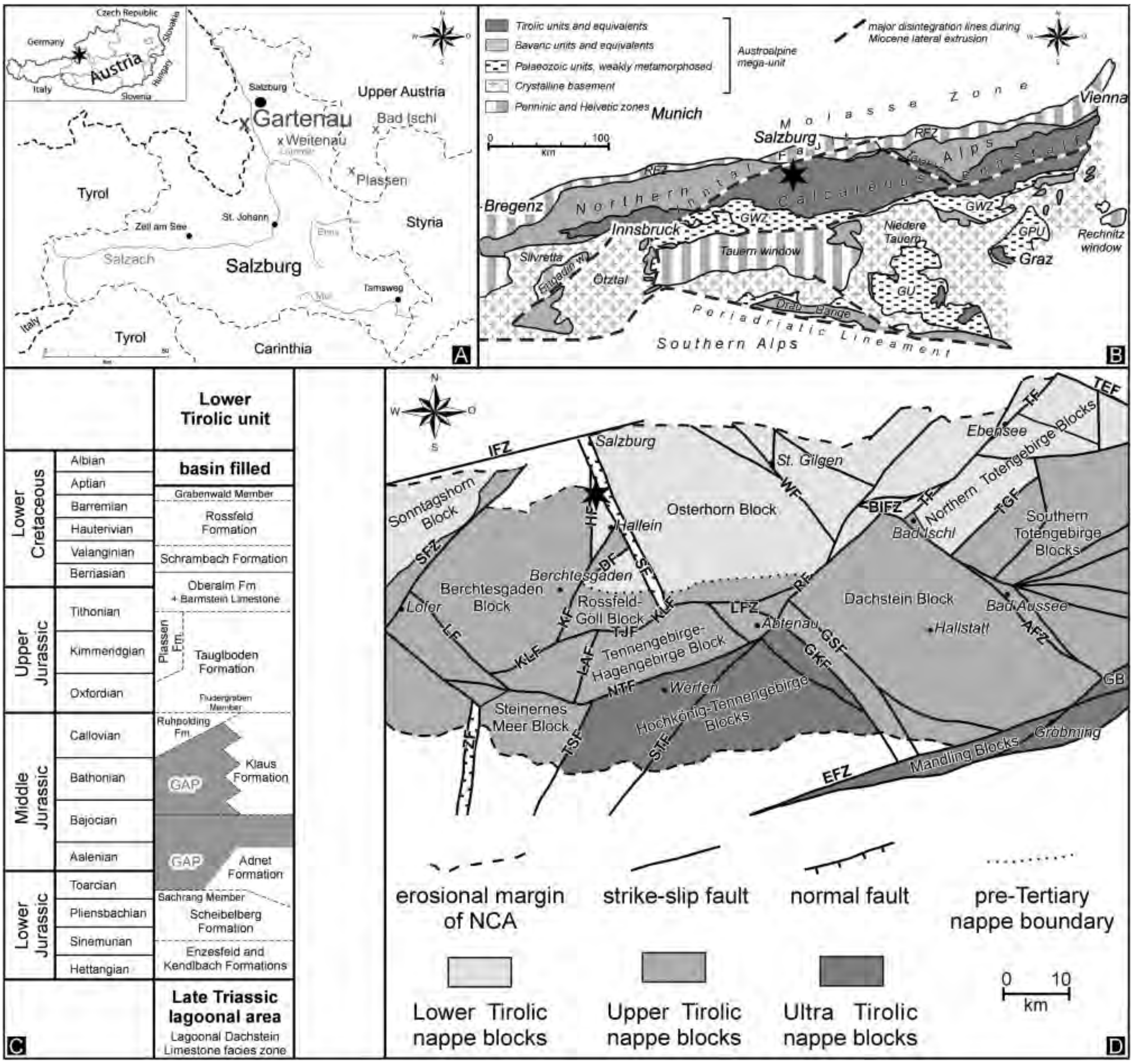


Figure 1: A: The Leube quarry is located near the village of Gartenau, south of the city of Salzburg, Austria. B: The main geological units of the Eastern Alps (modified after Frisch and Gawlick, 2003). GP-Graz Palaeozoic unit, GU-Gurktal unit, GWZ-Greywacke zone, RFZ-Rhenodanubian Flysch zone. C: Detail of the stratigraphy of the Northern Calcareous Alps, met in the Leube open pit. Indicated are the applied formation names according to Gawlick et al. (2009) and Missoni and Gawlick (2011a, b). D: Tectonic map with the recent block configuration of the central Northern Calcareous Alps and the studied area (star) (modified after Frisch and Gawlick, 2003. Major Miocene faults (F) and fault zones (FZ) are indicated: AFZ-Aussee, BIFZ-Bad Ischl, DF-Dürrnberg, EFZ-Ennstal, GKF-Gosaukamm, GSF-Gosausee, HF-Hellbrunn, IFZ-Inntal, KF-Königssee, KLF-Königssee-Lammertal, LAF-Landtal, LFZ-Lammertal, LF-Lofer, NTF-Northern Tennengebirge, RF-Rigaus, SF-Untersalzachtal, SFZ-Saalachtal, STF-Southern Tennengebirge, TEF-Teichl, TF-Traunsee, TGF-Totengebirge, TJF-Torrener Joch, TSF-Torscharten, WF-Wolfgangsee, ZF-Zeller See.

Exact biostratigraphic dates are, so far, rare in the central Northern Calcareous Alps. Most sections are either strongly condensed or incomplete/disturbed due to younger polyphase tectonics. In addition, good outcrops within these marly successions are rare because the occurrences in the Tirolic unit of the Salzburg Northern Calcareous Alps often make up hilly areas of lower altitudes, predestinated for the usage as grassland.

In recent times, detailed palaeogeographic and geodynamic reconstructions for the middle part of the Northern Calcareous Alps during the Middle to Late Jurassic time span proof that carbonate platform generation started even before the Oxfordian/Kimmeridgian-boundary (Auer et al., 2009). These new data and the step-by-step, complex platform drowning around the Jurassic/Cretaceous boundary (Gawlick and Schlagintweit, 2006, 2010) have clearly shown the need for more precise time control on the basinal sediments deposited between the platform areas, which, in addition, allows also a better understanding of the platform evolution.

The new biostratigraphical data presented here give rise to a refined stratigraphy of this Upper Tithonian to Lower Cretaceous basin succession deposited between the shallow-water realms and exposed nowadays in the Leube quarry south of Salzburg. Sedimentological and microfacies data help to specify the depositional environment and are useful for palaeogeographic and geodynamic reconstructions. The results shed new light on the geodynamic evolution of the controversially discussed Late Jurassic to Early Cretaceous tectonic history (e.g., Frank and Schlager, 2006; Ortner et al., 2008) and improve the understanding of the processes which led to the demise of the huge carbonate platforms around the Jurassic/Cretaceous boundary.

1.2 Investigated locality

The study area is situated in and around the Leube quarry, an open pit mine, where marly rocks are exploited for cement production. It is located in the central Northern Calcareous Alps south of Salzburg, near to the villages of Gartenau and St. Leonhard, and close to the border to Germany (Figs 1A, 1B).

The well known Leube open pit gives insight into one of the most interesting and important outcrop examples of hemipelagic Upper Jurassic to Lower Cretaceous basin successions in the central Northern Calcareous Alps (Fig. 2, compare to Lobitzer et al., 1994). In this quarry, a complete, virtually undisturbed section through a limestone and marl succession is well preserved. Due to the ongoing production the actual open pit situation is subject to permanent, in some places rapid changes though.

2. Materials and methods

Along the sections (Fig. 2), lithological, sedimentological and structural features were investigated by means of selective sampling for microfacies analyses and biostratigraphic dating, with thin section investigations for calpionellids as the most powerful tool. Calpionellids were photographed under the light microscope with a magnification of 80x. The applied biostratigraphy for calpionellids follows the system of Andreini et al. (2007) who modified the zonation of Blau and Grün (1997). For ammonites we follow the zonation of Hoedemaeker et al. (2003) and Reboulet et al. (2009). Thin sections are stored at the Montanuniversität Leoben, Austria, whereas the ammonites are preserved in the Palaeontological Museum, Eötvös University (labelled as PMEU) 1/C Pázmány Péter sétány, H-1111, Budapest, Hungary.

The systematics of *Ammonoidea* follows the system of Klein (2005). Apparent contradiction is raised regarding the nomenclature of the ammonite genus *Fauriella*. Klein (2005) maintained this name, however Hoedemaeker et al. (2003) applied *Subthurmannia* instead of *Fauriella* in ammonite biostratigraphy and biozonation. We therefore follow *Fauriella* sensu Klein (2005) when referring to the ammonite species in taxonomical sense but follow *Subthurmannia* sensu Hoedemaeker et al. (2003) and Reboulet et al. (2009) when referring to biostratigraphy.

3. Geological setting

3.1 Geological overview

The Leube quarry is part of the Lower Tirolic unit in the sense of Frisch and Gawlick (2003, Fig. 1D). It is situated on the northern Kaltenhausen Block (Missoni, 2003) which is bordered by post mid-Cretaceous and Miocene fault systems (e.g., Hellbrunn fault: Frisch and Gawlick, 2003; Pueyo et al., 2007). According to Gawlick (2000), Gawlick et al. (1999, 2005, 2007) and Missoni and Gawlick (2011a, b) the sedimentary cycle in the Tauglboden Basin of the Lower Tirolic unit (Fig. 1C) started in the Oxfordian with siliceous sediments and intercalated breccia layers (Tauglboden Formation). Sedimentation became calcareous from the Late Tithonian onwards with the Oberalm Formation and Barmstein Limestone succession which was deposited till the early Late Berriasian (Gawlick et al., 2009). In contrast, the next sedimentary cycle was characterised by increasing siliciclastic input. The Schrambach and Rossfeld Formations comprise Upper Berriasian/Valanginian to Lower Aptian (Plöchinger, 1968, 1990; Fig. 1C). The Jurassic to Lower Cretaceous stratigraphy of the Lower Tirolic unit drawn-out by Gawlick et al. (2009), modified by Missoni and Gawlick (2011a, b) and applied in this paper is pictured in Figure 1C.

3.2 Former investigations at the study area

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* v. Koenen, 1902) in the Schrambach and the Lower Rossfeld beds nearby the village Gartenau. Oedl (in: Plöchinger, 1955) reported the occurrence of *Fuhriella michaelis* (Uhlig, 1902) 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* (d´Orbigny, 1842) and *Kilianella roubaudiana* (d'Orbigny, 1850) from greenish-grey marls, indicating a Valanginian to Early Hauterivian age. Plöchinger (in: Matura and Summes-

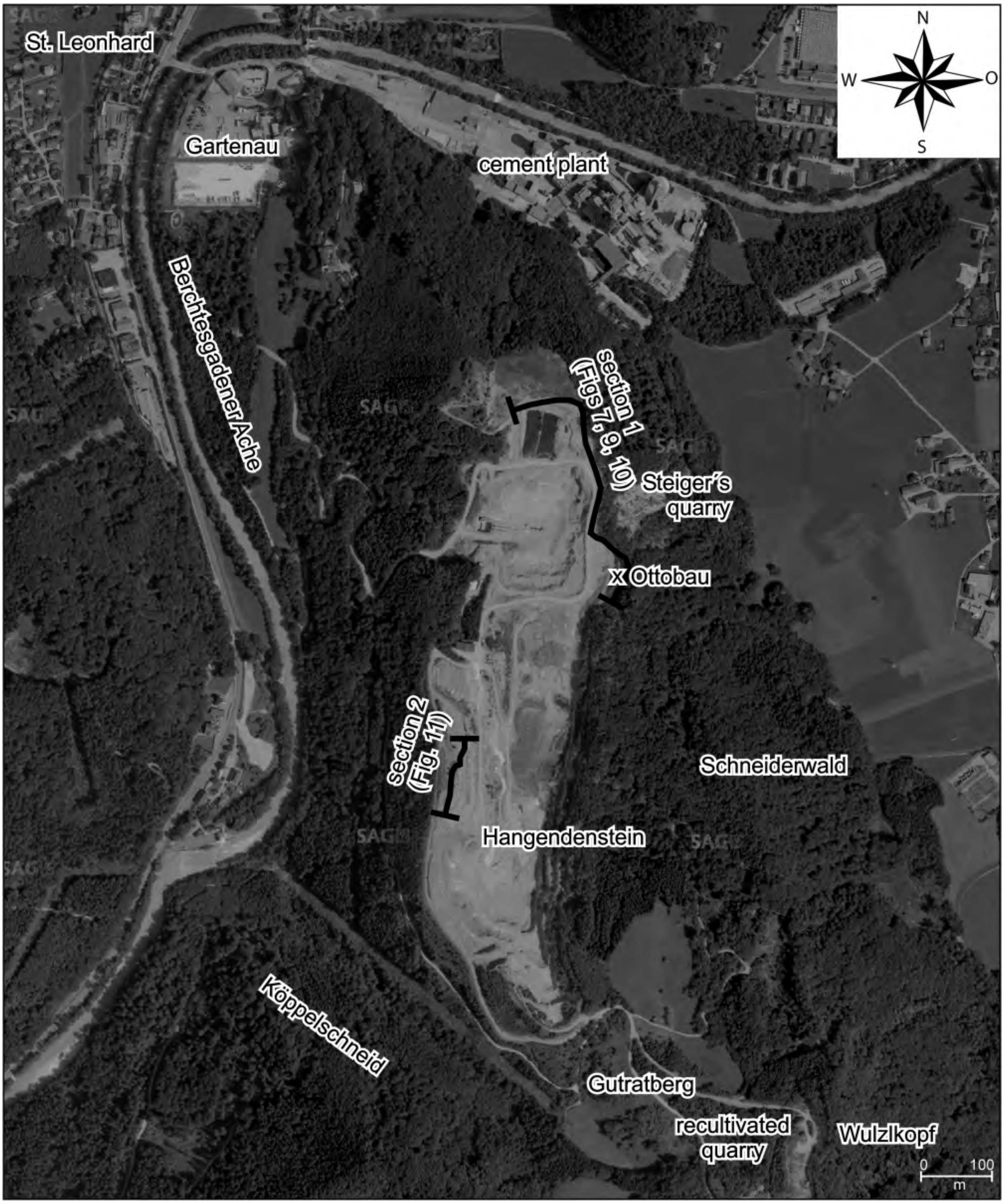


Figure 2: Orthophoto (2007-2009) of the Leube open pit mine and the surrounding villages (Geodaten Land Salzburg, Salzburger Geographisches Informationssystem SAGIS, www.salzburg.gv.at/sagis). The investigated section lines and geographic names mentioned in the text are indicated.

berger, 1980) also referred findings of *Olcostephanus*, *Berriasella* and *Neolissoceras* from the quarry. First lithological and microfacies analyses around the Schneiderwald (Fig. 2) and the eastern part of the open pit were executed by Plöchinger (1974, 1976, 1977) who included calpionellid biostratigraphy in his investigations (Fig. 3). Immel (1987) reported a Late Hauterivian ammonite assemblage with *Oosterella kittli* (Richarz, 1905), *Crioceratites* (*Crioceratites*) *nolani* (Kilian, 1910) and *Moutoniceras annulare* (d´Orbigny, 1840) from sandy limestones (Rossfeld Formation) of the Köppelschneid (Figs 2, 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 (Fig. 3). Boorová et al. (1999) and Dorner et al. (2009) mentioned very scarce occurrences of ammonites in their profiles.

Recent investigations, albeit with another main focus compared to this study, were undertaken by Gawlick et al. (2005) in the area of the old, recultivated quarry (Fig. 2) south of today's open pit and by Wagreich (2009) in the active Leube quarry. The latest survey was carried out by Bujtor et al. (2013) who investigated the ammonite assemblage of the active Leube quarry and described the occurring species palaeontologically and biostratigraphically.

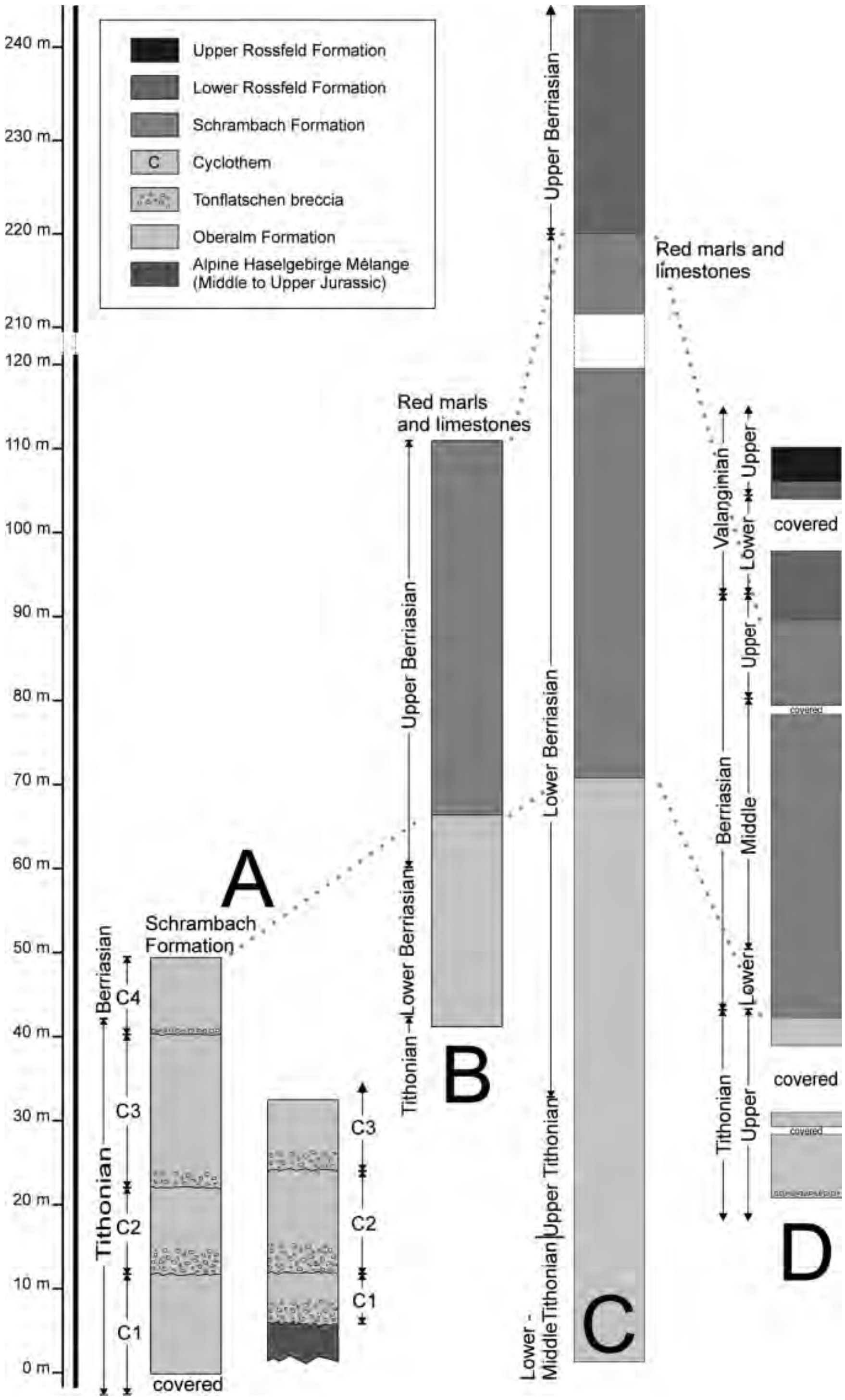


Figure 3: Standardised and simplified compilation of stratigraphic columns of the Leube open pit as found in the literature. From left to right: A: Plöchinger (1974, 1976), B: Steiger (1992), C: Reháková et al. (1996), D: Boorová et al. (1999). For comparison see also Fig. 5.

4. Results

To get out the most of the survey, the profile investigations in the open pit were combined with detailed mapping of the surrounding area (Fig. 4).

The basal part of the Leube quarry succession was investigated by Plöchinger (1977) in the framework of a drilling project at the Gutratberg. It is made up of Oberalm Formation and Barmstein Limestone. Alpine Haselgebirge Mélange (Spötl, 1989) of Middle to Late Jurassic age (Missoni and Gawlick, 2011a, b) follows with sedimentary contact on top of these hemipelagic Upper Tithonian rocks. It consists of a mixture of clay, salt and incorporated rock bodies of various origins (Plöchinger, 1977). In the Leube open pit area or east of it, respectively, Oberalm Formation primarily overlies the Alpine Haselgebirge Mélange. The sedimentary contact is well visible in the Ottobau underground mine (Fig. 2) which is geographically situated below the western Schneiderwald. Whilst the Alpine Haselgebirge Mélange is not exposed but well proven from subsurface outcrops (e.g., Plöchinger, 1974, 1977; own observations), the strata of the Oberalm Formation describe a N- to NNW-plunging anticline (Schneiderwald Anticline of Plöchinger (1974)). In the eastern Schneiderwald the beds dip steeply to the east. Close to the northern open pit, the bedding dips rotate to northeastern and northern directions, defining the hinge of the anticline. In the central eastern to northern part of the open pit the Oberalm and Schrambach formations dip moderately to steeply towards the west to northwest on the western limb of the anticline. In the middle part of the quarry flat to moderate westerly dip is found in the Schrambach Formation, whilst in the southwestern part of the quarry, the Rossfeld Formation dips steeply towards southwest and shows slightly more deformation with some flexures and minor folds. Whereas high-angle faults are presumed directly west of the open pit (Fig. 4), no appreciable strike-slip faults seem to cross-cut the quarry itself. Thus, the Leube quarry exposes a continuous sedimentary succession without substantial disturbances by thrusting/doubling or normal faulting/loss of strata, making it very appropriate for section logging. The gross profile is compiled based on the inves-

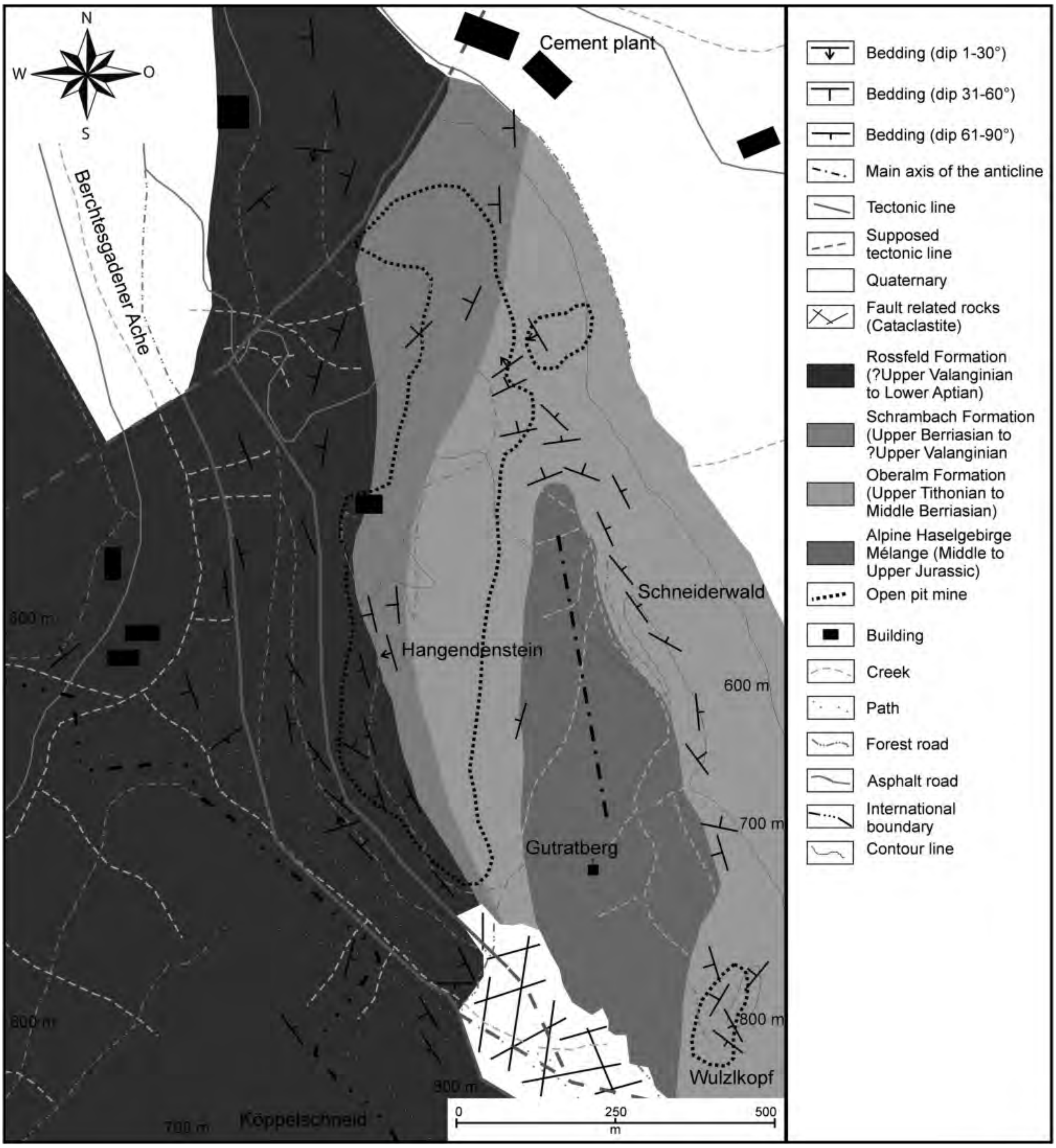


Figure 4: New geological map of the Leube open pit and the surrounding area.

tigations in the quarry and drawn in Figure 5.

4.1 Lithology and microfacies

The sedimentary contact between the underlying Middle Jurassic to Upper Jurassic Alpine Haselgebirge Mélange and the Oberalm Formation is illustrated in Figure 6.

Above a mixture of evaporites and green clay follow several depositional cycles (Figs 6, 7) each of which starting with coarse-grained breccia layers at the base (Tonflatschen breccia sensu Plöchinger, 1974). The strata of the missing section part between the Ottobau and Leube quarry profiles is outcropping in the eastern Schneiderwald, completing the overall composite Leube quarry section (Figs 2, 4, 5). The lithoclastic components of the breccias consist of greenish-grey clay and limestones. The limestone lithoclasts can be described as follows:

- Radiolarian-spicula wackestones
- Calpionellid-radiolarian wackestones
- slope derived bio- and lithoclastic wacke- to floatstones
- grainstones with pellets
- bioclastic, lagoonal wackestones

Occasionally green microsparitic and silty lithoclasts also occur within the component supported breccia beds (Fig. 8A). The breccia beds are overlain by wacke- and packstones with fine-grained biodetritus (Fig. 8B). The top of each cycle is represented by marly wackestones with radiolarians, filaments and calpionellids.

Above the graded cycles (Figs 5, 6, 7) follow stratified greenish, marly limestones (radiolarian wackestones with rare calpionellids, Figs 8C, 9). They alternate with green-grey-brownish marls and contain intercalations of turbiditic radiolarian packstones.

Both the lithology and the microfacies change upsection (profile metre 250, Fig. 10). 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 (Fig. 8D). 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. They are 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 and Gawlick, 2010) terminates the ammonite bearing beds. The marl beds on top are overlain by a well stratified limestone (pellets-sparite packstones with foraminifera, Figs 8F, 8G, 10, 11) and marl (marly wackestones with spa-

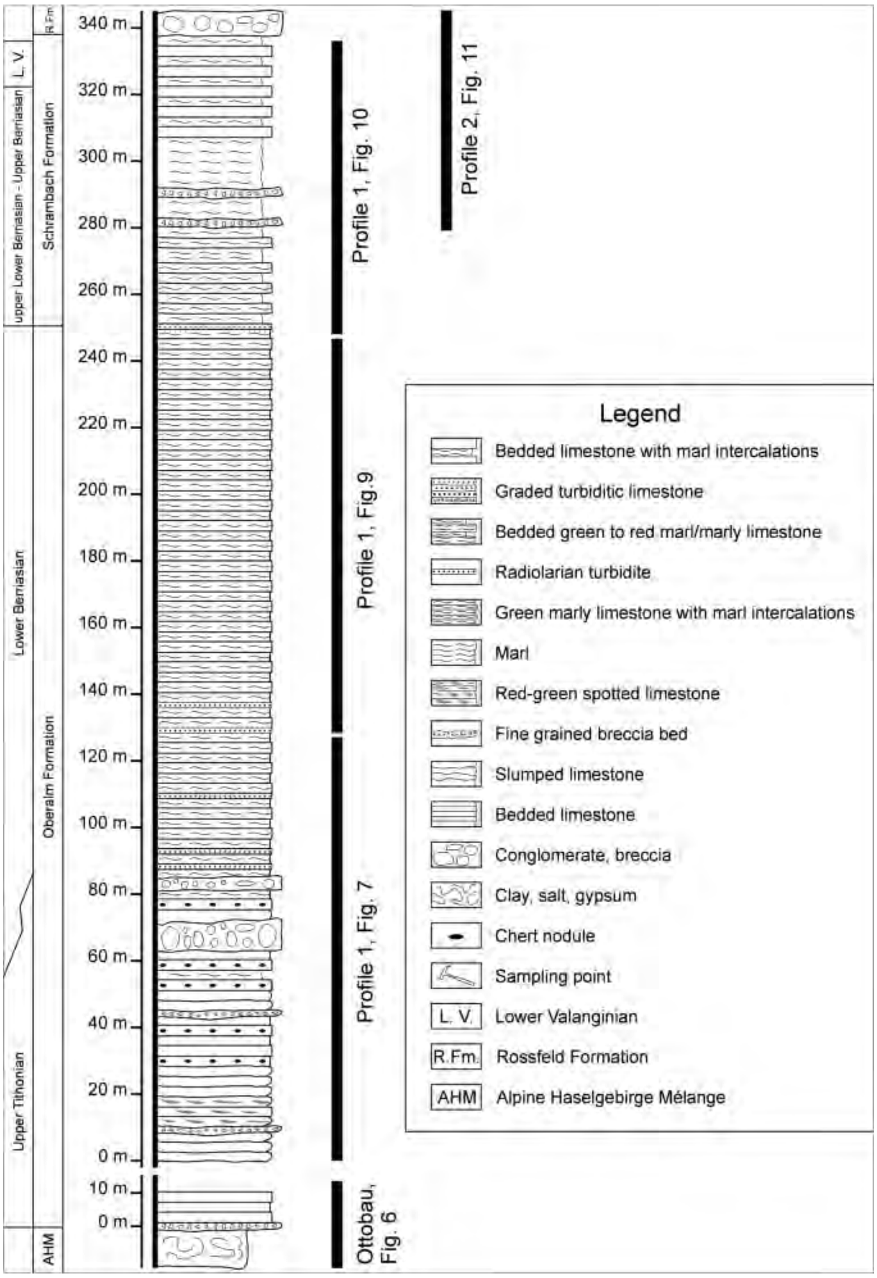


Figure 5: Standard lithostratigraphic column of the Leube quarry succession. The legend is valid also for the detailed profiles 1 and 2 (Figs 6, 7, 9 to 11).

rite and micrite clasts, calpionellids, filaments, spicula, Figs 8E, 8H, 10, 11) succession with occasional ammonite fragments. The stratified limestone-marl succession is erosionally truncated by a coarse-grained conglomerate bed of the basal Rossfeld Formation.

4.2 Calpionellid biostratigraphy

Based on the calpionellid stratigraphy, the Leube standard profile can be subdivided into five calpionellid zones and four subzones from the *Crassicollaria* intermedia Subzone up to the *Calpionellites* Zone. In general, calpionellids are rare in the marly wackestones. Only in turbiditic packstones they are more frequent. A mass occurrence is present in sample OK-L160 (Portland cement bed: Plöchinger, 1976; Fig. 10). Figure 12 gives an overview of the calpionellids occurring in the Leube profile.

The preservation of calpionellids is generally only moderate. The fine and tiny apertures of the loricas of remaniellids are rather poorly preserved. For more in depth descriptions of the faunal content and the diversity of the calpionellids further detailed work with additional sampling is necessary.

The first calpionellids were proven between the Tonflatschen breccia cycles at the base of the profile (Ottobau, Fig. 6). The co-occurrence of *Calpionella* sp., *Calpionella alpina* (Lorenz, 1902) and *Crassicollaria* sp. in the Oberalm Formation (above the Alpine Haselgebirge Mélange) indicate a Late Tithonian age (*Crassicollaria* Zone). In the lower part of Profile 1 (Fig. 7) some red-green marly limestones with slump structures are intercalated. The calpionellid assemblage between profile metre 15-20 (Fig. 7) with *Tintinnopsella carpathica* (Murgeanu-Filipescu, 1933), *Calpionella alpina* (Lorenz, 1902), *Crassicollaria* sp., *Crassicollaria massutiniana* (Colom, 1948) and *Crassicollaria intermedia* (Durand-Delga, 1957) refers to the *Crassicollaria intermedia* Subzone (Late Tithonian). The last crassicollarians (*Crassicollaria* sp., *Crassicollaria massutiniana* (Colom, 1948), *Crassicollaria intermedia* (Durand-Delga, 1957)) occur in bedded white limestones with chert nodules (Fig. 7, profile metre 55). The preservation of calpionellids and radiolarians, and the lack of ammonites do not allow a precise determination of the Jurassic/Cretaceous boundary on the basis of our data (Fig. 7). Samples between profile metres 83-255 (Figs 7, 9) are still indicating an Early Berriasian calpionellid assemblage (*Calpionella* sp., *Calpionella alpina* (Lorenz, 1902), *Remaniella* sp.) of the *Calpionella alpina* and the *Remaniella* Subzones. The Lower Berriasian (*Remaniella* Subzone of the Calpionella Zone) is still within the Oberalm Formation with only very rare calpionellids (Figs 7, 9, 10) like *Tintinnopsella carpathica* (Murgeanu-Filipescu, 1933), *Calpionella* sp., *Calpionella alpina* (Lorenz, 1902) and *Remaniella* sp.

The lithological and microfacies changes include a change in the calpionellid assemblage between profile metres 256-267 as well (Fig. 10). *Calpionella elliptica* (Cadisch, 1932) and *Remaniella duranddelgai* (Pop, 1996) become additional elements of the calpionellid assemblage. A late Early to Middle

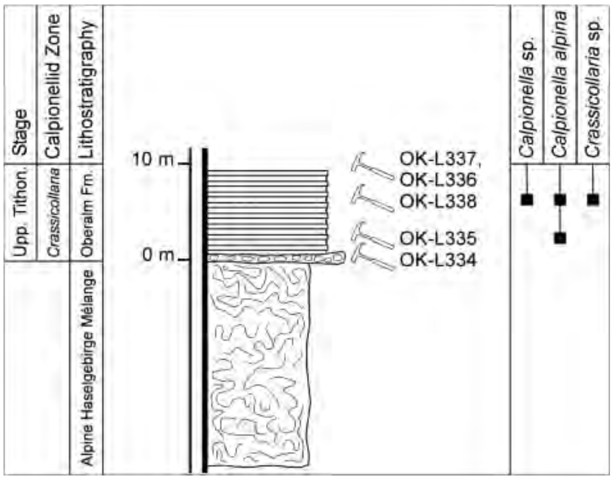


Figure 6: Lowermost part of Profile 1 based on the sedimentary logging in the Ottobau (Dynamite gallery of the former underground mine).

Berriasian age is constrained by the first occurrence of *Calpionella elliptica* (Cadisch, 1932) and *Remaniella cadischiana* (Colom, 1948) (*Calpionella elliptica* to *Remaniella cadischiana* Subzones). At Profile 1 (Figs 5, 10) *Calpionellopsis* sp. (Late Berriasian, *Calpionellopsis* Zone) firstly occurs around profile metre 290 (Fig. 10) within the graded, cherty, allodapic limestones (Schrambach Formation). Above the marly sequence the last indications of *Calpionella alpina* (Lorenz, 1902) and *Calpionella elliptica* (Cadisch, 1932) are observed in the bedded limestone-marl succession. Remaniella sp. and *Calpionellopsis* sp. (Fig. 10) indicate here the highest part of the *Calpionellopsis simplex* Subzone and the *Calpionellopsis oblonga* Subzone of the Late Berriasian. Samples from profile metres 318-322 (Fig. 10) with *Remaniella* sp., *Calpionellopsis* sp., *Tintinnopsella longa* (Colom, 1939), *Remaniella filipescui* (Pop, 1994) and the first occurrence of *Calpionellites* sp. constrain an Early Valanginian age (*Calpionellites* Zone). In addition, *Remaniella filipescui* (Pop, 1994) suggests this part of the section to take a low position within the *Calpionellites* Zone (*Calpionellites darderi* Subzone).

Profile 2 (Figs 2, 5, 11) exposes the continuation of Profile 1 up to the conglomerate beds. Calpionellids are generally very rare in this level of the profile. From profile metre 275 up to profile metre 290 (Fig. 11) there is a succession of variegated red-green limestones, marls and resedimented cherty, allodapic limestones as known from Profile 1. Above the marl beds (profile metres 290-315, Fig. 11) begins the Late Berriasian *Calpionellopsis* Zone with *Remaniella* sp. and *Calpionellopsis* sp. From profile metre 315 (Fig. 11), the co-occurrence of *Tintinnopsella carpathica* (Murgeanu-Filipescu, 1933) and *Calpionellites* sp. indicates an Early Valanginian age (*Calpionellites* Zone). The Lower Valanginian is proven until 3 m below the basal conglomerate of the Rossfeld Formation (Fig. 11).

4.3 Ammonite biostratigraphy

Ammonites are not evenly distributed along the profile. They are rare in the variegated marls and limestones but occur more frequently in the brownish plant debris (e.g., branches) bearing marls (Krische et al., 2010) and in the bedded limestone-marl sequence. All collected ammonites are palaeontologically, palaeobiogeographically, taphonomically and biostratigraphically described by Bujtor et al. (2013). Herein only the two biostratigraphical most important ammonite species are mentioned for correlations to the calpionellid stratigraphy. *Fauriella boissieri* (Pictet, 1867) was collected from the marl succession (Figs 11, 13) and from loose blocks of the limestone-marl succession. *Berriasella* (*Berriasella*) *calisto* (d´Orbigny, 1850) was also collected from loose blocks of the bedded limestone-marl sequence. Both occur in the *Subthurmannia boissieri* Zone (Hoedemaeker et al., 2003; Reboulet et al., 2009) (= *Fauriella boissieri* Zone: Klein, 2005) of the Late Berriasian. According to Company (1987), *Fauriella boissieri* (Pictet, 1867) ranges also into the Early Valanginian. The ammonite data fit well with the calpionellid data and confirm the Late Berriasian age of the limestone-marl sequence of the Schrambach Formation.

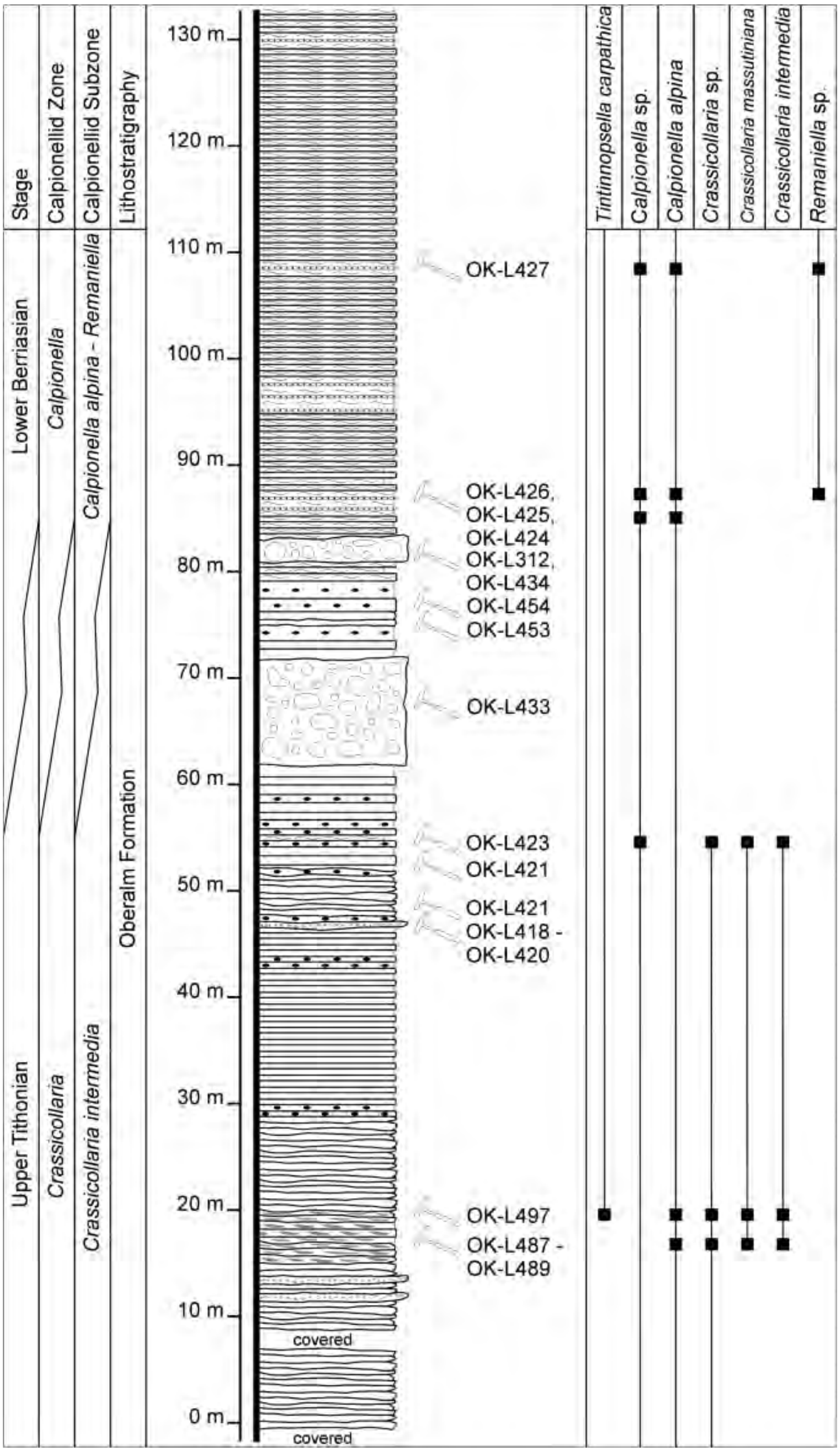
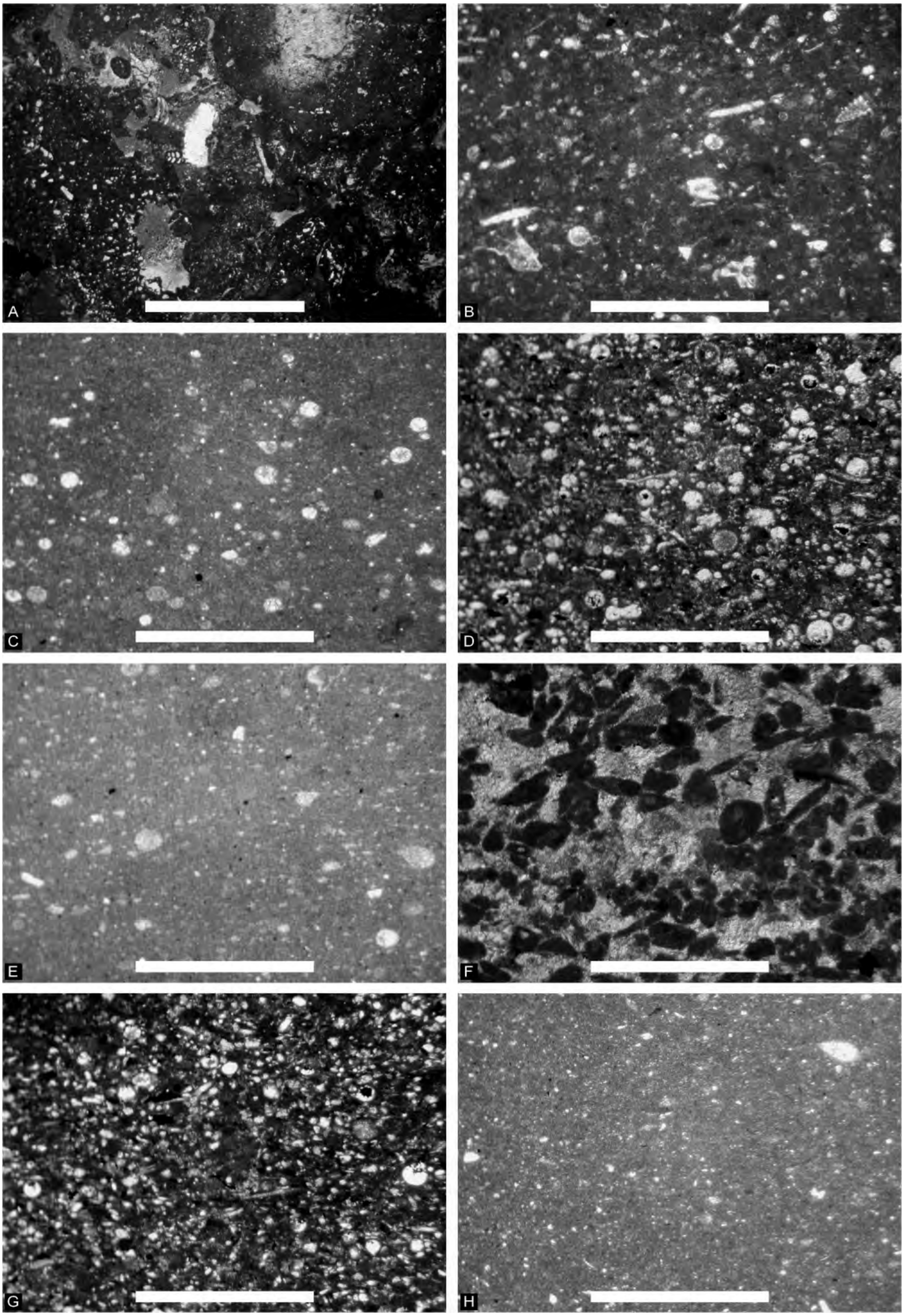


Figure 7: Lower part of Profile 1 as met in the northeastern open pit mine, stratigraphical above the Ottobau.

5. Discussion

The Leube quarry provides one of the best preserved and exposed uppermost Jurassic to Lower Cretaceous sedimentary successions of the central Northern Calcareous Alps. Our new calpionellid data, in combination with ammonite, microfacies and lithology analyses, form the basis for a detailed, revised biostratigraphy of this time interval. 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 Upper Jurassic to Lower Cretaceous shallow-water car-

Figure 8: Selected microfacies samples from the Leube open pit profiles (thin section photographs). A: Tonflatschen breccia (sensu Plöchinger, 1974) with different bio- and lithoclasts, Oberalm Formation, OK-L433_1. B: Wackestone with radiolarians, sparite clasts and calpionellids, Oberalm Formation, OK-L423. C: Marly radiolarian wackestone, Oberalm Formation, OK-L142. D: Radiolarian packstone with some sponge spicula, uppermost part of the Oberalm Formation, OK-L154. E: Marly wackestone with recrystallised radiolarians and sparite clasts, Schrambach Formation, OK-L176. F: Packstone with micrite pebbles and blocky calcite cement, Schrambach Formation, OK-L177_1. G: Dense packstone with recrystallised radiolarians, sponge spicula, sparite clasts and rare micritic pebbles, Schrambach Formation, OK-L194. H: Marly wackestone with recrystallised radiolarians and fine grained sparite clasts, Schrambach Formation, OK-L200. Scale bars: 5 mm for A, 1 mm for B-H.



A
B
C
D
E
F
G
H

bonate platform at the southern rim of the basin. The findings contribute to an improvement of the palaeogeographical and geodynamical model of the Northern Calcareous Alps for this time span.

The Jurassic sedimentary evolution in the Tauglboden Basin is well documented in Gawlick et al. (1999) and Missoni and Gawlick (2011a, b). The stratigraphical range recorded at the Leube quarry correlates only in parts with other sections of the same age in the Tauglboden Basin domain (e. g., Missoni and Gawlick, 2011a, b). In contrast to the conclusions of Reháková et al. (1996), the existence of Kimmeridgian or Lower Tithonian Oberalm type limestones must clearly be negated for the accessible part of the Leube succession. In a borehole south of the active quarry, about 200 to 300 metres below the oldest exposed Oberalm Formation rocks of the Leube open pit region, Upper Tithonian with Oberalm Formation and Barmstein Limestone was proven (Plöchinger, 1977). A huge slide block of Alpine Haselgebirge Mélange follows on top of these. The Alpine Haselgebirge Mélange is depositionally overlain by Oberalm Formation of Late Tithonian to Early Berriasian age (*Crassicollaria* Zone to Remaniella Subzone: see also Plöchinger, 1974, 1976) at the Leube quarry.

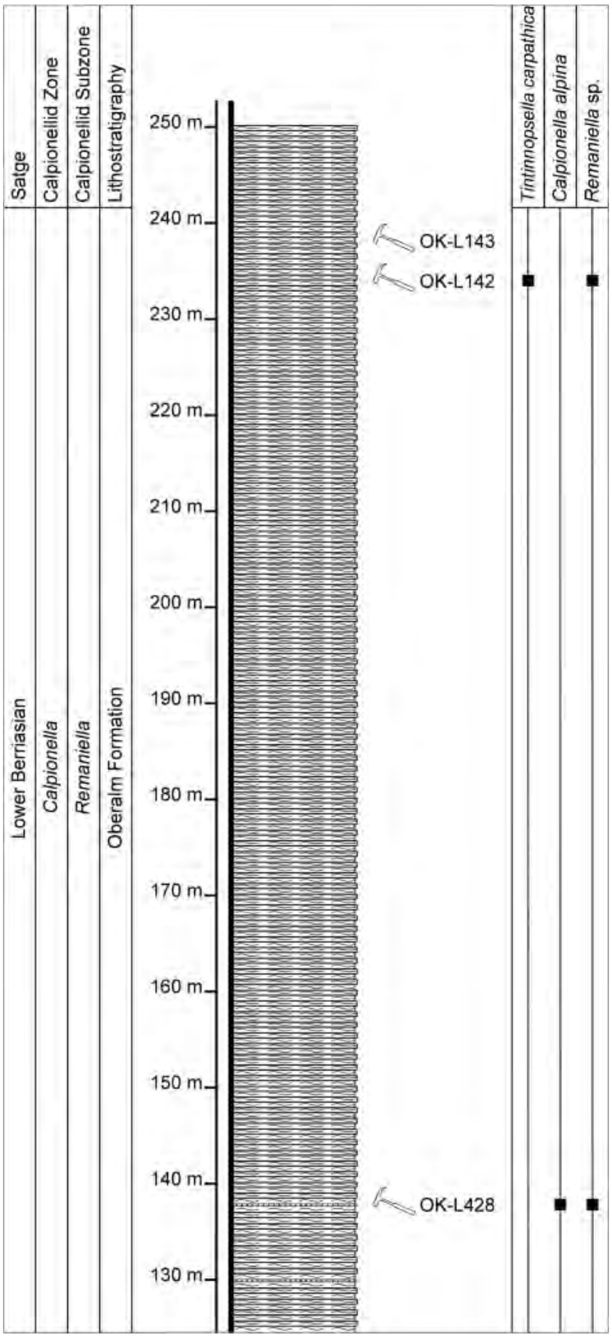


Figure 9: Detailed stratigraphy of the middle part of Profile 1.

At the surface, this basal Oberalm Formation sequence on top of the Alpine Haselgebirge Mélange is best seen in the western Schneiderwald to marginal eastern open pit, and in the subsurface in the Ottobau underground mine. At the surface the basal Oberalm Formation forms the steep limbs of the Schneiderwald Anticline (Plöchinger, 1974, 1977) whilst the subsurface proven Alpine Haselgebirge Mélange intercalation (Plöchinger, 1977) is not superficially exposed despite the intensive erosion of the anticlinal hinge area. Such massive intercalations of salt, gypsum and clay are not found in the standard Upper Tithonian Oberalm Formation successions of the Lower Tirolic unit (e.g., Gawlick et al., 2007: Fludergraben-Höherstein-Bad Ischl). Our new investigations in the proximal Trattberg-Rise realm of the Weitenau area (Fig. 1A) showed that the Alpine Haselgebirge Mélange occurrences of this region are intercalated neither in the Lower to Middle Tithonian Tauglboden Formation nor in the Upper Tithonian Oberalm Formation. Regarding this issue, the Leube quarry profile is distinctively different to all classical basin fills of the Tauglboden Basin profiles. In conclusion, we therefore interpret that the Late Jurassic to Early Cretaceous Leube succession cannot have been deposited in the Tauglboden Basin domain (e.g., Frisch and Gawlick, 2003) as one would assume from its current position. The determination of the Leube area´s palaeogeographical exact position at the time of deposition in regard to Late Jurassic basins needs further investigations.

The existence of cyclothemes of Tonflatschen breccia and Barmstein Limestone in the Upper Tithonian part of the Oberalm Formation are known since Plöchinger (1976) and herein confirmed. Plöchinger (1979, 1983, 1984) described these features also from the southern Weitenau area. These cycles, as shown in Profile 1 (Figs 6, 7), can be interpreted as the result of a backstepping Upper Jurassic carbonate platform to the south (Schlagintweit et al., 2003). The tectonically induced sedimentary Tonflatschen breccia horizons are basin wide features which need further investigations because of their great importance for the tectonic reconstruction of the Late Tithonian situation. In the Leube area, these breccia horizons are not restricted to the northern active quarry. They are also observable in the old recultivated quarry to the south (Fig. 2) where they take the same stratigraphic position and contain the same breccia components. The Upper Jurassic to Lower Cretaceous carbonate platform did not get completely drowned immediately but carbonate production continued for a substantial period as attested by the resedimented shallow-water bioclasts in the breccia and in the Barmstein Limestone.

The resedimentation processes of the Upper Tithonian to Berriasian carbonate platform ended here in this part of the basin around the Jurassic/Cretaceous boundary (Fig. 7).

Within the Oberalm Formation the change from white to green marly limestones with marly intercalations lies within the Lower Berriasian (Calpionella Zone). This is in contrast to the proposed change from the Oberalm Formation to the Schrambach Formation as investigated by Boorová et al. (1999, compare Reháková et al., 1996). Instead, the determined lithology and microfacies correlate well with Lower Berriasian limestones of the Oberalm Formation of other investigated locations. A more basinward position of the Leube quarry profile at the time of deposition explains the non-existence of resedimented allodapic limestones or Barmstein Limestone and the quantitative higher amount of greenish marl beds.

The transitional facies from Oberalm to Schrambach Formations was introduced by Boorová et al. (1999) for this part of the Leube quarry profile. The green marl beds contain only clay minerals and no siliciclastic quartz, heavy minerals or exotic components. The Lower Berriasian bedded limestone-marl part is incompatible with the definition of the Schrambach Formation as given by Tollmann (1976) and should therefore be labelled as Oberalm Formation. The higher clay content within the limestone beds indicates the ongoing erosion of the Alpine Haselgebirge Mélange and the redeposition of the fine grained clayey material within the Oberalm Formation (Gawlick et al., 2012). In contrast, exotic material from the hinterland was still shielded by the Plassen Carbonate Platform in the south and did not enter the depositional basin of the study area.

The newly described calpionellid zonation differs from the former given by Boorová et al. (1999). As known from the literature (Blau and Grün, 1997; Andreini et al., 2007), the last occurrence of crassicollarians was within the Early Berriasian *Calpionella alpina* Subzone. Afterwards, still in the Early Berriasian, the remaniellids appeared for the first time (*Remaniella* Subzone, Andreini et al., 2007). This calpionellid zonation is in concordance with the results from the Leube quarry section presented herein but is in contradiction to the calpionellid zonation of the Berriasian part of the profile introduced by Boorová et al. (1999). A major part of the very thick "Middle Berriasian" succession of Boorová et al. (1999) has to be included within the Lower Berriasian, based on the newly proven calpionellid assemblage.

The Jurassic/Cretaceous boundary cannot be exactly defined on our data basis. The last crassicollarians occur at profile metre 55 and the first remanellids at profile metre 85 (Fig. 7). Plöchinger (1976) put the boundary a little bit above the last Tonflatschen breccia horizon (Fig. 3). This is in good accordance with our data which suggest the position of the Jurassic/Cretaceous boundary as defined by calpionellids at around profile metre 80 (Fig. 7).

The lithological, microfacies and microfaunal change takes place in the upper Lower Berriasian (*Calpionella elliptica* to *Remaniella cadischiana* Subzones), still in the upper part of the calcareous Oberalm Formation. This variegated reddish-greenish limestone-marl succession from profile metre 250 to 268 (Figs 7, 10, 11) was defined as Anzenbach Formation (Plöchinger, in Matura and Summesberger, 1980) or as Anzenbach beds (Plöchinger, 1983). A detailed discussion on this topic is given in chapter 5.1.

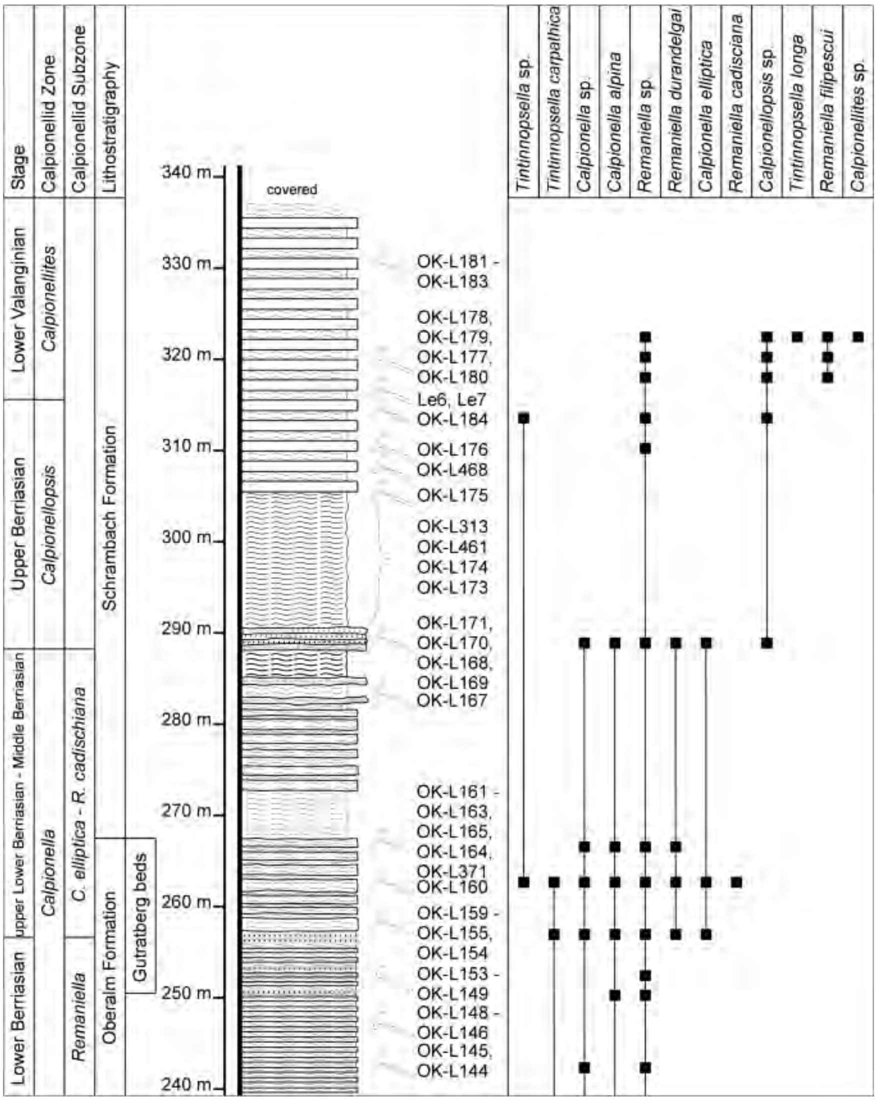


Figure 10: Detailed stratigraphy of the youngest part of Profile 1.

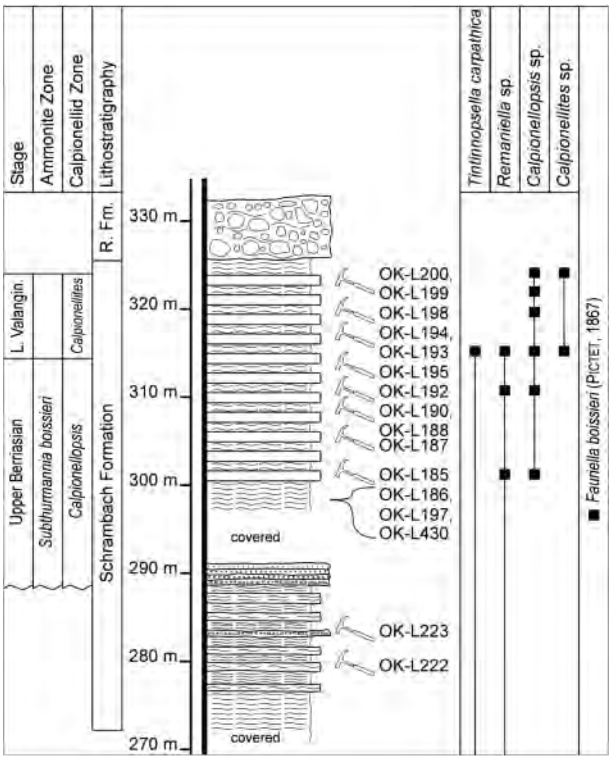


FIGURE 11: Profile 2 (Figs 2, 5) shows the middle and upper part of the Schrambach Formation including the contact to the basal Rossfeld conglomerates.

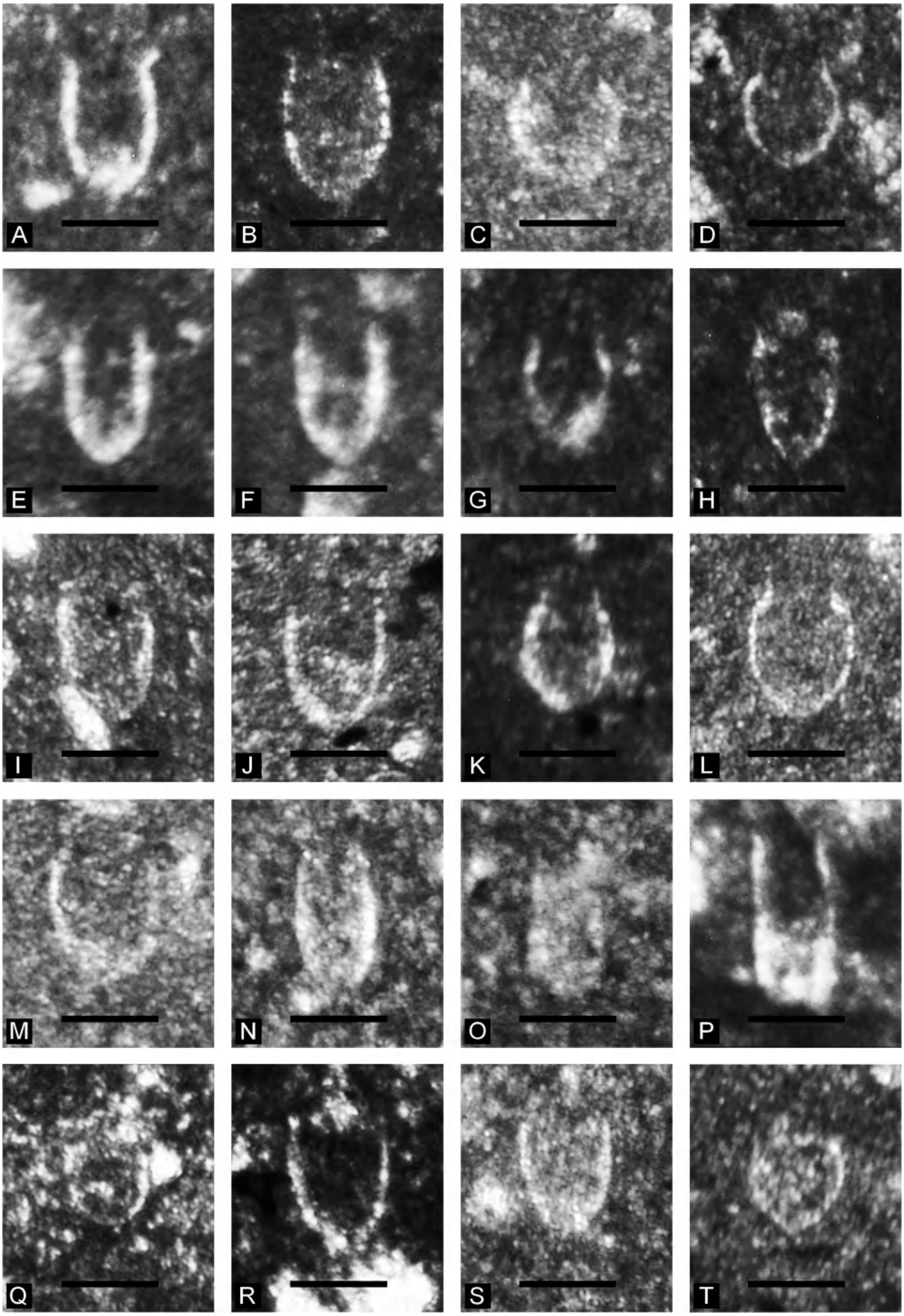
Allodapic limestone beds (Krische and Gawlick, 2010), firstly in detail described by Boorová et al. (1999), occur in Profile 1 within the uppermost Middle Berriasian and the lower Upper Berriasian ammonite moulds bearing marls (*Calpionellopsis* Zone) (Fig. 10). Our results show that the allodapic limestones are still part of the Schrambach Formation (Figs 5, 10). A similar situation is found in Profile 2 (Fig. 11). The component spectrum of the allodapic limestones is mainly composed by carbonatic lithoclasts and bioclastic material. The occurrence of crinoids, foraminifers and micrite clasts in the Upper Berriasian basinal succession shows that a newly evolving shallow-water carbonate area still influenced the deposition of these strata (Krische and Gawlick, 2010). Such resedimented limestone beds are known also from the Weitenau and Bad Ischl areas (own data). The shallow-water bioclasts prove that parts of the Upper Jurassic to Lower Cretaceous carbonate platform were not fully drowned until the Middle and earliest Late Berriasian or that a new shallow-water carbonate producing area was evolving at that time (e.g., Munella Carbonate Platform: Schlagintweit et al., 2008, 2012a). Above these graded carbonate limestone beds, marls with plant debris and some ammonite fragments of the Schrambach Formation appear again. The Late Berriasian age of the limestone-marl sequence is confirmed by calpionellids and ammonites (*Calpionellopsis* Zone; *Subthurmannia boissieri* Zone).

The Upper Berriasian/Lower Valanginian boundary is positioned within the bedded limestone-marl succession (Figs 10, 11) of the Schrambach Formation, based on the co-occurrence of *Calpionellites* sp., *Remaniella filipescui* (Pop, 1994), *Tintinnopsella longa* (Colom, 1939) and *Calpionellopsis* sp. (*Calpionellites darderi* Subzone). These biostratigraphic results fit more or less with that from Boorová et al. (1999) based on *Calpionellopsis* sp. and dinoflagellates. Former descriptions of that part of the Leube quarry profile (Boorová et al., 1999) allocated this limestone-marl succession to the Lower Rossfeld Formation. Lithology, microfacies and biostratigraphy of these rocks differ completely from those of the Lower Rossfeld Formation described in the literature (e.g., Weber, 1942; Plöchinger, 1955; Pichler, 1963; Faupl and Tollmann, 1979). They can, however, be correlated with corresponding rocks from the Weitenau, Bad Ischl and from the Schrambachgraben-Rossfeld area and are thus defined as part of the Schrambach Formation. These bedded limestones with shallow-water bioclasts prove that a shallow-water carbonate area still effectively influenced Late Berriasian to Early Valanginian (or even younger) deposition of the Northern Calcareous Alps. The resediment nature of these beds is clearly documented in the lithofacies of the limestones containing only minor siliciclastic grains (less than 5 %). These rocks are for sure not sandstones as commonly mentioned from the Schrambach and Rossfeld Formations of the central Northern Calcareous Alps (e.g., Weber, 1942; Plöchinger, 1955, 1968, 1983, 1990; Pichler, 1963; Faupl and Tollmann, 1979; Decker et al., 1987; Boorová et al., 1999; Rasser et al., 2003). The outcrop image in Dorner et al. (2009: p. 342, fig. 15) shows exactly this Upper Berriasian limestone-marl sequence of the Schrambach Formation and not the Oberalm Formation. The input of shallow-water material is not only a localised phenomenon of the Leube quarry area but it is a regional, basin wide feature of the central Tirolic realm also recorded in the Weitenau and Bad Ischl successions (own data).

The last calpionellids were proven in the Lower Valanginian, 3 m below the conglomerates of the Rossfeld Formation. This upper part of the limestone-marl succession cannot be resolved biostratigraphically within this study. Therefore it is not known how many metres of this Late Berriasian to Valanginian sequence are possibly missing due to the erosional force of the overlying conglomerates.

Boorová et al. (1999) showed with the help of non-calcareous dinoflagellates that the Lower to Upper Valanginian boundary is most likely 2 m below the conglomerates (Fig. 3). A Late Valanginian age of the conglomerates was described by

FIGURE 12: Calpionellids from the investigated section in the Leube open pit (thin section photographs). A, B: *Tintinnopsella carpathica* (Murgeanu-Filipescu, 1933), A: OK-L497, B: OK-L155. C, D: *Calpionella alpina* (Lorenz, 1902), C: OK-L338, D: OK-L426_1. E, F: *Crassicollaria massutiniana* (Colom, 1948), E: OK-L487, F: OK-L423. G, H: *Crassicollaria intermedia* (Durand-Delga, 1957), G: OK-L497, H: OK-L423. I, J: *Remaniella duranddelgai* (Pop, 1996), I: OK-L155, J: OK-L155. K, L: *Calpionella elliptica* (Cadisch, 1932), K: OK-L155, L: OK-L160_3. M: *Remaniella cadischiana* (Colom, 1948), OK-L160_3. N, O: *Calpionellopsis* sp., N: OK-L198, O: OK-L200. P: *Tintinnopsella longa* (Colom, 1939), OK-L179. Q: *Remaniella filipescui* (Pop, 1994), OK-L177_3. R-T: *Calpionellites* sp., R: OK-L179, S: OK-L193_2, T: OK-L199. Scale bar is 50 µm.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T

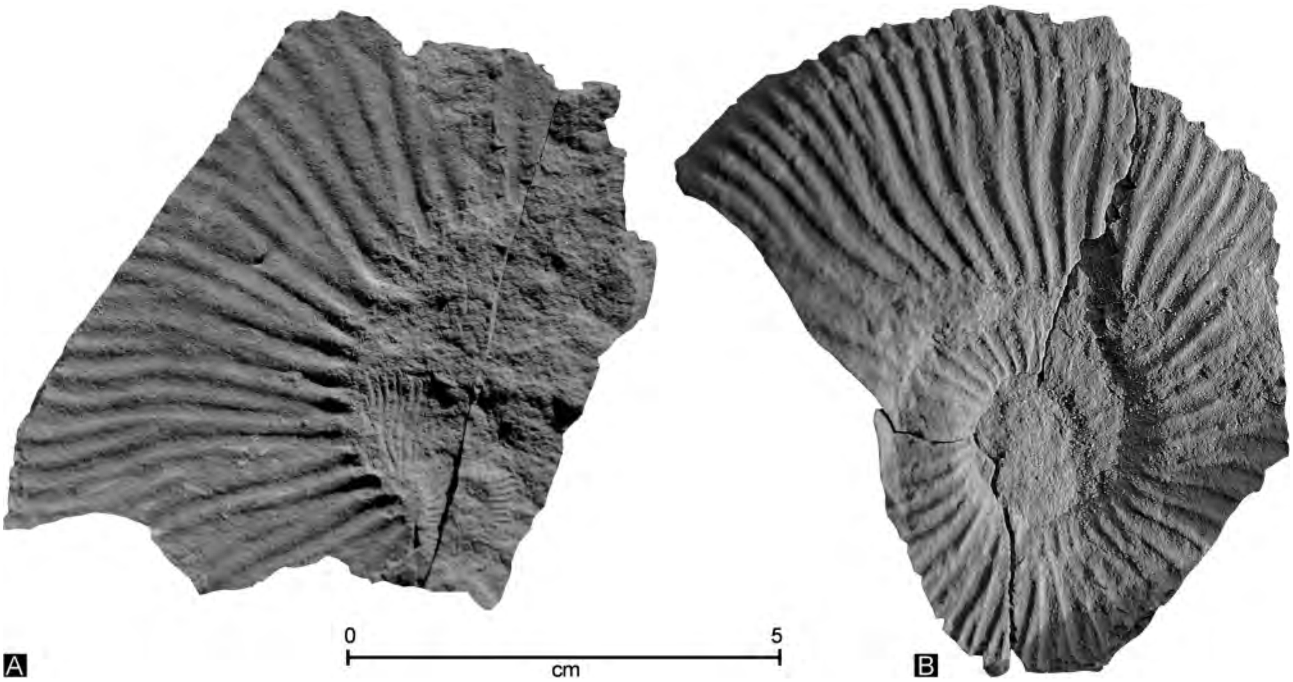


Figure 13: Two indicative ammonite fragments (print of the internal moulds) from the investigated section in the Leube open pit. A: *Fauriella boissieri* (Pictet, 1867), OK-L197. B: *Berriasella* (Berriasella) *calisto* (d´Orbigny, 1850), OK-L475.

Pichler (1963) whilst a Hauterivian age was mentioned by Plöchinger (1974). Foraminifera studies carried out by Weidich (1990) and Hradecká (2003) indicated a Valanginian to Hauterivian age - a Barremian age, however, cannot be definitely excluded. Dinoflagellate dating by Boorová et al. (1999) yielded a Late Valanginian age for the mud-flows ("Rosinenmergel") of the Rossfeld conglomerate and a possible Hauterivian age for the higher parts of the conglomerate beds.

The upper part of the Leube quarry section outcrops at the western Hangendenstein and at the Köppelschneid. The Late Hauterivian age of these rocks is based on ammonite data (Immel, 1987). The overlying Upper Barremian to Lower Aptian orbitolinid bearing arenites (Schlagintweit et al., 2012b) set the upper sedimentation age limit for the Rossfeld conglomerate of the Leube quarry section.

In conclusion, the onset of the conglomerate deposition cannot be dated exactly by means of the underlying limestone-marl succession. Integrating the ammonite data from Bad Ischl, a Late Valanginian age between the *Saynoceras verrucosum* Zone and the *Criosarasinella furcillata* Subzone (Lukeneder, 2005; own data) of the basal conglomerate beds seems most likely. This interpretation fits well with the main sea-level curve of Gradstein et al. (2004). After a main sea-level lowstand within the *Busnardoites campylotoxus* Zone, the basal Rossfeld conglomerates were deposited during the next sea-level rise from the *Saynoceras verrucosum* ammonite zone upwards (Rasser et al., 2003).

5.1 The Anzenbach-problem of the Tirolic realm

Variegated brown, purple to reddish, siliceous to slaty, marly limestones and brown, slaty, marly limestones of Berriasian age where described by Geyer (1909) from outcrops in the Reichraming region (Upper Austria). They overlie reddish Tithonian limestones with sedimentary contact. From other outcrops of that area, reddish to green, slaty, clayey marls and brown-grey to red marly slates were documented. They rest on top of the "Neocomian" Aptychi Limestone and are intercalated within the limestones or replace them within the sedimentary succession. Therefore, Geyer (1909) described two different levels of these variegated "Neocomian" rocks. Trauth (1954) investigated greenish to red marly slates within profiles of the Waidhofen area (Lower Austria). Ammonite data showed a Valanginian to Hauterivian age for these rocks. They overlie marly limestones of Berriasian age and are themselves overlain by fine-sandy marly slates and sandstones. Trauth (1954) correlated these rocks from the Waidhofen realm with those from the Reichraming area and called them Anzenbach beds (see Rasser et al., 2003). These Anzenbach beds were defined afterwards by Tollmann (1976) as the uppermost part of the Schrambach Formation, just below the Rossfeld Formation. This definition, specified in the Bavaric unit of the eastern Northern Calcareous Alps, was assigned to other Early Cretaceous occurrences of variegated limestone-marl beds within the Tirolic realm of the central Northern Calcareous Alps (Einbergalm, Moosbergalm: Plöchinger, 1982). The reddish-greenish marly limestone beds of the Leube quarry profile were also defined as Anzenbach Formation (Plöchinger: in Matura and Summesberger, 1980) or Anzenbach beds (Plöchinger, 1983), respectively.

Subsequently, all younger investigations and interpretations were based on, and referred to this definition. Further on, the greenish, stratified limestone-marl succession was interpreted as Schrambach Formation (Boorová et al., 1999), the variegated limestones and marls as Anzenbach Member (Plöchinger: in Matura and Summesberger, 1980; Plöchinger, 1983; Boorová et al., 1999) and the overlying ammonite bearing marls together with the bedded limestone-marl succession as Lower Rossfeld Formation (Boorová et al., 1999). The Late Berriasian age of the Anzenbach beds dated by calpionellids by Boorová et al. (1999) was conspicuous. The Leube quarry profile was seen as special case, since its lithological and biostratigraphical characteristics are in poor accordance with equal-aged sections from nearby localities (e.g., Schrambachgraben: Rasser et al., 2003). The new calpionellid data clearly prove a late Early Berriasian to Middle Berriasian age of the variegated limestone and marl beds of the Leube quarry section. They do not correlate with the Anzenbach beds of the Bavaric unit as defined by Geyer (1909) and Trauth (1954). In none of the Lower Cretaceous sections of the Tirolic realm (Leube quarry, Weitenau, Bad Ischl, Schrambachgraben: compare Rasser et al., 2003) there are red to green limestone and marl beds at the boundary between the Valanginian to Hauterivian Schrambach and Rossfeld Formations. Thus the marly and slaty Anzenbach beds of the Bavaric realm cannot be stratigraphically correlated with the variegated limestone and marl succession of the Tirolic realm neither from their biostratigraphic range nor from their lithology. As a consequence, the new name Gutratberg beds is introduced for these rocks forming the topmost part of the Oberalm Formation.

In the Leube quarry section clearly both microfacies and lithology change within the upper Lower Berriasian to Middle Berriasian succession. The carbonate content decreases and the fine grained siliciclastic content increases permanently with detrital quartz, apatite and garnet becoming more frequent. The siliciclastic input led to a decreased carbonate production of the shallow-water platform and its drowning beginning in the late Early Berriasian. This development correlates well with the evolution of the Plassen Carbonate Platform to the south (Gawlick and Schlagintweit, 2006). At Mount Plassen (Fig. 1A) the hemipelagic calpionellid limestones on top of the type-locality Plassen Formation are Late Berriasian in age (Calpionellopsis Zone: Gawlick and Schlagintweit, 2006).

In comparison to this, the Leube quarry profile was deposited in a more basinward position with more continuous conditions and thus the lithological change was less prominent. In the meantime drowning and successive backstepping of the carbonate platform took place, starting in the late Early Berriasian. According to the new data from the basinal sequences it seems most plausible that the shallow-water carbonate platform sedimentation continued until the end of the Middle Berriasian and was then replaced by the hemipelagic deposition of the Upper Berriasian drowning sequence. An alternative possibility, which must be taken into account, is the existence of depositional gaps between the Lower Berriasian shallow-water limestones and the Upper Berriasian hemipelagic sedimentary rocks. Based on the new data, the uppermost part of the Oberalm Formation, i.e. the newly introduced Gutratberg beds, can be correlated with the drowning sequence of the Plassen Carbonate Platform. The same basinal features are known from the Weitenau (see Plöchinger, 1990; own data) and Bad Ischl areas. The Gutratberg beds constitute the transitional series from the calcareous Oberalm Formation to the siliciclastic Schrambach Formation which is represented by ammonite bearing marls at the Leube quarry section. Consequently, a formalisation of the Gutratsberg beds as a member of the Oberalm Formation is suggested.

6. Conclusions

On the basis of our investigations the following overall results and conclusions can be drawn:

1) The Leube quarry profile can be exactly dated with calpionellids. The unravelling of the Upper Berriasian sequence is supported by ammonite occurrences.
2) Four calpionellid zones and five subzones from the *Crassicollaria intermedia* Subzone of the Upper Tithonian to the *Calpionellites darderi* Subzone of the Lower Valanginian are biostratigraphically approved. Based on the new calpionellid and ammonite data, the calpionellid zonation of Boorová et al. (1999) is revised.
3) The presence of the Upper Berriasian *Subthurmannia boissieri* ammonite Zone supports the calpionellid biostratigraphic investigations.
4) The formerly introduced Anzenbach beds or Anzenbach Formation within the Leube quarry standard profile do not correlate with the original description given in the literature. Uppermost Lower Berriasian to Middle Berriasian variegated reddish-green limestone-marl successions within the uppermost part of the Oberalm Formation should be termed as Gutratberg beds. Formalization of these beds as a member of the Upper Tithonian to Lower Berriasian Oberalm Formation, forming its uppermost part, is required.
5) The Early Cretaceous basin sedimentary evolution mirrors the stepwise drowning of a carbonate platform due to increasing siliciclastic input as seen by means of provenance analyses of the grains in the intercalated resediments.
6) Biostratigraphy in basin sediments, combined with component/provenance analyses of intercalated resediments, allows a detailed reconstruction of eroded hinterlands.

Concerning the geodynamic evolution of the central Northern Calcareous Alps the following aspects are concluded from the Leube quarry investigations:

A) Calpionellid biostratigraphy compared with ammonite data and complemented with findings from sedimentary, lithological and microfacies analyses, entails a redefinition of the occurring formations and a new interpretation of the sedimentological history and the geodynamic background.
B) The occurrences of allodapic limestone beds in the Upper Berriasian and of bedded limestone turbidites in the Upper Berriasian to Lower Valanginian - after the drowning of the Plassen Carbonate Platform to the south - is for the first time described from the central Tirolic unit of the Northern Calcareous Alps. This resedimented shallow-water material indicates a shallow-water carbonate producing area

close to the hemipelagic basins of the Northern Calcareous Alps at that time (e.g., Munella Carbonate Platform: Schlagintweit et al., 2008, 2012a).

C) The lithological and stratigraphical range for the main exploitation target at the Leube quarry is now well defined. Main resource rocks for the cement production are the greenish marly limestones. With a base at the Jurassic/Cretaceous boundary (Lower Berriasian Oberalm Formation) they reach up to the Middle Berriasian where the best quality is met at the Portland cement layer (Gutratberg beds of the Oberalm Formation).

D) The entire sedimentary geodynamic histories of both basins and adjacent shallow-water carbonate platforms are only preserved in complete hemipelagic basin sequences. The analysis of such sequences is a powerful tool as it sheds new light on the overall tectono-stratigraphic evolution.

Acknowledgements

We gratefully thank Dipl. Ing. Johannes Theiss for work permission in the quarry and guidance in the underground mine. Constructive and helpful suggestions from Michael Wagreich, Vienna, and an anonymous reviewer are gratefully acknowledged. Special thanks to the ammonite searching groups 2008, 2009 and 2010: Sigrid Missoni, Olga Piros, Géza Császár, Volker Diersche, Igor Vlahović, Stefan Neumeister, Balázs Szinger and Gerd Winterleitner. This research was supported by the UZAG programme of Styria, the Montanuniversität Leoben and the Akció Foundation (Austria-Hungary 2010-2011: project number 74oeu5). We acknowledge the field support and continuous encouragement of Prof. Géza Császár (Budapest/Hungary).

References

Andreini, G., Caracuel, J.E. and Parisi, G., 2007. Calpionellid biostratigraphy of the Upper Tithonian-Upper Valanginian interval in Western Sicily (Italy). Swiss Journal of Geosciences, 100, 179-198.

Auer, M., Gawlick, H.-J., Suzuki, H. and Schlagintweit, F., 2009. Spatial and temporal development of siliceous basin and shallow-water carbonate sedimentation in Oxfordian Northern Calcareous Alps. Facies, 55, 63-87.

Blau, J. and Grün, B., 1997. LateJurassic/Early Cretaceous revised calpionellid zonal and subzonal division and correlation with ammonite and absolute time scales. Mineralia Slovaca, 29, 297-300.

Bodrogi, I., Draxler, I., Filacz, E. and Lobitzer, H., with contributions from Stradner, H., Egger, H., Surenian, R., Sachsenhofer, R. F., Knauer, J. and 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. Unpublished manuscript, 31 pp.

Boorová, D., Lobitzer, H., Skupien, P. and 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, 273-318.

Bujtor, L., Krische, O. and 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, 267/3, 273-295.

Company, M., 1987. Los Ammonites del Valanginiense del sector oriental de las Cordilleras Béticas (SE de Espana). Thése Universidad de Granada, Granada, 294 pp.

Decker, K., Faupl, P. and Müller, A., 1987. Synorogenic Sedimentation on the Northern Calcareous Alps during the Early Cretaceous. In: Flügel, H.W. and Faupl, P.(eds.), Geodynamics of the Eastern Alps, pp. 126-141.

Dorner, R., Höfling, R. and Lobitzer, H., 2009. Nördliche Kalkalpen in der Umgebung Salzburgs (Exkursion H am 17. April 2009). Jahresberichte Mitteilungen Oberrheinischer Geologischer Verein, NF 91, 317-366.

Faupl, P. and Tollmann, A., 1979. Die Roßfeldschichten: Ein Beispiel für Sedimentation im Bereich einer tektonisch aktiven Tiefseerinne aus der kalkalpinen Unterkreide. Geologische Rundschau, 68/1, 93-120.

Frank, W. and Schlager, W., 2006. Jurassic strike slip versus subduction in the Eastern Alps. International Journal of Earth Sciences, 95/3, 431-450.

Frisch, W. and 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, 712-727.

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, Wien, 34 pp.

Gawlick, H.-J., 2000. Die Radiolaritbecken in den Nördlichen Kalkalpen (hoher Mittel-Jura, Ober-Jura). Exkursionsführer Sediment 2000, Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Österreich, 44, 97-156.

Gawlick, H.-J. and 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.

Gawlick, H.-J. and Schlagintweit, F., 2010. The Drowning Sequence of Mount Bürgl in the Salzkammergut Area (Northern Calcareous Alps, Austria): Evidence for a Diachronous Late Jurassic to Early Cretaceous Drowning of the Plassen Carbonate Platform. Austrian Journal of Earth Sciences, 103/1, 58-75.

Gawlick, H.-J., Frisch, W., Vecsei, A., Steiger, T. and Böhm, F., 1999. The change from rifting to thrusting in the Northern Calcareous Alps as recorded in Jurassic sediments. Geologische Rundschau, 87, 644-657.

Gawlick, H.-J., Schlagintweit, F. and 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, 236/3, 351-421.

Gawlick, H.-J., Schlagintweit, F. and Suzuki, H., 2007. Die Ober-Jura bis Unter-Kreide Schichtfolge des Gebietes Höherstein-Sandling (Salzkammergut, Österreich) - Implikationen zur Rekonstruktion des Block-Puzzles der zentralen Nördlichen Kalkalpen, der Gliederung der Radiolaritflyschbecken und der Plassen-Karbonatplattform. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 243/1, 1-70.

Gawlick, H.-J., Missoni, S., Schlagintweit, F., Suzuki, H., Frisch, W., Krystyn, L., Blau, J. and Lein, R., 2009. Jurassic Tectonostratigraphy of the Austroalpine Domain. Journal of Alpine Geology, 50, 1-152.

Gawlick, H.-J., Missoni, S., Schlagintweit, F. and 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, 189-291.

Gradstein, F., Ogg, J. and Smith, A., 2004. A Geologic Time Scale. University Press Cambridge, Cambridge, pp. 307-383.

Geyer, G., 1909. Über die Schichtfolge und den Bau der Kalkalpen im unteren Enns- und Ybbstale. Jahrbuch der Kaiserlich - Königlichen Geologischen Reichsanstalt, 59/1, 29-100.

Hoedemaeker, Ph., Reboulet, S., Aguirre-Urreta, M.B., Alsen, P., Aoutem, M., Atrops, F., Barragán, R., Company, M., González Arreola, C., Klein, J., Lukeneder, A., Ploch, I., Raisossadat, N., Rawson, P., Vašíček, Z., Vermeulen, J. and 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.

Immel, H., 1987. Die Kreideammoniten der Nördlichen Kalkalpen. Zitteliana, 15, 3-163.

Klein, J., 2005. Lower Cretaceous Ammonites I. Perisphinctaceae 1. Himalayitidae, Olcostephanidae, Holcodiscidae, Neocomitidae, Oosterellidae. Fossilium Catalogus I: Animalia. Backhuys Publishers, Leiden, 139, 484 pp.

Krische, O. and 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, p. 60.

Krische, O., Bujtor, L., Császár, G. and Gawlick, H.-J., 2010. Ammonite stratigraphy in Early Cretaceous sedimentary rocks of the central Northern Calcareous Alps (Salzburg, Austria). Journal of Alpine Geology, 52, p. 159.

Lukenender, A., 2005. Taphonomy and stratigraphy of Early Cretaceous ammonoid mass occurrences (Late Valanginian; Northern Calcareous Alps; Upper Austria). Austrian Journal of Earth Sciences, 98, 34-51.

Lobitzer, H., Bodrogi, I. and Filácz, E., with contributions of Stradner, H. and Surenian, R., 1994. Lebensspuren der Oberalmer, Schrambach- und Roßfeld-Formation (Oberjura/Unterkreide) der Salzburger Kalkalpen. Jubiläumsschrift 20 Jahre Geologische Zusammenarbeit Österreich-Ungarn, Teil 2, 285-322, Wien/Bécs.

Matura, A. and Summesberger, H., 1980. Geology of the Eastern Alps (An excursion guide). Abhandlungen der Geologischen Bundesanstalt, 34, 103-170.

Missoni, S., 2003. Analyse der mittel- und oberjurassischen Beckenentwicklung in den Berchtesgadener Kalkalpen - Stratigraphie, Fazies und Paläogeographie. PhD Thesis, University of Leoben, Leoben, 150 pp.

Missoni, S. and 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.

Missoni, S. and 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, 57/1, 137-186.

Ortner, H., Ustaszewski, M. and Rittner, M., 2008. Late Jurassic tectonics and sedimentation: breccias in the Unken syncline, central Northern Calcareous Alps. Swiss Journal of Geosciences, 1, 55-71.

Pichler, H., 1963. Geologische Untersuchungen im Gebiet zwischen Roßfeld und Markt Schellenberg im Berchtesgadener Land. Beihefte zum Geologischen Jahrbuch, 48, 129-204.

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, XCVIII, 93-144.

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

Plöchinger, B., 1968. Die Hallstätter Deckscholle östlich von Kuchl/Salzburg und ihre in das Aptien reichende Roßfeldschichten-Unterlage. Verhandlungen der Geologischen Bundesanstalt, 1968/1-2, 80-86.

Plöchinger, B., 1974. Gravitativ transportiertes permisches Haselgebirge in den Oberalmer Schichten (Tithonium, Salzburg). Verhandlungen der Geologischen Bundesanstalt, 1974/1, 71-88.

Plöchinger, B., 1976. Die Oberalmer Schichten und die Platznahme der Hallstätter Masse in der Zone Hallein-Berchtesgaden. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 151/3, 304-324.

Plöchinger, B., 1977. Die Untersuchungsbohrung Gutrathsberg B I südlich St. Leonhard im Salzachtal (Salzburg). Verhandlungen der Geologischen Bundesanstalt, 1977/2, 3-11.

Plöchinger, B., 1979. Argumente für die intramalmische Eingleitung von Hallstätter Schollen bei Golling (Salzburg). Verhandlungen der Geologischen Bundesanstalt, 1979/2, 181-194.

Plöchinger, B., 1982. Geologische Karte der Republik Österreich 1:50.000 Erläuterungen zu Blatt 95 St. Wolfgang. Geologische Bundesanstalt, Wien, 77 pp.

Plöchinger, B., 1983. Salzburger Kalkalpen. Sammlung Geologischer Führer, 73. Borntraeger, Berlin/Stuttgart, 144 pp.

Plöchinger, B., 1984. Zum Nachweis jurassisch-kretazischer Eingleitungen von Hallstätter Gesteinsmassen beiderseits des Salzach-Quertales (Salzburg). Geologische Rundschau, 73, 293-304.

Plöchinger, B., 1990. Geologische Karte der Republik Österreich 1:50.000 Erläuterungen zu Blatt 94 Hallein. Geologische Bundesanstalt, Wien, 76 pp.

Pueyo, E.L., Mauritsch, H.J., Gawlick, H.-J., Scholger, R. and 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. and 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, pp. 193-216.

Reboulet, S., Klein, J., Barragán, R., Company, M., González-Arreola, C., Lukeneder, A., Naser Raisossadat, S., Sandoval, S., Szives, O., Tavera, J.M., Vašíček, Z. and Vermeulen, J., 2009. Report on the 3rd International Meeting of the IUGS Lower Cretaceous Ammonite Working Group, the "Kilian Group" (Vienna, Austria, 15th April 2008). Cretaceous Research, 30, 496-502.

Reháková, D., Michalik, J. and 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.

Schlagintweit, F., Gawlick, H.-J. and Lein, R., 2003. Die Plassen-Formation der Typlokalität (Salzkammergut, Österreich) - neue Daten zur Fazies, Sedimentologie und Stratigraphie. Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich, 46, 1-34.

Schlagintweit, F., Gawlick, H.-J., Missoni, S., Hoxha, L., Lein, R. and Frisch, W., 2008. The eroded Late Jurassic Kurbnesh carbonate platform in the Mirdita Ophiolite Zone of Albania and its bearing on the Jurassic orogeny of the Neotethys realm. Swiss Journal of Geosciences, 101, 125-138.

Schlagintweit, F., Gawlick, H.-J., Lein, R., Missoni, S. and Hoxha, L., 2012a. Onset of an Aptian carbonate platform overlying a Middle-Late Jurassic radiolaritic-ophiolithic mélange in the Mirdita Zone of Albania. Geologica Croatica, 65/1: 29-40.

Schlagintweit, F., Krische, O. and Gawlick, H.-J., 2012b. First findings of orbitolinids (larger benthic foraminifera) from the Early Cretaceous Rossfeld Formation (Northern Calcareous Alps, Austria). Jahrbuch der Geologischen Bundesanstalt, 152/1-4, 145-158.

Spötl, C., 1989. The Alpine Haselgebirge Formation, Northern Calcareous Alps (Austria): Permo-Scythian evaporites in an alpine thrust system. Sedimentary Geology, 65/1-2, 113-125.

Steiger, T., 1992. Systematik, Stratigraphie und Palökologie der Radiolarien des Oberjura-Unterkreide-Grenzbereiches im Osterhorn-Tirolikum (Nördliche Kalkalpen, Salzburg und Bayern). Zitteliana, 19, 188 pp.

Tollmann, A., 1976. Monographie der Nördlichen Kalkalpen. Teil II. Analyse des klassischen nordalpinen Mesozoikums. Stratigraphie, Fauna und Fazies der Nördlichen Kalkalpen. Franz Deuticke, Vienna, 580 pp.

Trauth, F. 1954. Zur Geologie des Voralpengebietes zwischen Waidhofen an der Ybbs und Steinmühl östlich von Waidhofen. Verhandlungen der Geologischen Bundesanstalt, 1954/2, 89-140.

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.

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.

Weidich, K.F., 1990. Die kalkalpine Unterkreide und ihre Foraminiferenfauna. Zitteliana, 17, 1-312.

Received: 19 June 2012
Accepted: 16 March 2013

Oliver KRISCHE[1)*)], László BUJTOR[2)] & Hans-Jürgen GAWLICK[1)]

[1)] Department of Applied Geosciences and Geophysics, Chair of Petroleum Geology, Peter-Tunner-Straße 5, 8700 Leoben, Austria;

[2)] Department of Geology, University of Pécs, 6 Ifjúság útja, H-7624 Pécs, Hungary;

[*)] Corresponding author, oliver_krische@gmx.at