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Growth and termination of the Upper Triassic platform margin of the Dachstein area (Northern Calcareous Alps, Austria)

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Donnerkogelkalk
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Norian-Rhaetian

Abstract

From the margin of the Dachstein carbonate platform, i.e. the reef rim and slope usually mapped as “Dachsteinriffkalk Formation”, conodonts are described that allow an exact stratigraphic dating and a reconstruction of the depositional history. Reef growth starts in the earliest Norian and reaches a peak in the early Rhaetian. Nearly 1000 metres of limestone accumulated in this time interval. Thin pelagic intercalations indicate certain flooding events and allow the distinction of a thick Early Norian, a comparably thin Middle Norian and an again thicker Late Norian to early Rhaetian interval within the Dachsteinriffkalk. Phases of extended reef growth are found in the Early Norian and Rhaetian before the margin get drowned and covered by the pelagic Donnerkogelkalk in middle Rhaetian time. Reef building at the platform margin of the Dachstein area thus ended well before the top of the Triassic and the end-Triassic extinction event.

Aus dem Typusgebiet des Dachsteinkalkes werden vom Riffsaum und vom Hang der Karbonatplattform Conodontenfaunen beschrieben, die eine genaue stratigraphische Datierung und damit eine Rekonstruktion der Ablagerungsgeschichte erlauben. Das Riffwachstum beginnt im untersten Norium und erreicht ein Maximum im frühen Rhätium. Dabei wird ein Schichtstapel von nahezu 1000 Meter Mächtigkeit abgelagert. Dünne pelagische Einschaltungen zeigen mehrere Flutungsereignisse an und ermöglichen die Unterscheidung eines mächtigen unternorischen, eines geringer mächtigen mittelnorischen und eines wiederum dickeren obernorisch bis rhätischen Anteiles des Riffkörpers. Phasen von verstärktem Riffwachstum sind im Unter-Norium und im Rhätium zu erkennen, bevor das Riff ertrinkt und im mittleren Rhätium vom pelagischen – hier als lithostratigraphischer Terminus neu eingeführten - Donnerkogelkalk überdeckt wird. Das Riffwachstum am Plattformrand des Dachsteingebietes endet damit innerhalb der Trias und deutlich vor dem end-triassischen Aussterbe-Event.

1. Introduction

During Late Triassic time broad carbonate shelves bordered the northwestern Tethys margin over a lateral distance of more than 1000 km. These shelf carbonates are known as Dachsteinkalk and form large mountain plateaus in the Northern Calcareous Alps of central and eastern Austria (Mandl, 2000). Type locality of the Dachsteinkalk is the Dachstein Massif in the southern Salzkammergut region that consists of cyclical bedded lagoonal limestone with a south- and southwestward transition to a broad reefal rim and adjacent slope. Platform margin and slope were usually mapped together as “Dachsteinriffkalk”.

In this paper we call the reefal platform rim plus the adjacent slope deposits “platform margin”. The reasons for lumping the two facies belts are twofold. First, the separation is not crucial for the stratigraphic results presented here. Second, reef debris is common in both facies and bedding is very similar: Bedding surfaces in both facies tend to be widely spaced (tens to over 100 meters) and often discontinuous; as a consequence, reef rim and slope facies are often difficult to distinguish in tectonically deformed areas and this is the reason why both facies have usually been mapped as one formation called “Dachsteinriffkalk” in German-speaking literature. This formation is characterized by poor stratification and locally coarse fossil debris or in-situ boundstones.

At the Gosaukamm, the more than 800 m thick limestones of the platform margin (Wurm, 1982) prograde during Norian time over the adjacent Hallstatt basin in the southwest (Schlager, 1967; Kenter & Schlager, 2009). In other parts of the Dachstein Massif, the platform margin is still in normal sedimentary contact with the lagoon. At the Gosaukamm, this contact has been severed by alpidic strike slip movement and the range is thought to be displaced to the northwest by about 7 km with respect to main part of the Dachstein Massif (Mandl, 1984).

Due to an exceptionally diverse Norian-Rhaetian reef biota the Dachsteinkalk of the NCA has become a classical palaeontological study site (Flügel, 1963; Zankl, 1969, 1981; Wurm, 1982; Roniewicz, 1989, 1995). Its facial and sedimentological characters (Fischer, 1964; Zankl, 1971; Wurm, 1982; Satterley, 1994; Enos and Samankassou, 1998; Schwarzacher, 2005; Haas et al., 2007) are equally important for comparisons with similar Late Triassic shallow-water carbonate platforms. Dachstein-like reefs and lagoonal carbonates are widespread along the Tethys margins and known from the Carpa-

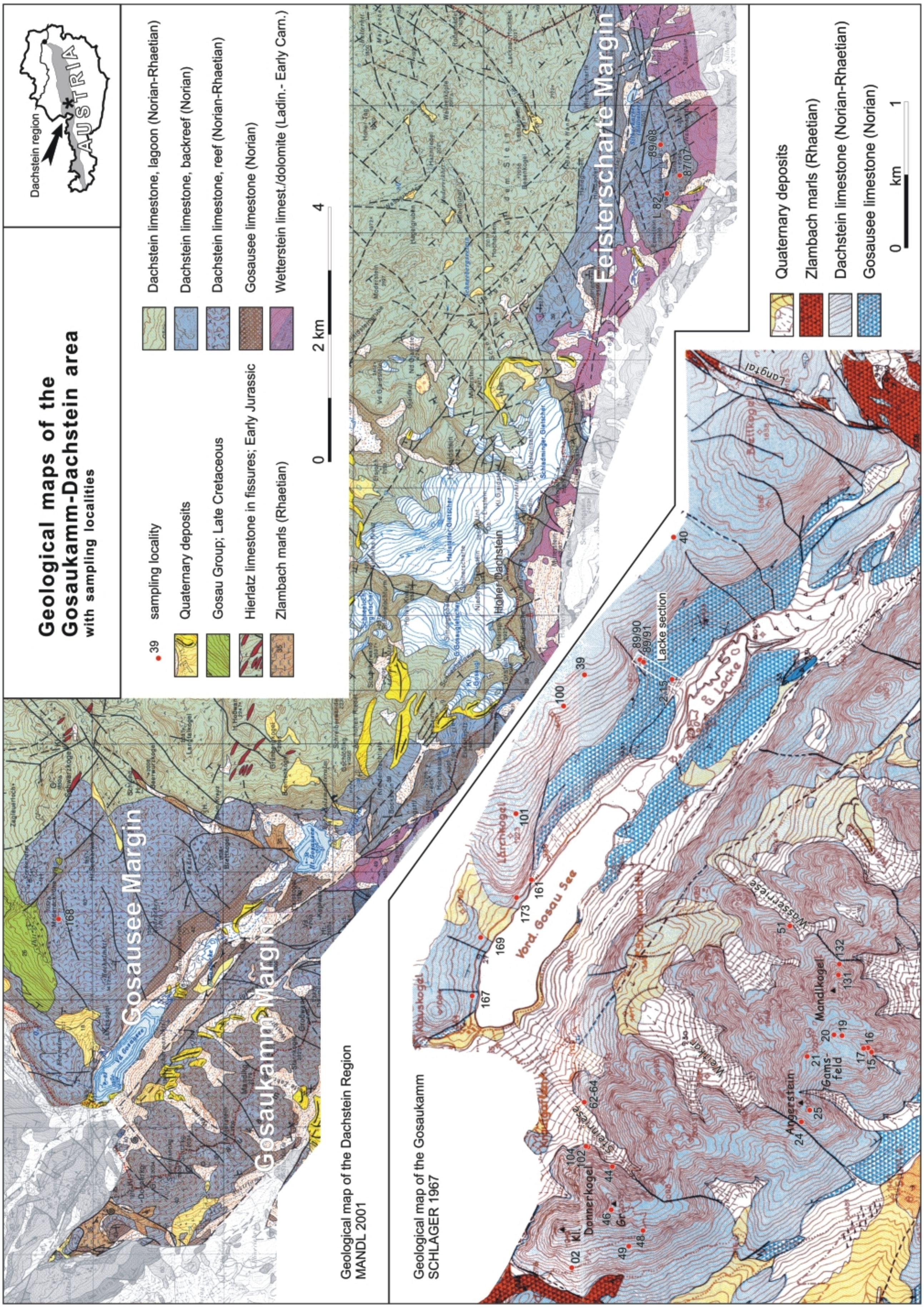


FIGURE 1: a) Geological map of southwestern Dachstein massif with location of the studied platform margins at Feisterscharte, Gosaukamm and north of Gosausee. b) Map of Gosausee area with conodont sampling sites; prefix “GK” in Gosaukamm sample numbers omitted.

thians, Dinarids, Greece, Turkey, Oman, till the Indonesian Islands (Flügel et al., 1996a,b; Flügel and Bernecker, 1996). Any new stratigraphic information is therefore of broader interest for many other Tethyan regions where this facies occurs.

A more general Norian to Rhaetian age assignment of the Dachsteinriffkalk dates back to the late nineteenth century (Bittner, 1884) and has not seen much age refinement since then (see Tollmann, 1976a). At the Gosaukamm, even the attempts to separate Norian and Rhaetian parts failed due to the low stratigraphic resolution of the available macrofossils (Zapfe, 1967, 1973). Age information was therefore rather poor before publication of the first conodont records (Krystyn, 1972; Schauer, 1984). Here we present a comprehensive biostratigraphic documentation of the growth history of the platform margin in the southwestern area of the Dachstein Massif between Feisterscharte in the east and the Gosaukamm and the Gosausee (= Lake Gosau) region in the west (Fig. 1). The age constraints are based on conodonts from hemipelagic Hallstatt-type limestones within the platform margin, or immediately overlying the margin. During the last decades, conodonts have turned out as powerful tool for fine-tuning stratigraphy in basinal sediments where they co-occur with ammonoids and can be calibrated against the ammonite-based time scale (Orchard and Tozer, 1997).

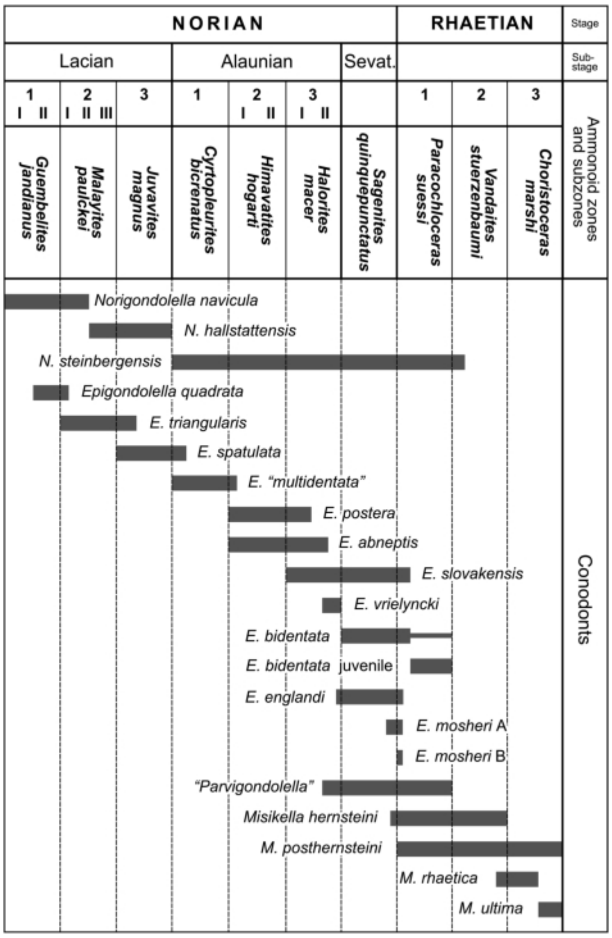


FIGURE 2: Conodont ranges plotted against the ammonoid zonation. Note position of Norian-Rhaetian boundary below *P. suessi* Zone.

2. Regional Geology

As parts of the Eastern Alps, the Northern Calcareous Alps (NCA) represent the sediments of an approximately 300 km wide and 500 km long sector of the northwestern margin of the former Tethys ocean. Along this, as well as in other parts of the Upper Triassic Tethyan passive margin, belts of marine sedimentation were arranged in a characteristic shore-parallel fashion. This is illustrated in particular by the spatial arrangement of classical Upper Triassic sedimentary environments, see Haas et al. (1995), Mandl (2000). The most landward zone was the Keuper belt, dominated by redbeds and evaporites. Seaward followed a wide belt of carbonate platforms with supratidal to subtidal deposits (Hauptdolomit and bedded Dachsteinkalk formations). The platform was flanked at its southwestern rim by reefs facing deeper, openwater. The Dachstein platform produced large masses of skeletal and non-skeletal carbonate detritus, which were deposited mostly along the platform slopes and on the proximal basin floors. Further offshore only a small amount of periplatform sediments reached the pelagic Hallstatt facies belt.

In the course of Alpine orogeny the Permian to Eocene sedimentary succession became detached from its continental basement and transformed into a complex fold-and-thrust-belt. The plate tectonic closure of the Tethyan ocean is not well documented in the Eastern Alps and poorly understood. Nevertheless, it is clear that large masses of rocks of the southern Dachstein and Hallstatt facies belt became detached from their basement at the level of the Permian evaporites, and were transformed to gravitational nappes, sliding blocks, olisthostromes and turbidites moving northward into the Jurassic radiolarite basins above the drowned platforms. During the Early Cretaceous a succession of several tectonic events and associated syntectonic clastic sedimentation created the NCA nappe stack (e.g. Tollmann, 1987; Faupl and Wagreich, 2000; Mandl, 2000). In this way the Dachstein Massif and Gosaukamm became part of the so-called Dachstein nappe, a major component of the Juvavic nappe system. The latter forms the uppermost nappe structures in the classical tectonic terminology of the NCA, see Tollmann (1976 b; 1985). A different tectonic classification has recently been proposed by Frisch and Gawlick (2003).

3. Biostratigraphy

A new definition of most Triassic stages is currently under consideration by the International Commission on Stratigraphy (ICS). Independent of any future agreement on the respective boundary definitions, we follow here the Tethyan Late Triassic ammonoid standard developed by Krystyn (1980, 1982, 1987) for a cross-correlation of our conodont data (Fig. 2). As such the base of the Early Norian (Lacian substage) is defined by the *Guembelites jandianus* Zone, that of the Middle Norian (Alaunian substage) by the *Cyrtopleurites bicrenatus* Zone and that of the Late Norian (Sevatian substage) by the *Sagenites quinquepunctatus* Zone. The Rhaetian starts with *Paracochloceras suessi* and the correlative *Sagenites* *reticulatus* Zone (Krystyn et al. 2007a, b) and contains two other zones, the *Vandaites stuerzenbaumi* Zone in the middle and the *Choristoceras marshi* Zone at the top. The exclusion of the *Paracochloceras* zone from the Norian has not only led to a shortening of the Sevatian substage (Krystyn et al., 2002), but also to a considerable lowering of the Norian-Rhaetian boundary in the Dachstein reefs.

Biostratigraphically relevant macrofossils including ammonoids and pelagic bivalves (*Halobia, Monotis*) are cited from many Dachsteinkalk platform margins of the NCA. However, these macrofossils are not common and most were collected in recent scree at the foot of the large mountain cliffs. From the Gosaukamm (Steinriese area) talus findings of *Monotis*, halobiids (*H. norica, H. plicosa*), the ammonoid *Rhabdoceras suessi* and the enigmatic hydrozoan *Heterastridium* are mentioned by Zapfe (1967) and discussed for their stratigraphic significance but without a definite age conclusion for the reef. Zapfe (1967) also placed the *Halorella*-bearing brachiopod fauna (Kittl, 1916) of the Gosausee (locality GK 167 in fig. 1) erroneously low in the Norian though geologically it belongs to the top part of the Dachsteinriffkalk.

Stratigraphic ranges of conodonts are shown in figure 2 and most of the species are illustrated in figure 4. Geographic location, lithology and microfacies (Fig. 5) of conodont bearing

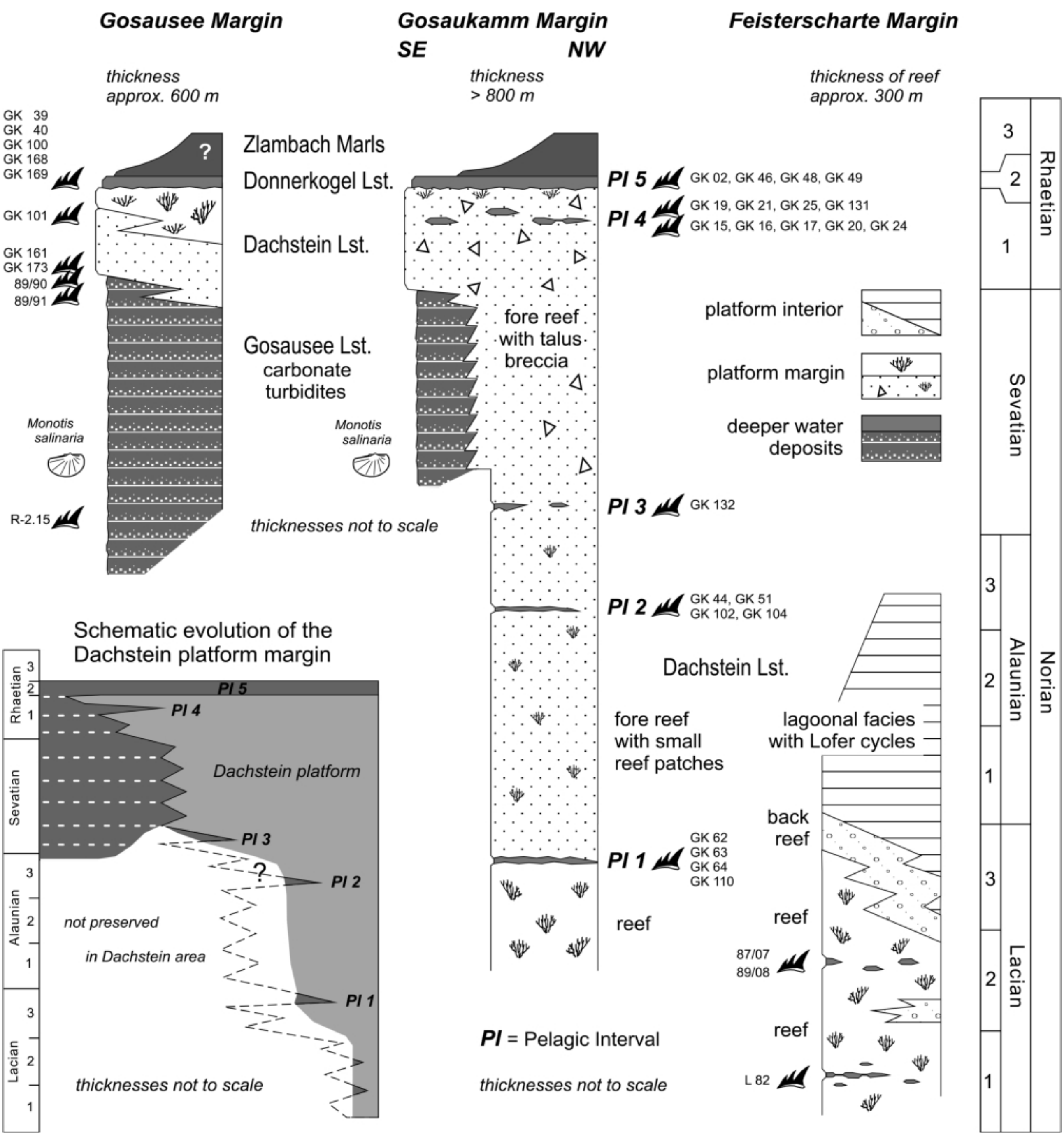


Figure 3: Stratigraphic and facial architecture of the Dachsteinriffkalk combined from Feisterscharte, Gosaukamm and northern Gosausee area.

samples are listed in table 1, and their relative position within the Dachsteinkalk sequence is shown in figure 3. On average 3-5 kg of rock had to be dissolved in acetic acid to obtain stratigraphically meaningful conodont faunas. The conodont and facies data of this paper are mainly based on the results of a doctoral thesis carried out by one of the authors (Schauer, 2002), except for the Feisterscharte region which was recently investigated by Roniewicz et al. (2007). Schauer's unpublished study of the Gosaukamm and other Alpine Dachstein reefs has demonstrated widespread, synchronous drowning of the platform margin in Rhaetian time with the termination of Dachstein reefs well before the end of theTriassic.

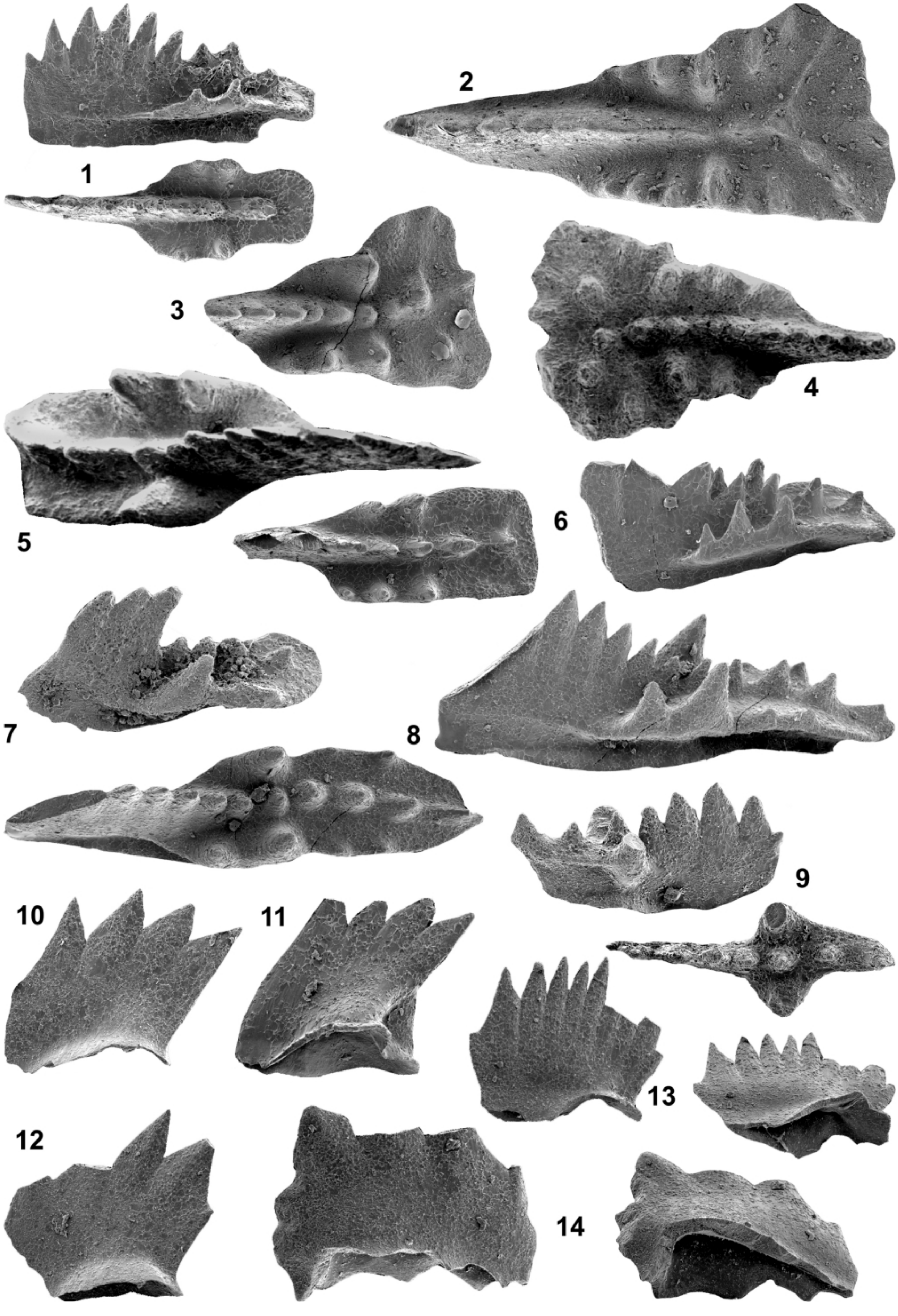
3.1 Dachsteinriffkalk

The oldest reefs currently known are from the Feisterscharte region where the conodonts *Epigondolella quadrata* (Fig. 4-1) in sample L 82 and *E. triangularis* in samples 89/08 (Fig. 4-2) resp. 87/07 (Fig. 4-3) prove the onset of platform margin growth in early Lacian time (Roniewicz et al., 2007). Platform progradation and concomitant migration of facies belts subsequently led to deposition of lagoonal carbonates in the area (Fig. 3). The late Lacian platform margin is also exposed in the Gosaukamm in the basal parts of the NE-facing cliffs above the Gosausee. It consists there of massive, variably coarse to finer grained slope deposits with small isolated buildups, dominated by calcareous sponges embedded in arenitic sediment (Schauer, 2002). A 2-3 metres thick interval of hemipelagic limestone made up of filament- and crinoid-bearing wackestones (Fig. 5-2, 3) marked as pelagic interval 1 (= *PI 1* in fig. 3) covers the margin and can be traced along strike over a lateral distance of 4 km at the footwall of the Großwand (sample GK 110, Fig. 1) in 1830 m. In the Steinriese it occurs in an altitude of 1340-1350 m (samples GK 62 to GK 64). Pelagic interval *PI 1* contains *Epigondolella spatulata* (Fig. 4-4) indicating a late Lacian age of this distinct flooding event. It is overlain by ca. 200 m of slope sediments similar to the Lacian ones, again with small mound-like patch reef buildups (Schauer, 1984). The next pelagic interval, *PI 2*, is of late Alaunian age and only 20 cm thick, built of red micritic limestone accompanied by micritic-lithoclastic beds without reefal debris. *PI 2* follows 100 to 200m above *PI 1*. This indicates that the Alaunian interval is considerably thinner than the Lacian or Sevatian to lower Rhaetian reef limestones whose thickness amounts to >300 and >500 m respectively. The *PI 2* contains *Norigondolelella steinbergensis*, *E. postera* (Fig. 4-5) and *Epigondolella ex E. abneptis* group (Fig. 4-6) and is recorded in samples from the Steinriese in 1430m (GK 102, GK 104) and 1550m (GK 44) and in the Wasserriese in 1795m (GK 51).

The following part of the Gosaukamm between *PI 2* and *PI 3* consists of frame building reef facies with up to 50% framestones (Schauer, 2002) interfingering with massive, more or less coarse grained forereef limestone. Lithofacies changes above *PI 3* to coarse-grained slope breccias with a SW dipping decametric bedding interpreted as clinoforms by Kenter and Schlager (2009, this volume). Along these bedding surfaces occur discontinuous, thin lenses of red micritic limestone which have delivered locally conodont faunas of Sevatian to early Rhaetian age. These patchy occurrences are shown as *PI 3* and *PI 4* in fig. 3. Due to their small size they could be easily overlooked and especially *PI 3* was difficult to detect. A single lens has been found at Mannlkogel in 2200 m (GK 132) where it bears *E. bidentata*, *E. slovakensis* and *N. steinbergensis*. In Steinriese, an up to 5 m thick interval of grey thin-bedded bioclastic wacke- to packstone package exposed in 1850 m is, from the stratigraphic position, thought to equal the *PI 3* but has not delivered a fauna. Early Rhaetian conodonts (*Misikella hernsteini*, *M. posthernsteini*, *N. steinbergensis*) occur in *PI 4* close to the top of the reef limestone. *PI 4* is a more widespread developed level of pelagic lenses found near the Angerstein in 2060 m (GK 24) resp. 2090 m (GK 25), in the Gamsfeldklamm between 1915 and 2060 m (GK 15 to GK 19), in the Gamsfeld in 2000 m (GK 20) and 2150 m (GK 21), and east of the Mannlkogel (spelled Mandlkogel in the official map) in 2270 m (GK 131). The pelagic interval *PI 4* could not be located in the Steinriese, probably because of sampling difficulties in the very steep and rough terrain.

Age and facies development of the presently exposed platform margin north of the Gosausee differ from that of the Gosaukamm. Due to a palaeogeographically more terminal position it starts considerably later and is underlain by a sequence of calciturbititic and cherty limestones of about 200m thickness that contains at several places (Schlager, 1967) Sevatian bivalves (*Monotis salinaria*) and, in the Lacke section (fig. 2, 3) also conodonts of Sevatian age: in 1050m (sample –2.15) *E. bidentata* and *E. slovakensis* (Fig. 4-7), in 1230m (89/91) *E. bidentata* and *M. hernsteini*. This so-called Gosauseekalk is therefore timely equivalent to the Gosaukamm margin from the *PI 3* to below the *PI 4* interval. Slightly higher, in 1250 m (Fig. 2), follows the transition to the Dachsteinriffkalk where sample 89/90 indicates an early Rhaetian age by the presence of common *M. hernsteini* together with dwarfed platform-less *Epigondolella bidentata* (=*Parvigondolela andrusovi* sensu Kozur). Other productive samples from the Dachsteinriffkalk base in 940 m near the road along the lake at the foot of the Lärchkogel (Fig. 1) have produced *E. bidentata* and *E. mosheri* A (Fig. 4-8) in GK 173 and *Epigondolella bidentata* (Fig. . 4-9), *M. hernsteini*, *M. posthernsteini* and *Oncodelella paucidentata* in GK 161. A younger, still early Rhaetian, age based on the co-occurrence of *N. steinbergensis* and *M. hernsteini* is reported from the higher part of the Dachsteinriffkalk along the forest road to the Lärchkogel in 1230m (GK 101), allowing a correlation with the *PI 4* of the Gosaukamm.

The platform margin north of Gosausee forms a large and coherent entity with a length of 5 km and a width of up to 3 km (Mandl, 2001) still in normal sedimentary contact with the well-bedded lagoon facies to the NE (Fig. 1). It shows indistinct decametric beds dipping about 20° towards SW that could be interpreted as clinoforms in analogy to the Gosaukamm. Reefal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boundstones are common between Brettkogel, Roßrücken, Lärchkogel and Ebenforstalm, and specifically well exposed along the forest road to the Ebenforstalm (Fig. 1). Significant is the high amount of micritic sediment between the reef builders. The latter consist mainly of calcareous sponges, *Solenopora*, Spongiostromata and corals *Retiophyllia*, *Distichophyllia* or *Actinastrea*. Especially the hermatypic *Retiophyllia* is more common than in the Norian Gosaukamm reef mounds (Schauer, 2002). Coarse reef debris is relatively infrequent and about 50% of the framebuilders are still in growth position. Rudstones and breccias are almost absent in the surrounding matrix and it is therefore assumed that reefal growth occurred in a sheltered position or in a water depth deep enough to escape storm and wave-induced destruction and reworking. Between the northwestern end of the lake and the start of the Ebenalm forest road thin-bedded bioclastic wacke- and brachiopod bearing packstones interfinger directly with the buildups without slope deposits in between. These preserved geometries of the Gosausee margin seem to fit better to a (distally steepened?) ramp position in contrast to the steep, brecciarich margin type of the Gosaukamm (Wurm, 1982; Kenter and Schlager, 2009, this volume).

Details of sedimentology and cyclicity of the Gosauseekalk in the Lacke section are described by Reijmer and Everaars (1991). According to them the variations in turbidite composition can be attributed to fluctuations in sea level resulting in flooding or exposure of the platform. The so caused variation of platform sediment production and basinward transport could be matched with Milankovitch quasi-periodicities allowing an approximate timing of the 100 m thick studied part to about 1 Ma (Reijmer et al., 1994: 338). Assuming a more or less constant sediment accumulation rate of the all in all 200 m thick Upper Norian in the Lacke section results in an estimated duration of 2 Ma for the Sevatian substage.

Figure 4: Conodonts of the Dachsteinriffkalk and the Donnerkogelkalk; Magnification: 2 - 4: 100 x; 1 and 5 - 14: 160 x

1: *Epigondolella quadrata* Orchard, lateral and upper view; L 82. Feisterscharte, Dachsteinriffkalk, Lacian 1/II.
2-3: *Epigondolella triangularis* (Budurov and Stefanov), upper view; 2: 89/08, 3: 87/07. Feisterscharte, Dachsteinriffkalk, Lacian 2.
4: *Epigondolella spatulata* Hayashi, upper view; GK 62. Gosaukamm, Steinriese, Dachsteinriffkalk, *PI 1*, Lacian 3.
5: *Epigondolella postera* (Kozur); upper view, GK 51. Gosaukamm, Wasserriese.
6: *Epigondolella abneptis* (Huckriede); lateral and upper view, GK 104. Gosaukamm, Steinriese, Dachsteinriffkalk, *PI 2*, Alaunian 3.
7: *Epigondolella slovakensis* Kozur and Mock, lateral view; 89/99. Gosausee, Lacke section, Gosauseekalk, Sevatian.
8: *Epigondolella mosheri* (Kozur and Mostler) morphotype A Orchard, 1994, lateral and upper view; GK 173. Gosausee road, Dachsteinriffkalk, upper *PI 3*, Sevatian.
9: *Epigondolella bidentata* Mosher, lateral and upper view; GK 161. Gosausee road, Dachsteinriffkalk, Sevatian.
10: *Misikella hernsteini* (Mostler), lateral view; GK 40. Roßrücken, Donnerkogelkalk, *PI 5*, Rhaetian 2.
11: *Misikella posthernsteini* Kozur and Mock, lateral view; GK 46. Gosaukamm, Donnerkogel, Donnerkogelkalk, *PI 5*, Rhaetian 2.
12: *Misikella koessenensis* Mostler, lateral and upper view; GK 49. Gosaukamm, Donnerkogel, Donnerkogelkalk, *PI 5*, Rhaetian 2.
13-14: *Misikella rhaetica* Mostler, lateral and upper view; 13: GK 39, 14: GK 40. Roßrücken, Donnerkogelkalk, *PI 5*, Rhaetian 2.

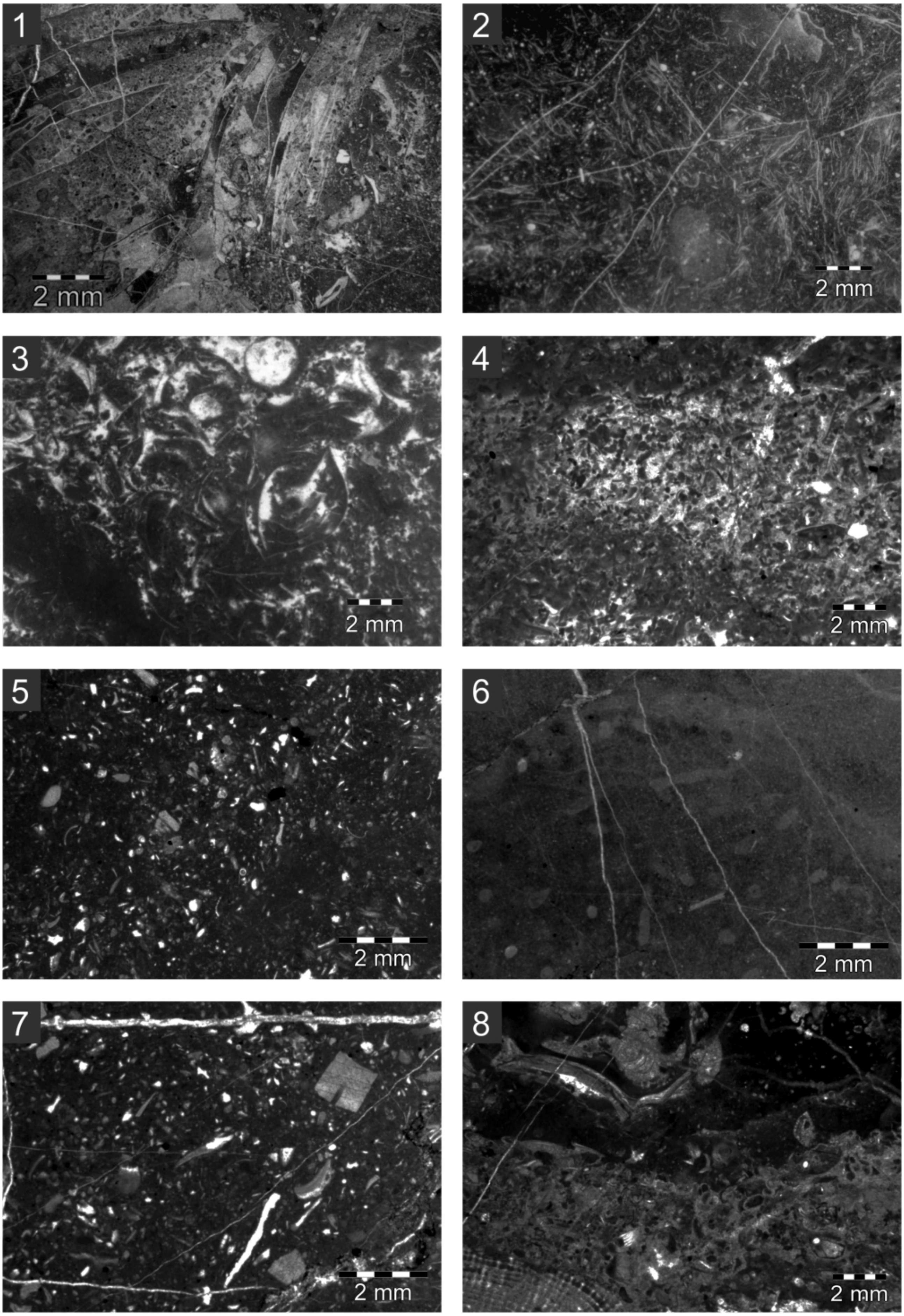
Specimens are housed in the micropalaeontological collection of Department of Palaeontology of Vienna University.

3.2 Donnerkogelkalk

Corresponding to the *PI 5* interval, this fine grained hemipelagic sequence of red to pale grey limestones follows abruptly and discontinuously above both the Gosausee and Gosaukamm margin. Crinoid-bearing wackestones (Fig. 5-5, 7) are dominating and fill the primary relief of the reef and slope and, rarely, the interspace of deeper water reef patches growing at the top of the Dachsteinriffkalk. Intercalated crinoid-brachiopod and/or reworked(?) reef debris bearing packstones (Fig. 5-8) with coquina layers indicate episodic higher energetic current events. The unit is often eroded, usually not more than 1m thick, but occasionally it can reach up to 5 m, for instance along the Donnerkogel path in 1850m, the type locality of this newly introduced lithostratigraphic unit. Biostratigraphic data – i.e. co-occurrence of *M. posthernsteini* and *M. rhaetica* in the sequence as well as the presence of late Rhaetian ammonoids (*Choristoceras* div. sp.) in the base of the overlying Zlambachmergel (Spengler, 1914; Zapfe, 1960) – suggest a duration of one ammonoid zone. Compared to similarly thin and condensed Hallstatt fossil accumulations, a considerably reduced sedimentation rate or temporary non-deposition may also be assumed as reasons for the reduced thickness of the Donnerkogelkalk.

Conodonts described by Krystyn (1972) had all been recovered from Donnerkogelkalk outcropping spottily on the southwestern flank of the Gosaukamm, especially between Kleiner and Großer Donnerkogel (Fig. 1). Most productive samples have been found along the path to the Großer Donnerkogel in 1840 m (GK 49) and 1920 m (GK 48), and at its top (GK 46), containing a middle Rhaetian, post-*Norigondolella* fauna with *M. hernsteini* (Fig. 4-10), *M. posthernsteini* (Fig. 4-11), *M. koessenensis* (Fig. 4-12), *O. paucidentata* and *Zieglericonus rhaeticus*. Patches of Donnerkogelkalk are widespread on top of the Gosausee margin and common between the Ebenforst road (GK 169) in the west, the Modereck (GK 168) in the north and the Roßrücken (GK 39, GK 40, GK 100) in the east. These red biomicritic limestone lenses often have been treated as Jurassic Hierlatzkalk but contain *Misikella*-dominated conodont faunas and are therefore of Triassic age. The presence of *M. rhaetica* (Fig. 4-13, 14) in some of the samples and the close neighborhood to Zlambachmergel points to a corresponding middle Rhaetian age as in the Gosaukamm cover.

The Zlambachmergel of the Langtal S of Brettkogel are here interpreted in analogy to the Gosaukamm sequence (localities Donnerkogel: Schlager, 1967:60 and pl. 3; Schneckengraben: Tollmann and Kristan-Tollmann, 1970:97) as the upper Rhaetian (Hillebrandt, written comm.) normal stratigraphic cover of the Dachsteinriffkalk, witnessing that growth of the Dachstein reefs terminated well before the end of the Triassic. The presently limited occurrence of Zlambachmergel NE and E of the Gosausee is explained by widespread erosion due to the soft sediment character. Except for the Koglgassenalm occurrence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(Schlager 1966, p. 102), preservation has been restricted to tectonic slivers in the Langtal fault zone (Fig. 1).

4. Sedimentary Evolution of the Dachstein Platform Margin

An early Lacian onset of reef growth is indicated by the ages obtained from the oldest parts of the margin facies in the Dachstein area. This fits well with data from the Tennengebirge (Krystyn, 1985), the Gesäuse (Dullo, 1980) and, beyond the NCA, from the Muran plateau in the Western Carpathians (Krystyn et al., 1990) and the Triglav, Slovenia (Schlaf, 1999).

Progradation of this early platform margin comes to a halt in the Gosaukamm in the late Lacian when the margin is draped by a thin pelagic cover (*Pl 1*). The subsequent return to slope facies suggests a stable margin during the Alaunian along a more or less aggrading platform. Slow progradation may be indicated in the Sevatian of both the southwestern Gosaukamm and the Gosausee margin (Lacke section) by increasing carbonate debris input into the proximal basin. Margin progradation accelerates in early Rhaetian time both in the Gosaukamm and north of Gosausee where the laterally most expanded margin area spreads over the proximal basin (Fig. 1, 2). The middle Rhaetian Donnerkogelkalk phase (*Pl 5*) marks the drowning of the Dachsteinriffkalk and the end of the Dachstein reef building not only in the type area but also in other parts of the NCA, at the Hochkönig (Heissel, 1953; Schauer, unpubl. data), the Jenner (Krystyn, unpubl.data) and Hohe Göll (Zankl, 1969; Braun, 1998) in Berchtesgaden, and the Tonion (Schauer, unpubl. data) in Styria. The event is also recorded on top of the Dachsteinriffkalk in the Drnava (=Pleskovy Pramen) locality of the Western Carpathians where criniod limestones rich in shelly fauna contain ammonoids of the *Vandaites stuerzenbaumi* ammonoid Zone (Kollarova-Andrusovova and Kochanova, 1973).

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Figure 5: Thin sections of pelagic intercalations in the Dachsteinriffkalk (1-4) and Donnerkogelkalk (5-8).
1: Sample 89/08, *Feisterscharte*; grey Halobiid-biomicrite/-sparite.
2: Sample GK 62, *Pl 1*; red wackestone with abundant filaments.
3: Sample GK 51, *Pl 2*; red wackestone with Halobiids.
4: Sample GK 161; light red bioclastic pack- to wackestone.
5: Sample GK 169, *Pl 5*; light red wackestone with echinoderms and spiculae.
6: Sample GK 49, *Pl 5*; red bioturbated mudstone.
7: Sample GK 02, *Pl 5*; red bioclastic wackestone with echinoderms.
8: Sample GK 02, *Pl 5*; contact between grey bioclastic grainstone (reef debris) and red bioclastic wackestone.

References

Bittner, A., 1884. Aus den Salzburger Kalkhochgebirgen – Zur Stellung der Hallstätter Kalke. Verhandlungen der Geologischen Reichsanstalt, 1884, 99-113.

Braun, R., 1998. Die Geologie des Hohen Göll. Forschungsberichte Nationalpark Berchtesgaden, 40, 192 pp.

Dullo, W.-C., 1980. Paläontologie, Fazies und Geochemie der Dachstein-Kalke (Ober-Trias) im südwestlichen Gesäuse, Steiermark, Österreich. Fazies, 2, 55-122.

Enos, P. and Samankassou, E.,1998. Lofer Cyclothems Revisited (Late Triassic, Northern Calcareous Alps). Facies, 38, 207-228.

Faupl, P. and Wagreich, M., 2000. Late Jurassic to Eocene Palaeogeography and Geodynamic Evolution of the Eastern Alps. Mitteilungen der Österreichischen Geologischen Gesellschaft, 92 (1999), 79-94.

Fischer, A. G., 1964. The Lofer Cyclothems of the Alpine Triassic. Kansas State Geological Survey Bulletin, 169, 107-149.

Flügel, E., 1962. Untersuchungen im obertriadische Riff des Gosaukammes (Dachsteingebiet, Oberösterreich), III. Zur Mikrofazies der Zlambach-Schichten am W-Ende des Gosaukammes. Verhandlungen der Geologischen Bundesanstalt, 1962/1, 138-146.

Flügel, E., 1963. Zur Geologie der Sauwand bei Gußwerk (Steiermark). Mitteilungen des naturwissenschaftlichen Vereins Steiermark, 93, 64-105.

Flügel, E., 1981. Paleoecology and facies of Upper Triassic Reefs in the Northern Calcareous Alps. In: Toomey, D. F. (ed.), European Fossil Reef Models. Society of Economic Paleontologists and Mineralogists, Special Publication, 30, 291-359.

Flügel, E., 1982. Evolution of Triassic Reefs: Current Concepts and Problems. Facies, 6, 197-328.

Flügel, E. and Bernecker, M., 1996. Upper Triassic Reefs of the Southern Tethyan Margin (Oman). In: Reitner, J., Neuweiler, F. and Gunkel, F. (eds.) Global and Regional Controls on Biogenic Sedimentation. I. Reef Evolution. Research Reports. Göttinger Arbeiten zur Geologie und Paläontologie, Sdb.2, 273-277.

Flügel, E., Kiessling, W. and Golonka, J., 1996 a. Phanerozoic Reef Patterns: Data Survey, Distribution Maps and Interpretation. In: Reitner, J., Neuweiler, F. and Gunkel, F. (eds.) Global and Regional Controls on Biogenic Sedimentation. I. Reef Evolution. Research Reports.- Göttinger Arbeiten zur Geologie und Paläontologie, Sdb.2, 391-396.

Flügel, E. and Senowbari-Daryan, B., 1996 b. Evolution of Triassic Reef Biota: State of the Art. In: Reitner, J., Neuweiler, F. and Gunkel, F. (eds.) Global and Regional Controls on Biogenic Sedimentation. I. Reef Evolution. Research Reports. Göttinger Arbeiten zur Geologie und Paläontologie, Sdb.2, 285-294.

Frisch, W. and Gawlick, H.-J., 2003. The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion – a contribution to understanding the orogenic evolution of the Eastern Alps. International Journal of Earth Sciences (Geol. Rundschau), 92, 717-727.

Haas, J., Kovacs, S., Krystyn, L. and Lein, R., 1995. Significance of Late Permian - Triassic facies zones in terrane reconstruction in the Alpine - North Pannonian domain. Tectonophysics, 242, 19-40.

Haas, J., Lobitzer, H. and Monostori, M., 2007. Characteristics of the Lofer cyclicity in the type locality of the Dachstein Limestone (Dachsteinplateau, Austria). Facies, 53, 113-126.

Heissel, W., 1953. Zur Stratigraphie und Tektonik des Hochkönig (Salzburg). Jahrbuch der Geologischen Bundesanstalt, 96, 344-356.

Kenter, J.A.M. and Schlager, W., 2009. Slope angle and basin depth of the Triassic platform-basin transition at the Gosaukamm, Austria. Austrian Journal of Earth Sciences, 102/1, 15-22.

Kittl, E., 1916. Halorellenkalke vom Vorderen Gosausee. Annalen des Naturhistorischen Hofmuseum Wien, 30, 51-54.

Kollarova-Andrusovova,V. and Kochanova, M., 1973. Molluskenfauna des Bleskovy Pramen bei Drnava (Nor, Westkarpaten). Slovakische Akademie der Wissenschaften, Bratislava, 234 p.

Krystyn, L., 1972. Conodonten im Dachstein-Riffkalk (Nor) des Gosaukammes (Salzburg). Anzeiger der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, 1972, 51-54.

Krystyn, L., 1980. Triassic Conodont Localities of the Salzkammergut Region. Abhandlungen der Geologischen Bundesanstalt, 35, 61-98.

Krystyn, L., 1982. Obertriassische Ammonoideen aus dem Zentralnepalesischen Himalaya (Gebiet von Jomson). Abhandlungen der Geologischen Bundesanstalt, 36, 63 pp.

Krystyn, L., 1985. Bericht 1984 über geologische Aufnahmen in den Kalkalpen auf Blatt 94 Hallein. Jahrbuch der Geologischen Bundesanstalt, 128/2, 263-264.

Krystyn, L., 1987. Zur Rhät-Stratigraphie in den Zlambach-Schichten (vorläufiger Bericht). Österr. Sitzungsberichte der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, Abt. 1, 196/3, 21-36.

Krystyn, L., Gallet, Y., Besse, J. and Marcoux, J., 2002. Integrated Upper Carnian to Lower Norian biochronology and implications for the Upper Triassic magnetic polarity time scale. Earth and Planetary Science Letters, 203, 343-351.

Krystyn, L., Lein, R., Riedel, J. and Piller, W., 1990. „Tisovec Limestone“ – an example of the problems of lithostratigraphic correlation between the Northern Calcareous Alps and the Central West Carpathians. In: Minarikova, D. and Lobitzer, H. (eds.): Thirty Years of Geological Cooperation between Austria and Czechoslovakia, Festive Volume, 125-136.

Krystyn, L., Richoz, S., Gallet, Y., Bouquerel, H., Kürschner, W.M. and Spötl, Ch., 2007 a. Updated bio- and magnetostratigraphy from Steinbergkogel (Austria), candidate GSSP for the base of the Rhaetian stage. Albertiana, 36, 164-173.

Krystyn, L., Bouquerel, H., Kürschner, W.M., Richoz, S. and Gallet, Y., 2007 b. Proposal for a candidate GSSP for the base of the Rhaetian stage. Museum of Natural History and Science, Bulletin, 41, 189-199.

Mandl, G. W., 1984. Zur Tektonik der westlichen Dachsteindecke und ihres Hallstätter Rahmens (Nördliche Kalkalpen, Österreich). Mitteilungen der Österreichischen Geologischen Gesellschaft, 77, 1-31.

Mandl, G.W., 2000. The Alpine sector of the Tethyan shelf - Examples of Triassic to Jurassic sedimentation and deformation from the Northern Calcareous Alps. Mitteilungen der Österreichischen Geologischen Gesellschaft, 92(1999), 61-78.

Mandl, G. W., 2001. Geologie der Dachsteinregion. Archiv für Lagerstättenforschung, 21, 13-37.

Mojsisovics, E.; 1886. Über den chronologischen Umfang des Dachsteinkalkes. Sitzungsberichte der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, Abt. I, 5-40.

Orchard, M.J. and Tozer, E.T., 1997. Triassic conodont biochronology, its calibration with the ammonoid standard, and a biostratigraphic summary for the Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology, 45, 675-592.

Reijmer, J.J.G. and Everaars, J.S.L., 1991. Carbonate platform facies reflected in carbonate basin facies (Triassic, Northern Calcareous Alps, Austria). Facies, 25, 253-278.

Reijmer, J.J.G., Sprenger, A., Ten Kate, W.G.H.Z., Schlager, W. and Krystyn, L., 1994. Periodicities in composition of Late Triassic calciturbidites (Eastern Alps, Austria). Special Publications International Association Sedimentologists, 19, 323-343.

Roniewicz, E. ,1989. Triassic Sceractinian Corals of the Zlambach Beds, Northern Calcareous Alps, Austria. Denkschriften der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, 126, 152 pp.

Roniewicz, E., 1995. Upper Triassic Solitary Corals from the Gosaukamm and other North Alpine Regions. Sitzungsberichte der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, Abt. 1, 202 (1995), 3-41.

Roniewicz, E., Mandl G. W., Ebli, O. and Lobitzer, H., 2007. Early Norian Scleractinian Corals of the Dachstein Limestone of Feisterscharte, Southern Dachstein Plateau (Northern Calcareous Alps, Austria). Jahrbuch der Geologischen Bundesanstalt, 147, 577-594.

Satterley, A. K., 1994. Sedimentology of the Upper Triassic Reef Complex at the Hochkönig Massif. Facies, 30, 119-150.

Schauer, M., 1984. Zur Altersstellung obertriadischer Dachsteinriffkalke. Anzeiger der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, 120(1983), 127-137.

Schauer, M., 2002. Stratigraphie und Fazies des Riffkalkes des Gosaukammes sowie angrenzender Beckensedimente und deren paläogeographische Interpretation. PhD Thesis, University Vienna, Vienna, 361 pp.

Schlaf, J., 1999. Muschelschille auf einem obertriadischen Vorriffhang (Julische Alpen, Slowenien) und ihre fazielle Aussagekraft. Geologisch Paläontologische Mitteilungen Innsbruck, 24, 79-98.

Schlager, W., 1966. Fazies und Tektonik am Westrand der Dachsteinmasse. I. Zlambachschichten beim Hinteren Gosausee (Oberösterreich). Verhandlungen der Geologischen Bundesanstalt, 1966, 93-106.

Schlager, W., 1967. Fazies und Tektonik am Westrand der Dachsteinmasse (Österreich) II. Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten Wien, 17 (1966), 205-282.

Spengler, E., 1914. Untersuchungen über die tektonische Stellung der Gosauschichten II. Das Becken von Gosau. Sitzungsberichte der Österreichischen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, Abt.I, 123, 267-328.

Schwarzacher, W., 2005. The stratification and cyclity of the Dachstein Limestone in Lofer, Leogang and Steinernes Meer (Northern Calcareous Alps, Austria). Sedimentary Geology, 181, 93-106.

Tollmann, A., 1976 a. Monographie der Nördlichen Kalkalpen, Teil II: Analyse des klassischen Nordalpinen Mesozoikums. Stratigraphie, Fauna und Fazies der Nördlichen Kalkalpen. Wien (Deuticke), 580 pp.

Tollmann, A., 1976 b. Monographie der Nördlichen Kalkalpen, Teil III: Der Bau der Nördlichen Kalkalpen. Orogene Stellung und regionale Tektonik. Wien (Deuticke), 457pp.

Tollmann, A., 1985. Geologie von Österreich, Bd. II: Außerzentralalpiner Anteil. Wien (Deuticke), 710pp.

Tollmann, A. and Kristan-Tollmann, E., 1970. Geologische und mikropaläontologische Untersuchungen im Westabschnitt der Hallstätter Zone in den Ostalpen. Geologica et Palaentologica, 4, 87-145.

Tollmann, A., 1987. Late Jurassic/Neocomian Gravitational Tectonics in the Northern Calcareous Alps in Austria. In: H.W. Flügel and P. Faupl (eds.), Geodynamics of the Eastern Alps, 112-125, Wien (Deuticke).

Wurm, D., 1982. Mikrofazies, Paläontologie und Palökologie der Dachsteinriffkalke (Nor) des Gosaukammes, Österreich. Facies, 6, 203-296.

Zapfe, H., 1960. Untersuchungen im obertriadischen Riff des Gosaukammes (Dachsteingebiet, Oberösterreich). I. Beobachtungen über das Verhältnis der Zlambach-Schichten zu den Riffkalken im Bereich des Großen Donnerkogels. Verhandlungen der Geologischen Bundesanstalt, 1960, 236-241.

Zapfe, H., 1967. Untersuchungen im obertriadischen Riff des Gosaukammes (Dachsteingebiet, Oberösterreich). VIII. Fragen und Befunde von allgemeiner Bedeutung für die Biostratigraphie der alpinen Obertrias. Verhandlungen der Geologischen Bundesanstalt, 1967, 13-27.

Zapfe, H., 1973. Mesozoikum in Österreich. Überblick über die stratigraphische Forschung 1963-1972. Mitteilungen der Geologischen Gesellschaft in Wien, 65 (1972), 171 – 218.

Zankl, H., 1969. Der Hohe Göll. Aufbau und Lebensbild eines Dachsteinkalk-Riffes in der Obertrias der nördlichen Kalkalpen. Abhandlungen der Senckenberger naturforschenden Gesellschaft, 519, 1-123.

Zankl, H., 1971. Upper Triassic Carbonate Facies in the Northern Limestone Alps. In: Müller, G. (ed.): Sedimentology of Parts of Central Europe, Guidebook, 147-185.

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