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Upper Triassic Subdivisions, Zonations and Events

Meeting of the late IGCP 467 and STS

Abstracts and Excursion-Guide

September, 28th - October, 2nd, 2008
Bad Goisern (Upper Austria)

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Content

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PREFACE

The Upper Triassic (encompassing the Carnian, Norian and Rhaetian stages) constitutes that time interval which in modern eventstratigraphic terms is currently the least well known of the Triassic. Bracketed between a minor extinction event soon after its beginning and a major one at its end, there is a long time span of about 35 million years where an “overall warm and dry” climate, tectonic quiescence without major volcanic activity, and a low but relatively minor varying sea level should have provided the basis for a steady and only slowly changing evolutionary biosphere. Whether this is true or not, and how certain changes in pelagic faunas or in the palyno-record may have influenced the bio- and chronostratigraphy of that time interval, will be the task of this meeting.

The Austrian landscape “Hallstatt-Dachstein-Salzkammergut” has been designated in December 1997 as a Cultural Heritage Landscape in the UNESCO World Heritage List. For prehistoric research the 7000 years of salt mining and settlement are unique in the world. But also for Earth Sciences the Salzkammergut offers considerable contributions: it contains the world most diverse Norian-Rhaetian low palaeolatitude invertebrate faunas (cephalopods, bivalves, gastropods, brachiopods, reefal organisms) which are found in both shallow carbonatic environments of the Dachstein Limestone and in the pelagic deep(er) water environments of the Hallstatt facies. Therefore the Austrian Salzkammergut seems to be the right place for such a meeting.

This final meeting of the late IGCP Project 467 (“Triassic Time”) is dedicated to three persons: - firstly to E. v. MOJSISOVICS (1839-1907), the pioneer of the study of Upper Triassic ammonoids in Austria and adjacent regions whose 100th death anniversary has just passed by; secondly to H. ZAPFE (1913-1996) who revived successfully Triassic research in Austria after a long 40 years break following the World War I and, finally, to E. T. TOZER who has made tremendous contributions to our understanding of Triassic biochronology and Panthalassan ammonoid evolution within the last decades.

Our thanks are due to the Community of Bad Goisern and the Studienzentrum BASIS (Dr. Michael Kurz) for the generous provision of the infrastructure, and the Commission for Stratigraphy of the Austrian Academy of Science and ICS/Subcommission of Triassic Stratigraphy for financial support. The Geological Survey of Austria and the Department of Palaeontology/Vienna University provided organisational and logistic support for the meeting, the Austrian Bundesforste are thanked for allowing long-time access to their forest roads.

Leopold KRYSTYN

STRATIGRAPHIC SIGNIFICANCE OF THE AMMONOID FAMILY *ARCESTIDAE* AROUND THE NORIAN/RHAETIAN BOUNDARY

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Based on new stratigraphically detailed sampling (from Austria and Timor) and analyses of classical Hallstatt collections a refined and more detailed NRB stratigraphy of ammonoids of the family Arcestidae is presented. This fossil group is of particular importance as it occurs in high abundance in pelagic LPL faunas and is also represented in relatively shallow water deposits such as crinoidal and reefal limestones allowing there a more accurate stratigraphic datation. Within the NRB internal three arcestid genera occur: *Arcestes, Stenarcestes* and *Rhaetites* – the latter is a rapid evolutionary offshoot of *Arcestes* appearing slightly below the NRB. The three genera can be distinguished on the basis of certain shell characters (umbilical width, constriction lining, form of adult body chamber and aperture) which will be discussed.

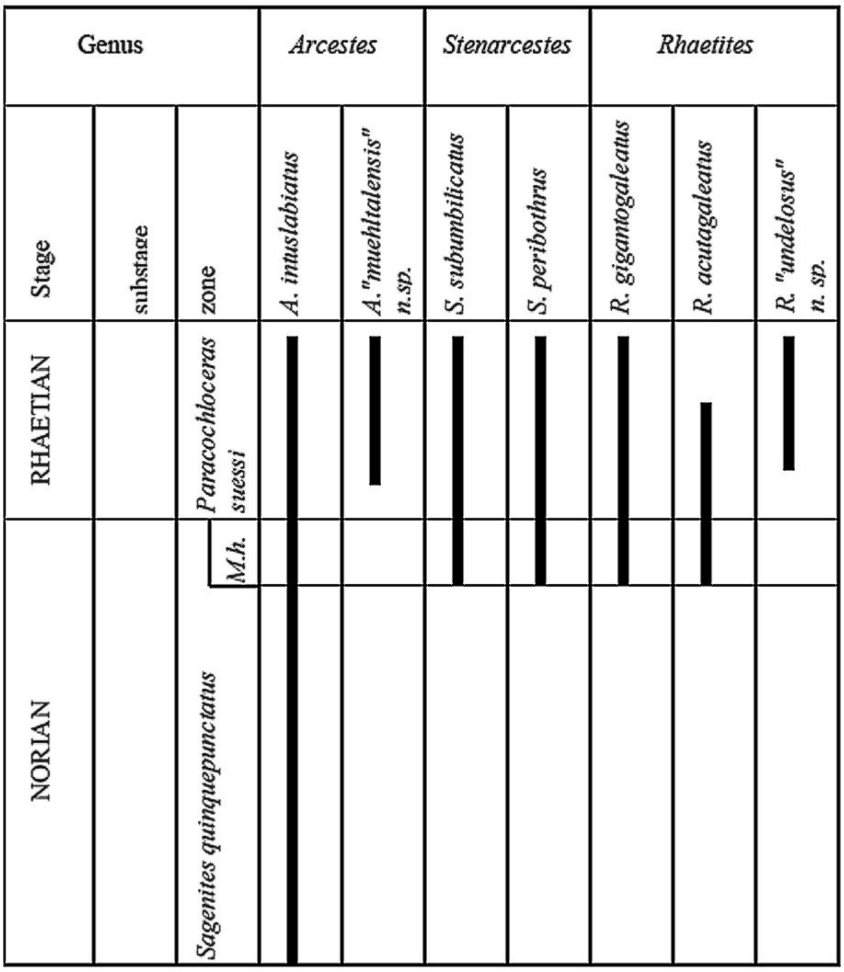

Fig. 1:
Tethyan ranges of selected Arcestids around the Norian-Rhaetian boundary.

Arcestes s. str. shows no significant changes around the NRB but is represented in the lower Rhaetian by a new form with a trumpet-shaped aperture that will be described as *A. muehltalensis* n. sp. after its type locality. The genus *Stenarcestes* develops two new forms around the NRB, *S. subumbilicatus* and *S. peribrotheus*, both with very distinct and easily identifiable adult body form. Of specific interest is the development of giant arcestids (till 30 cm in diameter) with a unique, externally sharpened body chamber of the "*A. galeati*" group of MOJOSISOVIC. This group recalls the genus *Rhaetites* and consists of three species that appear closely below (*R. gigantogaleatus*, *R. acutogaleatus*) and above the NRB (*Rhaetites "undelosus*" n. sp.).

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AN AMMONOID-CALIBRATED TETHYAN CONODONT TIME SCALE OF THE LATE UPPER TRIASSIC

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A refined conodont biochronolgy is presented for the late Middle Norian to the top of the Triassic of Tethyan pelagic sequences between the Alps and Timor. This conodont scale is intercalibrated with ammonoid zones of the Rhaetian and Norian stage and respective substages. Ammonoid-controlled early to middle Norian pelagic sequences are rather rare and in the Hallstatt facies often condensed (Austria, Oman, Timor) and incomplete or synsedimentary disturbed (Slovakia). A well documented and expanded conodont record from Austria, Turkey, Oman and Timor starts in the late Middle Norian *Halorites macer* Z. where at the base epigondolellids with still large platforms resembling *Epigondolella abneptis* (HUCKRIEDE) occur. In the upper part of this zone a rapid evolution takes place towards smaller forms with reduced platform leading to *Epigondolella vrielyncki* KOZUR and, in the very top of the *macer* Z. to bidentate forms. Those resemble *Epigondolella bidentata* but are distinguished by a higher posterior carina and more distal located "platform". The *macer* Z. is further recognizable by two very distinct epigondolellids with in lateral view a wall-like carina with an abrupt, step-wise posterior drop in front of the main denticle. Originally united in *Epigondolella slovakensis* KOZUR, they have been recently splitted in *E. slovakensis* (=s. str.) and *E. praeslovakensis* KOZUR, MASSET and MOIX on the basis of differences in the outline of the posterior keel. Both species appear together at the base of the *macer* Z. in Timor but may differ in their total range as *E. praeslovakensis* may be restricted to this zone whereas *E. slovakensis* ranges up to the lower Rhaetian, but is a rare and sporadic companion in pelagic faunas.

The Upper Norian *Sagenites quinquepunctatus* Z. is characterized by *Epigondolella bidentata* MOSHER and sporadically *E. englandi* ORCHARD, further accompanied by *E. mosheri* KOZUR in the upper half of this zone. The very top of the *quinquepunctatus* Z. is coeval to a conodont interval defined by the co-occurrence of *E. bidentata*, rare *Misikella hernsteini* MOSTLER and/*or Oncodella paucidentata* MOSTLER.

The Norian-Rhaetian boundary (NRB) has now been defined as the FAD of *M. posthernsteini* and is in ammonoid controlled sections (Austria, Oman) also recognized by a distinct frequence increase of *M. hernsteini* on the expense of *E. bidentata.* A first and short interval in the lower *Paracochloceras suessi* Z. shows still common epigondolellas of late Norian type together with *M. hernsteini,* rare *M. posthernsteini* and single *M. koessenensis* which appear around the NRB. Platform decrease and size reduction in *E. bidentata* during the upper *P. suessi* Z. leads to a predominance of small platform-less parvigondolellid forms in many pelagic sequences including the Hallstatt facies. Those forms have been named *Parvigondolella andrusovi* KOZUR & MOCK or *Parvigondolella lata* KOZUR & MOCK and are described as diagnostic for a time interval younger than that of *E. bidentata.* They are here called as *E. bidentata* juv. and co-occur in *E. bidentata* favourable facies throughout the *suessi*-Z. together.

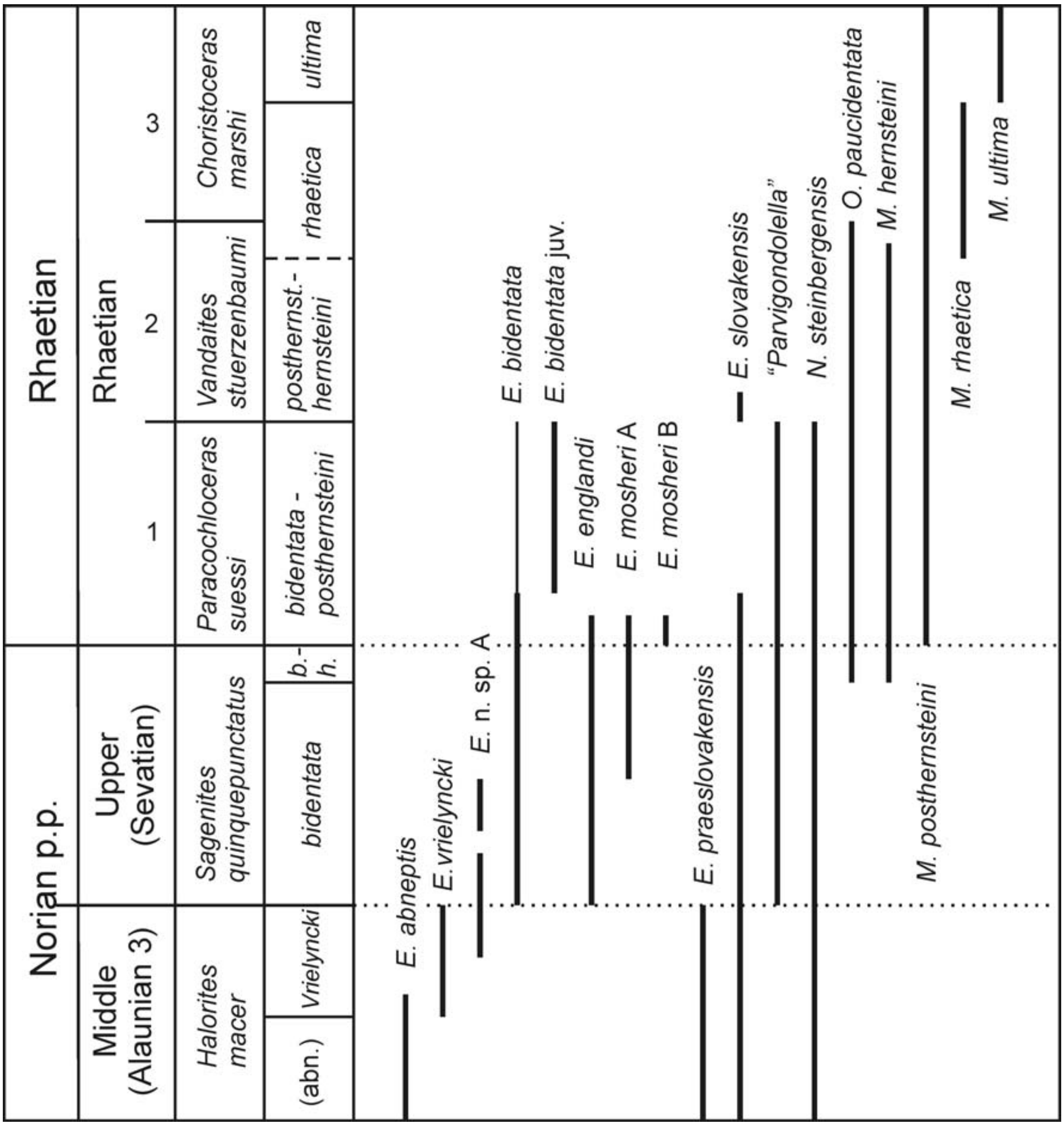

Fig.1: An ammonoid-calibrated Tethyan conodont time scale of the late Upper Triassic

The base of the *Vandaites stuerzenbaumi* Z. corresponds to the last occurrence (LO) of *E. bidentata* s.l. and shows a distinct frequency change in the represented misikellids, with *M. posthernsteini* now clearly dominating *M. hernsteini* by a ratio of 2:1 to 10:1. This conodont association characterizes a major part of the *V. stuerzenbaumi* Z. and is replaced in its top by another *Misikella* interval based on the appearance of *M. rhaetica* MOSTLER. The latter species reaches up into the lower *Choristoceras marshi* Z. as demonstrated in ammonoid bearing sections of the Zlambach and Eiberg basins in Austria.

Two *Misikella* range zones finally mark the top of the Triassic in Austria: the *M. rhaetica* R. Z. in the middle and the *M. ultima* R. Z. in the upper *marshi* Zone. Since the conodont record ends with *M. ultima* in carbonatic sequences and the topmost terrigenous Triassic above is devoid of conodonts in Austria, a post-*ultima* conodont interval as described from Hungary is missing but its existence can not be excluded.

HOW MANY TETHYAN TRIASSIC OCEANS?

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In recent years the number of independent oceanic basins within the Western Tethys has considerably increased. From an originally single Western Tethys ocean (LAUBSCHER 1971, BERNOULLI & LAUBSCHER 1972), especially STAMPFLI and collaborators (STAMPFLI et al. 1991, 1999, STAMPFLI & KOZUR 2006, STAMPFLI in MOIX et al. 2008) have introduced a system of at least four, more or less parallel E-W directed oceanic basins with intermediate small ribbon-continental blocks. These from Ladinian time onward existing oceans are from north to south the Meliata-, Maliac-, Pindos- and Neotethys oceans and are described to represent highly individual Triassic histories in space and time.

Starting from critical key areas for this concept we discuss its strength as well weakness and its reliability. Based on facial and tectonic considerations we see no reasons for this multiple splitting of the oceanic Western Tethys end and present arguments for combining at least the Meliata- and the Maliac ocean as well as the Pindos- and the Neotethys ocean into single oceans. Following the concept of SCHMID et al. (2008) and GAWLICK et al. (2008) for a far distance westward transport of the Pindos ophiolites in combination with their later complicated deformational history in their present place, (VAMVAKA et al. 2006), all western Tethys remnants of oceanic crust would fit in a single ocean paleogeography as classically supposed.

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An integrated palaeontological, geochemical & palynological study of the Rhaetian Zlambach marls in the Northern Calcareous Alps (Austria)

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The end-Triassic mass extinction event is regarded as one of the big five extinctions in the Phanerozoic. The cause and nature of this event is controversially discussed as one side favors a single catastrophic event while others favor a prolonged period of biotic turnovers throughout the Late Triassic. The “Kleine Zlambach” section near Bad Goisern (Salzkammergut, Austria) is one of the classical Rhaetian outcrops in the Northern Calcareous Alps where the top of the underlying Norian Pötschen limestone and the Zlambach marls are exposed. On the basis of ammonoid and conodonts this interval can be assigned to the early (“Sevatian 2”) – middle Rhaetian.

Throughout the section the pollen and spore assemblages are dominated by *Granuloperculatipollis rudis, Classopollis meyeriana, C. torosus,* and *Ovalipollis pseudoalatus*. Accompanying elements are *Rhaetipollis germanicus, Ricciisporites tuberculatus,* and *Tsugaepollenites pseudomassuleae*. In the lower part of the Zlambach marls *Enzonalasporites vigens, Vallasporites ignacii, Patinasporites toralis, Ellipsovelatisporites rugosus,* Partitisporites and Triadispora are present, while higher up in the section new elements, such as Chasmatosporites, *Quadraeculina anaeliformis, Limbosporites lundbladii* enter the record. These sporomorph assemblages correlate with the transition between the TL and LR concurrent-range zones of MORBEY (1975) within the Karparthian facies of the Koessen beds in the Kendelbach section. The same palynofloral turnover is also easily recognizable in the Germanic Triassic basin within the Exter Formation at the transition between the Postera and Contorta beds and in the Danish North-Sea sector (e.g. LUND, 1977, 2003).

Intriguingly, the marine organic-walled phytoplankton record shows a significant increase in abundance which reflects the mid-Rhaetian transgression. A concurrent acme of dinoflagellate cysts (Rhaetogonyaulax, Noricysta, Heibergella) at the maximum is further time-correlative to a very prominent ammonoid boundary with the additional FO of Cycloceltites, Vandaites and “Choristoceras” (s. l.) as well as the disappearance of Sagenites, Dionites and Pinacoceras. Other important bio-events are the appearance of the cosmopolitan bivalve Otapiria and the demise of the classical Dachstein barrier reefs of the western Tethys. The studied section is characterized by a long-term trend to more positive O - and C – isotopes values superimposed by several minor cycles.

We discuss the biostratigraphic, palaeo-environmental and palaeogeographical meaning of this important intra-Rhaetian event.

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TAXONOMY AND STRATIGRAPHY OF THE UPPER TRIASSIC HETEROMORPHIC AMMONOIDS: PRELIMINARY RESULTS FROM AUSTRIA

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Rhaetian strata in Austria are known to contain common heteromorphic ammonoids in the Eiberg basin of the Koessen beds and the Zlambach Formation of the Hallstatt zone. The Zlambach Fm. comprises a more than 100m thick continuous marine succession from the lower to middle and upper Rhaetian, consisting of alternating deeper water limestones and upward increasing marls. The well exposed sections at the Kleiner Zlambach-, Leislingbach- and Rossmoos creek near Bad Goisern (Salzkammergut, Upper Austria) are classical outcrops of the Rhaetian stage in the Northern Calcareous Alps with continuous outcrops throughout most of this time interval. The Zlambach Fm. may also be the richest source of heteromorphic Triassic ammonoids in the world. The present study of the ammonoid fauna has delivered new material of *Paracochloceras suessi, Choristoceras haueri, Vandaites stuerzenbaumi, Vandaites saximontanus* and *Choristoceras marshi* and supplied partly surprising stratigraphic results. One unpleasant surprise is the partial overlap of the ranges of *Paracochloceras* versus *Vandaites* and "*Choristoceras*" *haueri* (Fig. 1). Another is the stratigraphic low occurrence of *Ch. marshi,* wholly overlapping with *Ch. ammonitiforme.* The longer Zlambach range of *Paracochloceras* compared to that in the Hallstatt limestone is a presently unsolved question. Another important topic is the origin of *Paracochloceras* which appears rather abruptly and in great abundance at the bas of the Rhaetian during a time interval where widespread formation of submarine fissures created a specific biotop for the genus. Its appearance could therefore be environmentally controlled.

Of biochronological importance for the ammonoid zonation of the Rhaetian are three results:

1) "*Choristoceras*" *haueri* has a geographically restricted occurrence and is endemic to the Zlambach Formation. It makes no sense to use it as index for an ammonoid standard zone. This zone should nominally be replaced by *Vandaites stuerzenbaumi*, a genus with worldwide distribution within the tropical belt.

2) The *Vandaites stuerzenbaumi* Zone can be subdivided in two subzones based on *V. saximontanus* and *V. stuerzenbaumi* above. The *saximontanus* level is recorded in the Hallstatt limestone of Steinbergkogel and in sequence with the *stuerzenbaumi* Subzone in the Kleiner Zlambach.

3) The earlier propagated subzonal division of the *Choristoceras marshi* Z. is neither in the Koessen nor the Zlambach Fm. justified because *Ch. marshi* appears timely coincident with *Ch. Ammonitiforme*, but is very rare at the beginning. *Choristoceras ammonitiforme* disappears in well before the top of Triassic and may be used as local acme zone in the lower *marshi* Zone. None of the recently described *Choristoceras* species from Tibet or North America have been found in Austria.

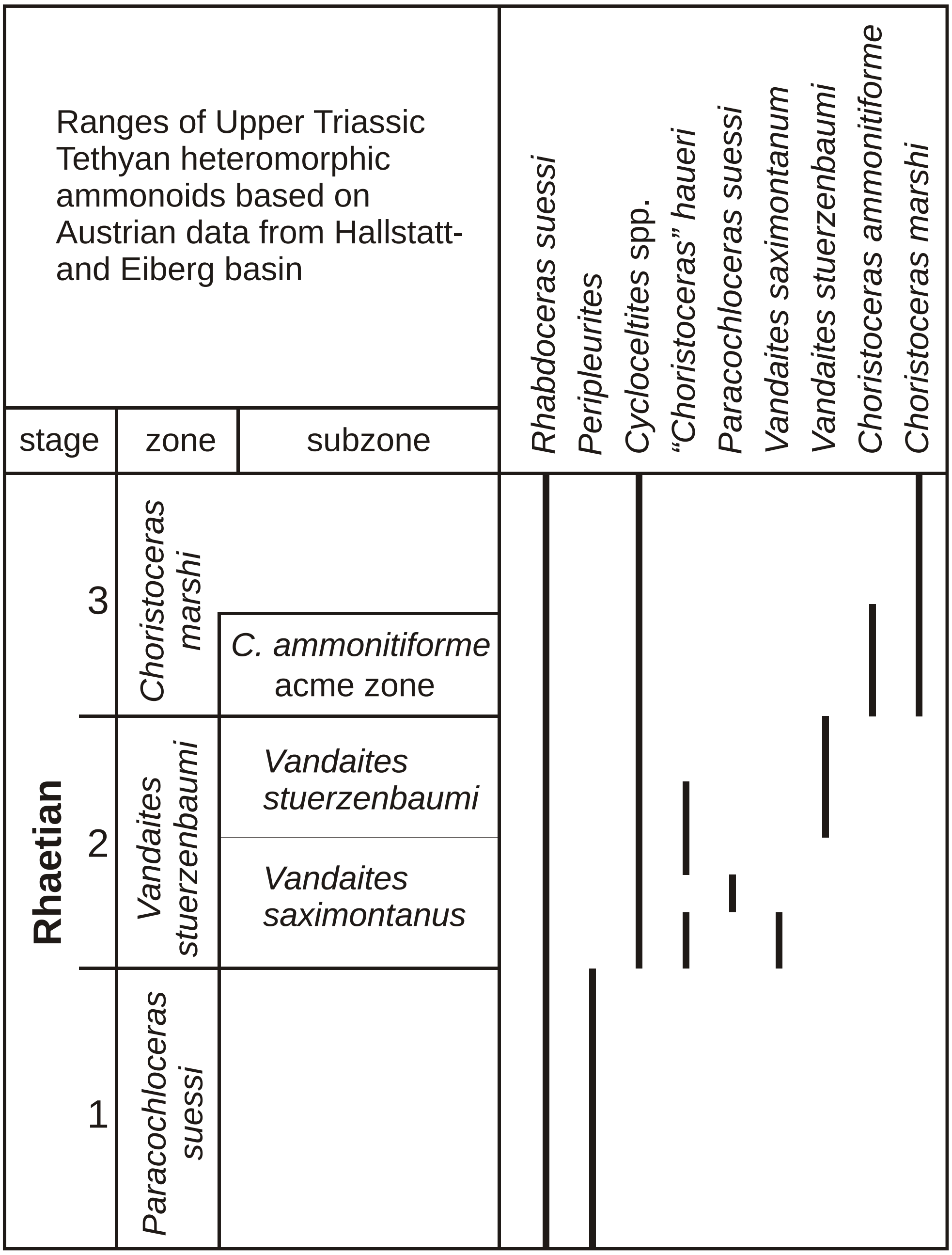

Fig. 1: Ranges of Upper Triassic Tethyan heteromorphoic ammonoids from Hallstatt and Eiberg basin.

BUILDING AN UPPER TRIASSIC CARBON ISOTOPE REFERENCE CURVE

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During the Upper Triassic, it appears that despite new originations, the general decline in biodiversity was punctuated by a series of accelerated steps between the Carnian and the Rhaetian, while the T-J boundary event may have been the final strike (McROBERTS & NEWTON, 1995, HALLAM, 2002). How these changes in the biosphere were related to oceanographic and/or geochemical changes during the Late Triassic biotic crisis events is a question of primary importance. In order to solve this issue, two principal questions have to be addressed: (1) are these extinctions best explained by a gradual process of environmental change or by (a series of) abrupt or even catastrophic events? and (2) how do Late Triassic patterns of biotic turnover correlate and couple with oceanographic geochemistry? An expansion of a well-calibrated carbon isotope reference curve for the whole Upper Triassic is an important first step to address these questions.

While a comprehensive isotopic data set is available for the T-J boundary (e.g. MORANTE & HALLAM, 1996; GUEX et al., 2004; KÜRSCHNER et al., 2007; WILLIFORD et al., 2007) only a few data are available for the Upper Triassic. To establish a carbon isotope reference curve and in addition of the sparse literature (ATUDOREI, 1999; GAWLICK & BÖHM, 2000; HAUSER et al., 2001; MUTTONI et al. 2004; HORNUNG & BRANDNER 2005; KORTE et al., 2005; HORNUNG et al., 2007a,b, WARD et al., 2004; SEPHTON et al., 2002), several Tethyan and Peritethyan sections were measured in the Austrian Alps, Slovakia, Turkey, Oman and the Indian.

The Upper Ladinian samples record an increase in $d^{13}C_{carb}$ until the Lower Carnian, followed by stable values until the Upper Carnian (MIETTO et al., 2007; RICHOZ et al., 2007a). This stability is, however, disturbed by some small negative excursions in the isotopic signal near the Reingraben event (Lower Carnian-Upper Carnian boundary, ATUDOREI, 1999; HAUSER et al., 2001; HORNUNG & BRANDNER, 2005 and HORNUNG et al., 2007a,b). We present here evidence from the Spiti valley, Indian Himalaya; Mayerling, Austrian Alps and several sections in Taurus. The Carnian-Norian boundary interval in Turkey and Slovakia is marked by a minor increase in the C isotope value (less than 1‰, MUTTONI et al., 2004; GAWLICK & BÖHM, 2000; RICHOZ et al., 2007b). The isotopic values then show an increase until the

Middle Norian followed by a decrease recorded in Oman, Sicily and Austria (MUTTONI et al., 2004; RICHOZ et al., 2007b). In the Upper Norian the isotopic values are relatively stable, and show no shift across the newly proposed Norian/Rhaetian boundary (Steinbergkogel, Austria and Oman, KRYSTYN et al., 2007) before increasing again through the classical Norian/Rhaetian boundary (Oman, Turkey, Austria, this study; British Columbia, WARD et al., 2004, SEPHTON 2004) into the Lower Rhaetian. The isotopic record then remains constant until the top of the Rhaetian and the significant negative shift of approximately 2.0 to 3.0‰, identified in a number of marine sections in close proximity to the Rhaetian-Hettangian boundary (e.g. KUERSCHNER et al. 2007; GUEX et al., 2004; WARD et al., 2004, VAN de SCHOOTBRUGGE et al 2008). These excursions begin below the highest occurrence of conodonts and Triassic ammonites and the lowest occurrence of Jurassic ammonites, allowing very good correlation, and demonstrating unequivocally that the base of the shift lies below the Triassic-Jurassic boundary. The isotopic trends could be compared to the one at the PT boundary.

The Reingraben event is marked by a disturbance of the carbon cycle. The Lower to Middle Norian crisis is marked by a turning point from slowly increasing carbon isotopic values to gradually decreasing values. The Upper Norian (in the classical sense) is marked by a shift from decreasing to increasing isotope values. From an isotopic point of view, only the Reingraben event (Lower Carnian-Upper Carnian boundary) and the Triassic-Jurassic Boundary can be interpreted as event, whereas other biotic crises of the Late Triassic seem to have occurred during periods of gradual changes in the carbon isotopic composition of the marine seawater.

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CARNIAN/NORIAN HALOBIIDS FROM PIZZO MONDELLO SUCCESSION (SICANI MOUNTAINS, SICILY)

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During the Upper Triassic, it appears that despite new originations, the general decline in biodiversity was punctuated by a series of accelerated steps between the Carnian and the Rhaetian Pizzo Mondello (Sicani Mountains, Western Sicily, Italy) is one of the best sections spanning a Carnian/Norian boundary interval. The 450 m thick pelagic-hemipelagic limestone succession exposed in this locality belongs to the Calcari con selce (Halobia limestone Auctorum; Cherty Limestone, MUTTONI et al. 2001, 2004) and shows a combination of great thickness, almost uniform facies, good exposure and easy accessibility, which makes this site perfect for sampling and study.

The Calcari con selce of western Sicily has been well known for its exceptionally rich and well preserved Late Carnian to Early Norian ammonoid fauna originally studied by G.G. GEMMELLARO (1904), as well as for the very rich halobiid bivalve record, studied by various authors in the past centuries (GEMMELLARO, 1882; MONTANARI & RENDA, 1976; CAFIERO & DE CAPOA BONARDI, 1982; DE CAPOA BONARDI, 1984).

The Pizzo Mondello succession is of great interest for the definition of the GSSP of the Norian stage, and two years ago a large group of specialists started new investigations aimed at the biostratigraphic calibration of the magnetostratigraphy and carbon isotope variations (MUTTONI et al. 2001, 2004) with conodonts, ammonoids, halobiids and radiolarians (GUAIUMI et al. 2007; NICORA et al. 2007; BALINI et al. 2008). The study of halobiids is still in progress, but here we provide new data. The halobiid bed-by-bed sampling was done, for the first time in this locality, in spring 2007 and February and May, 2008. Only the first 140 meters of the succession, straddling the Carnian/Norian boundary were sampled. The available material consists of about 650 halobiid specimens, most of them well to very well preserved, coming from about 100 levels.

From the Carnian/Norian interval we recognize ten halobiid species with biochronologic signficance: *Halobia carnica, H. lenticularis, H. austriaca, H. simplex, H. superba, H. radiata, H.* cf. *beyrichi, Halobia* of the group of *H. areata, H. styriaca* and *H. mediterranea*. Among these species, three have a great importance for the definition of the Carnian/Norian boundary interval. The relevance of *Halobia styriaca* has already been discussed in NICORA et al. (2007). The finding of the species *Halobia* cf. *beyrichi* is of particular interest since it is considered to be a marker of the Lower Norian both in North America (lower part of the *Kerri* Zone) and in the Tethyan realm (upper part of the Jandianus Zone; KRYSTYN & GALLET, 2002). This important form was already reported from this site by KRYSTYN & GALLET (2002), and now its range is calibrated within the halobiid succession. The group of *H. areata,* typical of the Lower Norian of other Tethyan localites, is reported for the first time from Sicily, and it is an useful for both definition of the Carnian-Norian boundary interval and correlations.

The ten species have been subdivided in six assemblages (from base to top):

1. *Halobia carnica* assemblage, with the species *H*. *carnica* and *H*. *lenticularis*. It is the oldest fauna of the succession;
2. *Halobia lenticularis* assemblage, with the species *H. lenticularis*, *H*. *austriaca*, *H*. *simplex* and rare *H*. *superba*. It is based on the disappearance of *H. carnica*, and indicates the last surely Carnian assemblage;
3. Halobia radiata assemblage, with the species *H*. *radiata* and subordinate *H. austriaca*, *H*. *simplex* and *H. superba*. It represents a transition fauna between Carnian and Norian groups;
4. *Halobia* cf. *beyrichi* assemblage, with the species *H.* cf. *beyrichi* and rare *H*. *areata-group* and *H*. *radiata* specimens. It is the first surely Norian assemblage;
5. *Halobia styriaca* assemblage, with only *H*. *styriaca* specimens. It marks the upper part of the first zone of the Norian (upper *Kerri* Zone in North America; upper *Jandianus* Zone in the Tethyan realm; KRYSTYN & GALLET, 2002);
6. *Halobia mediterranea* assemblage, with only H. *mediterranea* specimens. It is the youngest fauna found at Pizzo Mondello.

These assemblages, and in particular the newly calibrated ranges of *Halobia* cf. *beyrichi* and *Halobia* of the group of *H. areata* will prove to be very useful tools in the biostratigraphic correlation between North American and Tethyan successions.

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INTEGRATED STRATIGRAPHY OF THE NORIAN GSSP CANDIDATE PIZZO MONDELLO SECTION (SICANI MOUNTAINS, SICILY)

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Pizzo Mondello (Sicani Mountains, western Sicily, Italy) is one of the best localities in the world for the definition of the Carnian/Norian boundary. This site shows an unusual combination of features that fulfil most of the requirements of the “perfect” GSSP candidate section (SALVADOR, 1994). At Pizzo Mondello a 450 m-thick Upper Carnian to Upper Norian pelagic-hemipelagic limestone succession is well exposed and very easily accessible. The succession belongs to the *Calcari con selce* (*Halobia Limestone auctorum*; Cherty Limestone, MUTTONI et al, 2001; 2004) and is known since the XIX century for the rich ammonoid and bivalve record (GEMMELLARO, 1882, 1904). The Carnian /Norian (C/N) boundary interval is included into the lower 140 m of the section, that consists of a monotonous succession of well-bedded white-yellow calcilutites with black chert nodules.

Pizzo Mondello section is well known for the good primary magnetostratigraphic record and stable carbon isotope variations (MUTTONI et al, 2001, 2004) which became *de facto* the standard Tethyan marine reference for the Newark astrochronological polarity time scale (KENT et al., 1999; MUTTONI et al., 2004). The biostratigraphic calibration of the magnetostratigraphy and carbon isotope variations was based only on relatively few conodont samples (MUTTONI et al., 2004). In 2006 we started a new integrated biostratigraphic study of the section based on conodonts, ammonoids, pelagic bivalves and radiolarians. These investigations were also accompanied by new lithological and sedimentological analyses of the succession. GUAIUMI et al. (2007) and NICORA et al. (2007) presented the preliminary results of the new study on the lower 140 thick part of the section. Here we focus on the 30 m-thick C/N boundary interval straddling magnetozones PM4n and PM4r as well as the positive shift of $\delta^{13}C$.

Conodonts resulted the most promising tool for the selection of the GSSP marker event. Conodont taxonomy and phylomorphogenesis are described in detail in a separate contribution (MAZZA & RIGO, 2008). Two major bioevents were identified, namely the FAD of *Epigondolella quadrata* Orchard and the FAD of *Metapolygnathus communisti* Hayashi.

Ammonoids, albeit sparse, are useful for the calibration of the conodont bioevents, however they become extremely rare above the $\delta^{13}C$ shift. The fauna of the boundary interval is dominated by *Gonionotites* and ammonoids of the group of *Anatomites sensu* GEMMELLARO. *Dimorphites*, regarded as a good marker for the Lower Norian, was unfortunately found only in debris.

Halobiids are much more frequent than the ammonoids; moreover, they are of great interest for global correlations. Ten halobiids species were recognized, grouped in six assemblages (LEVERA & McROBERTS, 2008). Of special interest is the occurrence in the boundary interval of *Halobia* cf. *beyrichi* and *H.* group of *areata*, which are typical of the Lower Norian.

An additional tool for global correlations is represented by radiolarians, which were found in some samples with high diversity assemblages. In the 30 m-thick boundary interval there is an overlap between species previously considered Late Carnian with species usually regarded as Early Norian. The first Early Norian radiolarian assemblage occurs above the FAD of *E. quadrata*. This fauna consists of *Braginastrum curvatus* Tekin, *Capnuchosphaera deweveri* Kozur & Mostler, *Capnuchosphaera tricornis* De Wever, *Kahlerosphaera norica* KOZUR & MOCK, *Mostlericyrtium sitepesiforme* Tekin, *Podobursa akayi* TEKIN and *Xiphothecaella longa* (KOZUR & MOCK).

In conclusion, Pizzo Mondello is a good candidate for the definition of the global stratigraphic section and point (GSSP) for the base of the Norian because of its relatively high rates of sedimentation (20-30 m/m.y.), the good record of age-diagnostic conodonts, ammonoids, halobiids, and radiolarians, the relatively complete chemostratigraphic record and numerical age control, derived from magnetostratigraphic correlation with the Newark APTS.

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THE NORIAN/RHAETIAN BOUNDARY IN THE LAGONEGRO BASIN, SOUTHERN APENNINES, ITALY

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Geological Setting

The Lagonegro Basin was part of the southernmost Mesozoic oceanic basins of the Tethyan realm (FINETTI, 1985; 2005; STAMPFLI & MARCHANT, 1995; CIARAPICA & PASSERI, 2002; 2005). Its stratigraphy consists of a lower part represented by the "Lagonegro lower sequence" (MOSTARDINI & MERLINI, 1986; CIARAPICA & PASSERI, 2005: Monte Facito Fm., Calcari con Selce Fm., Scisti Silicei Fm., "Flysch Galestrino" (Late Paleozoic-Early Cretaceous in age). This lower part, always detached from its basement, is now dissected into many tectonic units that are piled up between the Apenninic and Apulian carbonate platforms due to the Apenninic orogenesis and forms a part of the Southern Apennines chain (Potenza province, southern Italy).

Our studies focus on the transitional interval between the Calcari con Selce and Scisti Siliei Fms, well represented in the Pignola, Monte Sant'Enoc, Monte Volturino, Sasso di Castalda and Madonna del Sirino sections, in which the Norian/Rhaetian boundary has been documented.

The Calcari con Selce Formation is characterized by thin-bedded limestones with cherty layers and nodules. In particular, they consist of mudstone-wackestone beds with radiolarians and bivalves (genus *Halobia*) and scattered calcarenitic (packstone-grainstone) layers. It is possible to recognize parts of the Bouma sequence (Tb and Tc) in very few beds, that testify that they were deposited by density currents (turbidites). The main part of Calcari con Selce beds is due to platform-derived micrite exported to the basin from the adjacent carbonate platforms and are organized in meter-thick cycles emphasized by very thin silt horizons (few centimeters). The overlying Scisti Silicei Fm. mostly consists of radiolarian cherts and shales. Intercalations of calcirudites and calcarenites, often silicified, are documented and usually contain material (e.g. foraminifers) exported from the carbonate platforms adjacent to the basin. The transition from the carbonate sedimentation of the Calcari con Selce Fm to the siliceous deposition of Scisti Silicei Fm documents the relative progressive lowering of the basin floor below the Carbonate Compensation Depth (CCD). This event already occurred during the Carnian stage (RIGO et al., 2007). The base of the "Transitional Interval" (AMODEO, 1999), is conventionally marked by a 3 m-thick interval of red shales, a useful lithomarker recognizable throughout the Lagonegro Basin. This lithomarker does not contain residual materials (low content of Al_2O_3) due to prolonged weathering as pointed out by X-ray analyses by REGGIANI et al. (2005). Above this 3m thick horizon of red shales, carbonate layers are still present, but they fade away upwards, becoming thinner and often silicified while radiolarites and shales become more common and thicker towards the overlying Scisti Silicei Fm. The Scisti Silicei Fm. has been informally subdivided in four members that are, in stratigraphic order from bottom to top, Buccaglione, Nevèra, Serra and Acqua Sulfurea members (AMODEO, 1999).

Different facies from proximal to distal, basing on the amount of re-sedimented platform materials such as calcarenites and calcirudites, have been traditionally recognized in the Calcari con Selce and Scisti Silicei Fms (SCANDONE, 1967; AMODEO, 1999; BERTINELLI et al., 2005). On this base, Pignola and Monte Sant'Enoc sections should be considered as "proximal" whereas Sasso di Castalda, Madonna del Sirino and Monte Volturino as "distal". It is necessary to point out that this differentiation is more evident in the Jurassic portion of the successions (PASSERI et al., 2005).

Evolution of the Lagonegro Basin

Despite the Norian – Rhaetian boundary is matter of discussion for its biostratigraphic problem, this interval is peculiar to understand the evolution of the Neotethys during the Late Triassic time. In the Tethyan basins important facies change occurred during the Late Triassic: around the Norian/Rhaetian boundary the marine fauna shows a turnover which has been interpreted as the precursor of the Triassic/Jurassic extinction event. The faunal changes, connected also to environmental changes, are evident in the well-exposed Lagonegro successions. The transitional interval between Calcari con Selce and Scisti Silicei Fms well represents the Norian/Rhaetian stratigraphic interval. In this interval the late Norian carbonate sedimentation was gradually replaced by a siliciclastic-radiolaritic deposition (PASSERI et al., 2005), beginning with a marked increase of shales, silicified limestones and some radiolarites (=meant as 30% of radiolarians in content). Although the beginning of the transitional interval from Calcari con Selce Fm to the overlying Scisti Silicei Fm results diachronous in proximal and distal facies basing on conodont investigations, the increase of shales and silicified limestones is evident throughout the Lagonegro Basin.

Biostratigraphical investigations

According to CARTER & ORCHARD (2007) radiolarians are of primary importance for the definition of the Norian – Rhaetian boundary due to the apparent provincialism of conodonts and the rarity of ammonoids. The Lagonegro Basin successions yielded a very rich record of conodont and radiolarian fauna, allowing a good calibration between these two important tools for biostratigraphical investigations.

The transitional interval between Calcari con Selce and Scisti Silicei Fms is characterized by the presence of conodont *Mockina bidentata, Parvigondolella andrusovi* and *Misikella hernsteini* (BERTINELLI et al., 2005; RIGO et al., 2005; GIORDANO et al., 2008), while the overlying Scisti Silicei Fm is characterized by a rich assemblage of radiolarians. According to radiolarian biozonation made by CARTER (1993), the radiolarians found in the first part of Buccaglione member (lowermost part of the Scisti Silicei Fm) are late Norian in age (GIORDANO et al., 2008). The remaining part of Buccaglione member is characterized by a Rhaetian radiolarian association (sensu CARTER, 1993), according to the occurrence of *Misikella posternsteini* in the upper portion of Buccaglione Member (BERTINELLI et al., 2005; RIGO et al., 2005).

The integrated biostratigraphy based on conodonts and radiolarians from the Lagonegro successions shows that *Betraccium deweveri* is still present within the *Misikella hernsteini-Parvigondolella andrusovi Z*one (sensu KOZUR and MOCK, 1991). According to CARTER (1993) and CARTER & ORCHARD (2007) the *Betraccium deweveri* Zone is the last of the Norian. Thus, basing on radiolarian zonation, the FAD of *Misikella hernsteini* does not mark the beginning of the Rhaetian, as already suggested by KOZUR (2003).

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FORAMINIFERA AND OSTRACODA FROM THE NORTHERN CALCAREOUS ALPS AND THE END-TRIASSIC BIOTIC CRISIS.

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Depositional and Regional Background

Three west-east directed sedimentary basins existed in the NCA around the Triassic-Jurassic boundary: Allgäu Basin in the north, Eiberg Basin in the middle part and Hallstatt/Zlambach Basin in the south. The Allgäu Basin was – at least in part – connected with the NW-European platform. The Eiberg Basin was in Rhaetian time an intraplatform depression, which can be traced over 200 km from the Salzkammergut (Austria) in the east to the Lahnewiesgraben valley in the west (NW Garmisch-Partenkirchen, Bavaria). The Hallstatt/Zlambach Basin was located south of the wide Dachstein lagoon and open towards the Tethyan Ocean.

The worldwide end-Triassic sea-level fall caused a biotic crisis in most fossil groups; it is recorded in the Northern Calcareous Alps (NCA) as a stepwise process that resulted in an end-Triassic sea level fall of at least 100 m as evidenced on the Steinplatte margin of the Eiberg Basin (KRYSTYN et al. 2005). The regression was fast and culminated near the end of the late Rhaetian, it was followed by a slow long-term sea-level rise that started in the latest Rhaetian, continued through the Hettangian and exceeded the Rhaetian highstand relatively late in the Upper Sinemurian (HILLEBRANDT et al. 2007). Caused by the sea-level fall, the Triassic carbonate platforms emerged. This is the reason why a hiatus exists between Triassic and Jurassic sediments in many shallow-water sections of the NCA. Sedimentation was continuous in the deeper part of the basins across the Triassic-Jurassic boundary but an abrupt lithological change from basinal carbonates of the Eiberg Mb. (Koessen Fm.) to marls and clayey sediments of the Tiefengraben Mb. (Kendlbach Fm.) occurred in the Allgäu- and Eiberg Basins. Within the Eiberg Basin and also parts of the Allgäu Basin all sections show the same sedimentary facies across the T-J boundary. A locally varying carbonate vs. clay content depends on the more marginal or more distal depositional position within the basins and has influenced also the microfossil content and composition. The boundary between the Eiberg and Tiefengraben Mbs. is lithologically recognizable all over the Eiberg basin. The topmost bed (bed T in HILLEBRANDT et al. 2007, Fig. 23a, b) differs by darker colour and platy weathering. The top of this bed is thin-bedded, bituminous and black, indicating an anoxic event and the lowstand of the regression (= Top-Koessen Event). The lowermost marls of the Tiefengraben Mb. are grey to yellowish (thickness < 50 cm) and may be called as Grenzmergel s. str. Above are following the Schattwald Beds which are mostly dark red coloured and sometimes laminated. Their type locality is found in the Allgäu mountains (Tannheim valley, Tyrol) in the west and can be traced over 300 km to the Restental (Enns valley, Upper Austria) in the east. The marls are more or less clayey, of variable thickness and have often been described to be of nonmarine origin. In the Eiberg Basin of the western Karwendel syncline a rhynchonellid brachiopod has been recorded from the lower part of the Schattwald Beds. Fragments of pectinid bivalves have been found in its middle and upper part. Intercalations of greyish marls contain complete pectinid bivalves. Therefore, at least parts of the Schattwald Beds of the Eiberg basin must have been deposited under marine conditions. The above following marls of the Tiefengraben Mb. are grey and more or less clayey with an increasing fraction of silt and fine sand in the middle, and limestone beds in the upper part.

Continuous Triassic-Jurassic sections up to now are not known from the Hallstatt/Zlambach Basin. Rhaetian sediments are strongly faulted and folded in the Zlambach area near Bad Goisern (Salzkammergut, Austria). Marly sediments predominate in the late Rhaetian and are rarely exposed. The ammonoid bearing early Hettangian was up to now found in morainic erratic blocks and only Middle and Late Hettangian are known from outcrops. A recently discovered section of clayey marls rich in mica resembles the more marly to clayey Tiefengraben Mb. of the western Eiberg basin, it may span the latest Rhaetian and earliest Hettangian and follows above late Rhaetian marls with *Choristoceras* of the *marshi* group.

Biostratigraphy of the T-J boundary in the NCA

In the last decades the T-J boundary in the NCA was commonly lithologically and variously drawn: sometimes between Kössen and Kendlbach Fm. but more often at the base of the Calliphyllum Bed which up to this time was considered in the NCA as oldest Jurassic ammonite horizon, within the upper Kendlbach Fm. The T-J boundary has now been fixed to the basal Tiefengraben Mb. (lower Kendlbach Fm.) a few metres above the Schattwald Beds after a recent international agreement to define it by the first appearance of *Psiloceras spelae*, declared as the earliest Jurassic psiloceratid. This species is also found in North America (Nevada) and South America (Peru). A section in the western part of the Eiberg Basin (Kuhjoch, Karwendel syncline) was proposed as candidate GSSP for the base of the Jurassic by HILLEBRANDT et al. (2007) where *P. spelae* occurs in the lower part of the marly Tiefengraben Mb., approx. 18 m below the Calliphyllum Bed. It thus is possible to distinguish a late Rhaetian containing the last *Choristoceras* (and conodonts), a latest Rhaetian without ammonites (5,8 m thick in the proposed candidate GSSP) and an earliest Hettangian below the Calliphyllum Bed of late early Hettangian age.

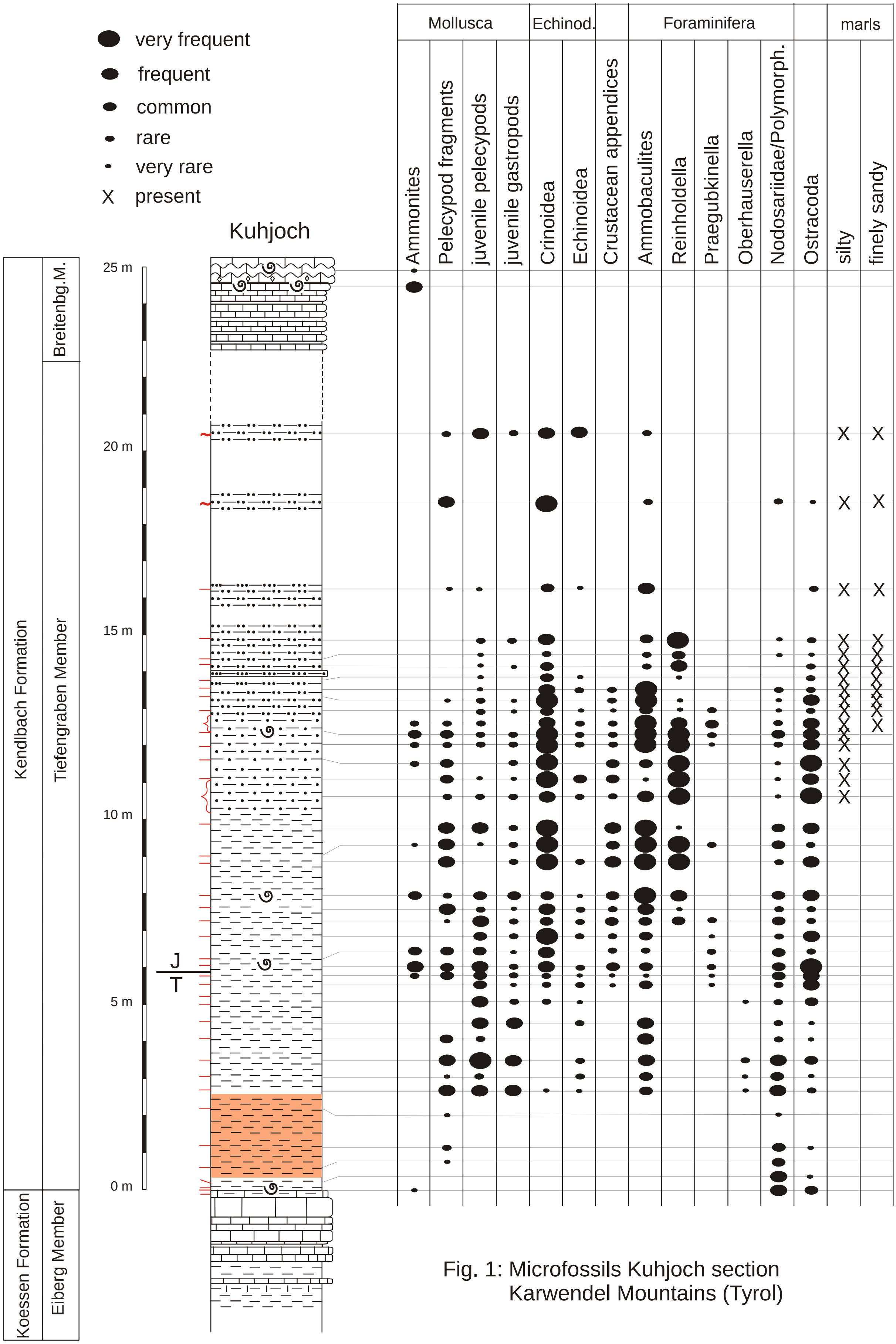

Fig. 1: Microfossils Kuhjoch section
Karwendel Mountains (Tyrol)

a. Foraminifera

The emersion of the carbonate platforms was the first step of the regression. The lagoonal facies of the Norian-Rhaetian carbonate platforms was dominated by *Triasina hantkeni*. This foram, like other Involutinidae (*Coronella, Semiinvoluta, Angulodiscus, Arenovidalina, Auloconus*), do not recur in Liassic sediments deposited under similar ecologic conditions (e.g. platforms of Southern Alps and Dinarids) after the top-Triassic emergence of the carbonate platforms and must have gone extinct. Other Involutinidae like *Involutina liassica* and *Trocholina* which were also adapted to basinal marly facies (e.g. Zlambach marls) survived the TJB biotic crisis.

The Rhaetian Zlambach marls are yielding a highly diverse fauna of Foraminifera. KRISTAN-TOLLMANN (1964) described 54 genera with 245 species which maybe taxonomically oversplitted. Nodosariacea predominate with 14 genera and 136 species. Agglutinated forams (Textulariina) are represented with 19 genera and 39 species. Miliolina are found with eight genera and 13 species. More than 50% of the Triassic Nodosariacea are also known from the Jurassic. 53 species of the other groups are restricted to the Triassic and 21 species also known from younger strata. The last representatives of the Paleozoic Tetrataxidae and Palaeonodosariidae are found in the Rhaetian. The last *Tetrataxis* occur in the latest Rhaetian, above the Top-Koessen Event. The Foraminfera of the Koessen Beds are not yet described in detail but are less diverse than those from the Zlambach Beds. URLICHS (1972) reports nine genera of Nodosariacea. *Ammobaculites* (agglutinated test) and *Nodosaria* can be very frequent. The Duostominacea (with aragonitic test and trochospirally enrolled) are mainly found in the Zlambach Fm. and less common in the Koessen Fm.. The late Triassic biostratigraphy of the Duostominidae was established by KRISTAN-TOLLMANN (1963) and that of the Oberhauserellidae by FUCHS (1967). Both families are of biostratigraphic importance, the Duostominidae are taller and the Oberhauserellidae smaller. The Duostominidae became extinct at the end of the Triassic, only one questionable species survived the Top-Koessen Event and is found in the latest Rhaetian. The Oberhauserellidae survived not only this event but also the T-J boundary. They are the source for the Jurassic Robertinina which gave way in middle Jurassic time to the planktonic Foraminifera.

A detailed study of the Foraminifera (and Ostracoda) across the T-J boundary was possible in the Eiberg basin (western Karwendel syncline and additional sections). Bed T of the Koessen Fm. yielded a diverse fauna of Nodosariidae with few Textulariina, some of them not found higher up. The diversity diminishes in the upper part of bed T in direction to the Top-Koessen Event. The beds between the Koessen event and the transition to the Schattwals Beds are characterized by small, mostly compressed, coarsely agglutinated *Trochammina* and an impoverished fauna of nodosariids often characterized by a large species of *Marginulinopsis*. *Hippocrepina* (a finely agglutinated siliceous foram with simply constructed test) dominates the Schattwald Beds of the Eiberg Basin and is accompanied by compressed *Trochammina* and an impoverished fauna of nodosariids (especially *Marginulinopsis*). The predominance of *Hippocrepina* points to unfavourable ecologic conditions most times unsuitable for the segregation of calcitic tests. Large *Ammobaculites* (species similar to that of the Koessen Fm.) are common to frequent in many samples of the marls above the Schattwald Beds where small agglutinated forams (in part attached) and an impoverished fauna of small Nodosariidae and Polymophinidae occur. The latter are more frequent in the lower part of that interval. Nodosariidae are more frequent from the first Jurassic ammonite level upwards. The Robertinina are represented by an evolutionary line that begins above the Schattwald Beds with tiny *Oberhauserella* (~ 0,06 to 0,12 mm) related to late Rhaetian species from the Zlambach Beds. *Praegubkinella turgescens* (~ 1,5 to 0,2 mm) appears in the interval around the first Jurassic ammonite horizon and a new species of *Reinholdella* (~ 0,2 to 0,3 mm; a typical Jurassic genus) can be very frequent in the middle and upper part of the Tiefengraben Mb. (HILLEBRANDT 2008) Biostratigaphically important genera like *Ichthyolaria* or species of the *Lingula tenera* plexus are missing or very rare in the lower and middle part of the Tiefengraben Mb. as a result of unfavourable ecologic conditions in the Eiberg basin at that time. This is probably due to a lower oxygen level at the sea floor favouring the aragonitic Robertinina and the occurrence of nuculid bivalves and the ostracode *Cytherelloidea*.

Only a few continuous T-J boundary sections are exposed in the Allgäu Basin. Typical Triassic Oberhauserellidae were found directly above the Top-Koessen Event and below the Schattwald Beds. The thick Schattwald Beds do not contain forams or ostracodes and a nonmarine environment can thus not be excluded. Oberhauserellidae were also found above the Schattwald Beds, similar to those below the first Jurassic ammonite horizon of the Eiberg basin.

The series of clayey marls with mica above late Rhaetian Zlambach marls near Bad Goisern, which are comparable to the Grenzmergel s. l. of the Eiberg basin, contains simply constructed agglutinated forams predominating in the lower part. The Nodosariids are much lesser diverse than those of the Zlambach marls but more diverse and taller than those of the Tiefengraben Mb. The genera and species are of Triassic appearance. The very well preserved aragonitic Oberhauserellidae exhibit the same evolutionary trend as observed in the Tiefengraben Mb. The youngest fauna of this outcrop has Oberhauserellidae with a very similar variability to those of the basal Jurassic beds of the Eiberg basin with *Praegubkinella turgescens*. Unfortunately, the section is incomplete both downward to an equivalent of the Top-Koessen Event and upward into the lower Hettangian.

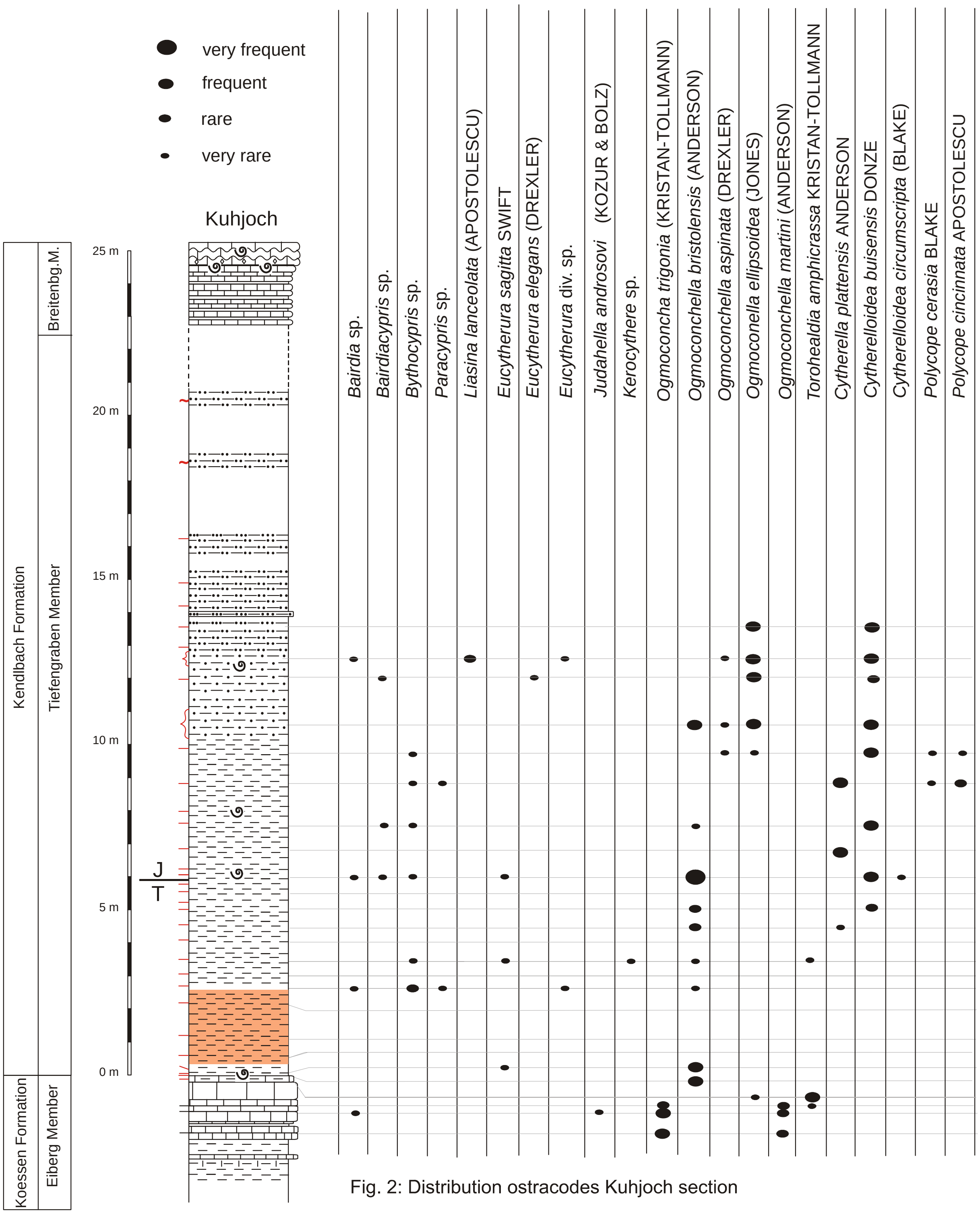

Fig. 2: Distribution ostracodes Kuhjoch section

b. Ostracoda

The late Triassic ostracodes of the NCA are well known: ostracodes of the Zlambach marls were described by KOLLMANN (1960, 1963), KRISTAN-TOLLMANN (1969, 1970) and BOLZ (1970, 1971), those of the Koessen Formation by URLICHS (1972). Less well known are the early Jurassic ostracodes of the NCA. Some species were published by KOLLMANN (1960, 1963) and KRISTAN-TOLLMANN (1990). HARLOFF & JÄGER (1994) described 77 species from the Liassic of the NCA. Latest Rhaetian and earliest Hettangian ostracodes are now under study by Urlichs (URLICHS in HILLEBRANDT et al. 2007).

The Zlambach marls are yielding a high diverse fauna of ostracodes. BOLZ (1971, p. 245) found in these marls 173 species. The Bairdiidae dominate with approx. 100 species and the Healdiidae with approx. 30 species. Some species of the Bairdiidae are very tall (length up to 2 mm). URLICHS (1972) described 25 species of ostracodes from the Koessen Beds where only few Bairdiidae are known and Healdiidae are more frequent. Small Eucytheruridae are more frequent in species in the Rhaetian than in the early Hettangian. Typical Rhaetian ostracodes (different species of Bairdiidae and Healdiidae) are represented in bed T of the Koessen Beds (various localities) and in the Grenzmergel s. str. directly above. Many species of the Cytheracea disappear above the Koessen event, especially most of the Bairdiidae and many Healdiidae. The faunal change between the Rhaetian and Hettangian is very distinct though some species occur from the Rhaetian up to the Hettangian. *Cytherelloidea* and *Polycope* survived the biotic crisis and new species were developed. Ostracodes are very rarely found in the Schattwald Beds and may eventually be reworked. The ostracode fauna is poor in species in the basal Tiefengraben Mb. between the Schattwald Beds and the first Jurassic ammonite. Smooth ostracodes of the Healdiidae are usually the most frequent ostracodes in the Tiefengraben Mb. and *Cytherelloidea* can be frequent in the middle and upper part of it. This genus is indicating unfavourable oxygen conditions. New species of small *Eucytherura* appear during the earliest Hettangian. The survivors from the Rhaetian to the Hettangian indicate that the ecologic conditions have been unchanged euhaline, probably with exception of the Schattwald Beds. The ostracod species of the Tiefengraben Mb. are found later in NW Europe, at first in younger Hettangian beds.

Conclusions

In the NCA the biotic crisis at the T-J boundary was taking place step-by-step probably through a time-interval of some hundred thousand years and paralleled a stepwise change in lithology. The crisis started in the well-studied Eiberg Basin with the Top-Koessen Event and ended gradually during the upper part of the Early Hettangian. The Top-Koessen Event was caused by the abrupt sea level fall which resulted in a very important marine biotic extinction. Many groups of forams and ostracodes are affected by this event, especially those specialized to restricted and/or specific ecologic conditions. Some species survived the Koessen event. A fauna poor in species remained within the Grenzmergel s. str. between the Koessen event and the Schattwald Beds. The ecologic conditions once more got worse during the sedimentation of the Schattwald Beds where eventually nonmarine conditions predominated in the Allgäu Basin. Abnormal marine conditions prevailed in the Eiberg Basin and at times segregation of calcitic tests must have been impeded, probably caused by acidification of the sea. The ecologic drawback also occured in the Hallstatt/Zlambach Basin at that time. The ecologic conditions improved above the Schattwald Beds during the lower Tiefengraben Mb. Many survivors reappeared and new species evolved. This recovery came from the Tethyan Realm and reached the NCA basins from South continuing to the North and finally to NW Europe.

The end-Triassic biotic crisis seems to have mainly been caused by the relatively quick and strong sea-level fall. Climatic changes from arid to more humid mainly are reflected in a sedimentary change from carbonatic to more siliciclastic and the ecologic conditions changed. The calcification potential probably was affected by the beginning of the CAMP volcanism and an acidification by a to high concentration of carbon dioxide. The temporarly change to anoxic sea floor conditions also can have been important.

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EARLY NORIAN SCLERACTINIAN CORALS OF THE DACHSTEIN LIMESTONE OF FEISTERSCHARTE, DACHSTEIN PLATEAU (NORTHERN CALCAREOUS ALPS, AUSTRIA)

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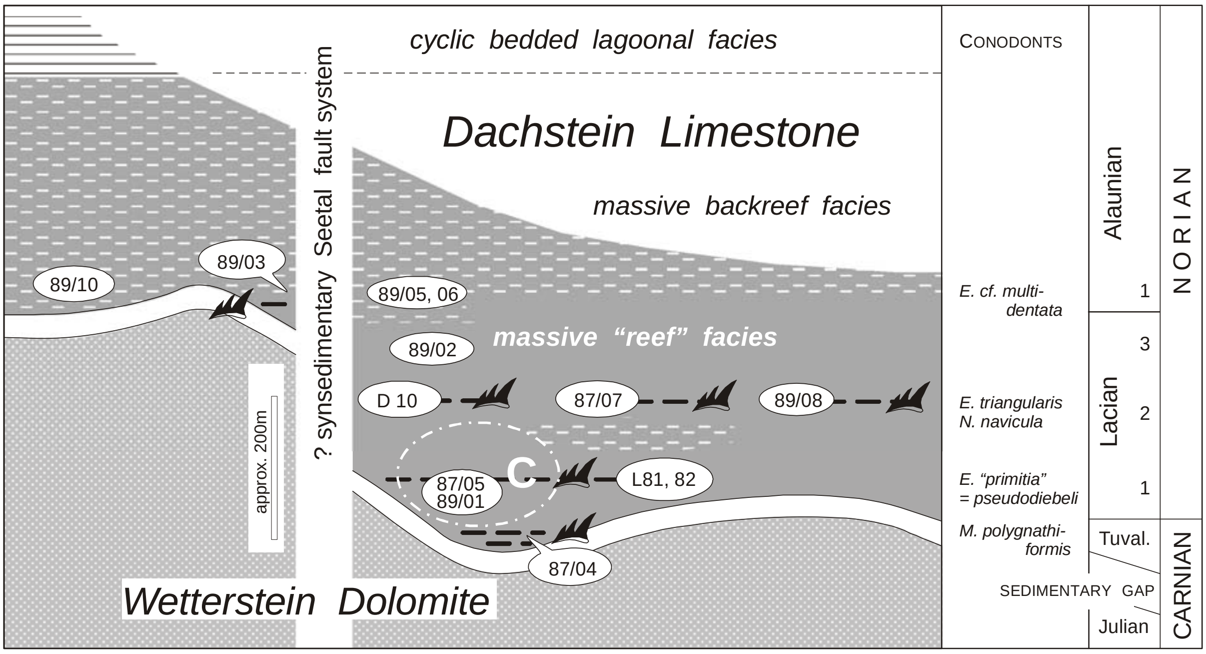
This refers to the first report concerning Early Norian coral fauna from the Northern Calcareous Alps. The coral-bearing limestones outcrop in the vicinity of the Feisterscharte, in the southern Dachsteinplateau. The rocks represent the initial growth stage of the Norian to Rhaetian Dachstein carbonate platform.

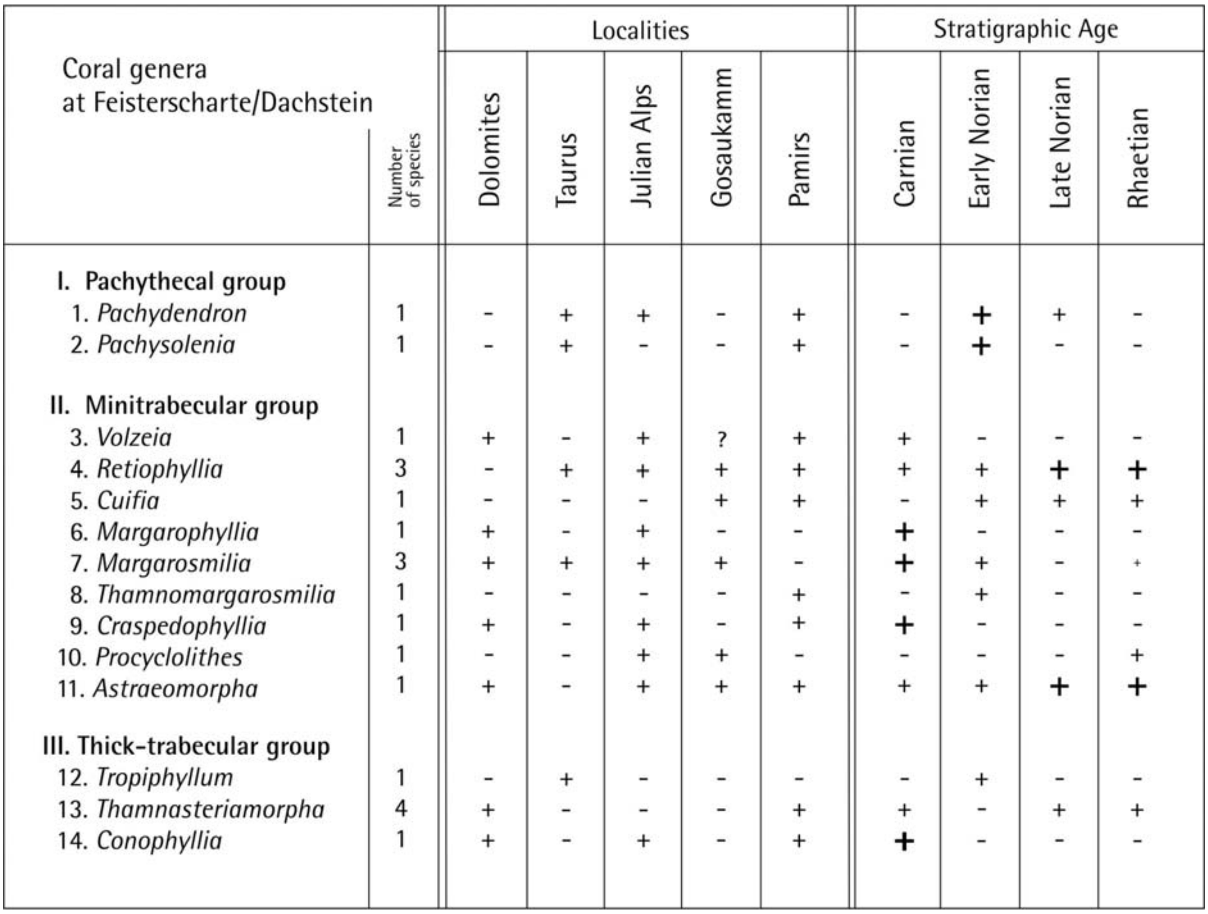
The sedimentary environment of the Northern Calcareous Alps is dominated by extended carbonate platforms in Middle and Late Triassic times. During an Early Carnian sea level drop the Wetterstein platform emerged and has been exposed to remarkable erosion, creating a relief of several 10th of meters.



Tab.1: Stratigraphic scheme of the Feisterscharten area. Encircled area „C“ marks the stratigraphic position of coral samples.

In the latest Tuvalian a distinct transgressive pulse led to widespread pelagic conditions, covering the drowning platform. The persisting seafloor relief caused a complex pattern of local reef patches, separated by depressions, where massive, often micritc limestones have been deposited. They exhibit a mixture of components from the platform interior (ooids, oncoids, porostromate algae and dasycladaceeans), of reef debris, crinoids and pelagic biogenes (ammonoids, halobiids and „filaments“, radiolarians and conodonts).

This initial stage of Dachstein platform growth has been terminated by rapid progradation of lagoonal limestones, the reefs became concentrated at the southern platform margin. The open platform situation changed into a rimmed platform configuration, characteristic for the Dachstein facies during Middle Norian to Rhaetian and exposed e.g. at Gosaukamm and Grimming.



Coral genera at Feisterscharte/Dachstein	Number of species	Localities					Stratigraphic Age			
		Dolomites	Taurus	Julian Alps	Gosaukamm	Pamirs	Carnian	Early Norian	Late Norian	Rhaetian
I. Pachythecal group										
1. *Pachydendron*	1	-	+	+	-	+	-	**+**	+	-
2. *Pachysolenia*	1	-	+	-	-	+	-	**+**	-	-
II. Minitrabecular group										
3. *Volzeia*	1	+	-	+	?	+	+	-	-	-
4. *Retiophyllia*	3	-	+	+	+	+	+	+	**+**	**+**
5. *Cuifia*	1	-	-	-	+	+	-	+	+	+
6. *Margarophyllia*	1	+	-	+	-	-	**+**	-	-	-
7. *Margarosmilia*	3	+	+	+	+	-	**+**	+	-	+
8. *Thamnomargarosmilia*	1	-	-	-	-	+	-	+	-	-
9. *Craspedophyllia*	1	+	-	+	-	+	**+**	-	-	-
10. *Procyclolithes*	1	-	-	+	+	-	-	-	-	+
11. *Astraeomorpha*	1	+	-	+	+	+	+	+	**+**	**+**
III. Thick-trabecular group										
12. *Tropiphyllum*	1	-	+	-	-	-	-	+	-	-
13. *Thamnasteriamorpha*	4	+	-	-	-	+	+	-	+	+
14. *Conophyllia*	1	+	-	+	-	+	**+**	-	-	-

Tab. 2: In the Tethyan ocean realm, Early Norian coral finds are rare, in contrast to the Late Norian. The table shows an overview in comparison to the fauna of Feisterscharte.

The exposures at Feisterscharte show one of the most diversified taxonomically Early Norian coral assemblages known so far. In the assemblage, Carnian genera are prevailing in number, and Early Norian index species, *Pachysolenia cylindrica* and *Pachydendron microthallos*, are frequent. The Early Norian age is proofed by conodonts.

The estimated number of coral taxa is 26, the majority having been identified to the generic level (Table 2) and some to species level. Despite recrystallization, the skeletons show enough traces of the original microstructure to be classified into three microstructural groups from the four groups known in the Triassic:

I. Pachythecal coral group (e.g. *Pachythecaliina* ELIÁSOVÀ, 1975),
II. Minitrabecular corals (*Caryophylliina* VAUGHAN & WELLS, 1943)
III. Thick-trabeculare corals (a group, containing families from the Ar*chaeocoeniina* ALLOITEAU, 1952 and *Microsoleniina* MORYCOWA & RONIEWICZ, 1994 - earlier *Fungiina* VERRILL, 1865),
IV. Fascicular or non-trabecular corals (*Stylophyllina* BEAUVAIS, 1981) are missing in the examinated Early Norian fauna, but flourishing in the marly facies of the Rhaetian (RONIEWICZ 1989).

This brief review shows that the coral assemblage from the southern Dachsteinplateau belongs taxonomically to the most diversified finds in the western Tethys. It equals that from the Taurid Mountains, differing from it in ecological type. On Dachsteinplateau, as in the whole Alpine region and on Hydra Island, phaceloid and solitary growth forms prevail, while massiv colonies (cerioid, thamnasterioid) are of a minor significance.

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RHAETIAN BIVALVES AND THE NORIAN / RHAETIAN BOUNDARY

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As the youngest stage of the Triassic, the status of the Rhaetian has long been under contention with conflicting definitions and even a proposal to abandon the stage name altogether. At the heart of the issue is correlating the type Rhaetian which was defined by GÜMBEL (1859) using the pteriid bivalve *Rhaetavicula contorta* from shallow-water facies of the Kössen Formation which is otherwise poor in age-diagnostic macro and micro fauna. In practice, however, most researchers would delimit the boundary between the Norian and Rhaetian stages either on the first occurrence of several ammonoid taxa such as *Sagenites reticulatus*, *Paracochloceras/Cochloceras*, and *Choristoceras*, or with the apparently global disappearance of the pectinacean bivalve *Monotis* (e.g. DAGYS & DAGYS, 1994). With few exceptions, the uppermost stage of the Triassic is characterized not so much by the emblematic pelagic bivalves (e.g. *Monotis* and *Otapiria*), but by level bottom shallow-water bivalve assemblages with long-ranging species. A few notable species, such as *Rhaetavicula contorta*, however, have significant biochronologic value.

The basal Rhaetian and the question of the Kössen Formation

Based on recent voting and lack of acceptable alternatives, it appears likely that the Subcommission on Triassic Stratigraphy will define the Norian/Rhaetian boundary as the first occurrence of the conodont *Misikella posthernsteini* from the upper part of the Hallstatt Formation in the Steinbergkogel, Austria (KRYSTYN et al. 2007a, 2007b). Although this clear choice seems to satisfy many issues, it still leaves in question a precise correlation into the shallow-water sequence in the Kössen basin and, perhaps more importantly, to strata of the circum-Pacific where *Misikella* in general and *M. postherstieni* in particular is not only rare or absent, but likely first occurs in significantly younger strata (e.g. ORCHARD &TOZER, 1997; CARTER & ORCHARD, 2007). In these and other areas, palynomorph, radiolarian or other biochronologic or geochemical proxies will need to employed.

With respect to a Norian/Rhaetian boundary within the Kössen, recognition of the first occurrence of *Misikella posthernsteini* in the Kössen Formation is most important. At the type section of the Kössen Formation at Weißloferbach, *Misikella posternsteini* occurs within 1 meter of the base of section B and nearly 20 meters below the first occurrence of *Rhabdoceras suessi* (URLICHS,1972; MOSTLER et al.,1978). Subsequently, GOLEBIOWSKI (1990) reports some tens of meters between the first occurrence of *Misikella hernsteini* and *M. posthernsteini* which first appears in Unit 2 of the Hochalm member. Thus, GOLEBIOSKI (1990, see also 1991) attributed most of the Hochalm member of the lower Kössen Formation to the upper Norman (Sevatian I). More recently, however, KOZUR (1996) reports the occurrence of *M. posthernsteini* within the basal Kössen. Within the Hallstatt sequences, the stratal thickness between the FOD of *M. hernsteni* and *M. posternsteini* is much less. For example, at proposed GSSP at Steinberkogel, KRYSTYN *et al.* (2007a, 2007b) report 40 cm between the two events. At the Hernstein section in Lower Austria, the difference between the FOD of *M. hernsteini* and *M. posterhsteini* is still less than 1 meter (McROBERTS et al. 2008). Caution should be exercised, however, when interpreting depositional rates to the stratal thickness between the FODs of *M. hernsteini* and *M. posthernstini*,

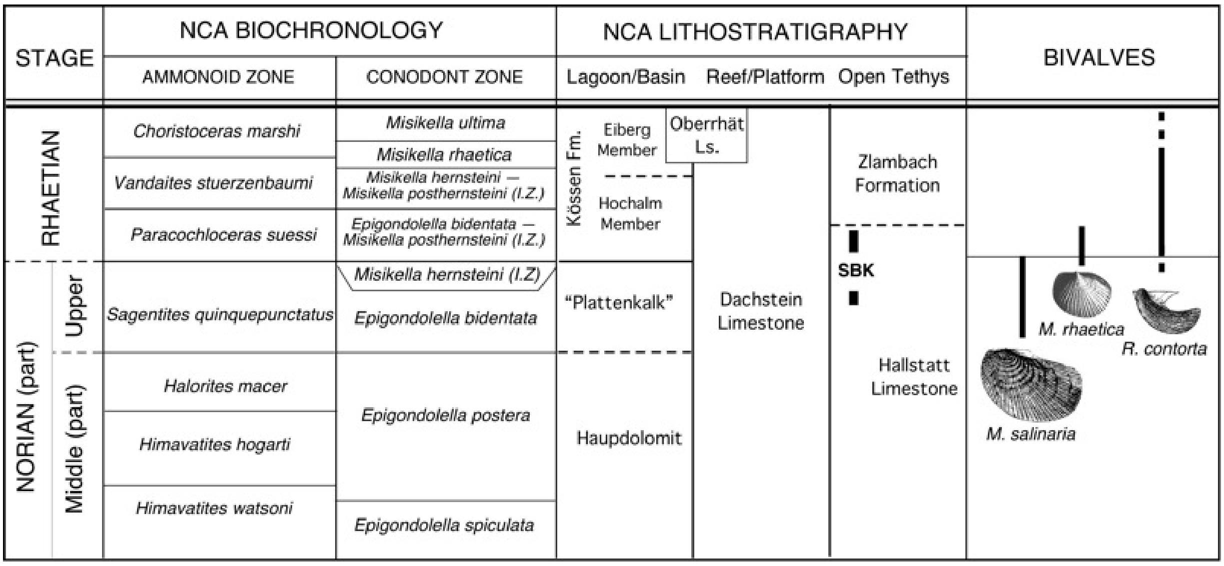

Fig. 1: Distribution of important upper Norian and Rhaetian bivalves within the Northern Calcareous Alps. SBK = Steinbergkogel section.

Bivalves and the Norian/Rhaetian boundary

Many researchers have long recognized that. It has been long assumed that *Monotis* experienced mass extinction close to the Norian/Rhaetian boundary as defined by first appearance of the conodont *Misikella posthernsteini* and its ammonoid equivalents (various *Paracochloceras* and perhaps *Sagentites reticulatus*). Recent finds in Hallstatt limestone in Austria records two surviving and dwarfed species of *Monotis* above this event, one of which, *Monotis rhaetica* is new (McROBERTS et al. 2008).

Although species of *Otapiria* are known from strata as old as Carnian and continue through the Early Jurassic, they take particular temporal significance in the Norman and Rhaetian. For example, *Otapiria ussuriensis* (Voronetz) is the name bearer of a well established zone in the Middle Norman of Siberia (KIPARASOVA et al. 1966; ZAKHAROV et al. 1997) and *Otapiria dissimilis* is distinctive of the Rhaetian of New Zealand (MARWICK 1957). A species referred to as *Otapiria marshalli alpina* is known with *Misikella hernsteini* from the Zlambach Formation at Raschbergwiese section near Goisern and at other localities in the Austrian Alps (ZAPFE, 1973). Although the generic assignment of *Otapiria marshalli alpina* is questionable (see GOLEBIOWSKI, 1990), it remains a potentially valuable index of regional biochronologic significance.

The distinctive pteriid bivalve *Rhaetavicula contorta* is perhaps the most commonly recognized bivalve and key index of the Rhaetian in shallow-water facies of the western Tethys, southern Germany and across northwestern Europe. GOLEBIOWSKI (1990) provided a most useful summary of the facies, geographical, and temporal distribution of *R. contorta*. Based on the then current interpretations of a Norian/Rhaetian boundary, GOLEBIOWSKI (1990, see also 1991) attributed most of the Hochalm member of the lower Kössen Formation, in which *R. contorta* is most common, to belong to the upper Norman. Accepting the base of the Rhaetian to be the first occurrence of the conodont *Misikella posternsteni* (see above) which is already present in the basal Hochalm Member of the Kössen Formation (KOZUR 1996), most *R. contorta* likely occur safely within the Rhaetian. Other claims of *R. contorta* in the eastern Tethys and circum-Pacific (e.g. HEALEY 1908; MULLER & FERGUSON 1939) may indeed be Rhaetian, but have yet to receive satisfactory study to warrant assignment to *R. contorta*.

In the Boreal realm, the Rhaetian is characterized by the pectinid *Tosapecten*. *Tosapecten sensu stricto* can be traced as early as the Carnian of Japan and other east-Asian, western Panthalassa, and Boreal regions. *Tosapecten efimovae* Polubotko has been a key index for the Rhaetian strata of Boreal Russia (e.g. POLUBOTKO & REPIN 1990). This zone encompassing the entire Rhaetian can be subdivided into a lower *Campontectes nanus* subzone and an upper *Tosapecten efimovae* subzone (POLUBOTKO & REPIN 1990; DAGYS & DAGYS 1994). ZAKHAROV et al. (1997) seems to have inverted the *Tosapecten effimove* and *Camptonectes nanus* subzones.

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UPPER TRIASSIC CONODONTS FROM NORTHEASTERN RUSSIA: PALEOBIOGEOGRAPHY, EVOLUTIONAL STAGES, BIOSTRATIGRAPHY

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A detail biogeographic division of Late Triassic Tethyan and Boreal seas based on conodonts makes troubles for researchers. Firstly, this is due to the fact that the data on the fauna from southern and northern latitudes are understudied. Secondly, there is an ambiguity in treating of lots of genus taxa. Studying the area of the north of Asia in Russia, we have found new occurrences of Upper Triassic conodonts there. This allows us to draw the paleogeographic zoning taking into account the data on Boreal regions.

Upper Triassic

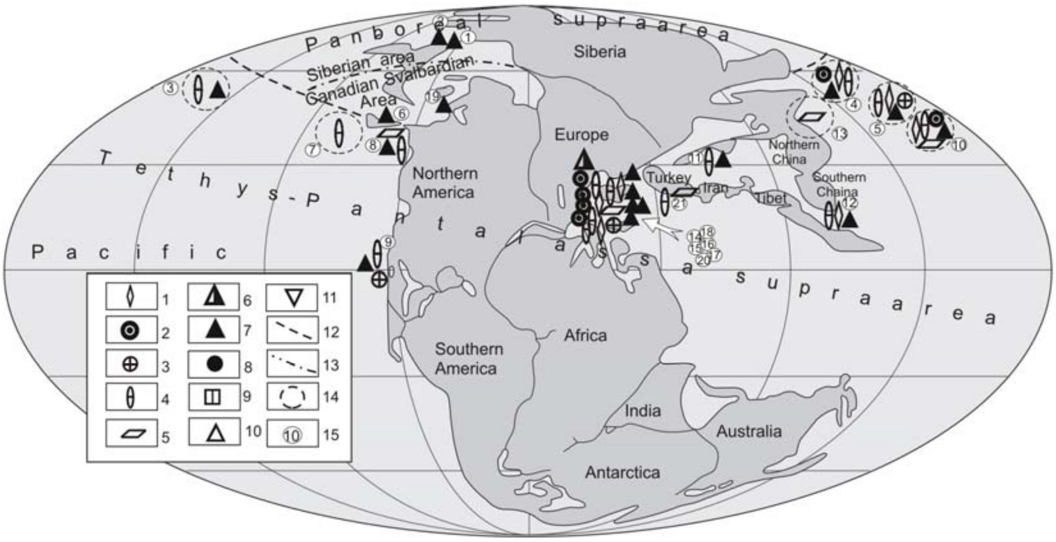

Fig. 1.: Geographic distribution of conodonts in Carnian.

Tethyan genera: 1 – Gladigondolella, 2 – Budurovignathus, 3 – Mosherella, 4 – Epigondolella, 5 – Metapolygnathus, 6 – Pseudofurnishius; cosmopolite genera: 7 – Paragondolella, 8 – Norigondolella, 9 – Mockina, 10 – Parvigondolella, 11 – Misikella; paleobiochores boundaries: 12 – supraarea, 13 – area; 14 – conodonts localities in terraines; 15 – regions; 1 – Kotelny Island; 2 – Zyryanka river; 3 – Koryak uplift; 4 – Middle Sikhote-Alin; 5 – Primoriye; 6 – Northern Alaska;7 – eastern Alaska; 8 – British Columbia; 9 – South-western USA; 10 – Japan; 11 – South-eastern Pamir (Tajikistan); 12 – Southern China; 13 – Northeastern China; 14 – Austria; 15 – Slovenia; 16 – Hungary; 17 – Yugoslavia; 18 – Slovakia, 19 – Northern Arctic Islands; 20 – Northern Italy; 21 – Turkey.

Carnian Age. Together with a decrease of systematic diversity, the conodont associations were renewed at the beginning of the Late Triassic. *Gondolathus* and *Celsigondolella* had become extinct, but *Mosherella* had occurred by this time. *Paragondolella foliate*, *P. inclinata, P. tadpole, P. polygnathiformis,* and *P.* aff. *polygnathiformis* dominating in associations had spread in all latitudes. *Epigondolella* and *Metapolygnathus* had appeared at the end of the Carnian.

Carnian conodonts are currently known from British Columbia and Queen Charlotte Islands, south-western USA, northern and eastern Alaska, Northern Arctic Islands, Japan, southern and northeastern China, Tajikistan, Russia (Koryak uplift, Kotelny Island, Zyryanka river, middle Sikhote-Alin), Austria, Slovenia, Hungary, Slovakia, Yugoslavia, northern Italy, Turkey (Fig. 1).

Carnian conodonts are scarce in northern latitudes. Boreal conodont associations differ from the Tethyan ones by a low diversity of the fauna represented only by cosmopolite *Paragondolella*. The differences between Canadian-Svalbardian and Siberian areas become negligible and can be observed only at the level of species. Basically, in the history of conodonts in the Carnian, evolution resulting in taxa change reaches a new peak only in Tethyan regions. In the seas of the northern part of the Tethys, *Pseudofurnishius, Mosherella, Budurovignathus,* and *Gladigondolella,* together with cosmopolite *Paragondolella,* were characteristic genera at the beginning of the Carnian, but *Epigondolella* and *Metapolygnathus* had widely spread by the end of the Carnian.

Norian – Rhaetian Ages. Together with a continuous decrease of taxa diversity in associations, the next stage of evolution took place again at the beginning of the Early Norian. *Epigondolella abneptis*, *E. quadrata, E. triangularis, E. primitia, E. nodosa,*

Mockina postera, M. multidentata, Norigondolella navicula, N. hallstattensis and *N. steinbergensis* dominated in seas in this time. Genera *Parvigondolella, Misikella* and *Mockina bidentata* predominated from the end of the Norian to the Rhaetian.

Norian and Rhaetian conodons are known from Russia (Kotelny Island, middle Sikhote-Alin, Primoriye), Tajikistan, Japan, British Columbia and Queen Charlotte Islands, south-western USA, northern and eastern Alaska, Austria, Slovenia, Poland, Slovakia, Yugoslavia, Turkey, Australia, Tibet (Fig. 2).

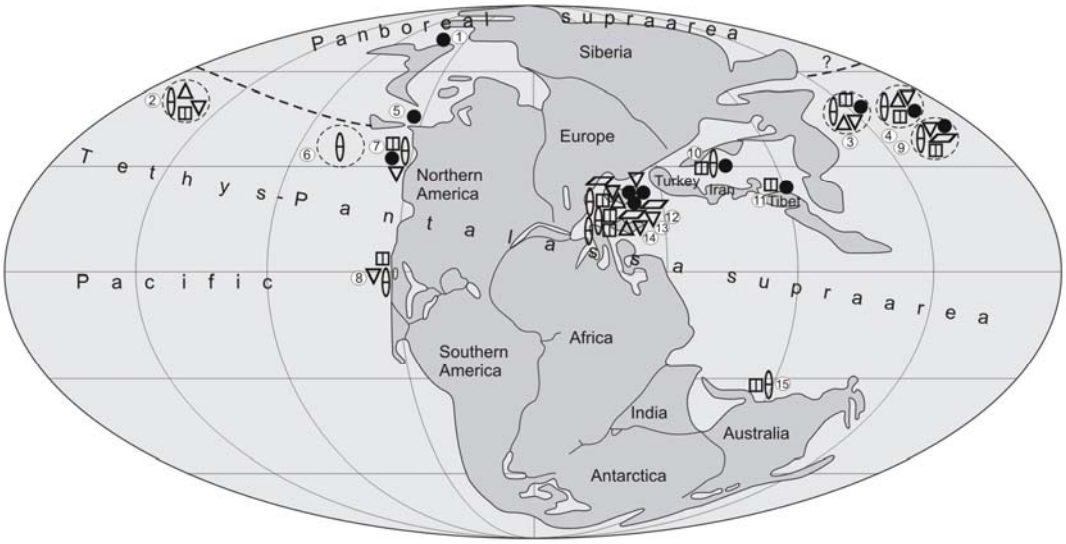

Fig. 2. Geographic distribution of conodonts in Norian and Rhaetian.
Regions: 1 – Kotelny Island; 2 – Koryak uplift; 3 – Middle Sikhote-Alin; 4 – Primoriye; 5 – Northern Alaska; 6 –Eastern Alaska; 7 – British Columbia; 8 – South-western USA; 9 – Japan; 10 – Tajikistan; 11 – Tibet; 12 – Austria, Slovakia; 13 – Slovenia; 14 – Yugoslavia; 15 – Australia; 16 – Turkey; see genera on Fig.1.

Almost all conodont occurrences mentioned above take place in northern Tethyan regions where sculptured *Epigondolella* and *Mockina* dominated. In northern latitudes only cosmopolite genus *Norigondolella* represented by two species inhabited in the Norian. In Boreal regions rare conodonts were found only in Kotelny Island in the *Monotis ochotica* Zone and in Alaska Peninsula in the Shublik formation.

There is no possibility to estimate a differentiation of the conodont fauna within the Panboreal Supraarea for the Norian Age. Rhaethian conodonts in northern latitudes were not established. *Misikella* characterized by very simple morphologic features represented the largest group in the Tethys-Pantalassa supraarea in the Raethian. The northern regions of the supraarea were the only place where they were found.

As study has shown, the evolution of conodonts from northern and southern latitudes paced differently at the final stage of their development that reflects in zone timescales. By example of conodont evolution in the Siberian region (Arctic basin) in the Late Triassic, the stage of development in the Carnian-Norian is divided into two phases. In the northwestern Pacific the stage is divided into Early Carnian and Late Carnian-Norian substages consisting of six phases and Rethian substage (Fig. 3).

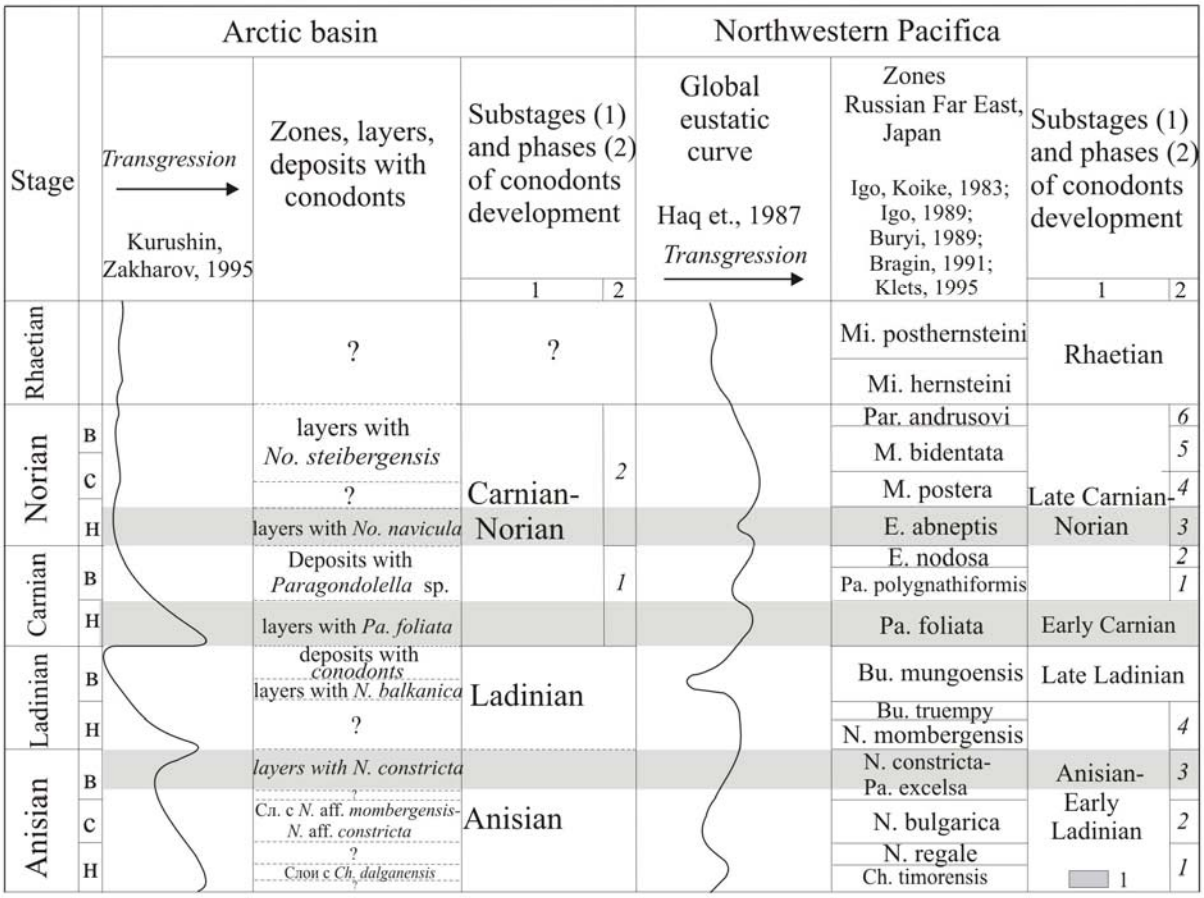

Fig. 3: The stages of development and surface leveling of conodonts associations in Middle and Late Triassic. 1 – surface leveling.

The increase of paleotemperature of the sea water and gigantic rise of the World Ocean at the beginning of the Late Triassic and beginning of the Norian (HAG et al., 1987; KURUSHIN, ZAKHAROV, 1995) conduced to the taxonomic change of conodont associations in southern seas & synchronic invasion of taxa in northern seas (Fig. 3).

Conclusion

1. The main principle of geographic differentiation of Triassic conodonts was climatic zonation.
2. ***Tethys-Pantalassa supraarea*** characterized by the largest taxonomic diversity seems to be in the tropic belt or nearby, since this place was the most propitious for the development of marine faunas. The fact that southern Tethyan conodont associations are scarce indicates that the water of this part of the Tethys was relatively cool.
3. ***Panboreal supraarea*** comprising the basins only of northern latitudes is represented by less taxonomic diversity and it is characterized by cosmopolite long-living, mainly, smooth unsculptured genera. Boreal associations are peculiarly scarce in the Late Carnian and

Norian Ages. In the Rhaetian in the northern seas conodonts seemed to be absent. In the Carnian, ***Sibirian area*** comprising Northeastern Asia and ***Canadian-Svalbardian area*** including archipelago Svalbard, Norway and northern parts of Canada segregated in the ***Panboreal supraarea***.

4. Renewal of taxonomic composition and increase of association diversity in the Siberian area are characteristic for the time of paleotemperature increase and/or the rise of the World Ocean resulting in immigration of conodonts from the Tethys to the northern seas.
5. To find such stratigraphic intervals (surface levels) corresponding with the time of the leveling of fauna taxonomic composition is of great importance, since it lets researchers correlate accurately Boreal and Tethyan regions.

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TAXONOMY AND PHYLLOMORPHOGENESIS OF THE CARNIAN / NORIAN CONODONTS FROM PIZZO MONDELLO SECTION (SICANI MOUNTAINS, SICILLY)

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Pizzo Mondello (Sicani Mountains, Western Sicily, Italy) is one of the best sites for the study of the Carnian/Norian boundary and of Upper Triassic conodonts phylogenesis as well. Pizzo Mondello section is a 450 m thick continuous succession of pelagic-hemipelagic limestones (*Calcari con selce* or *Halobia Limestone auctorum*; Cherty Limestone, MUTTONI et al, 2001; 2004) consisting in evenly-bedded to nodular claciluites (mostly mudstones/wackestones with radiolarians) rich in bivalves (*Halobia*) and ammonoids, with cherty lists and nodules (GUAIUMI et al., 2007; NICORA et al., 2007).

Conodonts are very abundant giving the opportunity to observe and to point out clear relationships among the four most widespread Upper Carnian/Lower Norian conodont genera (*Paragondolella*, *Carnepigondolella*, *Metapolygnathus* and *Epigondolella*) and to identify trends of the genera turnovers.

Genera have been classified and separated following the original diagnosis given by the Authors, regarding also as discriminating for the genera taxonomy the following morphological elements: position of the pit, with respect both to the platform and to the keel; shape of the keel end; length of the platform and occurrence of nodes and/or denticles on the platform margins.

Studies on conodont populations allowed recognizing precise trends in the evolution of the platform morphology that are common to the four genera listened above (*Paragondolella*, *Carnepigondolella*, *Metapolygnathus* and *Epigondolella*): a) forward-shifting of the pit, b) shortening of the platform and c) development of nodes and denticles on the platform margins (see also ORCHARD, 1991a,b). Through the analyses of these elements and the finding of transitional forms occurring among forerunners and descendants, it was possible to assign the four main Late Carnian-Early Norian genera considered to two separate monophyletic lineages: i) the *Paragondolella-Metapolygnathus* lineage and ii) the *Carnepigondolella-Epigondolella* lineage, according also to KOZUR, 2003:

- transitional forms, here referred to *Metapolygnathus* n. sp., between the genus *Paragondolella* and the genus *Metapolygnathus* have been found at Pizzo Mondello section from sample PM6A to NA35 (NICORA et al., 2007), before the first occurrence of *Epigondolella quadrata* Orchard (sample FNP88A, NICORA et al., 2007). This new species represents the transition between *Paragondolella noah*

(Hayashi) and *Metapolygnathus communisti* Hayashi. In fact forward-shifting of the pit towards the centre of the element, posterior prolongation of the keel, shortening of platform margins and occurrence of little nodes at the geniculation points are observed. These morphological variations are clearly transitional to *Metapolygnathus communisti* and thus suit *Metapolygnathus communisti* as the immediate descendant of *Paragondolella noah* (according to KOZUR, 2003);

- transitional forms (occurring from sample FNP51A to sample NA33, NICORA et al., 2007) between the genus *Carnepigondolella* and the genus *Epigondolella* are represented by *Carnepigondolella orchardi* (KOZUR) (=*Epigondolella orchardi* in KOZUR, 2003). This species, in fact, shows intermediate features between *Epigondolella quadrata* (the first real representative of genus *Epigondolella*) and its forerunner, *Carnepigondolella pseudodiebeli* (KOZUR). *Carnepigondolella pseudodiebeli* evolves into *Epigondolella quadrata* through the shifting of the pit to the centre of the element, the shortening of the platform and the evolution of nodes into denticles on the platform margins. The gradual evolution of these morphological elements is clearly present in *Carnepigondolella orchardi*, suiting this species as the morphocline between *Carnepigondolella pseudodiebeli* and *Epigondolella quadrata*.

The finding, at Pizzo Mondello section, of morphoclines between *Carnepigondolella pseudodiebeli-Epigondolella quadrata* and between *Paragondolella noah* - *Metapolygnathus communisti*, demonstrates that:

1) the evolution of *Paragondolella noah* and *Carnepigondolella pseudodiebeli* into their relative descendent occurred surely in the Sicano Basin and thus, *Metapolygnathus communisti* and *Epigondolella quadrata* did not migrate from other provinces;
2) because of the recognition of the morphoclines with their ancestors, the first occurrence of *Epigondolella quadrata* in sample FNP88A and of *Metapolygnathus communisti* in sample NA35 represents their phylogenetic first appearance and, thus, their FAD (according to Remane, 2003).

On these bases we consider the FAD of both *Epigondolella quadrata* and *Metapolygnathus communisti* at Pizzo Mondello section as two possible primary biomarkers for the base of the Norian.

Semi-quantitative curves of the conodont abundances for each of the four main Carnian/Norian genera have been provided. The analysis of these curves show three turnovers involving the four genera:

Turnover 1: genus *Paragondolella* extinguishes while genus *Carnepigondolella* almost disappears and it is replaced by the occurrence of genus *Epigondolella*.

Turnover 2: genus *Epigondolella* abruptly decreases and is overturned by a mass occurrence of genus *Metapolygnathus*.

Turnover 3: genus *Metapolygnathus* almost disappears and is replaced by the re-occurrence of genus *Epigondolella*.

These three turnovers, along with the curve trends, seem to evidence some sort of competition first of genus *Carnepigondolella* versus genus *Paragondolella* and, later, of genera *Carnepigondolella* and *Epigondolella* versus genus *Metapolygnathus* (see also KOZUR, 2003). The competition between genera *Paragondolella* and *Carnepigondolella* is also mirrored by the competition between their descendent genera *Metapolygnathus* and *Epigondolella* respectively, which probably inherited the same ecological niche of their forerunners. This competition thus reflects and strengthens the phylogenetic relationships of the *Paragondolella-Metapolygnathus* and *Carnepigondolella-Epigondolella* lineages.

Further integrated studies and correlations with other stratigraphic sections will provide a better understanding of the causes that might generate conodont genera turnovers and thus better define the base of the Norian.

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UPDATED CORRELATION OF THE GERMANIC TRIASSIC WITH THE TETHYAN SCALE AND ASSIGNED NUMERIC AGES

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The correlation of the Germanic Triassic with the Tethyan Triassic is well constrained biostratigraphically. However, radiometrical data are lacking and have to be imported for numerical calibration of lithostratigraphic units. These imported data can be extended to intervals without primary numerical data by astronomical calibration with Milankovitch cycles that are well recognisable in continental lake deposits of the Germanic Triassic, and correlated to the marine realm. Such cross-correlation is a powerful method for improving numerical stage ages in the marine realm.

The numerical ages (in Ma) of Figs. 1–3 were calculated by KOZUR (2003), KOZUR & BACHMANN (2003) and BACHMANN & KOZUR (2004), and for the base Jurassic by KOZUR & WEEMS (2007), by improved biostratigraphic dating of radiometric data in continental magmatics and by cross correlation of marine beds (with radiometric data) with lake deposits (containing well recognisable Milankovitch cycles). Our calculations are remarkably close to the subsequently published most recent radiometric data of different authors (Figs. 1, 4, FURIN et al., 2006; GALFETTI et al., 2007, LEHRMANN et al., 2006; OVTCHAROVA et al., 2006). A particularly good example is the numerical age (improved by astronomic calibration) of 252.6 Ma for the Permian-Triassic boundary (PTB) that was published by KOZUR (2003), which age was later confirmed with new radiometric data by MUNDIL et al. (2004).

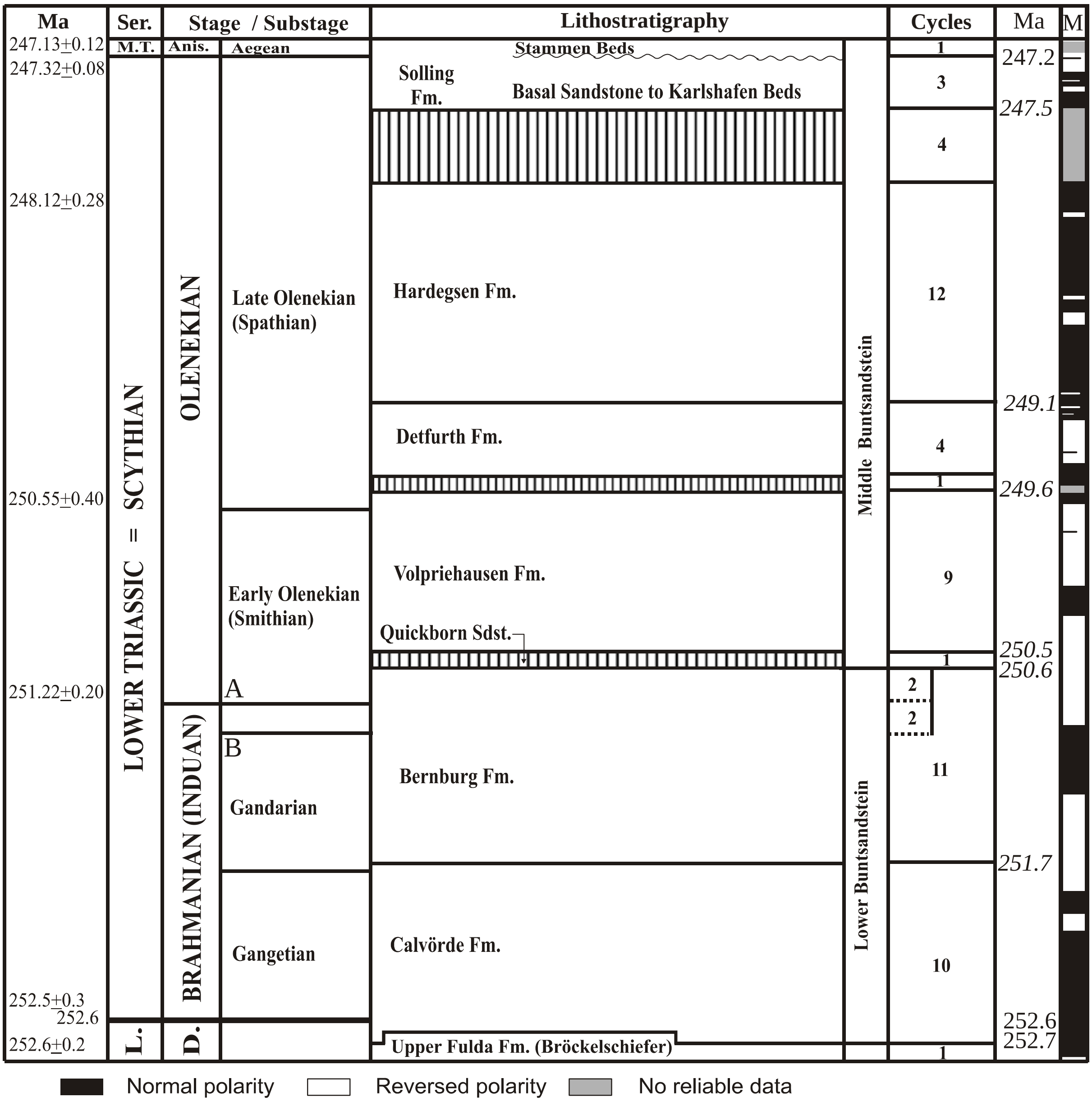

Figure 1: Numeric ages, cyclicity and palaeomagnetic of the Lower Triassic in the Germanic Basin. Slightly modified after Kozur & Bachmann (2003) und Bachmann & Kozur (2004). Palaeomagnetic and cyclicity after Szurlies (2007), but 11 cycles in the Bernburg Fm. Left column: Compiled new radiometric ages of the marine Lower Triassic after Galfetti et al. (2007), Lehrmann et al. (2006), Mundil et al. (2004) and Ovtcharova et al. (2006). Right column: Extrapolated numerical ages of the Germanic Triassic in italic script.
A: Biostratigraphically correlated base of the Olenekian after Kozur & Seidel (1983) and Kozur (1999).
B: Olenekian base by palaeomagnetic correlation (Bachmann & Kozur, 2004; Szurlies, 2007).

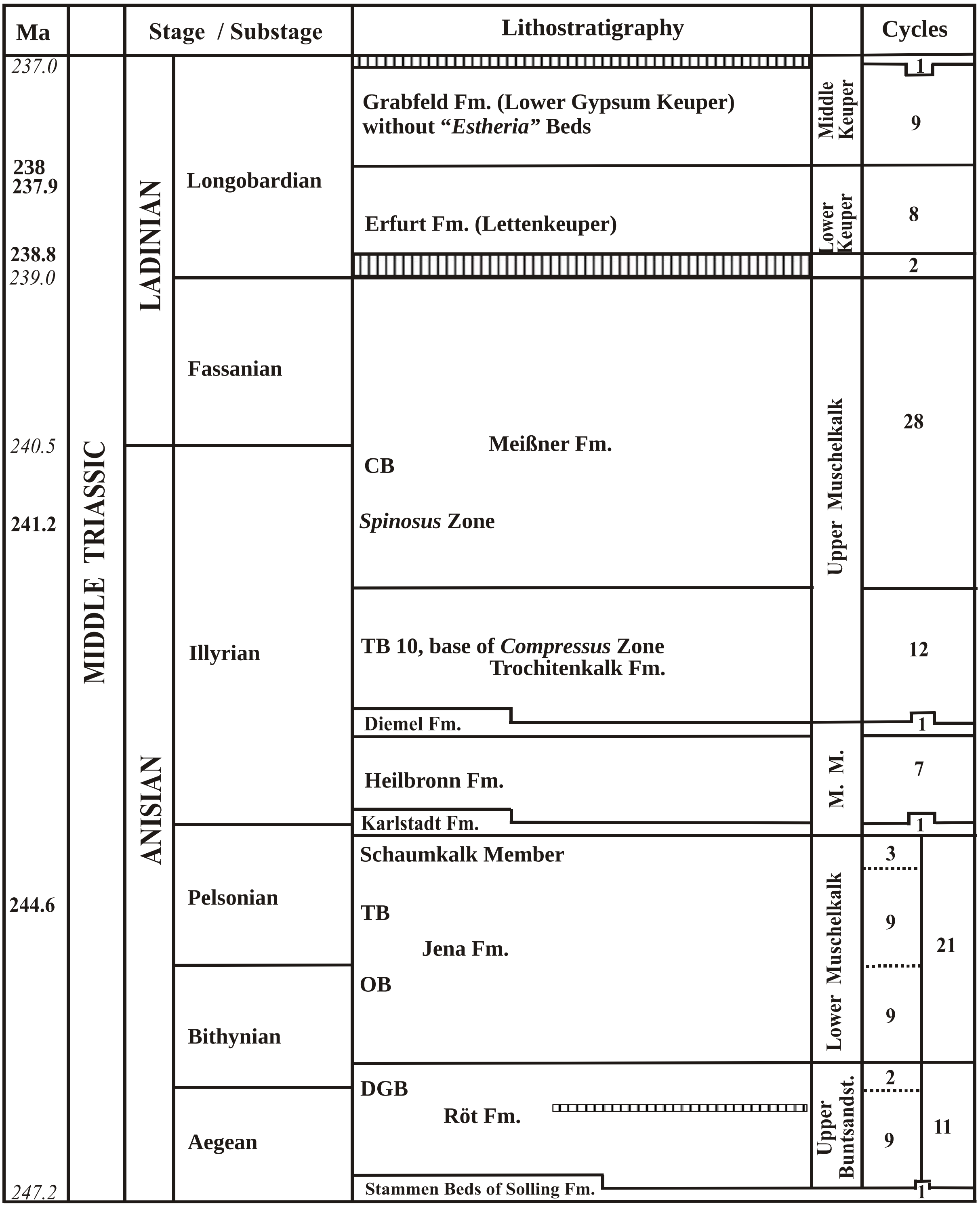

Figure 2: Numeric ages of the Germanic Middle Triassic after Bachmann & Kozur (2004), slightly modified.
DGB: Dolomitische Grenzbank, LO of Costatoria costata, FAD of Myophoria vulgaris. OB: Oolithbänke. TB: Terebratelbänke. CB: Cycloidesbank. TB: Trochitenbank. M. M.: Middle Muschelkalk.
Numeric ages in bold script: Compiled measured radiometric data.
Numeric ages in italic script: Calculated numeric ages for the base of the Anisian, Ladinian and Carnian stages as well as Longobardian substage.

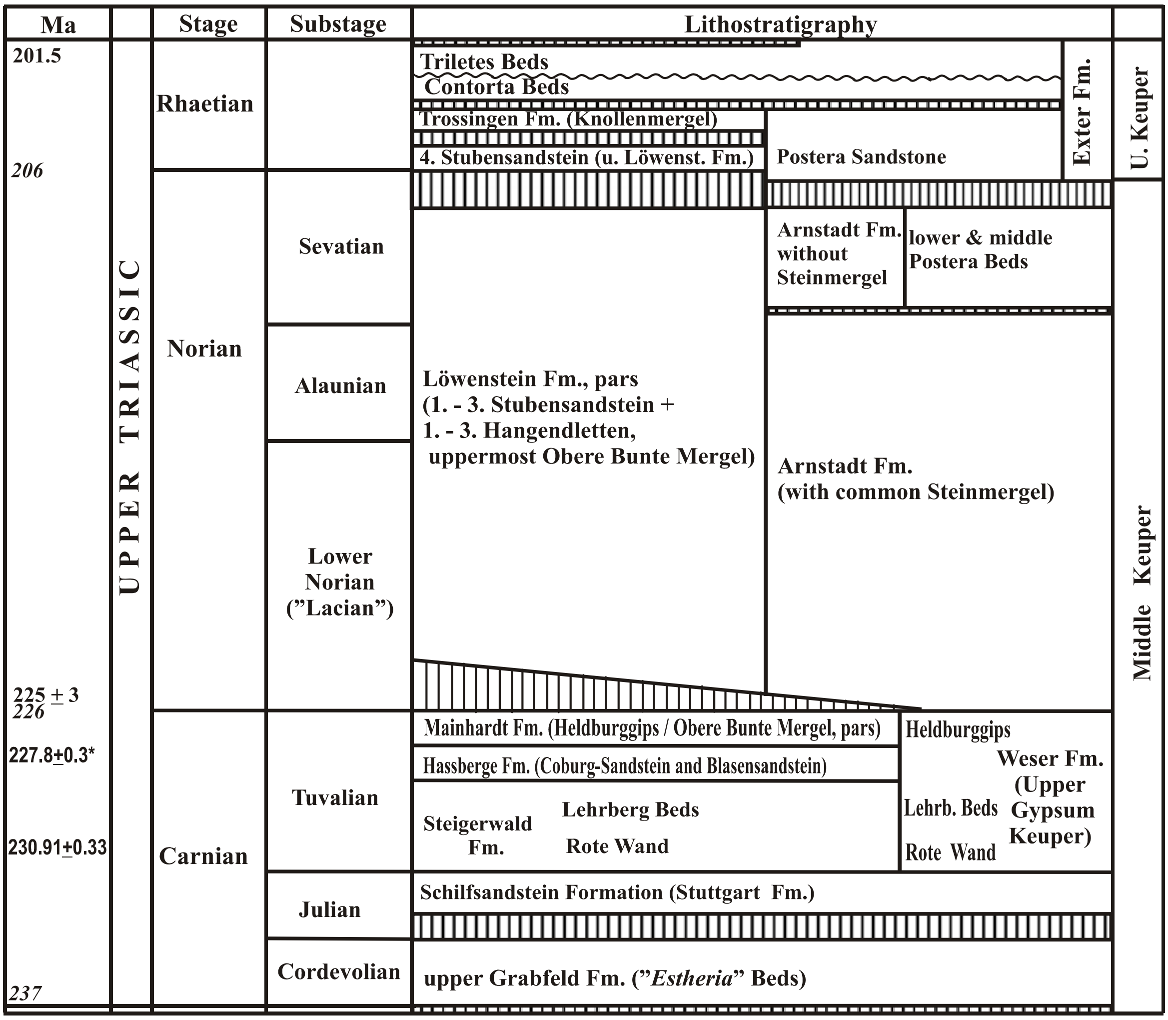

Figure 3: Numeric ages of the Germanic Upper Triassic, modified after Bachmann & Kozur (2004).

*^{40}Ar/^{39}Ar data from the Adamanian of Ischigualasto, Argentina (Rogers et al.1993), corresponding to a middle to late Tuvalian level between the Lehrberg Beds and the top of the Weser Fm. Only very few radiometric data are known from the Late Triassic. The 230.91±0.33 Ma of Furin et al. (2006) is from the basal *Carnepigondolella zoae* Zone, a level somewhat older than the Lehrberg Beds of the Weser Fm. The 225±3 Ma (Gehrels et al., 1986, 1987) is from volcanics in the lower Norian *E. quadrata* Zone in SE Alaska. The 201.5 Ma for the Triassic-Jurassic boundary is based on a biostratigraphic re-dating (Kozur & Weems, 2007) as latest Rhaetian of the lower lava flow of the CAMP volcanics in the Newark Supergroup, and on new radiometric data from a well-dated Rhaetian-Hettangian boundary section in Peru by Schaltegger et al. (2008). Calculated numeric ages for the base of the Carnian, Norian and Rhaetian stages in italic script.

Figure 4 (next page): Calculated numeric ages for selected lithostratigraphic units of the Germanic Triassic and most important radiometric ages of the marine Triassic. Not to scale. Gaps not shown.

* = ^{40}Ar/^{39}Ar age; all other radiometric ages are zircon U-Pb ages.

The first numeric ages for the lithostratigraphic units of the Germanic Triassic were estimated by Menning (1991–2002). Menning did not take into account the late Tuvalian (Adamanian) ^{40}Ar/^{39}Ar age of 227.8±0.3 Ma from Ishigualasto (Argentina) by Rogers et al. (1993), the basal Norian 225±0.3 Ma age from SE Alaska (Gehrels e al., 1986, 1987), and the estimated duration of the lithostratigraphic units was partly arbitrary. Such caused a jitter of several million years in the assumed numeric ages of Menning (1991) to Menning et al. (2005 a, b), referred to as "paternoster stratigraphy" by Menning et al. (2005b). Later, Bachmann & Kozur (2004) calculated the duration of the lithostratigraphic units by using Milankovitch cycles; data that seem to have been adopted by Menning et al. (2005a).

Menning 1991	Menning 1995	Menning 1997	Menning et al. 2002	Bachm. & Kozur 2004	Menning et al. 2005a	This paper	Selected Lithostratigraphic Units	Radiometric data outside Germanic B.
208	208	206	199.6	199.6	199.6	**201.5**		201.5
							Triletes Beds	
	208.5		201.5		201.4		Contorta Beds	Rhaetian
	210		203.5		203.3		Trossingen Fm.	
			206.5		206.5		4. Stubensandstein	
	212	210	207	206	207	206	Arnstadt Fm., pars, with common Steinmergel/ 1.-3. Stubensandstein + Hangendletten, upperm. Obere Bunte Mergel	Norian
222	220	218	221	226	226	226	Weser Fm: Heldburggips	225 ± 3
							Lehrberg Beds	227.8 ± 0.3*
							Rote Wand	230.91 ± 0.33 Carnian
224.5	224	222	224.5	231	230	232	Schilfsandstein Fm. (Stuttgart Fm.)	
225.5	225	223	226		231		*"Estheria"* Beds	
	229	226	231	237	237	237	Grabfeld Fm.	238.0 + 0.4/-0.7
228.5	230	228.5	232.5	238	239	238	Erfurt Fm	Ladinian
230	232	231	235	238.8	240	238.8		238.8 + 0.5/-02
234	234	234	235.8	240.5	241	240.5	Meißner Fm. Upper Muschelkalk	241.2 ± 0.8
			237	241.8	242	241.8	Trochitenkalk Fm.	242.6 ± 0.7
234.5	235.5	235	238.5	243.0	343.4	243	Middle Muschelkalk	
236	237	236.5	240	243.9	244.6	243.9	Lower Muschelkalk (Jena Fm.)	Anisian 244.6 ± 0.36
239.5	240	240	243	246	246.6	246	Röt Fm.	246.77 ± 0.13
	242	242	244.5	246.9	247.4	247.1	Stammen Beds	247.13 ± 0.12
				247		247.2	Solling Fm.	247.32 ± 0.08
242	243		245	247.4	247.8	247.5	Hardegsen Fm.	248.12 ± 0.28
	245	245	247	248.6	249	249.1	Detfurth Fm.	Olenekian
	246		247.5	248.9	249.4	249.5	Volpriehausen Fm.	250.55 ± 0.4
244.5	247.6	247.7	249	250.2	250.6	250.5	Bernburg Fm.	251.22 ± 0.2
	249.2		250	251.6	251.6	251.7	Calvörde Fm.	Brahmanian (Induan)
				252.6		252.6		252.5± 0.3
247	251	251	251	252.7	252.6	252.7	Zechstein, pars	252.6 ± 0.2 Changhsing. pars

Figure 4

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LATE MIDDLE TO EARLY LATE TRIASSIC RADIOLARIAN FAUNAS FROM THE IZMIR-ANKARA SUTURE BELT IN WESTERN TURKEY: REMARKS ON THE EVOLUTION OF THE NEOTETHYAN IZMIR-ANKARA OCEAN

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Izmir-Ankara Suture Belt (IASB) in north Turkey comprises the remnants of Neotethyan Izmir-Ankara Ocean (GONCUOGLU, 2000) and is an almost 200 km wide E-W trending belt between the Sakarya Composite Terrane in the north (GONCUOGLU et al., 1996) and the Tauride-Anatolide Platform (TAP) in the south. Within the suture belt several tectonic units of three different main tectonic settings were recognized as thrust sheets above the units of the TAP:

1. Northern and uppermost one including more or less complete successions of the IAO lithosphere.
2. Median one with tectonic mélanges of the subduction-accretionary complex of IAO, comprising blocks of ophiolites, fore-and back-arc volcanics, radiolarian cherts, pelagic limestones and blueschists,
3. The southern and lower one belonging to the Maastrichtian –Early Paleocene flysch complex (Bornova Flysch Zone) with olistoliths and olistostromes of the former two settings and the TAP margin successions. It was formed in a peripheral foreland basin on the northern edge on the TAP, in front of the southward advancing nappes (GONCUOGLU et al., 2006b).

The olistoliths within the melange, especially volcanics associated with sediments provide evidence for the geological evolution of the TAP continent margin as the well as the initial stages of the rifting and opening of Izmir-Ankara oceanic sea-way. Our long-lasting study along the IASB has shown that the oldest radiolarian sediments associated with volcanism are not older then Triassic. From the Bornova Flysch Zone to the NW of Manisa W Turkey) five different Triassic radiolarian assemblages have been derived from the blocks in the IASB (Tekin et al., 2006). Four of assemblages have been obtained from isolated blocks mainly composed of a radiolarian cherts- mudstones alternation. Their ages are: Late Ladinian, coinciding the *Muelleritortis cochleata* zone; early Carnian, coinciding the *Tritortis kretaensis* Zone; late Early Carnian, coinciding the “unnamed radiolarian zone” between *Tritortis kretaensis* and *Tetraporobrachia haeckeli* zones and early Middle Carnian, coinciding the lower part of *Tetraporobrachia haeckeli* zone established by KOZUR & MOSTLER (1994, 1996) and KOZUR (2003).

One continuous section (Komurcu Measured Section) with an alternation of chert and mudstone was recognized in a mega- block further NW. Diverse radiolarian faunas were obtained from this section that ranges from late Ladinian, coinciding the *Muelleritortis cochleata* zone to late Early Carnian, coinciding the "unnamed radiolarian zone" between *Tritortis kretaensis* and *Tetraporobrachia haeckeli* zones. *Pseudostylosphaera mostleri* n. sp. was defined from this section.

The new data obtained from the Bornova Flysch Zone reveals that the earliest radiolarian chert deposition to the N of the TAP commenced during the late Middle Triassic. Combined with geochemical data from the associated volcanic rocks it is shown that this event is related to the opening of the of the Izmir-Ankara Branch of Neotethys confirming our earlier suggestions (GONCUOGLU et al. 1996, 2001, 2003, 2006a; GONCUOGLU, 2000; and TEKIN et al. 2002, 2006) from the Eastern parts of IASB.

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CONODONT BIOSTRATIGRAPHY OF THE LATE TRIASSIC IN THE WESTERN BERGAMASC ALPS (ITALY)

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In the Lombardian succession, the last Triassic depositional system, developed after the demise of the Dolomia Principale carbonate platform, is represented by a subtidal, mixed and cyclic ramp depositional environment (Riva di Solto Shale and Zu Limestone formations), developed on the tilted blocks affected by the Norian rifting event (Jadoul et al., 1992; 1994; 2004). This succession passes upward into a relatively homogenous outer carbonate ramp environment of the earliest Hettangian Malanotte Formation (GALLI et al., 2007) followed by the Bahamian-type carbonate platform of the Albenza Formation (*Conchodon* Dolomite *Auctorum*; JADOUL & GALLI, 2008).

In the last decades the biostratigraphy of the aforementioned units has been carried out mainly with bivalves, benthic foraminifers and palynomorphs. Here, we present the conodont biostratigraphic characterization of the subtidal shale - carbonate succession of the Zu Limestone Formation (Zu1, Zu2 and Zu3 members) through the investigation of the Imagna Valley sections. A useful conodont fauna composed of *Misikella hernsteini* and *Misikella koessenensis* has been also recorded from the base of the upper Argillite di Riva di Solto (ARS2), restricting thus the age of this unit to Sevatian 2 (latest Norian) (KOZUR & MOCK, 1991; MOIX at al., 2007). Even if rare, *Misikella koessenensis* can be found in the latest Sevatian (MOIX et al., 2007).

A major dataset has been collected for the Zu limestone Fm., in particular from the Zu1 member. In the transitional interval between the Argillite di Riva di Solto and the Zu Limestone Formation only species *Misikella hernsteini* occurs, along with *Misikella koessenensis*. This fauna is the same collected from the underlying upper Argillite di Riva di Solto (ARS2). At the base of the Zu1 member, and thus the base of the Zu Limestone Formation, *Misikella posthernsteini* occurs. Conodont investigations have been also carried out at the top of the Zu1 member where a fauna composed by *Misikella hernsteini, Misikella posthernsteini* and *Misikella koessenensis* occurs. The base of the Zu2 member has been also investigated for conodont biostratigraphy, but the samples resulted barren as expected. The upper Zu Limestone Formation (Zu3 member) yielded only a species of *Misikella ultima* which has been collected from the last calcareous layer, just below the net contact with the overlying Malanotte Fm. which is Hettangian in age basing on palynomorphs and isotopic data (CIRILLI et al., 2000; GALLI et al., 2005; 2007).

The first occurrence (FO) of *Misikella posthernsteini* is commonly used to define the base of the Rhaetian (KOZUR & MOCK, 1991) and it has been recently calibrated with the FO of *Paracochloceras suessi*, an ammonoid largely used to define the base of the Rhaetian stage (KRYSTYN et al., 2007).

Furthermore, KOZUR & MOCK (1991) recognized the upper Rhaetian with the appearance of *Misikella ultima*, never found from Jurassic strata.

The conodont fauna collected from the western Bergamasc Alps allowed to constrain the whole Zu Limestone Formation to the Rhaetian stage and to reconsider and relocate the previous stratigraphic boundaries of the Late Triassic in the Lombardian succession.

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REVIEW OF THE UPPER TRIASSIC BRACHIOPODS IN THE NORTHERN CALCAREOUS ALPS

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Shallow-water Carnian brachiopod fauna of the NCA is relatively poor in its diversity (e.g. *Adygella* and some species of *Cruratula* and koninckinids in the Raibl and Cardita Beds). It is markedly different not only from partially synchronous assemblages of the Hallstatt Limestone, which lived in deeper parts of the Tethys but totally from those of the Norian and Rhaetian. At that time the diversification of the brachiopod assemblages was already more intensive.

The Hallstatt facies yielded already more varied, often smooth fauna of the Carnian and Norian age. The differences in composition between them are rather insignificant.

Some brachiopod taxa (*Camerothyris*, some species of the characteristic genus *Austriellula* – *A*. *nux, A*. *longicollis, A*. *dilatata* etc.) are known from both Carnian and Norian levels, some other (terebratulids *Nucleatula* and *Juvavella*, athyridid *Pexidella strohmayeri*, and rhynchonellids *Austriellula juvavica, A*. *laevis, Norella geyeri* etc.) are reported from the Norian only. Curious local neptunian dyke "Weisser Crinoidenkalk" on the GSSP candidate Steinbergkogel near Hallstatt is according to KRYSTYN et al. (2007a) the youngest fossil horizon of the Hallstatt Limestone (top of *Paracochloceras suessi* Zone). It yielded according to BITTNER (1890) „*Juvavella Suessii, Rhynchonella Geyeri, Rhynchonella nux, Koninckina blandula and Spirigera deslongchampsi",* all of them held for the Norian species.

The Uppermost Triassic brachiopod fauna is most abundant in the intraplatform Kössen Formation represented by basinal Kössen Beds or by reef limestones (Oberrhätkalk). It was studied in detail and modern revision published by PEARSON (1977). Recently were these faunas studied in the Kössen Basin between Kufstein and Bad Ischl by GOLEBIOWSKI (1991 etc.) who according to the dominating genera recognized basing on different palaeoecology and palaeobathymetry stratigraphically oldest *Rhaetina*- biofacies , and then younger *Zugmayerella* -, *Fissirhynchia*- and *Oxycolpella* biofacies. From his scheme it is well-visible that the short-looped terebratulids prefered shallower environments, while deeper waters were commonly inhabited by spire-bearing athyridids. Other Uppermost Triassic deposits like Zlambach Marls or Dachstein Reef Limestone contain brachiopod fauna only rarely. Nevertheless, the Dachstein Limestone of the Hochschwab massif yielded recently except halorellid lumachelles abundant brachiopod fauna with five characteristic Kössen brachiopods (SIBLÍK & BRYDA, 2005).

Environmental disturbances at the end of the Triassic led to brachiopod turnover on the superfamily level and the spondylospiroid, dielasmatoid, athyridoid and thecospiroid groups that had played great role in the Triassic disappeared. New, already Hettangian brachiopod communities had already different compositions. The discussions on the Triassic/Jurassic boundary (IGCP project 458 – in 2001-2005) and quite recently on the Norian/Rhaetian boundary brought also new views on the distribution of the brachiopods in the Upper Triassic.

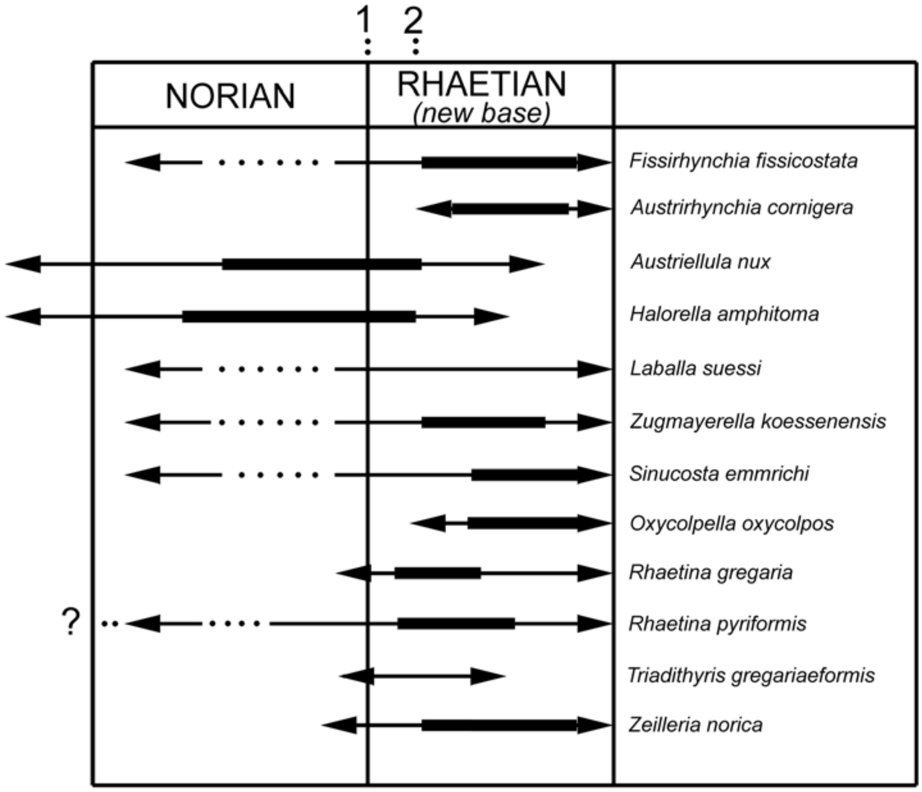

Fig. 1: Approximate stratigraphical ranges of some important Upper Triassic brachiopods (adapted according to SIBLÍK - in print).

New proposals for the Norian/Rhaetian boundary (KRYSTYN et al., 2007a, 2007b) locate the N/R boundary between *Sagenites quinquepunctatus* Zone below and *Sagenites reticulatus* Zone above (it corresponds to the FOD of *Misikella posthernsteini*). Between these zones the important changes in the composition of the ammonite, pelecypod and also brachiopod faunas can be observed, including appearance of the bulk of the Kössen species. Referring to a new scale, rhynchonellids *Halorella* and *Halorelloidea* regarded up to now as leading Norian genera raise into the Rhaetian. In regard to the new base of the Rhaetian, only *Austrirhynchia cornigera* and *Oxycolpella oxycolpos* seem to be Rhaetian indicators.

Higher up at the end of the Triassic, the most abundant brachiopods in the Rhaetian belonging to the dielasmatoid, spondylospiroid and athyridoid groups disappeared. At that time rhynchonellids were relatively rare.while zeillerioids common, as well as later in the Jurassic, then together with spiriferinoids, rhynchonellids and terebratuloids.

There are some older literary data that *Rhaetina gregaria* and *Fissirhynchia fissicostata* were not restricted to the Triassic only and ranged into the Earliest Liassic in Austria and Italy. However, it should be necessary to take modern critical measures to prove given data. E. g. GEYER reported in his monograph (1889) *Terebratula gregaria* and *Rhynchonella* cf. *fissicostata* from the classical locality Hierlatz near Hallstatt. PEARSON later (1977) revised also internally that material of „*gregaria*“ and proved its belonging to *Rhaetina gregaria*. Since GEYER´s times neither of mentioned 2 species has been ascertained in the new, very rich samplings in the Liassic at the locality. With regard to the tight contact of the fissure-rich Dachstein Limestone with the Hierlatz Limestone at the Hierlatz locality and its vicinity, there could arise some doubts about proclaimed Liassic provenance of those 2 species (cf. SIBLÍK, 2001).

Precise stratification should be made of the future finds of brachiopods, supported by the accompanying ammonite and conodont fauna. In this way only, it would be possible to clear better the stratigraphic ranges of individual brachiopod species.

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REVISED U-PB AGES OF THE TRIASSIC-JURASSIC BOUNDARY AND THE EARLIEST JURASSIC AND THEIR IMPLICATIONS

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The end of the Triassic period is marked by one of the five largest mass extinction events, and concomitant changes in the global climate and carbon cycle. The terminal Triassic and earliest Jurassic therefore represent a critical interval for the Earth system, and assessing the chronology of events and rates of processes need a precise and accurately calibrated time scale. Key calibration points for the current geological time scale (GTS2004, GRADSTEIN et al. 2004) are U-Pb ages of 199.6 ± 0.4 Ma from immediately below the Triassic-Jurassic boundary (TJB) on Kunga Island (Queen Charlotte Islands, Canada) (PÁLFY et al. 2000) and 200.4 +2.7/-2.8 Ma from the Middle Hettangian of Puale Bay (Alaska, US) (PÁLFY et al. 1999). The first one effectively serves as the best estimate of the TJB in GTS2004. Both dates were obtained on air-abraded multi-grain fractions of zircons separated from volcanic ash layers intercalated in marine sediments with precise biostratigraphic age control. However, the accuracy of the ages is compromised by unrecognized Pb loss (due to averaging effects from the use of multi-crystal samples for the former) and a combination of inheritance, Pb loss and age discordance for the latter age. Here we report preliminary results of re-dating the same samples using chemical abrasion pretreatment (CA-TIMS) on single zircons which effectively eliminates the effects of Pb loss. The use of single crystals allows recognizing of and accounting for age dispersion. Eleven single crystals were analyzed from the Kunga Island sample; three of them carried minor inherited older Pb and one remained affected by Pb loss. A coherent cluster for seven analyses yields a weighted mean $^{206}Pb/^{238}U$ age of 201.7 ± 0.6 Ma that we regard as the crystallization age and use as the revised best estimate of the TJB age. Twenty single crystals were analyzed from the Puale Bay sample; one of them was affected by inheritance and another three showed Pb loss. Sixteen analyses are mutually overlapping and yield a median $^{206}Pb/^{238}U$ age of 200.8 +0.6/-0.4 Ma (ages are 2σ, not including uncertainties on the ^{238}U decay constant).Our results are in good agreement with recently reported CA-TIMS zircon U-Pb ages from Peru (SCHALTEGGER et al. 2008) which suggest 201.58 ± 0.28 Ma for the TJB and 199.53 ± 0.29 Ma for the Hettangian-Sinemurian boundary. These new data together firmly suggest that the end-Triassic extinction and environmental events were indeed synchronous with volcanism in the Central Atlantic Magmatic Province and the biotic recovery in the Hettangian took place in a relatively short time, when the early Hettangian did not exceed 1 Ma in duration. Several other samples from both the uppermost Triassic and lowermost Jurassic of the Queen Charlotte Islands are being analyzed and it is expected that their CA-TIMS U-Pb ages will help further constrain the time scale at the Triassic-Jurassic transition.

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A BRIEF HISTORY OF GEOLOGICAL RESEARCH OF THE DACHSTEIN-HALLSTATT-SALZKAMMERGUT REGION

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Besides its unique scenic beauty, the area around Hallstatt is well known for its long tradition in salt mining. Mining of rock salt commenced around 7000 years ago. Also the name "Salzkammergut" refers to the traditional economic resources of this region, the salt mining. In addition, the Salzkammergut - and in particular the region around Hallstatt and Bad Aussee - has been a classical area for geoscientific research in the Tethyan Mesozoic for over 200 years. It is recorded in early travel reports, that the salt miners of Hallstatt collected ammonites and sold them to tourists and also to museum collections. Most of the ammonites were collected in the famous red limestones of Upper Triassic age ("Hallstatt limestone"), close to the Hallstatt salt mine. Smaller faunas are derived from Lower Jurassic red limestones ("Hierlatz Limestone"), more rarely from "Klauskalk", a red limestone of Middle Jurassic age, both also from the surroundings of Hallstatt.

Already in 1782 the Bohemian naturalist J. BOHADSCH mentions the nearby fossil-rich rock formations, in particular in the area of Gosau. Gastropods, corals, ammonites and other petrefacts from this Upper Cretaceous Gosau Group could be purchased from local commercial collectors; this is true even for today!

The Early Beginnings

The first remarkable geognostic study of the Salzkammergut dates back to the year 1802, when the renowned German naturalist Leopold von BUCH published his 2-volume booklet "Geognostische Beobachtungen auf Reisen durch Deutschland und Italien" (volume 2 was published in 1809). An extensive treatise in Volume 1 entitled "Geognostische Uebersicht des Oesterreichischen Salzkammerguths" deals with observations in this region, which he carried out in part together with his fellow and mentor Alexander von HUMBOLDT in the years 1797-1799. BUCH noticed the dominance of limestone and speculated on its striking colour variations. BUCH also realized the abundance of fossils in the red limestones, which never occur as individual specimens but always as clusters. As a consequence of the aforementioned concentration of red limestones in the valleys, BUCH draws the conclusion, that the rich "Fossil-Lagerstätten" are concentrated in the red limestones of the valleys, while the white limestones are widely devoid of fossils. However, besides these odd hypotheses, BUCH identified already coquinas of Pecten-like bivalves in the region of the Hallstatt salt mine (named by BRONN 1830 Halobia and Monotis) and mentions orthoceratids, ammonites and nautiloids.

BUCH also deals with the origin of limestone bedding and the reasons for varying dipping directions, the latter he attributes to variable underground conditions, which force the beds to change their striking and dipping directions. There is no evidence, that BUCH understood already the primary sedimentary or diagenetic origin of limestone bedding, respectively the effect of tectonic forces in respect to mountain building. Of course BUCH dealt also extensively with the origin, mineralogy and the age of the Hallstatt salt mine. The discussion about the origin and age of the Haselgebirge persists up to the present and only due to more sophisticated geochemical and paleontological methods has a better understanding been obtained during the last decades.

BUCH showed also interest in hydrogeological questions, such as the water balance of Lake Hallstatt, where he considers hidden subsurface springs as important contributors. Last but not least, he records an earthquake in Hallstatt on March 12, 1789, which lasted 4-5 seconds. It started with a bang, while the shock wave spread from south to north, accompanied by sonorous humming.

Astonishingly enough, the pioneer paper by Leopold von BUCH (1802) did not trigger immediate further research activities, but only almost twenty years later were the next studies on this region published, showing already the considerable progress made in our science.

1821-1845: Laying the foundation-stone

The following period of research in Salzkammergut was largely dominated by the excellence of British geoscientists.

William BUCKLAND's "Uebersicht über die Struktur der Alpen" (1821) is one of the first attempts to subdivide the "Alpenkalk" into several lithologic units. According to him the Alpenkalk comprises the complete stratigraphic sequence from the Magnesian Limestone (Upper Permian) till the Chalk (Upper Cretaceous). The evaporitic sediments of the Haselgebirge are already considered to be of Upper Permian age, the red marly sandstones (Werfen Formation) from Hallstatt are equivalent to the New Red Sandstone, while the ammonites from Hallstatt represent the Liassic.

The famous Bavarian geologist Ch. KEFERSTEIN edited a journal entitled "Teutschland, geo-gnostisch-geologisch dargestellt". In volume 5 of this journal, KEFERSTEIN (1828) describes in detail a walking tour from Hallstatt over the Salzberg to Gosau. For him the formation of the salt and gypsum deposits occurred due to "osmotic respiration processes" within the clays. Besides this odd hypothesis, KEFERSTEIN gains merit in that he introduces the comparison of fossils as a new stratigraphic method. He studied and compared especially the fauna of Gosau with stratigraphically well dated faunas from abroad. This approach represents an enormous step forward! However, his main error was, that he considered the "Sandstone Formation" (Gosau Group) as older/underlying rock unit superimposed by the "Limestone Formation" of the Alpenkalk.

In 1828 the Bohemian born Carl Lill von LILIENBACH published his paper on "Allgemeine Lagerungsbeziehungen der Steinsalz-Lagerstätten in den Alpen". He lists many fossils, however, is very cautious about their stratigraphic significance. Subsequently there was a rapid series of publications. In 1829 the famed British geologists SEDGWICK & MURCHISON published their paper "On the Tertiary deposits of the Vale of Gosau in the Salzburg Alps", followed in 1830 by the papers by the French born Ami BOUE entitled "Description du Basin de Gosau" and by . Lill von LILIENBACH "Ein Durchschnitt aus den Alpen mit Hindeutungen auf die Karpaten". SEDGWICK & MURCHISON's paper represents the first detailed stratigraphic study of the Gosau *locus classicus*, however, they considered the sequence as being Tertiary in age. BOUE considers the Gosau Group as stratigraphically coeval with the Greensand. Lill von LILIENBACH's paper from 1830 represents the first attempt to subdivide the sequence of the Northern Calcareous Alps into clearly defined rock units, comparable to the present "Groups". For instance he coined the name "Werfen Shales", into which he also placed the evaporitic Haselgebirge. Lill's paper is also fundamental as a first attempt to compare rock units of the Northern Calcareous Alps with coeval ones from the Carpathians.

The paper by SEDGWICK & MURCHISON from 1831 "A sketch of the structure of the Eastern Alps" can be considered a real milestone in the history of research of the Austrian Alps. It demonstrates the progress in the application of new methods, as for instance using fossils as useful tools in biostratigraphy, or the comparison of sequences on an European wide scale. In addition, SEDGWICK & MURCHISON were drawing a series of geo-traverses through the Eastern Alps perpendicular to the striking direction of geological units. The main axis of the Eastern Alps ("Zentralzone") was already recognized, as well as the existence of the Northern and Southern Calcareous Alps. In the Salzkammergut the British in cooperation with Lill von LILIENBACH (who accompanied them in the field), continued the subdivision of the rock units, in particular of the Alpenkalk. The red shales of the Werfen Formation were seen in close association with the evaporitic Haselgebirge. Furthermore they introduced terms such as Lower and Upper Alpine Limestone and Greensand respectively Cretaceous Deposits; all these terms were later replaced by new and more precise ones.

1846-1853: On the age of the "Alpenkalk"

For a long period the "Alpenkalk" was considered to be of Liassic age by some workers (especially the formation called Dachstein Limestone from 1847 onwards) and by others as being Jurassic in general. The famous German geoscientist F.A. QUENSTEDT still believed in 1845, that the Alpenkalk represents the Neocomian - based on (incorrect) ammonite determination. The breakthrough came closer, when HAUER started detailed systematic studies of the ammonite fauna of the Hallstatt Limestone in 1846. It became more and more evident that Triassic formations contribute substantially to the sequence of the Northern Calcareous Alps. The first definite short references, regarding the important role of the Triassic in the sequence of the Northern Calcareous Alps, we owe to the Swiss geologist A.v. MORLOT, 1847 and also to HAUER, 1848. Following these initial findings, new lithostratigraphic units were defined in the following years, replacing the obsolete term Alpenkalk. In his classical paper from 1853 "Ueber die Gliederung der Trias-, Lias- und Juragebilde in den nordöstlichen Alpen" Franz von HAUER presents the following sequence for the Triassic of the Northern Calcareous Alps: Werfen Formation (including the Haselgebirge) = Buntsandstein, Guttenstein Formation = Lower Muschelkalk, Hallstatt Formation = Upper Muschelkalk, Dachsteinkalk = Lower Liassic. The Liassic age of the Hierlatz Limestone was confirmed by Eduard SUESS in 1852 while the Upper Jurassic age of the Plassen Limestone was already recognized by HAUER in 1850. The fauna of the Plassen Limestone was described by MOJSISOVICS in 1868.

The Salt rock “Haselgebirge”

The so called Haselgebirge is represented by a melange of evaporitic minerals - mostly rock salt - and clays. For a long time it was argued, that the primary sediments of this melange represent an environment, where biota cannot live, respectively cannot be preserved, and therefore the stratigraphic age of the Haselgebirge remained speculative.

A breakthrough was achieved by Wilhelm KLAUS (1953, ff.). It was already known since 1913 that in salt-clays of the North-German Zechstein sporomorphs had been found. Finally KLAUS systematically investigated all Alpine salt deposits for pollen and spores. He found, that the preservation of palynomorphs is best in pure salt and also still acceptable in the salt-clays, however, in the latter strong fragmentation of the palynomorphs can be occasionally observed. Already in his first paper concerning these investigations (1953), KLAUS proudly stated: "In the Eastern Alps palynology became the paleontology of the salt". Later on, sulfur-isotope studies (e.g. HOLSER & KAPLAN, 1966, PAK & SCHAUBERGER, 1981) confirmed the Upper Permian age, which KLAUS postulated, for a large part of the Haselgebirge. Recently Christoph SPÖTL was also successful in confirming, that the main part of the Haselgebirge is of Permian age and only a comparatively small portion shows an Early Triassic age (SPÖTL & PAK, 1996).

Hallstatt - An Early Standard for Upper Triassic Timescale

The region around Hallstatt and Bad Aussee is famous for its "Fossil-Lagerstätten" in the Hallstatt Limestone Group. The Hallstatt Limestone Group comprises variegated coloured (mostly red) micritic limestones from the Upper Anisian (Schreyeralm Limestone) till the Upper Triassic Carnian and Norian Hallstatt Limestones sensu strictu. Franz von HAUER with his famous paper from 1846 "Die Cephalopoden des Salzkammergutes aus der Sammlung seiner Durchlaucht des Fürsten von Metternich" opened the Austrian participation in Mesozoic biostratigraphic research. With HAUER and later on by his contemporary, the brilliant Eduard SUESS, an incredible story of success started. In 1849, the Geologische Reichsanstalt was established and soon HAUER and SUESS jointly established a Mesozoic working group, which later on became famous as the "Viennese School of Paleontology/Geology", among them scientists such as M.V. LIPOLD, Edmund von MOJSISOVICS, Alexander BITTNER, Ferdinand STOLICZKA, Melchior NEUMAYR, Moriz HOERNES, Dionys STUR, Georg GEYER, Gustav von ARTHABER, (later also Carl DIENER), and others. However, also German scientists contributed a substantial share to early stratigraphic research in the Triassic and Liassic of Salzkammergut, as for instance GÜMBEL, KOKEN, OPPEL, ZITTEL, FRECH, and others. Even though grave stratigraphic errors still persisted, the monographic studies on Triassic ammonites by MOJSISOVICS remain unrivaled to the present day (e.g. "Das Gebirge um Hallstatt", 1873 ff. and "Cephalopoden der mediterranen Triasprovinz", 1882). However, also the facies relations of various rock units were attracting attention, as for example in the spectacular paper by MOJSISOVICS from 1868 "Faunengebiete und Faciesgebilde der Trias-Periode in den Ostalpen". It was only about 40 years ago, that the classical profiles by MOJSISOVICS were re-investigated (e.g. KRYSTYN et al., 1969, 1971; KRYSTYN, 1973; SCHLAGER, 1969, a.o.). Since these modern studies, the complex interplay of sedimentation and synsedimentary tectonics is evident and many of the classical sections in the Hallstatt Triassic and Early Jurassic have been shown to represent not concordant sequences, but neptunian dykes. Tim TOZER (1967) from Canada has studied this fascinating period of research, which can be apostrophized as a peak in systematic-paleontological research, however, which was somehow overshadowed by insufficient understanding of the sedimentological parameters. At present, out of 13 Upper Triassic Tethyan ammonite zones, 10 are described from the Salzkammergut, respectively all Upper Triassic substages, except the Lower Carnian ones, are also defined in this region (KRYSTYN, unpubl. Manuscript). The Salzkammergut also contains the richest Upper Triassic ammonite sites in the world. From the Feuerkogel nearby Bad Aussee more than 500 ammonoid taxa of Carnian to Norian age have been described (HAUER, 1846 f., MOJSISOVICS, 1873 f., DIENER, 1923) and from the Sommeraukogel an additional 100 Norian ammonoid species have been described by MOJSISOVICS, 1873 ff.

The Dachstein Limestone

The landscape of Salzkammergut is dominated by the Dachstein Limestone, which shows exposures in the Hallstatt environs of more than 1500 m thick (e.g. Hierlatz-Wand). The classical region of the Dachstein Limestone is the large karst plateau of Mt. Dachstein (2996 m). The Dachstein Limestone is represented for the main part by well bedded "lagoonal" limestones, which are bordered to the south by a reef development (we will visit the reef-tract of the Gosaukamm and the lagoonal facies on Mt. Krippenstein).

The plateau of Mt. Dachstein is not only the classical region of the Dachstein Limestone (name coined by Friedrich SIMONY, 1847), but is also a spectacular area of Alpine limestone karst research. Also the geomorphological studies of the Dachstein limestone karst, which represents an important water resource, are closely bound to the name Friedrich SIMONY, who dedicated his life to the study of the glacial phenomena and the influence of the atmosphere on limestone weathering in higher altitudes. The most characteristic fossils of the Dachstein Limestone are the heart-shaped cross-sections of megalodontid bivalves. The famous Bavarian geologist C.W. GÜMBEL (1862) was the first to give a detailed description of these characteristic bivalves in the Northern Calcareous Alps. It was also GÜMBEL, who pleaded for an Upper Triassic (Norian/Rhaetian) age of the Dachstein Limestone; before a Liassic age seemed already generally accepted! The question, which bivalve genus or species did the "Dachstein-bivalve sensu strictu" represent started already in the 18th century, when HACQUET (1781) and WULFEN (1793) gave the first systematic descriptions. The next generation, which dealt intensively with this "causa prima", were geoscientists from Lombardy and Veneto, especially CATULLO, CURIONI and STOPPANI. In Switzerland Escher von der LINTH and MERIAN participated in this discussion and SCHAFHÄUTL in Bavaria. In Austria the French born all-round scientist Ami BOUE and later on Franz von HAUER dealt with this question. Finally Leopold von TAUSCH pleaded in his monography from 1892 "Über die Bivalvengattung Conchodus und Conchodus Schwageri n.f. aus der obersten Trias der Nordalpen" for this genus to represent the one and only "Dachsteinbivalve" - the real thing sensu strictu. Several of the specimens described and figured by TAUSCH were collected in the vicinity of Hallstatt, in particular in Echernthal, Wiesberg Höhe, Mitterwand and Hierlatz. Also in later papers by ZAPFE (1957, 1964), TICHY (1974) and VEGH-NEUBRANDT (1982) from Budapest, the species Conchodus infraliasicus is considered one of the main representatives of the "Dachstein-bivalves". Probably the last word has not yet been spoken on this (local) key question for geosciences.

Studies on carbonate facies

Two phenomena of eminent importance drew the attention of many sedimentologists to the Dachstein region, i.e. the origin of the bedding, respectively cyclicity of the lagoonal Dachstein Limestone and the phenomenon of neptunian dykes. The latter caused tremendous long lasting misinterpretations in Triassic and Liassic stratigraphy, because many of the classical ammonite localities in the Hallstatt region are bound to neptunian dykes or - in some cases - represent stratigraphic condensation of faunas (Feuerkogel). Eduard SUESS (1888) explained the bedding, respectively cyclicity of the Dachstein Limestone, as a consequence of subaerial exposition of the beds and subsequent weathering of the bedding planes. In 1928 Kurt LEUCHS assumed, that the variegated coloured thin intercalations in the Dachstein Limestone represent a rudimentary Hallstatt facies, while SCHWARZACHER (1948) studied the Norian Hallstatt Limestone of the Steinberg- und Sommeraukogel. The well-known study by Alfred G. FISCHER (1964) deals with the cyclicity of the Dachstein Limestone. Results of recent investigations by HAAS, LOBITZER & MONOSTORI (2007) will be shown by Janos HAAS during the excursion to Mt. Krippenstein/Dachstein plateau.

In addition, the working group led by Alfred G. FISCHER also carried out early studies of deeper water limestones by means of electron microscope in the Salzkammergut region (e.g. paper by FISCHER, HONJO & GARRISON (1967), which opened a new dimension in lithogenetic studies.

More recently the focus changed to the Dachstein reef-limestone. After the initial study of H. ZANKL (1968) on the Upper Triassic reef of Hoher Göll south of Salzburg, the Erlangen reef research Group around Erik FLÜGEL investgated also Dachstein reefs in the Salzkammergut area. The Gosaukamm reef has been described by Detlef WURM (1982) and the Grimming reef by Florian BÖHM (1986).

Micropaleontological studies

The study of rock thin-sections was probably established in England as a consequent follow-up of microtomic botanical and medical studies. In the Austrian Northern Calcareous Alps Karl PETERS was the first geoscientist to apply these new techniques. In his classical study from 1863 "Über Foraminiferen im Dachsteinkalk", PETERS reports on planktonic foraminifers ("Globigerinas") in the Dachsteinkalk of Echerntal in the vicinity of Hallstatt. Later on, the finding of these early Globigerinas was thought to be dubious by KITTL (1903), who considered the limestones to be Upper Jurassic Plassenkalk. In 1913 A. HEINRICH reports on Globigerinas in the Carnian Hallstatt-Limestone of Feuerkogel/Rötelstein, close to Bad Aussee. In more recent times Rudolf OBERHAUSER (1960) and Edith KRISTAN-TOLLMANN (1964) described early "Globigerinas" from the Rhaetian Zlambach Marls of

Salzkammergut and finally Werner FUCHS (1967, 1969, 1975) provides a systematic description of this rather neglected group of planktonic foraminifera from material from the Italian Dolomites and from the Salzkammergut. Also various other groups of foraminifera and ostracodes have been described first from the Salzkammergut region by KRISTAN-TOLLMANN – see in TOLLMANN 1976. Stratigraphic more or less usefull microscopic remains of organisms (Holothurians, Ophiures, Echinids, Sponges, Radiolarians, Scolecodonts, Conodonts) from Hallstatt and Pötschen limestone have been investigated by H. KOZUR and H. MOSTLER 1973 – more references see TOLLMANN 1976.

The region around Hallstatt and Bad Aussee is also a classical area for Triassic conodont research. The first review paper was published by the German R. HUCKRIEDE (1958): "Die Conodonten der mediterranen Trias und ihr stratigraphischer Wert", followed by the papers by the American L. MOSHER (1968). MOSHER succeeded in using the evolutionary trend of platform conodonts for worldwide stratigraphic correlation. His reference sections also include the classical Upper Triassic ammonite localities Sommeraukogel and Steinbergkogel, nearby Hallstatt, which were previously described by MOJSISOVICS. Later on, Walter C. SWEET and especially Leopold KRYSTYN successfully continued this challenging work on a worldwide scale, including also the classical key sections in the Salzkammergut.

Enigmatic Tectonics

MOJSISOVICS (1903) in one of his last papers summarized his ideas of the palaeogeographic position of the Hallstatt zones. He postulated an in situ position of the sediments of Hallstatt type deposited in "channels" cutting through the Dachstein Limestone platform.

One year later the paper of HAUG & LUGEON (1904) marks a fundamental break through in the history of geological research in the Salzkammergut area: the concept of nappe tectonics was established. In the sequel the "nappists" entered into competition with the "autochthonists". KOBER and his school (e.g. MEDWENITSCH, 1958, TOLLMANN, 1960 and others) plead for an extreme nappism. On the other hand DIENER, LEUCHS, TRAUTH and in modern time ZANKL and SCHLAGER followed a modified version of the autochthonous concept of MOJSISOVICS. PLÖCHINGER, 1974, 1976 and SCHÄFFER, 1976 revealed the significance of Jurassic gravitative nappe movements in the Salzkammergut area for the geodynamic history of the Northern Calcareous Alps. TOLLMANN, 1976, 1981 has briefly summarized all the contradictory models, which have been suggested to explain the complex geology of this exciting part of the Northern Calcareous Alps. Gerhard W. MANDL´s (1984a,b, 2000) investigations on the lateral transitions between several Hallstatt limestone lithologies, Pötschen limestone and carbonate platform margins led to a moderate “nappistic” model, combined with Jurassic gravitative movements and later thrusting.

Recently Hans-Jürgen GAWLICK et al.(1994, 2001, FRISCH & GAWLICK 2003) contribute new ideas, based on better biostratigraphic datas of the Jurassic sedimentary history and on new insights in the thermal history by using the Conodont Colour Alteration Index (CAI).

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EXCURSION 1

The Hallstatt pelagics – Norian and Rhaetian Fossillagerstaetten of Hallstatt

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The Hallstatt facies of Austria consists mostly of red, subordinately also whitish to grey bedded wackestones rich in filaments (juvenile shells of pelagic bivalves) and echinoderms (microcrinoids). It accumulated a thickness of more than 100 m with a mean sedimentation rate of 3 m per million years over a period of 40 Ma, from Middle to Late Triassic. In the middle Rhaetian, concurrent with the formation of the siliciclastic intraplatform Kössen basins, accumulation of pelagic limestone ceased and was replaced by grey and later blackish marls of the Zlambach Formation. This is in sharp contrast to the dinarid and southern Tethys margin where Hallstatt Limestone and/or pelagic carbonate deposition continued to the top of the Triassic (e.g. Csövar, Sicily, Greece, Turkey, Oman).

Two types of particularly different Hallstatt limestone sequences are known. The "normal" type is widespread and remarkably poor in megafauna, especially cephalopods. Biostratigraphy is based on halobiids or presently on more frequently occurring conodonts. Rich cephalopod faunas usually dominated by ammonites are found in another type of Hallstatt limestone. It consists of red bioclastic limestone layers that are only centimetres thin and laterally often discontinous with corroded and Fe-Mn-oxid coated surfaces. Most of the common cephalopod shells are fragmented, but the rare complete ones are excellently preserved and due to their thin black Mn-coating, often extractable in nearly perfect condition. As long as sediment accumulation is not below 10-20 cm per Ma, these limestones may record a sequence of several ammonite zones in less than one-meter thickness still without stratigraphic condensation (KRYSTYN, 1991). This is the famous fossil-rich Hallstatt facies known as Fossillagerstätten from many Alpine mountain chains between the Alps and the Indonesian island of Timor (e.g. Dinarids, Hellenids, Taurus Mountains, Oman Mountains, Himalayas).

The specific stratigraphic importance of the cephalopod-rich Hallstatt facies of the Salzkammergut is due to the fact that stratotypes of or references to Upper Triassic chronostratigraphic and biostratigraphic subdivisions are designated herein (KRYSTYN et al. 1971a, b, KRYSTYN & SCHLAGER, 1971).

St.		ammonoid zone	locality
Rhaetian	M.	*Vandaites stuerzenbaumi*	ST1
	L.	*Paracochloceras suessi* (*Sagenites reticulatus*)	ST2, ST3, ST5, STK A-C
Norian	U.	*Sagenites quinquepunctatus*	ST4, STKA-C SK: Metternichi-Lager (P: VI)
	M.	*Halorites macer*	SK: Bicrenatus-Lager (P: III - IV)
		Himavatites hogarti	
		Cyrtopleurites bicrenatus	
	L.	*Juvavites magnus*	SK: Patens-Lager (P: II, 68/123)
		Malayites paulckei	SK: (P: I)
		[*Guembelites jandianus*] *Halobia styriaca*	Sommeraukogel (=SK) (P: XV)

Fig. 1: Norian to middle Rhaetian ammonoid zones and respective Fossillagerstaetten in Steinbergkogel and Sommeraukogel (localities numbers refer to fig. 5 and 12). The ammonoid-free *Guembelites jandianus* Z. is substituted by *Halobia styriaca*.

All Upper Triassic substages, except that of the Lower Carnian, are defined in the Salzkammergut. Of currently 13 Upper Triassic Tethyan ammonoid zones in use, 10 are described from the Salzkammergut (Fig. 1). Centred around lake Hallstatt within a radius of about 15 km, there is a bulk of fossil localities (DIENER, 1926, KRYSTYN et al., 1971a), such as e.g. Siriuskogel, Millibrunnkogel, Raschberg, Schneckenkogel near Bad Goisern as well the world famous locations of the Feuerkogel close to Bad Aussee and the Sommeraukogel above Hallstatt (Fig. 2). Together with the nearby Steinbergkogel, Sommeraukogel is further important as the type locality of the Hallstatt formation and the historical stratotype of the Norian stage (KRYSTYN et al., 1971). The region is also the richest source of Upper Triassic ammonites in the world. From the Sommeraukogel, close to a famous saltmine active since prehistoric times (Hall = Celtic word for salt), about 100 Norian ammonoid species have been named by MOJSISOVICS (1873-1902) in his spectacular monograph. Compared on a genus level, the Austrian input to the knowledge of Upper Triassic ammonites is even larger. Of roughly 140 Tethyan ammonoid genera known in the early 1980’s according to TOZER (1981; 1984), 90 or nearly two third of the genera (65%) have been described from the Hallstatt Limestones of the Salzkammergut; the Himalayas follow next with 25 genera (20%). Half of the remaining 15% have been found in the Hallstatt facies of Timor (Indonesia) and only 7% (10 genera) have been described from the other 20,000 km of Tethyan strands. The study of the Austrian Hallstatt faunas is still not finished, with many new taxa yet to be described. Their documentation will further enlarge the faunal record of the Salzkammergut, as well as extend our knowledge of the pelagic life of the Triassic. Recent studies (KRYSTYN et al., 2007) have demonstrated the faunistic and biochronologic significance of the Steinbergkogel for documenting the Norian-Rhaetian boundary and defining a GSSP for the base of the Rhaetian stage.

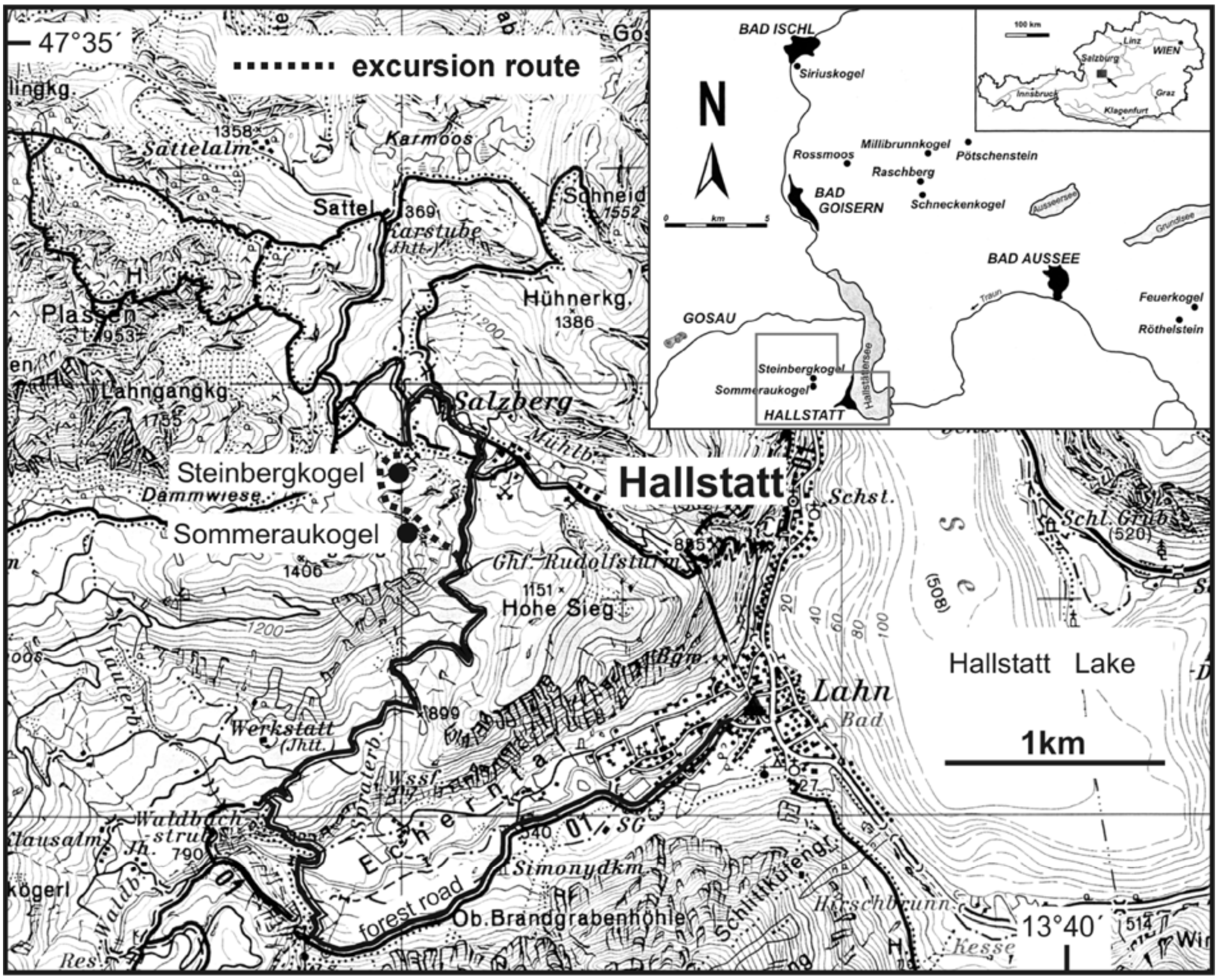
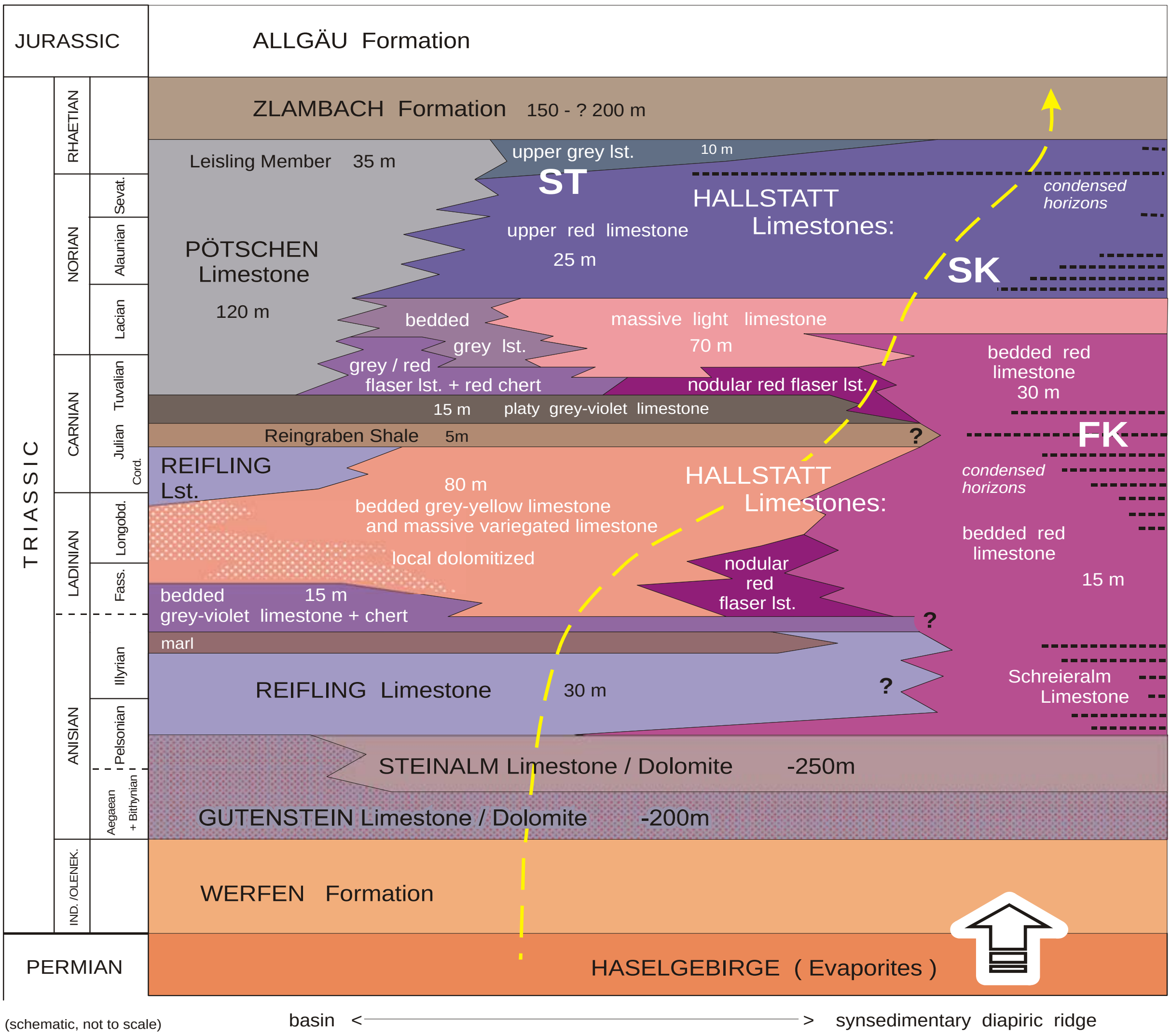


Fig. 2: Hallstatt map with excursion route and location of the Steinbergkogel and Sommeraukogel.

A comprehensive study on lithology, thickness and petrology of the Hallstatt Limestone of the Salzkammergut region was carried out by SCHLAGER (1969). According to him the Hallstatt sequence can be divided into several parts, each characterized by distinct lithologic features (fig. 3). Between these basic Hallstatt lithotypes and the coeval Reifling- and Pötschen limestones additional types of transitional character may occur, caused by variations in colour, bedding, flaser structures and content of clay minerals, as well as content and colour of chert-nodules/layers. The following summary is based on SCHLAGER (1969), KRYSTYN (1980) and MANDL (1984):



(schematic, not to scale)
Numbers refer to maximal reported thickness

Yellow dashed line represents “sedimentary path” and sequence of Sommeraukogel
Classical ammonoid bearing sites : FK Feuerkogel, SK Sommeraukogel, ST Steinbergkogel

Fig. 3: Lithostratigraphy of the Hallstatt Triassic.

Grauvioletter Bankkalk (= greyish-violet bedded lst.): Well bedded to nodular bedded, 10 to 20 cm thick microsparitic to pelsparitic, in part siliceous limestone beds. At its base chert nodules may frequently occur. Colour and the brittle fracture are distinct features of this type which hardly can be mixed with any other limestone type.

Graugelber Bankkalk (= greyish-yellow bedded and massive lst.): Partly well bedded (10 to 20 cm), partly indistinct bedded limestone. Colour varies between greenish-grey, yellow and light brownish. Biomicrite to microsparite with pellets/peloids, filaments, intraclasts/

resedimentation and bioturbation. Often very similar to *Massiger Hellkalk* (= massive light limestone) but distinctly older (see fig. 3).

Roter Knollenflaserkalk (= red nodular flaser-limestone): Reddish and regularly bedded, nodular Flaser-limestone consisting of 10 to 30 cm thick beds separated by thin marly partings. In terms of microfacies this limestone is a biomicrite with bivalves and radiolarians as main constituents of the fauna. Formation of nodules and flaser structure is explained by pressure solution during an early diagenetic stage.

Roter Bankkalk (= red bedded limestone): Reddish to pink coloured biomicritic limestone with strong bioturbation causing mottled and irregular textures. Beds are 20 to 50 cm thick and well developed. Individual beds are mostly homogenous but locally interstratal reworking can be found. Particularly at Feuerkogel subsolution patterns with Fe-Mn crusts are frequent. In the upper part lateral changes may occur within short distances. The transition to the overlying massive "Hellkalk" is gradually; locally an alternation between both types occur.

Massiger Hellkalk (= massive light limestone): Irregularly thick bedded to massive micritic limestone. Colour predominantly white, grey or light pink. Another characteristic feature is the great thickness. First reports on this lithotype were published by Mojsisovics, 1905 from Raschberg ("Wandkalk") and from Sommeraukogel.

Hangendrotkalk (= upper red limestone): Platy to nodular bedded biomicritic limestone with mostly strong bioturbation pattern. Locally flaser-structure can be found but this feature is less dominating than in the *Knollenflaserkalk*. Subsolution patterns occur frequently, in particular at Sommeraukogel (thinning of individual beds in the direction of a submarine ridge).

The so-called *Hangendgraukalk* is regarded as a lateral equivalent of the *Hangendrotkalk*; apart from the colour, this type is also more argillaceous and usually thinner bedded. It replaces the uppermost Norian to Rhaetian portion of the *Hangendrotkalk* at Steinbergkogel near Hallstatt.

The Steinbergkogel

The Steinbergkogel is a small und unnamed summit (1245 m above sea level) situated in the south-western corner of sheet 96 (Bad Ischl), official topographical map of Austria 1:50,000. It is located just south of the westerly-most salt mine gallery symbol (crossed hammers in fig. 2), corresponding to the entrance of the Ferdinandstollen (Stollen = gallery in English) in an altitude of 1140 m.

There is a wealth of literature referring to invertebrate faunas of the Steinbergkogel. Ammonoids have been described by MOJSISOVICS (1873-1902), pelagic bivalves by KITTL (1912), gastropods by KOKEN (1897), brachiopods by BITTNER (1890) and conodonts by MOSHER (1968) and KRYSTYN et al. (2007a,b). A comprehensive faunal list is found in SPENGLER (1919) with reference to specific locations.

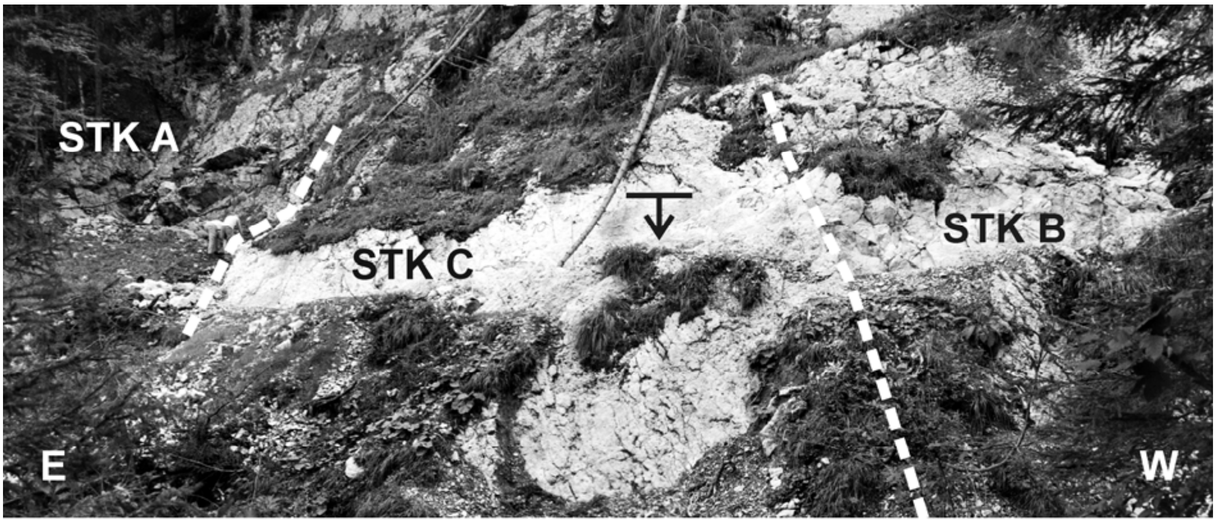


Fig. 4: STK quarry photo with sections A, C and B.

Access to Steinbergkogel is possible by a forest road that starts in the Echerntal and reaches after 7 km the Salzberg and the Ferdinandstollen from where the quarry STK with the candidate section for the NRB GSSP can be seen in a distance of 25 m when looking to the south (Fig. 4). Alternatively one can reach the Steinbergkogel directly from Hallstatt by taking the cable car to Rudolfsturm (855 m) and following then a marked footpath along the prehistoric burial ground of the Hallstatt (Celtic) period and some Salt mine buildings in north-westerly direction towards the Plassen peak to arrive at Ferdinandstollen within a one hour of walk. The proposed candidate (coordinates 47°33’50’’N, 13°37’34”E) is exposed in a long abandoned quarry where blocks have been extracted to mantle the galleries of the salt mine. Most of the classical Steinbergkogel ammonoid fauna (MOJSISOVICS, 1873-1902) may have been collected by miners from that place, but DIENER (1926) mentions another fossil locality about 100 m on strike to the west (ST 2 in fig. 5). As the latter is of slightly younger age than the quarry rocks, the old faunal record may be of stratigraphically mixed origin in the sense of “rucksack-condensation”.

The Steinbergkogel is composed of a uniformly (70°N) dipping sequence starting with a thick whitish, massive and unfossiliferous Lower Norian variety (*Massiger Hellkalk* Member) overlain by about 30-40 metres of bedded predominantly red (*Hangendrotkalk* Member) and in the top grey, finegrained pelagic limestones (bioclastic wackestones) of latest Norian to lower Rhaetian age (in new sense); the upper half of the grey limestone (*Hangendgraukalk* Member) develops thin clay interbeds that have eased the quarrying of stones and indicate a gradual transition to grey marls of the Zlambach Formation building usually only short-time exposures like the present one behind the Ferdinandstollen.

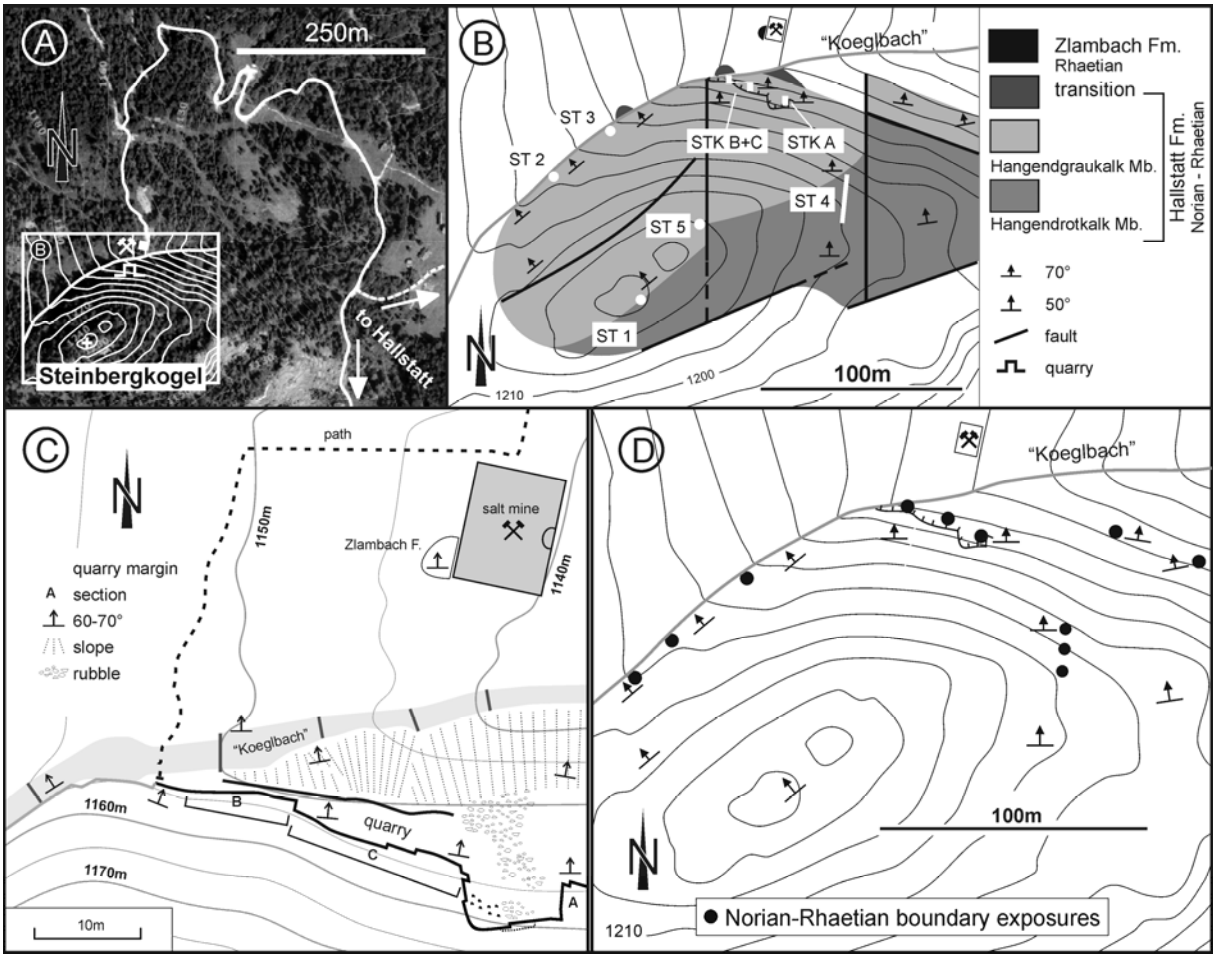


Fig. 5: Detailed Steinbergkogel maps: A) arial view, B) geology with sections and fossil localities, C) quarry STK and D) location of NRB exposures.

The important Norian-Rhaetian boundary interval corresponds to the basal part of the *Hangendgraukalk* and is well exposed along strike for 200-300 m along the northern footwall of the Steinbergkogel (fig. 5) close to and within a small ravine (Koegl creek) that follows the lithological boundary from compact limestones to the less resistent transition beds. Stratigraphically below the quarry section are more than 20 m of red Upper Norian limestones (ST 4 in fig. 5) containing several layers with *Monotis salinaria, Heterastridium*, ammonoids and conodonts that allow a cross-correlation with the quarry sections (fig. 6).

The STK quarry consists of 4 meters of medium to thin bedded micritic limestones with the proposed candidate section STK A located at the eastern end (Fig. 5). About 20 beds have been studied in detail, numbered from bottom to top as 103 to 122 (fig. 7). Of boundary relevance have been identified bed 108 to bed 112A representing one meter of thickness and differing from over- and underlying rocks by a high bioclastic fossil content made up of ammonoids and subordinate echinoderms. Above bed 113 the microfacies shifts to a shelly-poor, mud-dominated facies type. Rock colours change around bed 107 from red to grey and return locally to grey-reddish mixed above bed 115. A low CAI of 1 excludes any thermal overprint and favors the preservation of the original palaeomagnetic signal and of a primary δ^{13}C-record (fig. 7). Another measured sequence 10 m to the west (STK C) with faunistically comparable results strengthens the biochronologic significance of section STK A and enlarges the palaeomagnetic database into the lower Rhaetian considerably (fig. 8).

To achieve stratigraphically reliable conodont ranges at least 10 kg of limestone have been dissolved from each bed between 108 and 112. This intense search has led to p-element recoveries of 50-100 specimens per sample, with *Epigondolella bidentata* dominating up to bed 110 and replaced by a *Misikella* dominance above (fig. 9). *Norigondolella steinbergensis*, usually the most frequent faunal element in this time interval is fortunately rare as well as ramiform elements. Taxonomic terminology for conodonts of the genus *Misikella* follows KOZUR & MOCK (1991) and ORCHARD (1991) for *Epigondolella* (including *Mockina*) *bidentata*. Increasing platform and size reduction in the latter species during its phylogenetic end phase (*Cochloceras* interval) leads to a predominance of small platform-less parvigondolellid forms in *Epigondolella* unfavourable environments. Those forms have been named *Parvigondolella andrusovi* KOZUR & MOCK or *Parvigondolella lata* KOZUR & MOCK and are described as diagnostic for a time interval younger than that of *E. bidentata*. In *Epigondolella* favourable facies "parvigondolellids" are, however, either fully (*P. andrusovi*) or for a major part (*P. lata*) time equivalent to *E. bidentata* and therefore considered here as morphological variants or ecostratigraphic morphotypes of the latter species (GALLET et al., 2007).

A first conodont event is seen in bed 108 where *Oncodella paucidentata* and *Misikella hernsteini* appear – without known forerunners identified only as FO dates. *Misikella hernsteini* is rare between bed 108 and 110 (max. 10%) but gets frequent from 111A onwards (fig. 9). Bed 111A marks the FAD of *M. posthernsteini*, as phylogenetic successor of the fore-mentioned species, responsible for the most diagnostic conodont datum in the section and probably the worldwide best-documented FAD of *M. posthernsteini* in co-occurrence with *Paracochloceras*. With just two specimens in 111A and four in 111B *M.*

posthernsteini is, however, very rare at the beginning but becomes frequent 30 cm above in bed 112 to get rare again higher up (fig.9).

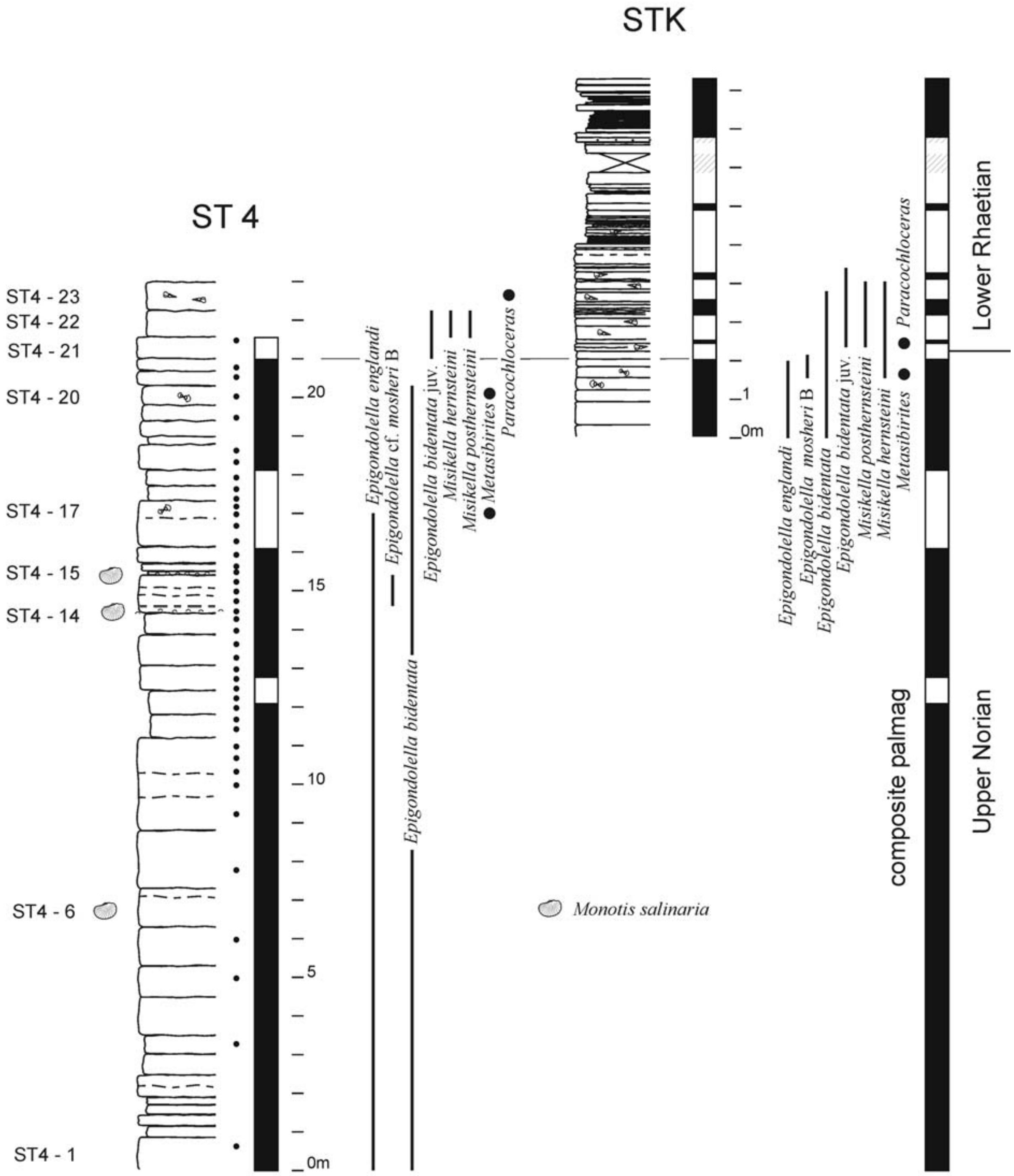


Fig. 6: Composite Upper Norian to lower Rhaetian magnetostratigraphy of the Steinbergkogel (combining sections ST4, STK A and B/C).

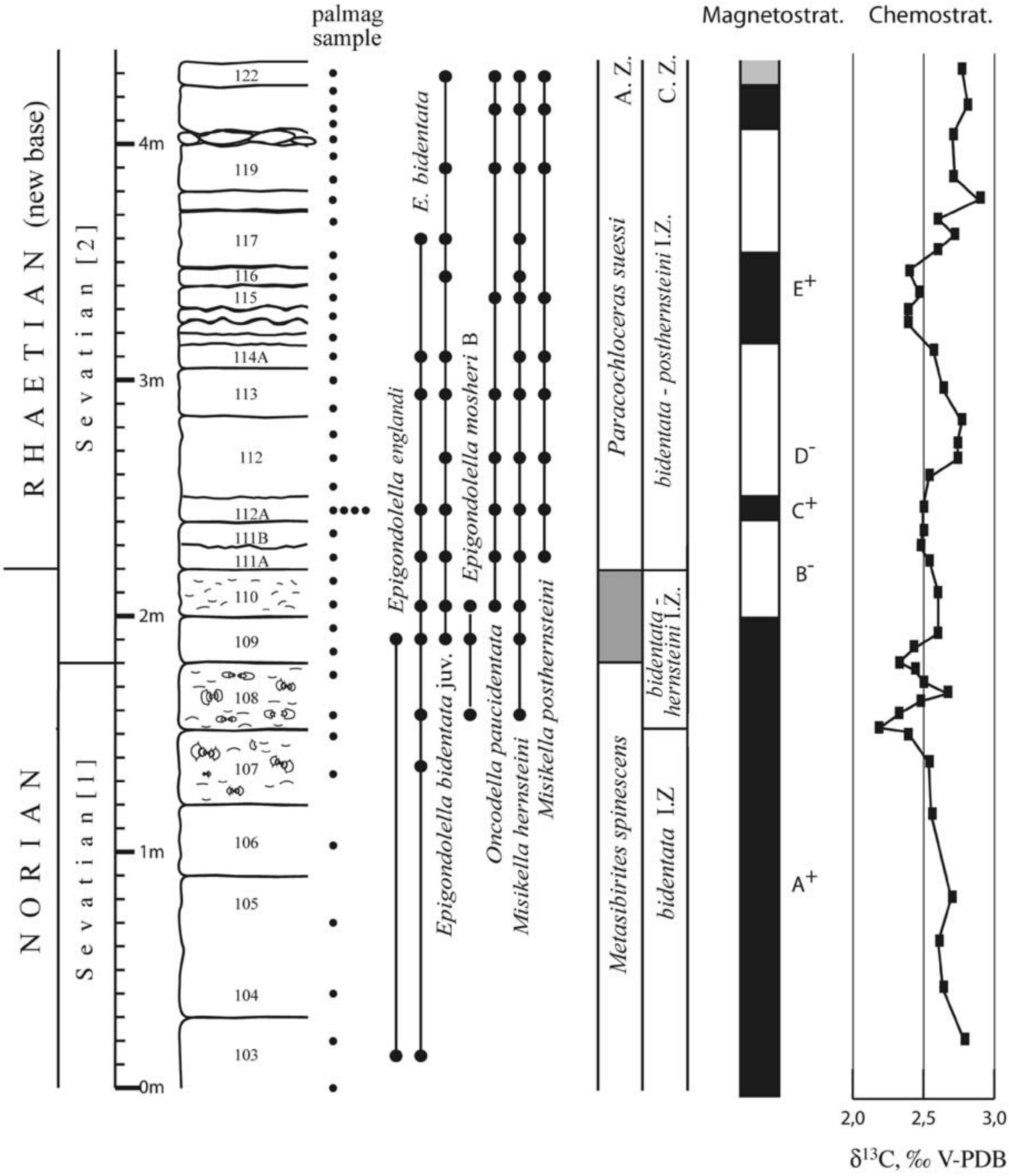


Fig. 7: Integrated bio-, magneto- and chemostratigraphy of GSSP candidate section STK A. Note: Sevatian 1 and 2 refer to previous Upper Norian classification (from KRYSTYN et al., 2007).

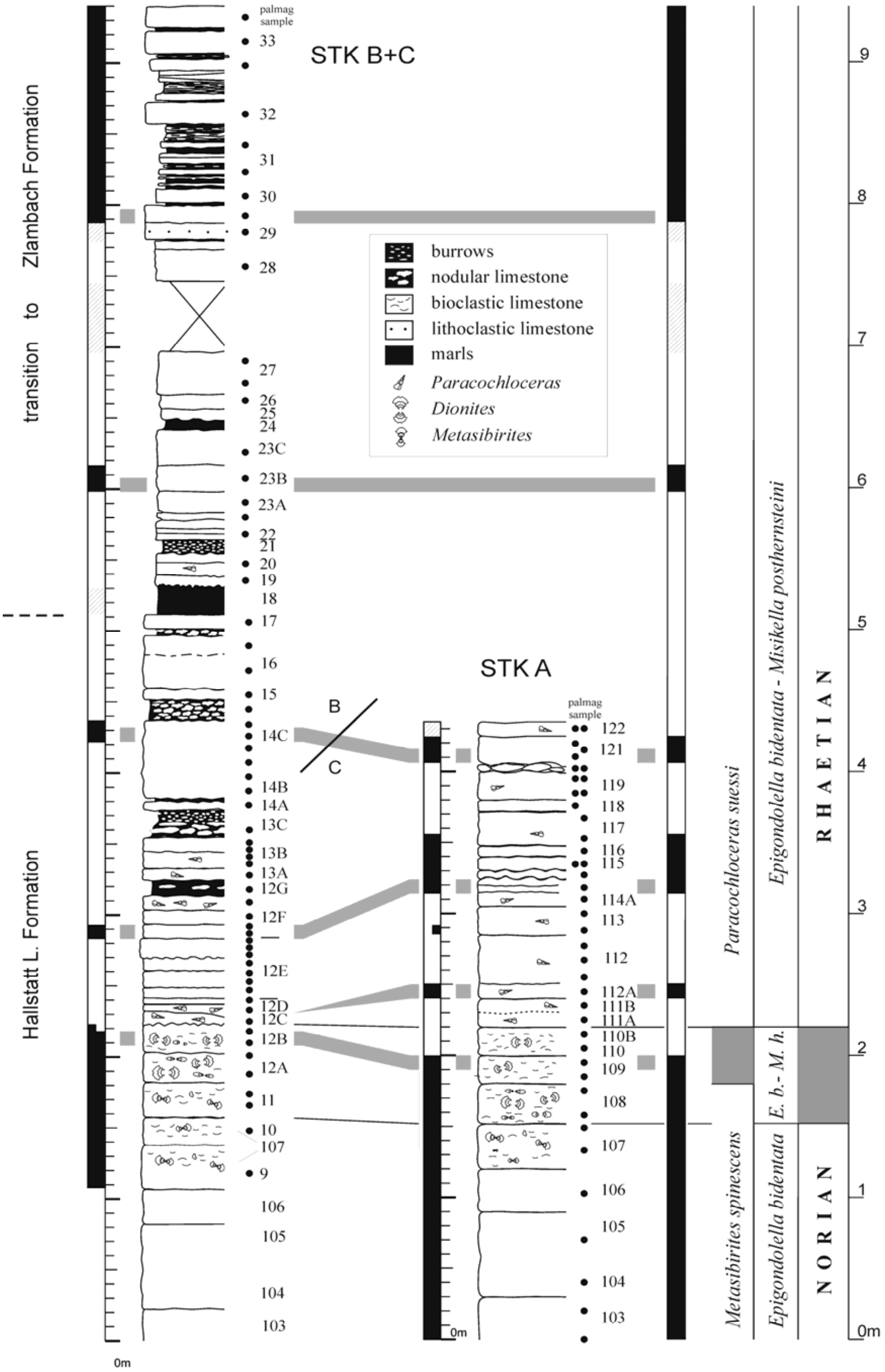


Fig. 8: Bio- and magnetostratigraphic correlation of section A with section B/C in quarry STK; note the high coincidence of bio- and magneto-events between the two sections.

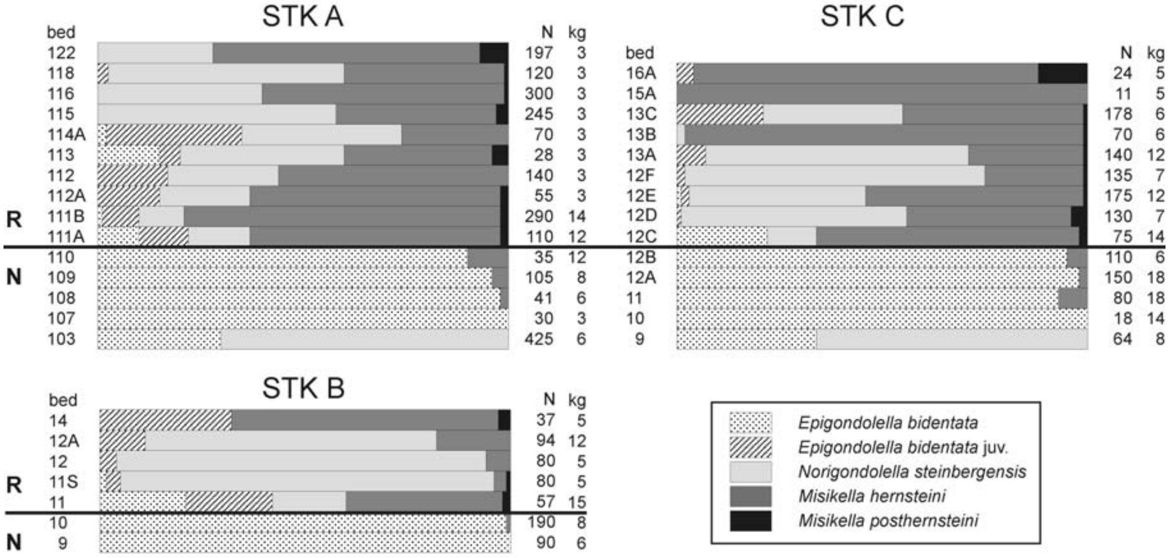


Fig. 9: Relative platform conodont abundances in the STK quarry sections. Note in all three sections the same distinct frequency change between *Epigondolella* and *Misikella* at the NRB and the overall rare occurrence of *M. posthernsteini* in the lower Rhaetian.

The initial infrequence highlights the problem how to recognize the FAD of *M. posthernsteini* in biofacially less favourable environments and use of this event without additional control may cause uncertainties in regional or intercontinental correlations.

Two conodont zones can be distinguished in the NRB interval of the proposed candidate section based on the successive appearances of species of the genus *Misikella*: 1) *Epigondolella bidentata – Misikella hernsteini* Interval Zone, characterized by the co-occurrence of common *E. bidentata* and rare *M. hernsteini* in beds 108 to110 of STK-A and beds 11 to 12B of STK-C respectively, and 2) *Epigondolella bidentata – Misikella posthernsteini* Interval Zone, from bed 111A resp. bed 12C onwards containing *M. posthernsteini* in low quantities compared to the very frequent *M. hernsteini* (fig.9). Bearing in mind the large sample size (more than 5 kg) it may be difficult to detect the base of zone 2 with “on average” sampling. Normal seized *Epigondolella bidentata* becomes rare in Zone 2 and is usely replaced by juveniles resembling the genus *Parvigondolella* (fig. 9). Considerable provincialism limits this zonation to the Tethyan realm where it has successfully been applied to sections in Austria (McROBERTS et al., 2008), Turkey (GALLET et al., 2007), Oman and Timor (KRYSTYN, unpublished data).

Vertical ranges of newly collected time-diagnostic ammonoids are shown in figure 10. *Metasibirites spinescens* is very common in beds 107 and 108 of STK-A and in 9 to 11 of STK-C, *Paracochloceras* starts in bed 111 resp. 12C and is frequently found up to bed 113 with rare occurrences till the top (bed 122) in STK-A, and further up in STK-B/C till bed 22. Other trachyostracean ammonoids are currently rare except for rare juvenile nodose sagenitids (110 and STK-B 11), *Dionites* (beds 109 and 110) and a tiny specimen of

Gabboceras from bed STK-B10 corresponding to bed 109. *Gabboceras* has recently been described by TAYLOR & GUEX (2002) from the basal Gabbs Formation of New York Canyon (Nevada) in a position that may closely match the NRB interval in Steinbergkogel. The genus *Dionites* may have a range across the Norian-Rhaetian boundary and as such may not be boundary-diagnostic. More important is a conodont-dated correlative of bed 111 in ST 2 that contains *Sagenites reticulatus* and *Dionites caesar*. Combining all above cited faunal records permits the discrimination of two ammonoid zones (Fig. 10), a lower with *Metasibirites* (bed 107 to 108) and an upper with *Paracochloceras* (from bed 111A upwards). An alternative and closely matching zonal scheme with *Sagenites quinquepunctatus* below and *Sagenites reticulatus* above seems also justified from these data. A remarkable evolutionary and biostratigraphically useful change is recorded in the family Arcestidae with several species newly appearing closely below the Norian – Rhaetian boundary (fig. 10). Stratigraphically indifferent taxa including *Rhabdoceras suessi, Pinacoceras metternichi, Placites, Arcestes, Cladiscites, Paracladiscites, Rhacophyllites* and *Megaphyllites* are represented in all beds.

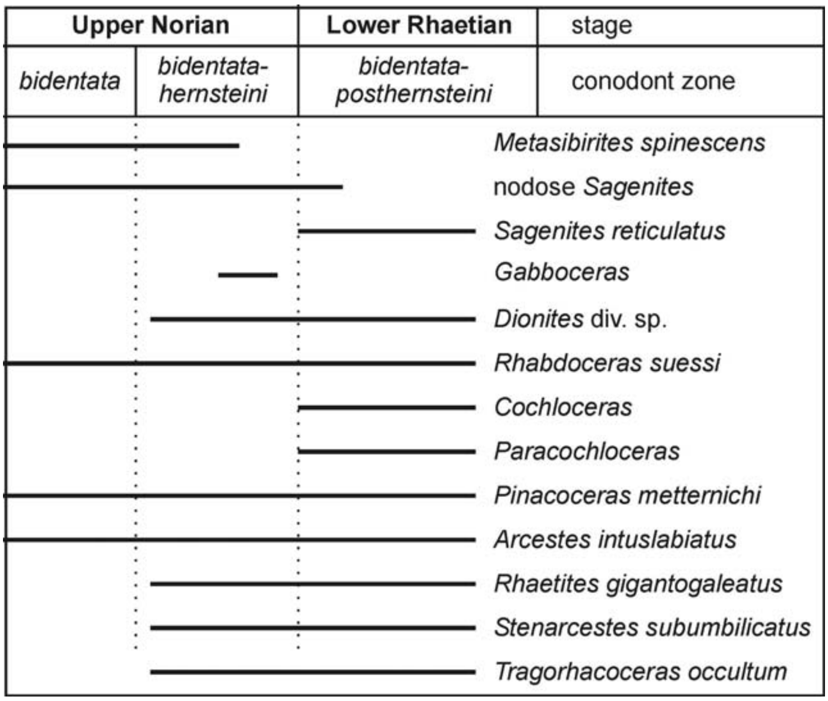


Fig. 10: Ranges of selected ammonoids around the NRB in quarry STK.

Monotids of the *Monotis salinaria* group are common in Steinbergkogel (KITTL, 1912; SPENGLER 1919, p. 359) and almost restricted to the *Hangendrotkalk* Member where they appear in several layers within an interval of 10-15 m (fig. 6). Of special interest is a single unhorizoned large specimen of *M. salinaria* preserved as grey micritic limestone and housed in the collections of the Center of Earth Sciences (of Vienna University). According to the

Steinbergkogel lithologies, this piece must have been derived from the short interval corresponding to beds 108 and 109. This supposed position would confirm the top-Sevatian occurence of *Monotis salinaria* in the Hallstatt Limestone and, in agreement with *Monotis* data from Hernstein, Lower Austria (McROBERTS et al., 2008), its pre-Rhaetian disappearance.

The Steinbergkogel bears beside the STK A and C sections three other ammonoid localities of high stratigraphic importance: 1) 40 m west of the GSSP candidate exposes a corresponding sequence at the western quarry end (STK B) a promising but still not exploited fossil bed (11) in the basal *Paracochloceras* interval; 2) in the Koegl creek 100 m to the northwest of the quarry lies locality ST 2 with a fossil-rich bed that due to a high *M. hernsteini* ratio should more likely correspond to the basalmost *bidentata-posthernsteini* I. Z. rather than to the earlier assumed *bidentata-hernsteini* I. Z. (KRYSTYN et al., 2007a); it has delivered *Dionites caesar* and a large *Sagenites reticulatus* and may be the original site of some of the *Sagenites* species described in Mojsisovics (1893) and 3) on top of the Steinbergkogel but

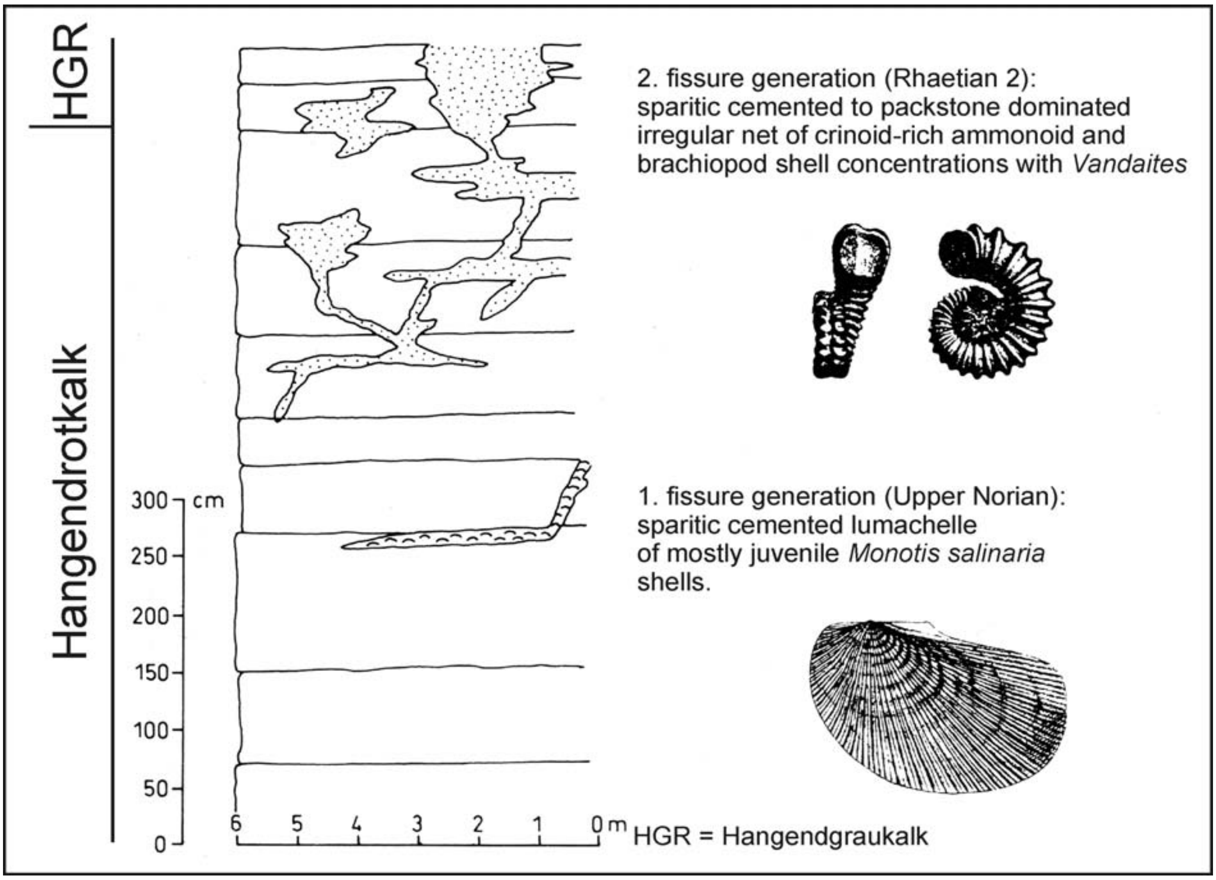


Fig. 11: Stratigraphic log of the middle Rhaetian Fossillagerstätte ST1 at the top of the Steinbergkogel (from KRYSTYN, 1991).

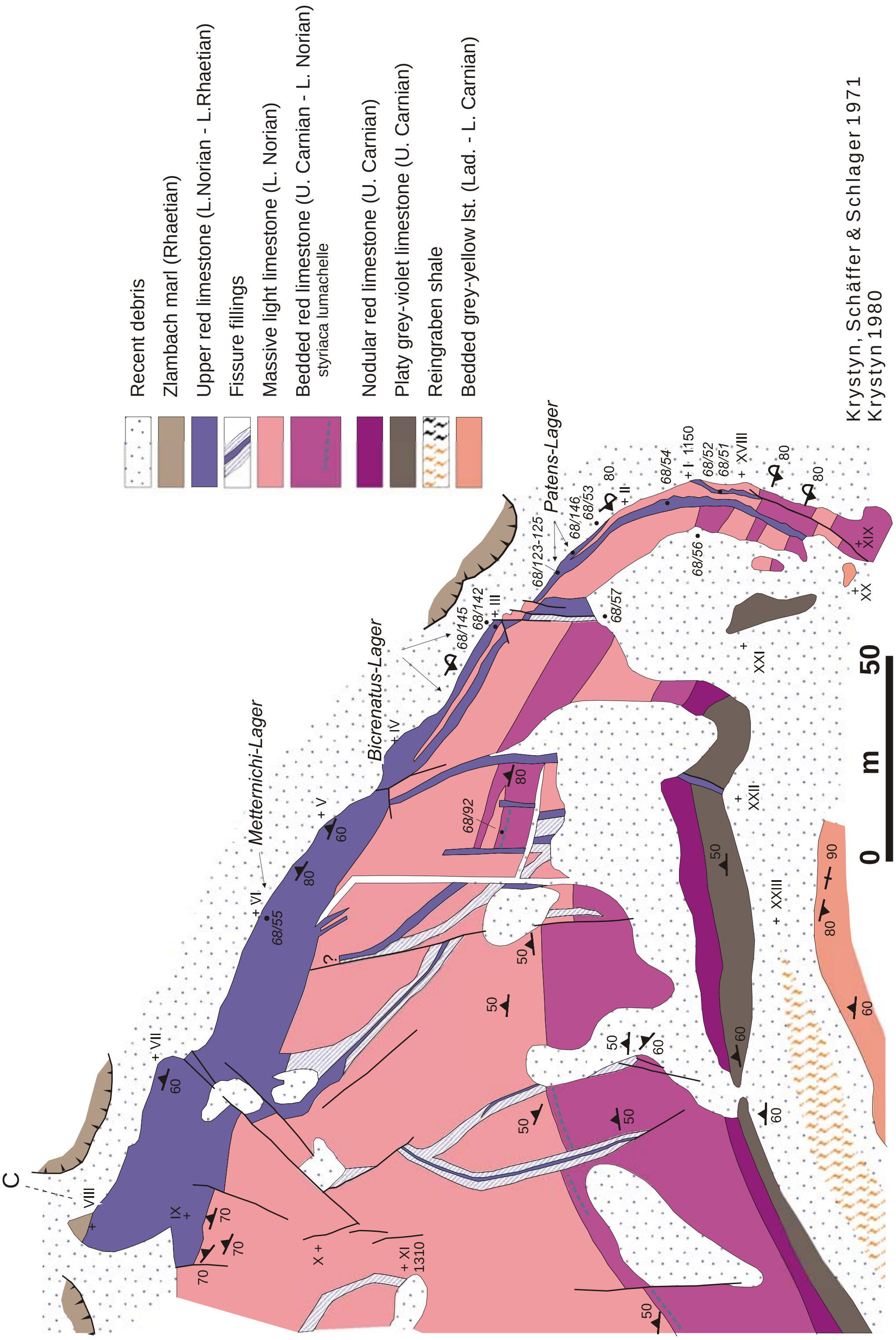
without any stratigraphic connection to the GSSP candidate is a local neptunian dike (ST 1 in fig. 5) named by MOJSISOVICS (1893) as “Weisser Crinoidenkalk” with a unique ammonoid assocation containing *Vandaites* (formerly *Choristoceras*) *saximontanum* and *Cycloceltites arduini*. This is now known as the youngest fossil horizon of the Hallstatt Limestone equalled to the basal *Vandaites stuerzenbaumi* Zone. The fossils occur in a vertical, up to 50 cm wide, irregular fissure system (fig. 11) that cuts through the whole *Hangendgraukalk* Member down to a level of at least 10 m below the transition from the Hallstatt to the Zlambach Formation (KRYSTYN, 1991). The fissure is easily distinguished from the surrounding red and micritic host rock by its light grey or whitish colour due to the matrix-poor grain-supported, shell- and crinoid-dominated fabric.

Sommeraukogel

On air distance just 200 m south of the Steinbergkogel located**,** the Sommeraukogel exihibits a more complete Hallstatt limestone sequence ranging in age from the Ladinian to the lower Rhaetian. Though separated by younger, Rhaetian and Liassic strata, the two sites have long been regarded as parts of a continuous sequence (SPENGLER, 1919). A more reasonable interpretation explains the Steinbergkogel as the original lateral continuation of the Sommeraukogel and its present separation by a left-lateral fault movement (KRYSTYN, 1980). Sommeraukogel and its western continuation, the Solingerkogel, together form a northeast – southwest striking asymmetrical anticline. Its northward steepening to over-tilted limb exposes the famous Norian fossil layers forming the historical stratotype of the Norian stage (KRYSTYN et al., 1971). All the classical faunal horizons are embedded in a Fe-Oxid rich condensation facies of the Hangendrotkalk, which thins out towards southeast in direction of a submarine ridge (Fig. 12). Both the thickness and age of the individual fossil layers (“Lager” in German) thus depends highly on their respective position in relation to the ridge top - the more distant they are the younger they get. Nearest to the ridge top, close to point (P) II of fig. 12, beds of the top-Lower Norian (Lacian 3) Patens-Lager (“Linse mit *Discophyllites patens*” sensu MOJSISOVICS) are developed.

Thirty meters to the west, between (P) III and IV of fig. 12, the Bicrenatus-Lager (“Linse mit *Cyrtopleurites bicrenatus*” sensu MOJSISOVICS) was located where an up to 4 m thick package of a complete Middle Norian (Alaunian 1 – 3) ammonoid sequence has largly been removed by historic collectors with the drill holes still visible. The next fossil locality follows 150 m to the west (P: VI) and contains Upper Norian (Sevatian) ammonoids and large heterastridians corresponding to the Metternichi-Lager of KRYSTYN et al., 1971. Another 100 m westerly (at P: VIII of fig. 12) the transition from lower Rhaetian Hallstatt Limestone, developed as thin-bedded red nodular limestone, to grey marls of the ?late Rhaetian Zlambach Formation (?*Choristoceras marshi* Z.) is exposed.

Fig. 12 (below): Geological map of the Sommeraukogel with position of the Norian Fossillagerstaetten (Patens-, Bicrenatus- and Metternichi-Lager) and the Rhaetian section at (P) VIII.



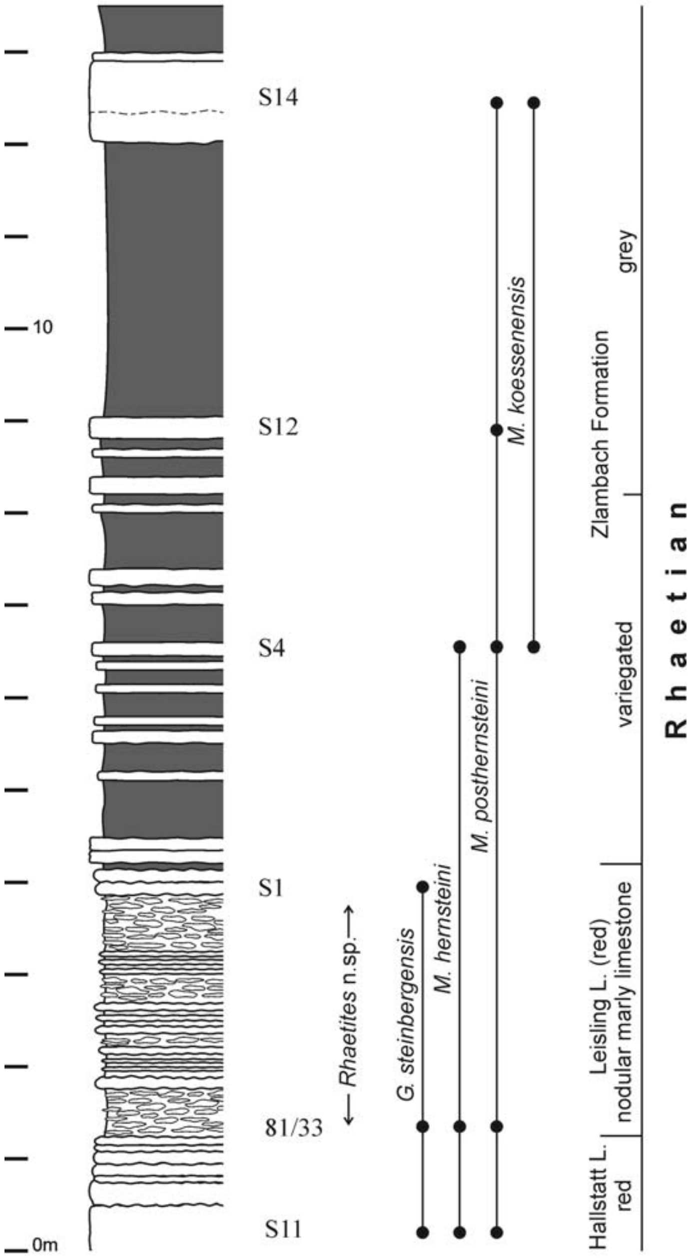


Fig. 13: Stratigraphic log with Rhaetian fossil data at (P) VIII, Sommeraukogel.

The Patens-Lager corresponds to the *Juvavites magnus* Z. and contains as common platform conodont *Epigondolella spatulata* (Hayashi). For most of the Alaunian no detailed ammonoid and conodont calibration has been possible due to missing exposure except for the upper Alaunian *Halorites macer* Z., which contains *Epigondolella abneptis* (Huckriede) and at the top *Epigondolella vrielyncki* KOZUR and *Epigondolella* n. sp. A (close to and a possible forerunner of *Epigondolella bidentata* MOSHER). The Rhaetian transition beds and Zlambach marls are poor in conodonts, dominated by species of the genus *Misikella* with rare *Norigondolella steinbergensis* (fig. 13).

Acknowledgments

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EXCURSION 2

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

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Introduction

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

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

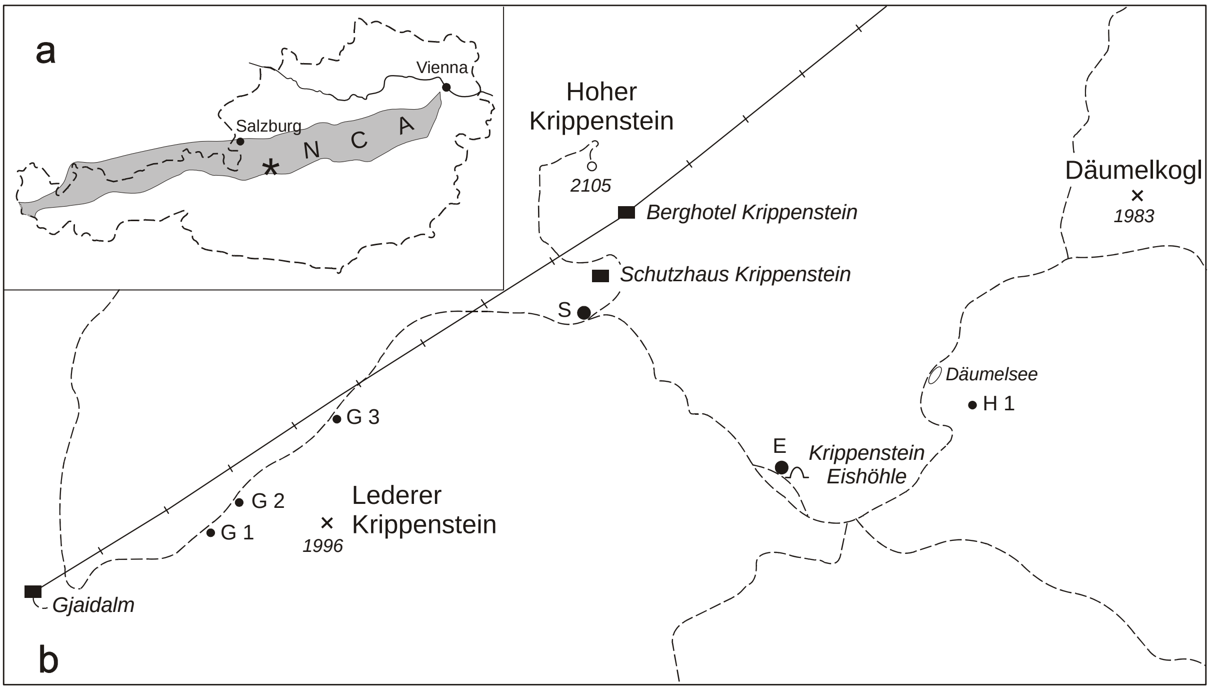

Fig. 1: a) Geographic setting of the study area. b) Location of the studied sections on the Dachstein Plateau. G 1–3 sampling points near to Gjaidalm, S section at Krippenstein Schutzhaus, E section at Krippenstein Eishöhle.

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

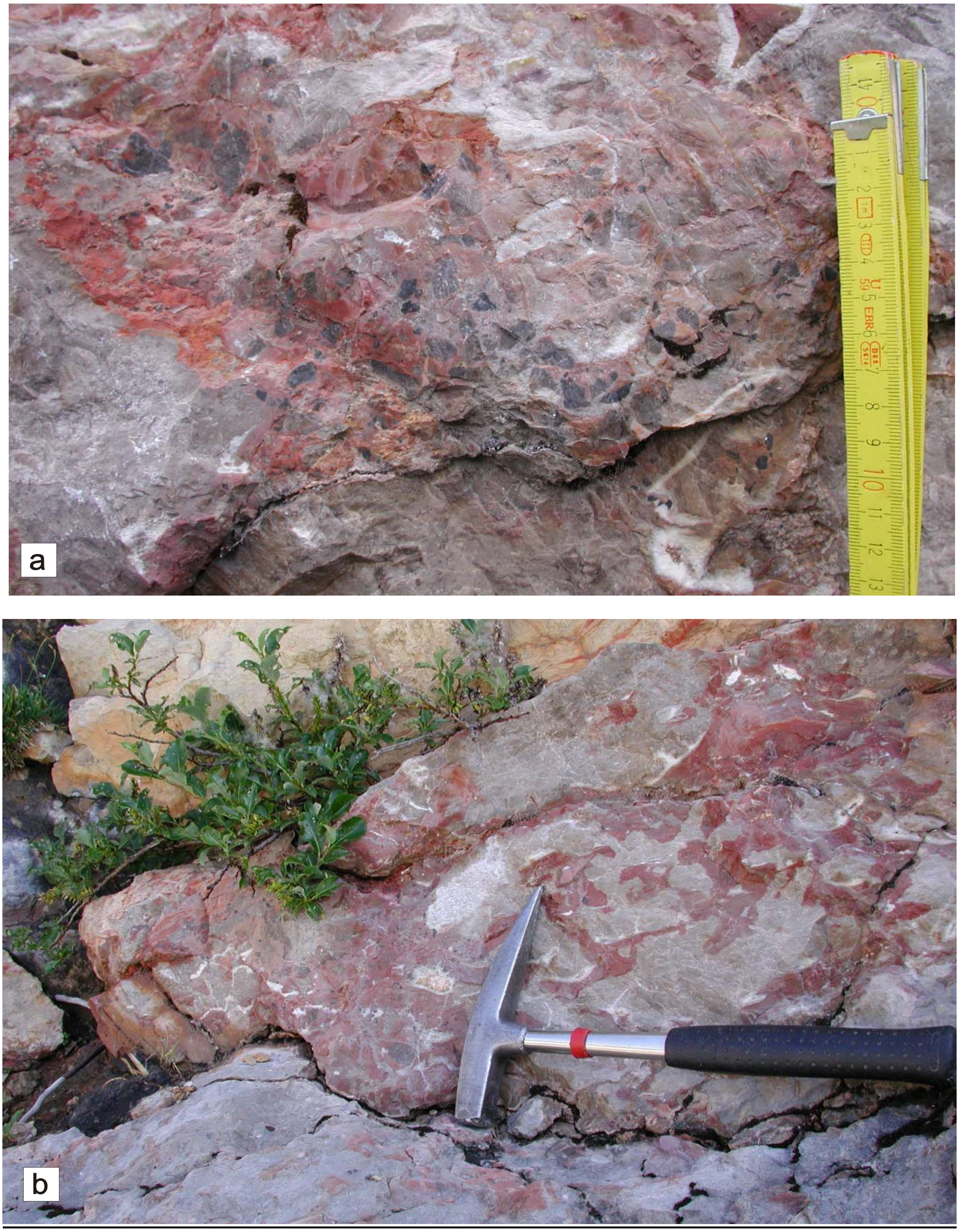

Fig. 2: a) Uneven disconformity surface overlain by red limestone with black pebbles. Ski trail between Gjaldalm and Krippenstein (G2 on Fig 1/b); b) Network of solution pipes and cavities filled by red mudstone–wackestone. Ski trail between Gjaldalm and Krippenstein (G2 on Fig1/b).

1. Outcrops along the ski trail between Gjaidalm and Krippenstein

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

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

2. Krippenstein Schutzhaus

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

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

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

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

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

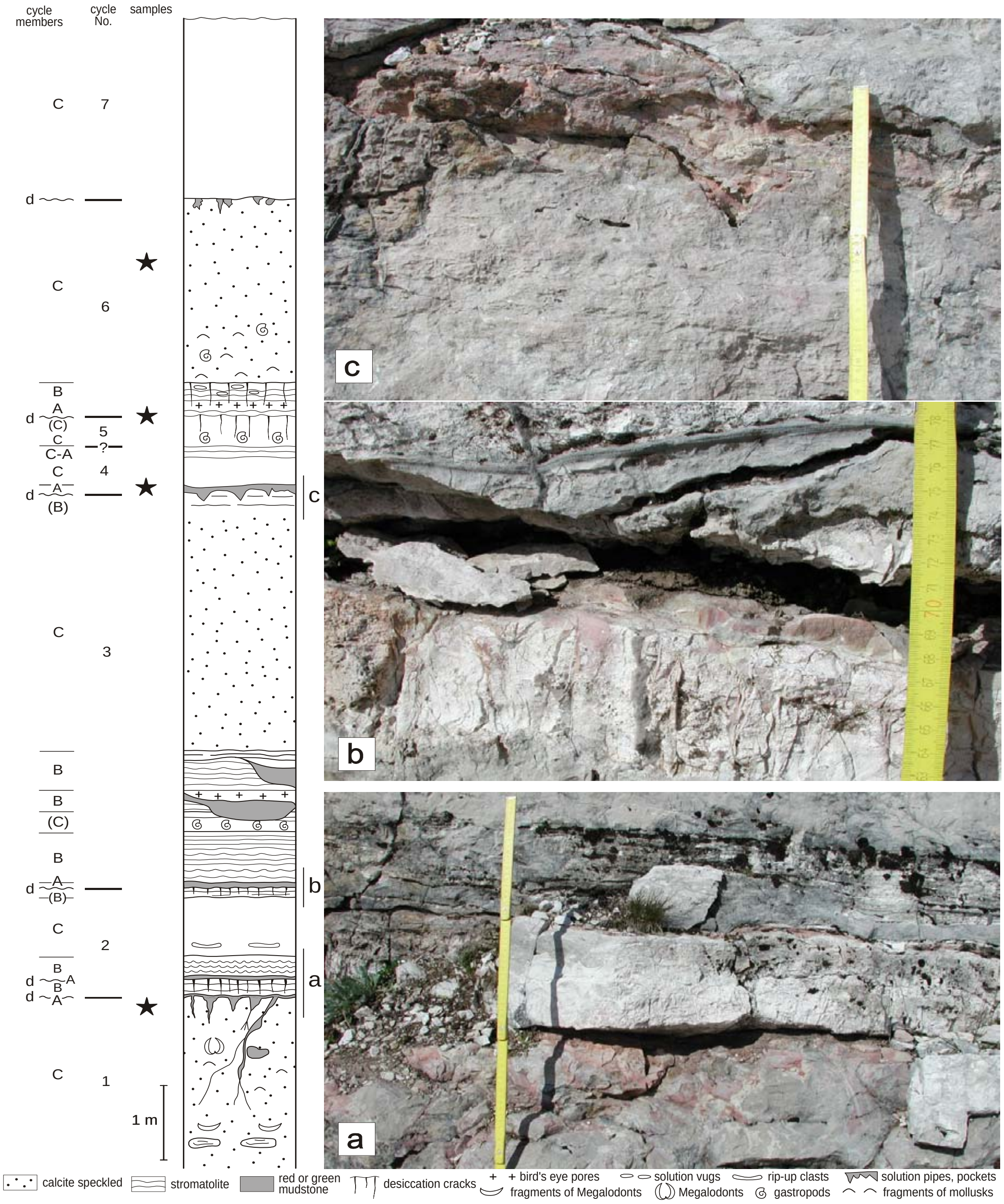

Fig. 4: Section south of the Krippenstein Schutzhaus. Lithologic log, cycles and facies types; location of the samples referred in the text is marked by asterisk; a) karstified disconformity surface of the lowermost exposed cycle and the overlaying peritidal beds; b) the upper boundary interval of the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

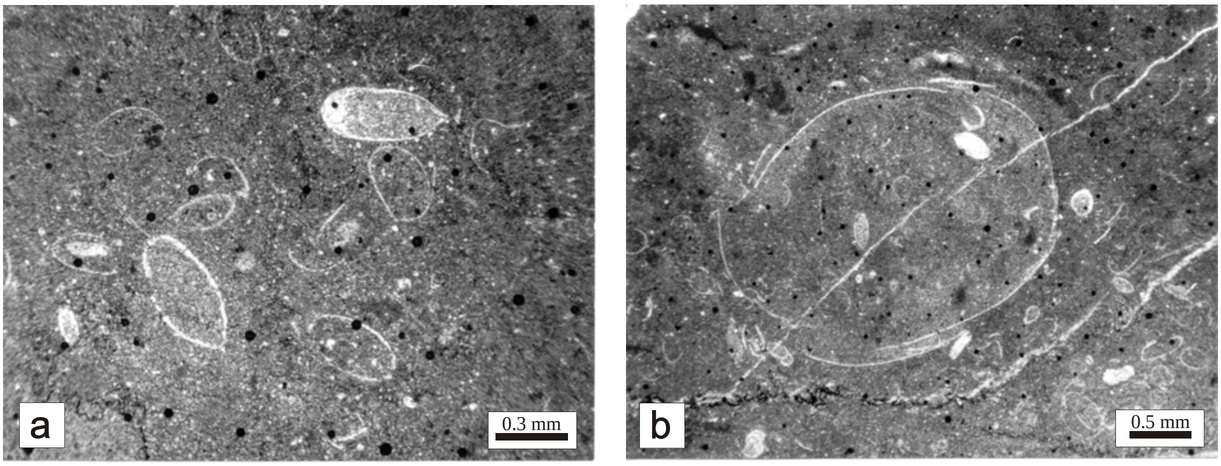

Fig. 5: Typical microfacies of facies A. a) ostracodal wackestone ; b) ostracodal wackestone. The large fragmented shell in the central part of the photomicrograph is probably also an ostracode carapace.

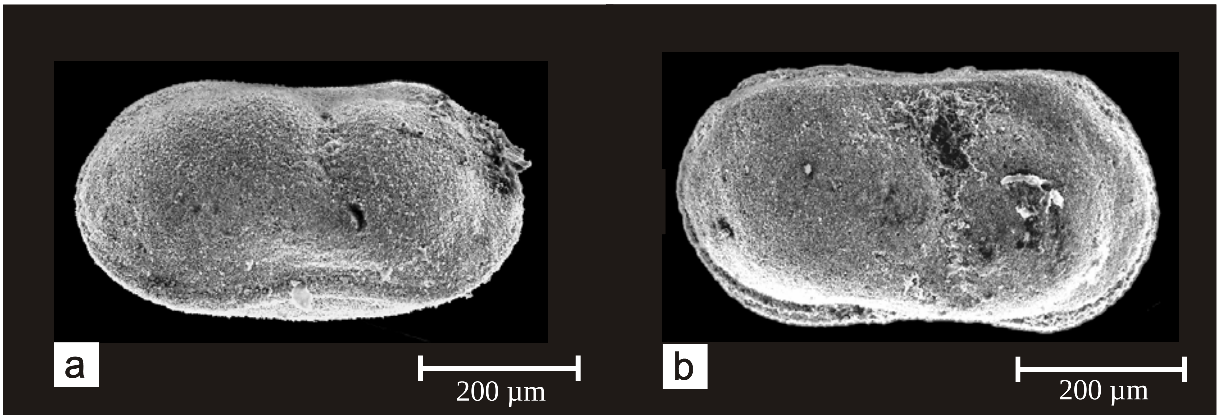

Fig. 6: *Lutkevichinella* aff. *grammi* Kozur, 1972. Carapaces (right valves)

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

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

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

3. Krippenstein Eishöhle

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

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

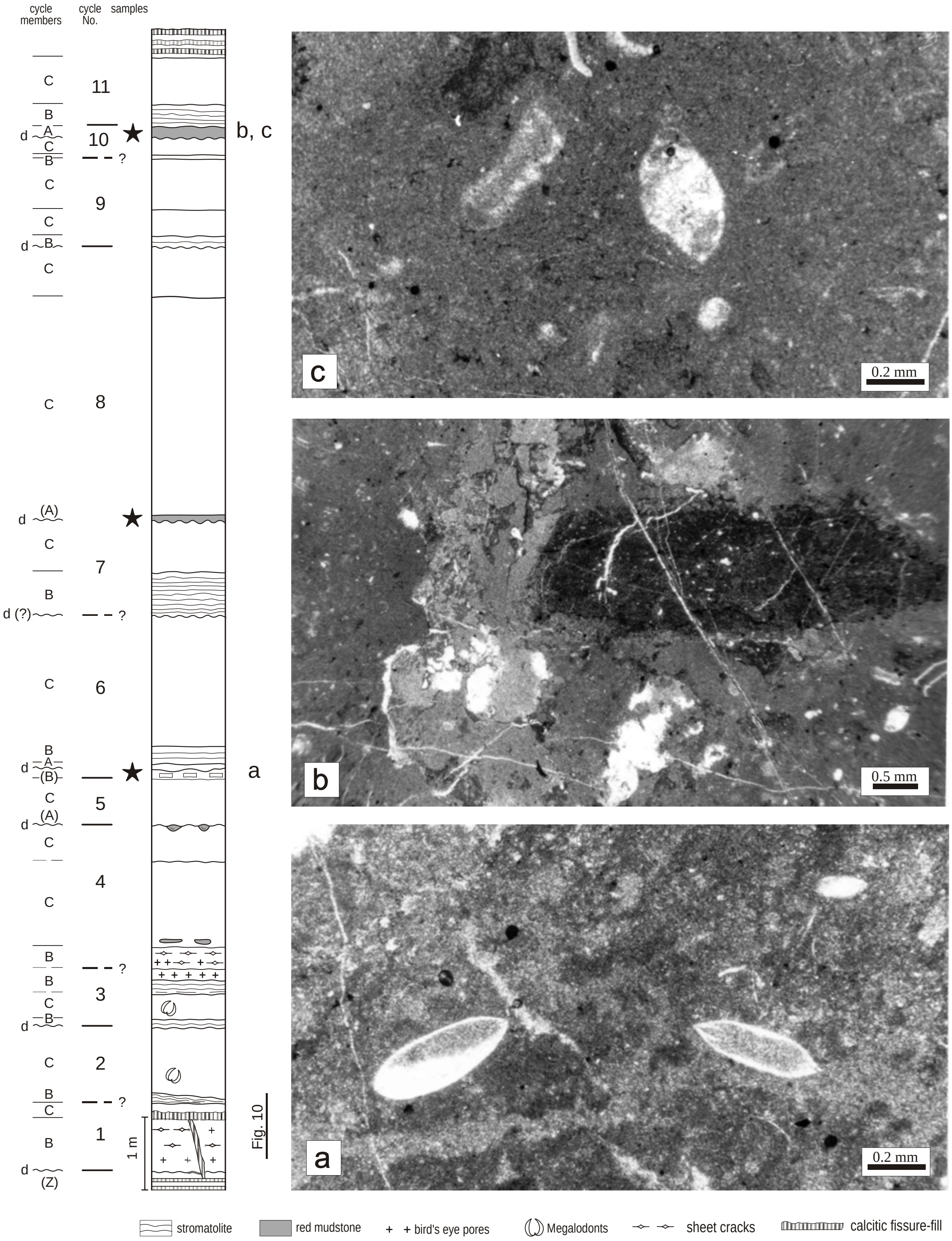

Fig. 8: Section at Krippenstein Eishöhle. Lithologic log of the section, cycles and facies types. Typical microfacies of facies A: a) Ostracodal wackestone; b) Intraclast in ostracodal wackestone c) Redeposited marine foraminifera in ostracodal wackestone.

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

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

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

The B or rarely the A facies is overlain by light brown, greyish brown finely crystalline limestone that rarely contains megalodonts (member C). Their thickness varies between 0.7–3 m.

In the studied section the composition of the Lofer cycles is rather variable. The following patterns were found: ABC; ACB; BCB; BC; AC. This means that the cycles are incomplete and/or truncated as a rule.

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

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

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

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

Summary of the observations and conclusions

1. In the visited sections on the Dachstein Plateau the boundaries of the Lofer cycles are usually erosional disconformities showing features of karstification. Penetration of the karstic solution was not more than a few decimetres (microkarst) since during the recurrent sea-level drops the platform was only slightly emerged above the sea-level.

2. The reddish or greenish argillaceous carbonate member that is facies A cannot be interpreted as palaeosol although it may contain reworked palaeosol-derived material. Facies A represents tidal flat deposit consisting predominantly of subtidal carbonate mud redeposited by storms. The subtidal mud was mixed with airborne fines and/or reworked lateritic soil that were accumulated and subjected to further weathering and alteration on the subaerially-exposed platform. Rip-ups from consolidated sediment, blackened intraclasts and carbonate mud formed in the tidal flat ponds, and skeletons of tidal flat biota may have also contributed to the material of facies A. The ostracodes (*Lutkevichinella*) found in facies A suggest very low salinity to freshwater conditions.

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

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

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EXCURSION 3

The Dachstein-reef of the Gosaukamm - An Upper Triassic carbonate platform margin

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The Gosaukamm massif forms the northwestern extension of the central Dachstein mountains, separated by the deep furrow of the Gosau lakes. Both mountain ranges belong to the Dachstein nappe, which was part of the large Upper Triassic carbonate platform of the Austroalpine sector of the Tethyan shelf. The general investigation and mapping was done by SCHLAGER (1966, 1967), additional refinements have been contributed by TOLLMANN & KRISTAN-TOLLMANN (1970) and MANDL (1984). Palaeontological and microfacial research of the Dachstein reefs was done by the reef working group from University Erlangen, summarized in FLÜGEL (1981); details from the Gosaukamm have been reported by WURM (1982). Short reports on the macrofauna are given by ZAPFE (1962, 1967). A recent study of corals was done by RONIEWICZ (1995).

Whereas the Dachstein and the adjacent karst plateaus consist to a large extent of the lagoonal interior of this platform, the Gosaukamm mostly represents a marginal fore reef tract, facing toward the deeper marine Hallstatt basinal facies – similar to the palaeogeographic model of ZANKL (1971), developed for the Hohe Göll area south of Salzburg, see Fig. 1.

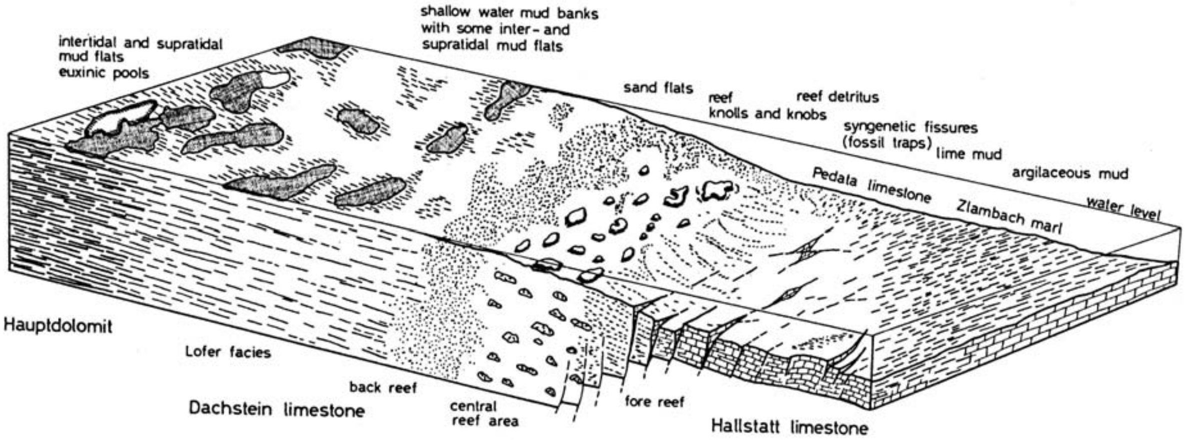


Fig. 1: Palaeogeographic interpretation of the depositional environments in the Salzkammergut region during Norian-Rhaetian, after ZANKL (1971; not to scale).

The former platform margin has been dissected during orogenesis by several dextral strike slip faults, see Fig. 2. The northwestern front part of the moving block was squeezed into the deformed basinal sequences of the Törleck- and Zwieselalm-anticlines. In this way the syncline of Roßmoos was formed, where Rhaetian Zlambach marls are preserved below a thin layer of the overturned Dachstein Limestone of the Kesselwand.

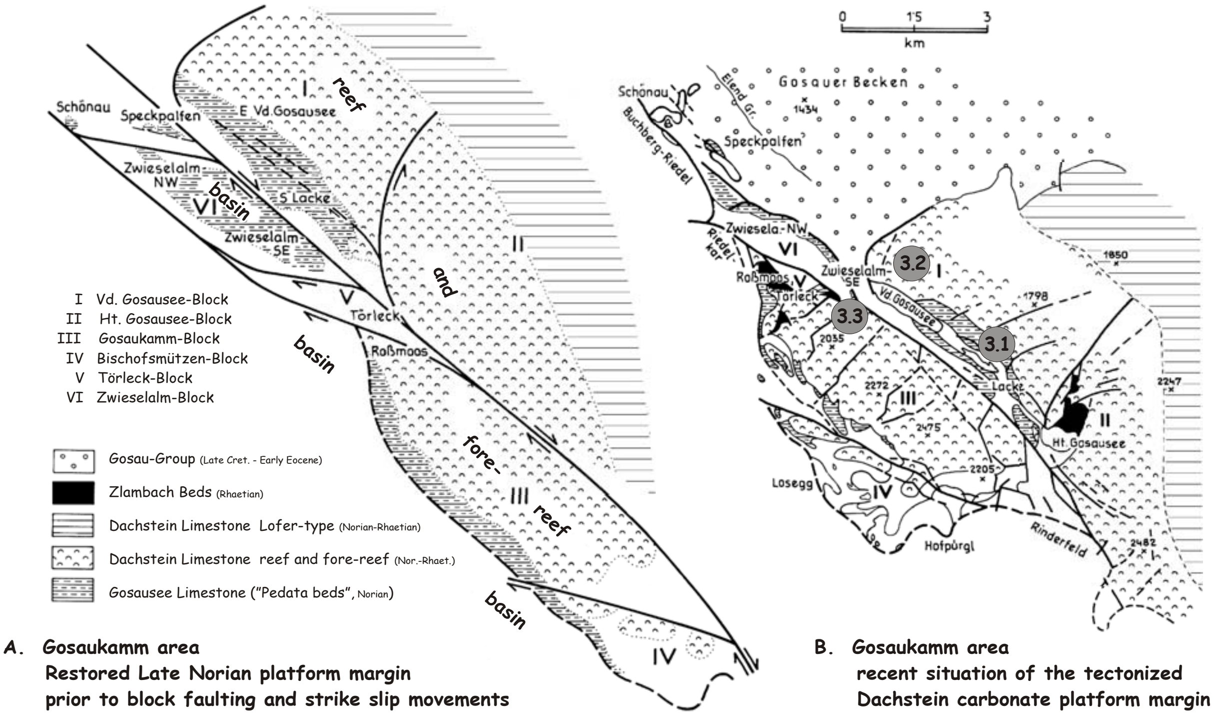
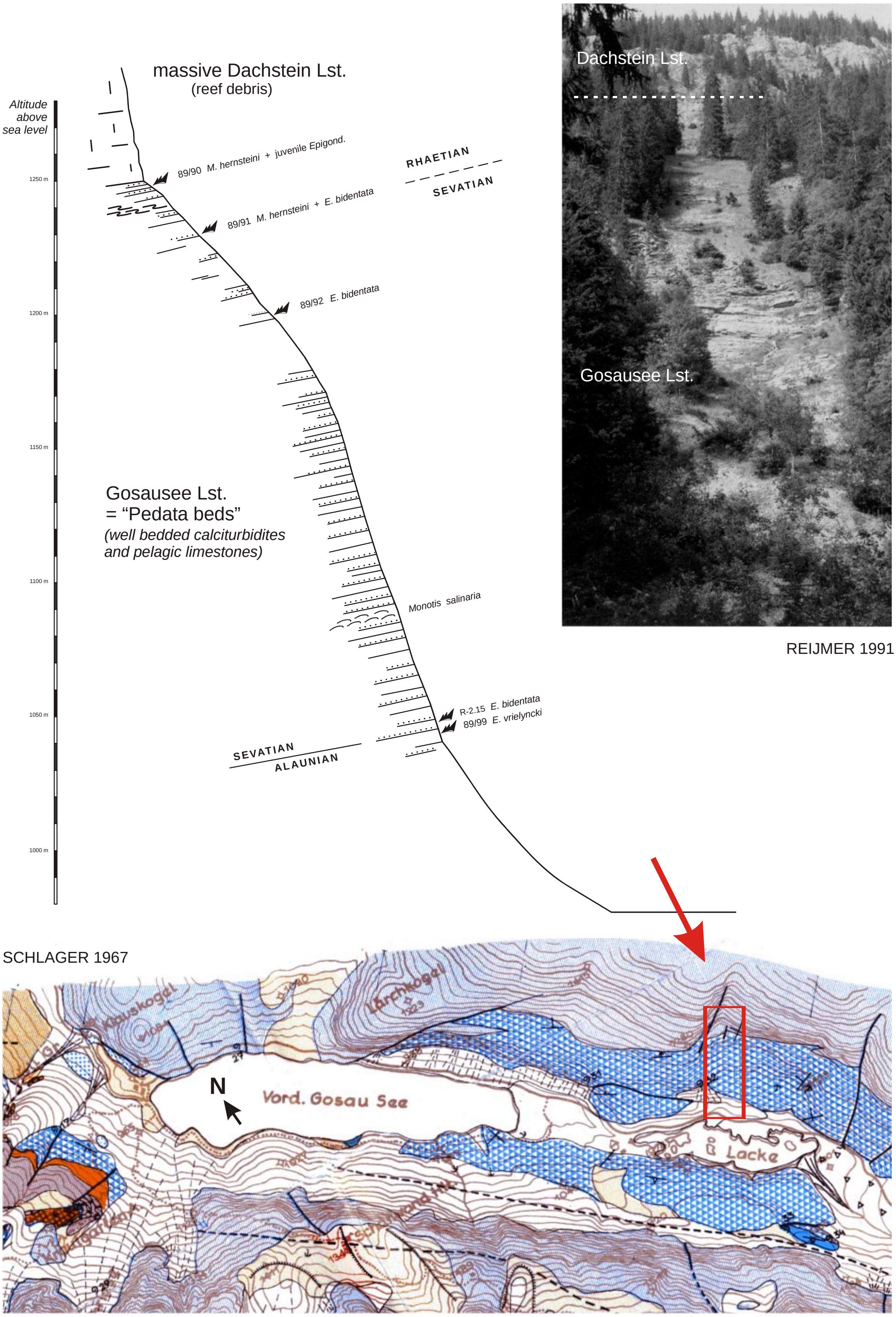


Fig. 2: Facies zones of the Dachstein platform margin in the Gosaukamm area. Restored geometry before strike-slip faulting, after MANDL (1984).

Transitional beds of slope- and nearby basin-facies are characterized by carbonatclastic sedimentation, derived from the platform as well as from the slope. These sediments are summarized under the term „Gosausee Limestone“, in literature often referred as „Pedata Schichten“ according to the locally abundant brachiopod *Halorella pedata*. Exposures can be found mainly around the Gosau lakes and on the southwestern slopes of the Gosaukamm. Details of sedimentology and cyclicity of this bedded calciturbiditic limestone are given by REIJMER (1991). According to him the variations in turbidite composition can be attributed to fluctuations in sea level and resulting flooding and exposure of the platform. The so caused variation of platform sediment production could be matched with Milankovitch quasi-periodicities. The section of REIMERS (1991) has been investigated for conodonts and shows a more than 100m thick sequence with top-middle and late Norian conodonts at the base, a 2m thick Monotis salinaria interval above and conodonts representing the Norian-Rhaetian boundary at the top (Fig. 3).

Gosau-Lacke section



REIJMER 1991

SCHLAGER 1967

Fig. 3: Log and biostratigraphy of the Gosau-Lacke section.

(Fauna according to SCHAUER 1983, revised):

Niveau 4 = SW dipping summit surfaces - *M. hernsteini, M. posthernsteini, O. paucidentata*

Niveau 2 - *N. steinbergensis, E. bidentata, E. slovakensis*

Niveau 1 - *E. spatulata*

Fig. 4: View of Steinriese-Donnerkogel (Loc. 3.3 in Fig.2) with location of time diagnostic conodont bearing flooding levels within the Dachstein reef limestone.

The Dachstein reef limestone of the Donnerkogel group dominantly is composed of coarsegrained rud/floatstones and reef debris with only small, widely distributed patch reefs. The microfacies may be subdivided into up to 10 types – WURM (1982). A large scale bedding (some 10 meters) can be seen. The original dip of the reef slope was not 30° as today, but about 10-15° concerning displaced geopetal fabrics. The patch reefs show a dominance of non-segmented calcareous sponges as main framebuilders. Branched corals are less frequent. Fauna and flora of the patch reefs and the detrital limestones is very rich.

More then 50 species contribute to the construction of the reef framework, more than 60 species must be regarded as benthonic reef-dwellers. Pelagic elements from the open sea are known with *Heterastridium* and rare ammonoids. Stratigraphically significant conodonts occur along certain thin flooding intervals throughout the Gosaukamm and have been mapped and dated by SCHAUER (1983). The respective faunas (Fig. 4) provide a late Lower Norian to early Rhaetian age for the Steinriese section. Reef and platform margin have been drowned at the base of the Middle Rhaetian and are sealed with a thin hemipelagic cover of gray crinoidal-brachiopod bearing or red finegrained limestone also containing Rhaetian conodonts (*Misikella posthernsteini).*

The central reef front of the Dachstein platform is exposed over several kilometers along the northern margin of the Lake Gosau and easily accessible along the Ebenalm forest road (excursion point 3.2 in fig. 2). The facies differs from the Gosaukamm fore reef by a more fine-grained matrix with in situ frame builders and the rare occurrence of sedimentary breccias.

The marls and limestones of the Zlambach Formation at the locality Roßmoos are well known for a rich coral fauna – FRECH (1890). Additional elements are non-segmented calcareous sponges, spongiomorph hydrozoans, bryozoans, brachiopods, ammonites (*Choristoceras haueri* MOIS.), echinoderm, serpulids, solenoporaceans.

Flügel (1962) interpreted the environment as off-reef shoals within a muddy basin somewhat deeper as and near to the fore reef of the Gosaukamm reef. The deeper and distal part of the Zlambach basin facies is not preserved at the Gosaukamm, but several kilometers to the northeast, at the type region within the Hallstatt unit of Ischl-Aussee – for details see BOLZ (1974), PILLER (1981), MATZNER (1986).

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