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Resedimented Upper Paleocene shallow-water clasts (Kambühel Formation) in the Zwieselalm Formation of the Weitenau area and their tectonic implications (Northern Calcareous Alps, Austria)

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Abstract

Upper Paleocene (Thanetian) carbonate arenites are for the first time described from the Weitenau area in the central Salzburg Calcareous Alps. Their occurrence north of the Lammer Basin fill sheds new light on the tectonic evolution of the Northern Calcareous Alps in Palaeogene to Neogene times. According to our findings, northward thrusting of the Lammer unit seems to be related to the Eocene orogenic phase of the Northern Calcareous Alps. It can be separated from northeastward thrusting during the Miocene lateral extrusion stage. An Early Cretaceous age of thrusting must be refused. Resedimented bioclastic material of the Kambühel Formation is rarely preserved in the Northern Calcareous Alps. Thus the newly-discovered is of great relevance. Exact biostratigraphic dating alongside component analysis of these resediments allow a better palaeogeographic-tectonic reconstruction of the investigated area.

Durch die erstmalige Beschreibung von oberpaleozänen (Thanetium) Karbonatareniten aus der nördlich der Lammer-Beckenfüllung gelegenen Weitenau (zentrale Salzburger Kalkalpen) können die tektonischen Prozesse im Paläogen und Neogen der Nördlichen Kalkalpen besser interpretiert werden. Die Überschiebung der Lammer-Einheit nach Norden über die Weitenau steht demnach im Zusammenhang mit der eozänen Gebirgsbildungsphase und nicht mit nordostgerichteten Überschiebungen im Zuge der miozänen lateralen Extrusion. Ein frühkretazisches Überschiebungalter kann durch die neu gewonnenen Daten ebenfalls ausgeschlossen werden. Da resedimentierte Flachwasser-Bioklasten der Kambühel-Formation in den Nördlichen Kalkalpen sehr selten sind, ist das neu nachgewiesene Vorkommen der Weitenau von großer Bedeutung. Deren mikrofazielle und biostratigraphische Untersuchung erlaubt ein besseres Verständnis sowohl der Sedimentationsbedingungen als auch der paläogeographisch-tektonischen Situation der Nördlichen Kalkalpen im Paleozän.

1. Introduction

The Weitenau area is situated in the central Northern Calcareous Alps north of the Lammer valley, between the township Golling and the village Voglau (Figs 1A, 1B).

The study area north of Mount Gollinger Schwarzenberg is located in the southern part of the “Weitenau syncline” (Plöchinger, 1953). The geology is made up of Upper Jurassic to Lower Cretaceous rocks with gypsum of the Alpine Haselgebirge incorporated (e.g., Plöchinger, 1968, 1987, 1990). According to Decker et al. (1994), the Gollinger Schwarzenberg complex was slightly thrusted northeastward over the “Weitenau syncline” in the framework of the Miocene lateral extrusion processes. Decker et al. (1994) reported also older structures in connection with northward directed thrusting, the exact age which could not be constrained though. Schweigl and Neubauer (1997) and Neubauer et al. (2010) interpreted the northward thrusting of the Gollinger Schwarzenberg complex in the context of Early Cretaceous orogenic processes (compare Gawlick et al., 1990). The model of Schorn and Neubauer (2011) is a modification of the model of Schweigl and Neubauer (1997). It suggests the emplacement of Mount Gollinger Schwarzenberg to be the result of a two-phase process: the detachment and consecutive WNW-directed stacking event in the Early Cretaceous, generating the general structural built of the Northern Calcareous Alps, and smaller-scale northerly movement supposedly sometime in the Oligocene to Middle Miocene with the Schwarzenberg massif forming the frontal edge of the Göll-Lammer thrust mass. In contrast, Frisch and Gawlick (2003) and Missoni and Gawlick (2011) interpreted these thrust movements as features of the Palaeogene orogenesis. Today’s nappe configuration of the Northern Calcareous Alps was intensly formed by these northward thrust and southward backthrust movements. The time of these thrust movements is well constrained at the northern edge of the Dachstein and Berchtesgaden nappes (Frisch and Gawlick, 2003; Missoni and Gawlick, 2011), where Upper Cretaceous to Palaeogene sediments of the Gosau Group both rest on top and are overthrusted by these nappes.

The youngest deposits of the Gosau Group in the investigated area (Zwieselalm Formation) consist of marly sediments with intercalated calcarenitic breccia beds as well as litho-

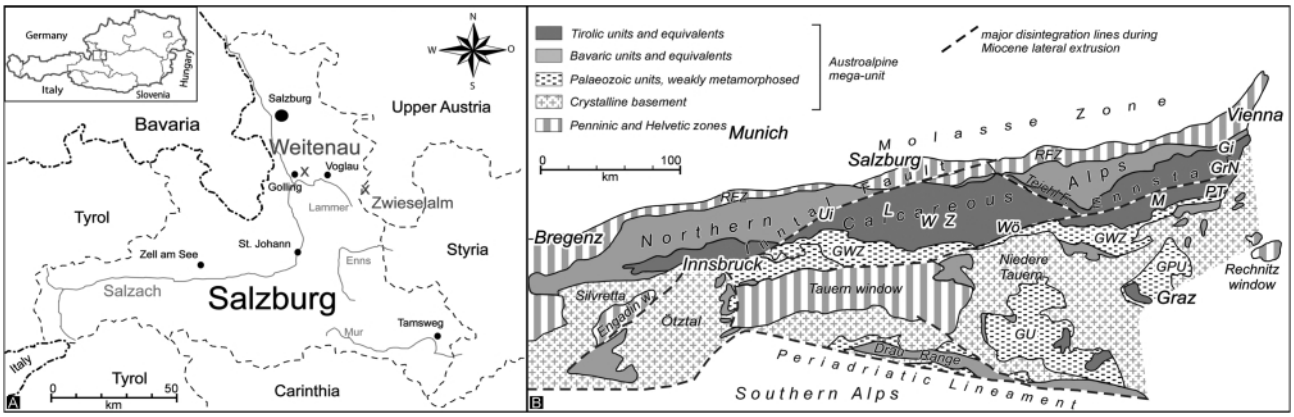


Figure 1: A: Geographic overview and location of the investigated area. B: Main geotectonic elements of the Eastern Alps (modified after Frisch and Gawlick 2003). GPU-Graz Palaeozoic unit, GU-Gurktal unit, GWZ-Greywacke zone. Gi-Gießhübl, GrN-Grünbach Neue Welt, L-Lattengebirge, M-Mürzalpen, PT-Prigglitz Ternitz, Ui-Unterinntal, W-Weitenau, Wö-Wörschach, Z-Zwieselalm.

clastic-rich sandstones (Wille, 1964; Wille-Janoschek, 1966). They are of Maastrichtian to Eocene age (e.g., Wagreich and Decker, 2001). These occurrences were affected by Miocene strike-slip tectonics as proven on the western side of the Dachstein Block (e.g., Decker and Jarnik, 1992; Jarnik, 1994). Therefore, in the area around the western and northern Dachstein nappe, the polyphase tectonic overprint of the Gosau Group is well proven. For the Weitenau area of the Northern Calcareous Alps no direct proof of Gosau Group deposits existed until now. Due to this lack of young strata, the age of the northward thrusting of the Gollinger Schwarzenberg complex and its equivalents was only loosely constrained.

Investigations on an outcrop close to Berggasthof Bachrainer, northwest of Mount Gollinger Schwarzenberg, resulted in the detection of Gosau Group rocks with a shallow-water fossils association indicating a Late Paleocene (Thanetian) age.

Outcrops of such Thanetian carbonate arenites with redeposited shallow-water material are scarce both in the surrounding and the complete Northern Calcareous Alps (for locations, see Fig. 1A). Some kilometers to the east, around the type locality of Gosau, hemipelagic marly rocks of the Gosau Group (Zwieselalm Formation) occur (Plöchinger, 1982). According to Kollmann and Summesberger (1982), near the Liesenhütte of the Zwieselalm area (Fig. 1A), resediments (calcarenites) of shallow-water bioclasts of the Kambühel Formation (Tollmann, 1976) are exposed. The shallow-water material and the underlying marly rocks at this locality were studied by Schlagintweit et al. (2003). Resedimented shallow-water biota in turbiditic sandstones were also reported by Krenmayr (1999) from the Nierental Formation in the Lattengebirge (Berchtesgaden Northern Calcareous Alps). More to the west, in the Unterinntal, the Upper Oligocene conglomerates of the Oberangerberg Formation contain Paleocene shallow-water clasts as well (Moussavian, 1984). Pober

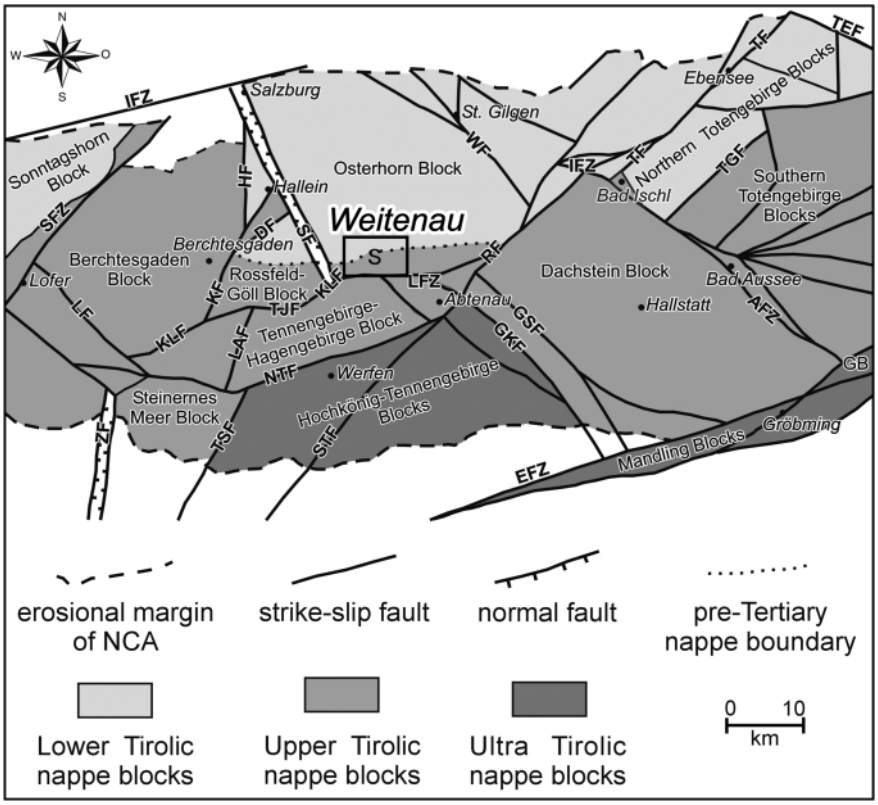


Figure 2: Recent block configuration of the central Northern Calcareous Alps and location of the investigated area (modified after Frisch and Gawlick, 2003). Major Miocene faults (F) and fault zones (FZ) are indicated: AFZ-Aussee, DF-Dürrnberg, EFZ-Ennstal, GKF-Gosaukamm, GSF-Gosausee, HF-Hellbrunn, IFZ-Bad Ischl, IFZ-Inntal, KF-Königssee, KLF-Königssee-Lammertal, LAF-Landtal, LFZ-Lammertal, LF-Lofer, NTF-Northern Tennengebirge, RF-Rigaus, SF-Untersalzachtal, SFZ-Saalachtal, STF-Southern Tennengebirge, TEF-Teichl, TF-Traunsee, TGF-Totengebirge, TJF-Torrener Joch, TSF-Torscharten, WF-Wolfgangsee, ZF-Zeller See. S: Schwarzer Berg.

(1984) described resedimented shallow-water material of Paleocene age from the Gosau Group of Wörschach. Moreover, Paleocene reefal pebbles are frequent components in deep-water Gosau Group formations of the Mürztal Alps as investigated by Lein (1982). From the southeastern Northern Calcareous Alps, Plöchinger (1967) described these shallow-water biota from a whitish Paleocene reefal limestone at the Kambühel (Kammbühel) north of the village Ternitz. Another locality north of Prigglitz (Tollmann, 1976) resembles the Kambühel type locality. A modern description of Paleocene reefal limestones of the Northern Calcareous Alps was made by Tragelehn (1996) who investigated the type locality of the Kambühel Formation and other occurrences. Resedimented shallow-water bioclasts in Paleocene marls are well known from the localities of Grünbach, Neue Welt and Gießhübl (Plöchinger, 1956, 1961, 1967) in Lower Austria.

The aim of this paper is to describe the new findings of Thanetian coarse-grained carbonate arenites in the central Salzburg Calcareous Alps. Identification, description and biostratigraphic dating of these rocks and the documentation and analysis of their regional occurrences help to reconstruct the Palaeogene palaeogeography of the Northern Calcareous Alps. Additionally, their occurrences help to solve regional tectonic problems.

2. Geological setting

The hilly mountain range of the Weitenau area is commonly interpreted as a Late Jurassic to Early Cretaceous Tirolic (Lower Tirolic unit in the sense of Frisch and Gawlick, 2003) sedimentary basin fill, today preserved in the so called "Weitenau syncline" (Plöchinger, 1953, 1990; Neubauer et al., 2010; Schorn, 2010; Schorn and Neubauer, 2011). Our investigations show that the Weitenau area is a complex puzzle of mountain-sized blocks of different palaeogeographic origin (Krische et al., 2011). The sedimentary succession of the Gosau Group seals the mid-Cretaceous tectonic event in the entire Northern Calcareous Alps (e.g., Faupl and Wagreich, 2000; Wagreich and Decker, 2001). Three units, which border against each other along polyphase faults with different ages of activity and movement directions, make up the area around Berggasthof Bachrainer.

The western outcrop area (Fig. 3) exposes blackish to grey cherty limestones with chert nodules. These rocks were described by Plöchinger (1977) as cherty, sandy limestones (Hochreith Limestone) of the Rossfeld Formation. The alleged sandy part of the rocks, however, does not contain detrital quartz grains but is composed of radiolarians and sponge spicula as seen in thin sections (own data). An Early Cretaceous age is proven by radiolarians (own data). In the middle part, the Alpine Haselgebirge Mélange (Spötl, 1989) with evaporites (gypsum) and clay is exposed. Upper Jurassic hemipelagic whitish to grey limestones (*Saccocoma* Limestone) with resedimented shallow-water material of the Plassen Carbonate Platform (Barmstein Limestone) (e.g., Gawlick et al., 2009) on top, rest with original, albeit slightly tectonically overprinted, sedimentary contact on top of the Alpine Haselgebirge Mélange. Separated by a fault, blackish to brown cherty limestones, marls and conglomerates of the Valanginian to Lower Aptian Rossfeld Formation (Plöchinger, 1968, 1990) outcrop around the weekend cottage Bachbauer.

Following Missoni and Gawlick (2011), we interpret that the Alpine Haselgebirge Mélange with its Plassen Carbonate Platform resediments cover is part of a block which was palaeogeographically situated south of or below the Kimmeridgian to Early Tithonian Plassen Carbonate Platform, respectively. In the Weitenau area, the north-directed final emplacement of the Haselgebirge Mélange including parts of the Plassen Carbonate Platform occurred in the Late Tithonian, before deposition of the Rossfeld basin succession commenced.

Close to the cherty limestones and the Alpine Haselgebirge Mélange, the Paleocene rocks are exposed (Fig. 3). Only a few platy arenitic blocks witness the presence of Gosau Group rocks. These blocks with maximal footprints of about 50 x 30 cm were found within brown soil which is the residue of highly weathered, degraded marl. Macroscopically, they can be described as 10 to 20 cm bedded, slightly silicified carbonate arenites with a brownish weathered surface colour (Figs 4A, 4B).

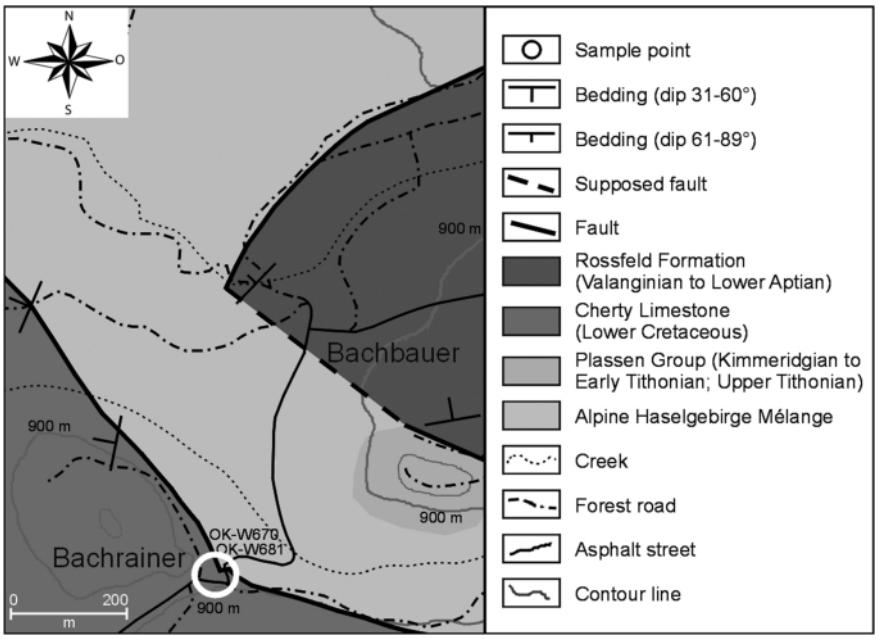


Figure 3: Detailed map of the investigated area between Bachrainer and Bachbauer with the sample location indicated. Quarternary is not shown. Polyphase faults and supposed faults border the different formations.

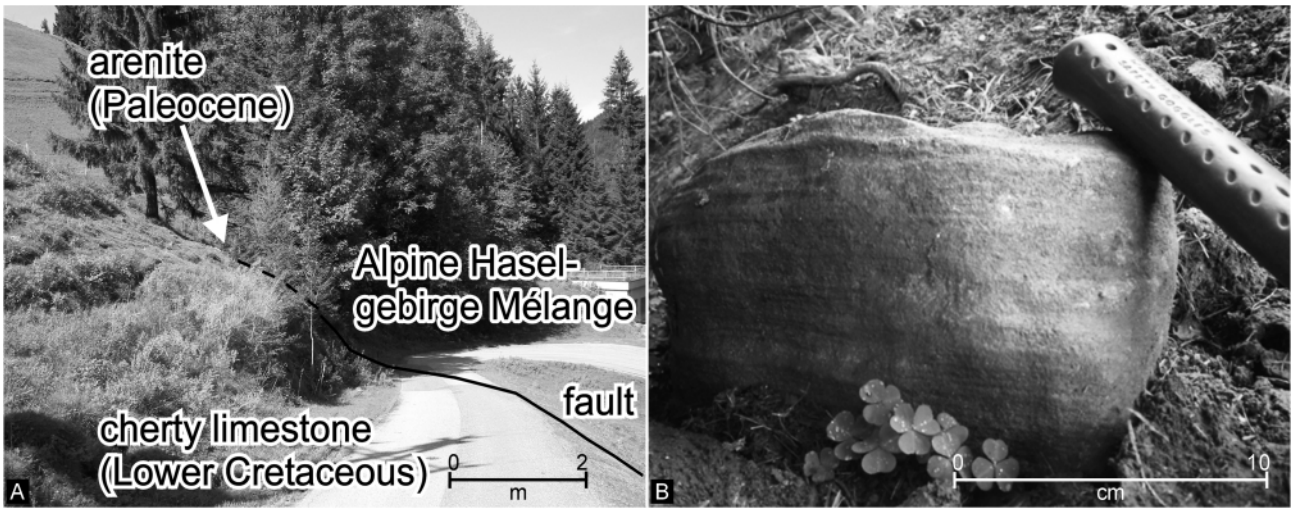


Figure 4: A: Geological situation along the road east of Berggasthof Bachrainer. B: Typical calcarenitic rock as typically found at the outcrop. The moderately weathered, subangular sample was digged out from highly weathered marly country rocks almost completely degraded to soil.

3. Results

3.1 Microfacies

Samples for thin section investigations were taken from the arenitic rocks near Berggasthof Bachrainer. The bulk of the unsorted, angular to rounded, mixed carbonatic and siliciclastic grains are sized between 0.1 and 1 mm. Grains up to 2 mm are common but only very few grains are bigger than 2 mm. Two different microfacies types are present:

Microfacies-1 (Fig. 5): This microfacies is dominated by densely-packed bioclasts (Fig. 5A) with larger benthic foraminifera (*Discocyclina* sp., *Ranikothalia* sp.) (Figs 5B, 5C), red algae, e.g., *Lithophyllum* sp., *Distichoplax biserialis* (Dietrich) (Fig. 5D), *Polystrata alba* (Pfender) (Fig. 5E), planktonic foraminifera (Globigerinidae, Globotruncanidae), arenaceous textulariids, calcareous lenticulinids and rotaliids (Fig. 5F), remnants of framework building organisms, crustaceans (*Carpathocancer* sp.), bryozoans and echinoderms. The amount of the siliciclastic fraction with angular to subangular quartz, weathered brown clay-rich lithoclasts (probably soil remnants) and green rounded glauconite is less than 5 %. Plant fragments occur subordinated. The presence of a clayey to marly matrix with some fine grained silt components is restricted to some small lenses.

Microfacies-2 (Fig. 6): This microfacies type can also be described as packstone (in parts rudstone) with larger-sized litho- and bioclasts and distinctly less dense packing as Microfacies-1. Large wackestone clasts with globigerinids occur. Their Paleocene age is evidenced by some scattered reworked bioclasts of the solenoporacean alga *Parachaetetes asvapatii* Pia (Figs 6A, 6F). Other constituents are dense, grey, micritic lithoclasts, angular to subangular quartz (up to 20 %) and bioclasts like bryozoans, crustacean remains (*Carpathocancer* sp., Fig. 6B), echinoderm fragments (partly bored), agglutinating foraminifera, miliolids, lenticulinids and, more common, *Pseudocuvillierina* cf. *sireli* (Inan) (Figs 6C, 6E) or *Miscellanea* sp. (Fig. 6D), the solenoporacean alga *Parachaetetes asvapatii* Pia and corallinaceans (Fig. 6G). Rare debris of dasycladacean algae, e.g., *Jodotella veslensis* (Morellet and Morellet), is also present (Fig. 6H). Rock fragments are very scarce (less than 5 %) and include greenish phyllites, dark, laminated claystones with fine grained quartz, angular quartz siltstones with chlorite and subangular, orange to whitish, recrystallized radiolarites. The pore space between the litho- and bioclasts is filled with fine grained, grey calcareous silt and blocky calcite cement. Glauconitisation of different bioclasts and micritic clasts can also be noticed.

Compared to the Microfacies-1, the siliciclastic fraction in Microfacies-2 is much higher whilst the amount of bioclasts is lower in favour of higher amounts of planktonic foraminifera. Also the percentage of marly wackestone pebbles is increased. Among the bioclasts, the absence of discocyclinids and Late Cretaceous globotruncanids (Fig. 7) as well as the common occurrence of *Parachaetetes asvapatii* Pia and *Miscellanea* sp. furthermore distinguish both microfacies types.

3.2 Biostratigraphy

The well preserved redeposited shallow-water organisms, namely benthic foraminifera and calcareous algae, permit a rather precise age determination of the arenitic rocks from the Weitenau area. The solenoporacean alga *Parachaetetes asvapatii* Pia was for a long time considered to occur only in the Thanetian (Moussavian, 1984, 1989), but in fact has a much wider age range. For example, it has been recorded from Danian to Ypresian strata (Aguirre and Barattolo, 2001). *Distichoplax biserialis* (Dietrich) ranges from Thanetian to Early Lutetian (Moussavian, 1984). *Pseudocuvillierina sireli* (Inan) is known from the Late Paleocene (Thanetian) to the Early Eocene (Cuisian) (Inan, 1988; Sirel et al., 1986; Babazadeh, 2005). Perhaps starting already in the Danian, the dasycladale *Jodotella veslensis* (Morellet and Morellet) is known particularly from the Thanetian (Deloffre and Granier, 1992).

This microfossil association constrains a Thanetian age of the sample rock.

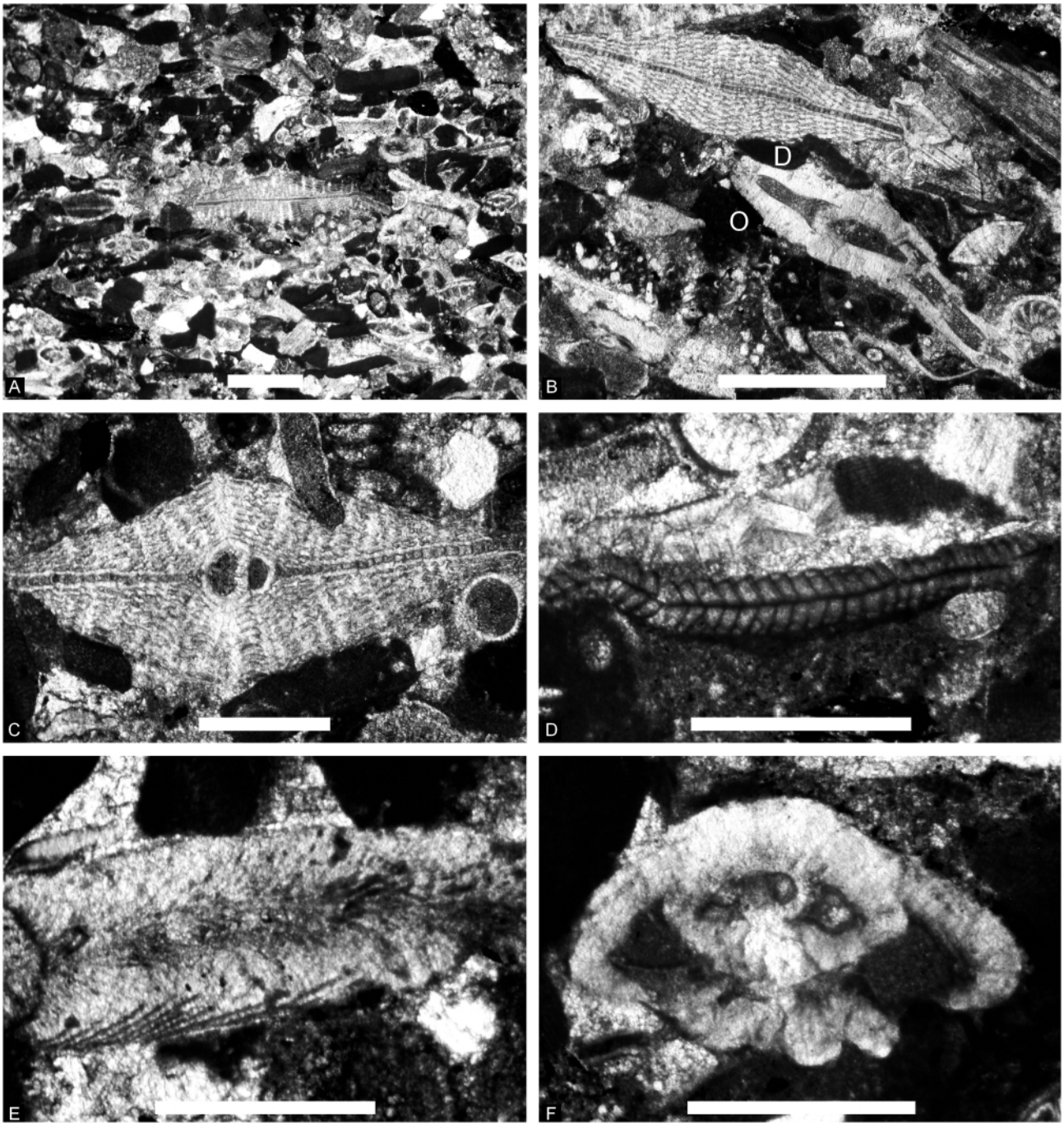
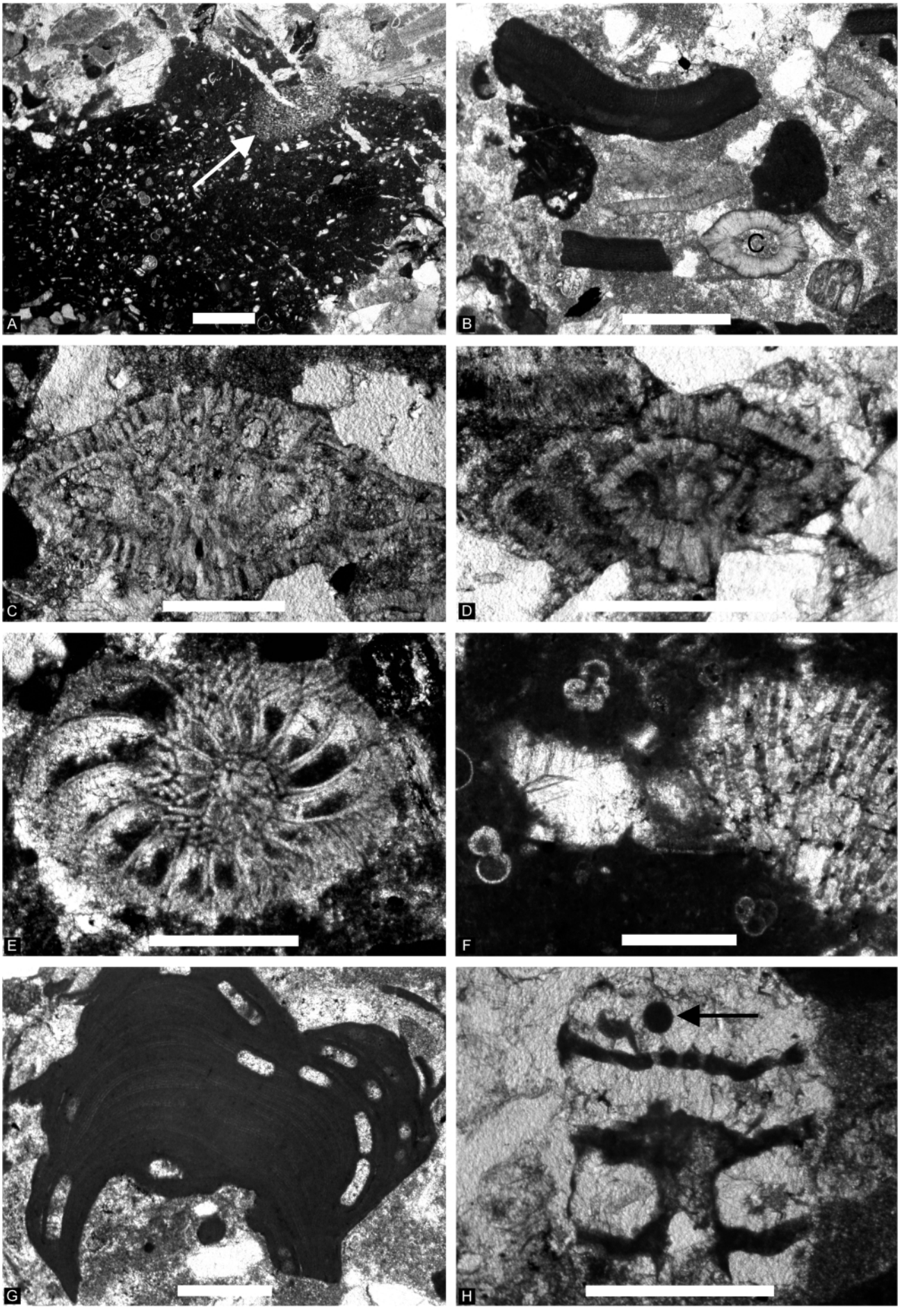


Figure 5: Microfacies-1 (sample OK-W670). A: Packstone with closely packed bioclasts (mainly foraminifera, red algae) and lithoclasts. Note the almost complete lack of matrix. B: Closely packed foraminifera, including small calcareous forms and large *Discocyclina* sp. (D) and *Operculina* sp. (O). C: *Discocyclina* sp. with embryonic chambers. D: Monotypic red alga *Distichoplax biserialis* (Dietrich). E: Peysonelliacean red alga *Polystrata alba* (Pfender). F: Rotaliid foraminifer (*Rotalia/Pararotalia*). Scale bars: 1 mm for A-B, 0.5 mm for C-F.

4. Discussion

The investigated mixed carbonatic-siliciclastic arenites from the Weitenau area shed some light on the sedimentological and palaeogeographical evolution of the central part of the Northern Calcareous Alps in the Salzburg area. The resedimented shallow-water bio- and lithoclasts from the southern Weitenau area are similar to those described by Moussavian (1984), Krenmayr (1999) and Schlagintweit et al. (2003). The siliciclastic components coincide with the clast spectra described from other lithoclastic sandstones of the same age (Plöchinger, 1961, 1963, 1967; Janoschek, 1963; Wille, 1964; Tollmann, 1976; Faupl et al., 1987; Jarnik, 1994). The occurrence of sedimentary and

Figure 6: Microfacies-2 (sample OK-W681). A: Large clast of a wackestone with abundant globigerinids and a fragment of *Parachaetetes asvapatii* Pia (arrow). B: Loosely dispersed bioclasts, including debris of bryozoans, crustaceans (*Carpathocancer* sp., C) and red algae. C, E: *Pseudocuvillierina* cf. *sireli* (Inan) in axial (C) and equatorial-oblique (E) section. D: *Miscellanea* sp., axial section. F: Wackestone clast with globigerinids and fragment of *Parachaetetes asvapatii* Pia. G: Corallinacean alga *Lithothamnium* sp.. H: Dasycladalean alga *Jodotella veslensis* (Morellet and Morellet). Scale bars: 1 mm for A, B. 0.5 mm for C-H.



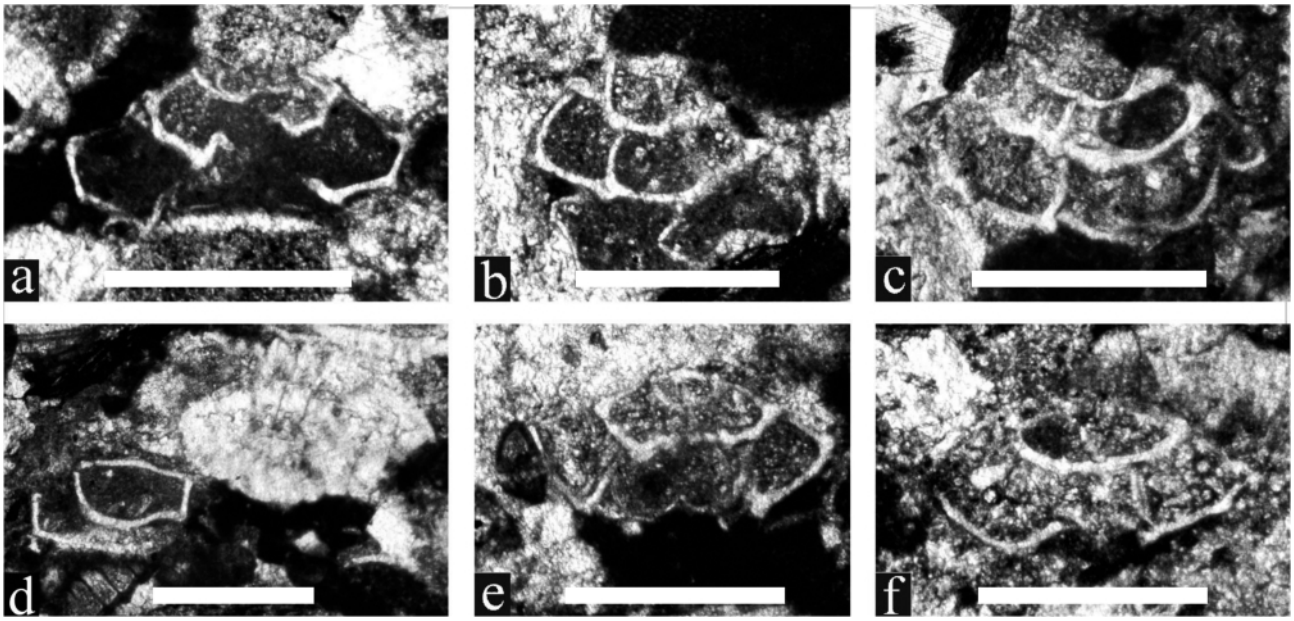


Figure 7: Late Cretaceous (Campanian to Maastrichtian) globotruncanids reworked in the Thanetian carbonates (sample OK-W670). A: *Globotruncana* aff. *arca* (Cushman). B, C: *Globotruncana* sp. aff. *conica* (White). D: Fragment of globotruncanid foraminifer (left below) and *Miscellanea*? sp. (upper right). E: *Globotruncana* aff. *stuarti* (De Lapparent). F: *Globotruncana* aff. *dupeubli* (Caron). Scale bars are 0.5 mm.

slightly metamorphosed rock fragments confirm the suggestion of Faupl et al. (1987) of a hinterland with older sedimentary and higher metamorphosed rocks exposed. The radiolarite rock fragments indicate erosion of a radiolarite bearing source. The weathered, clay-rich soil fragments show that also dry land existed in the source area of the siliciclastic rocks.

Reworked Upper Cretaceous deep-water litho- and bioclastic material (Globotruncanidae) is well known from other outcrops of the Zwieselalm Formation also (Plöchinger, 1956, 1967; Wille, 1964; Tollmann, 1976). The comparable, moderately to high trochospirally coiled globotruncanids (e.g., *arca*-group) are typical Campanian to Maastrichtian faunal elements (Fig. 7) (van Hinte, 1963; Wille, 1964; Sari, 2006).

All shallow-water organisms, carbonate lithoclasts, siliciclastic components and soil fragments, the eroded, marly material from the underlying sedimentary rocks and the pelagic organisms were brought together and deposited in a deeper slope, outer shelf or basinal setting. These coarse-grained, mixed debris flows to turbidites (turbidity currents according to Wille, 1964) are normally intercalated in the marly rocks of the Paleocene Zwieselalm Formation. This is similar to the situation reported from outcrops in the Zwieselalm (Kollmann and Summesberger, 1982; Schlagintweit et al., 2003) and Lattengebirge (Krenmayr, 1999) areas. A more precise palaeogeographic reconstruction of the former shallow-water area of the Kambühel Formation is limited by the very rare outcrops and needs further investigations.

The complicated, polyphase tectonic evolution of the Northern Calcareous Alps between the Dachstein and the Berchtesgaden blocks becomes better constrained by this newly proven occurrence of Paleocene sedimentary rocks. Sedimentation in the southern Tauglboden Basin area and the northern rim of the Trattberg Rise ended in the Early Aptian (Plöchinger, 1968). After a long-lasting gap, a new depositional cycle started with sediments of the Gosau Group. An Early Cretaceous thrusting of Mount Gollinger Schwarzenberg onto the Weitenau area can be excluded by detailed microfacies analyses from the conglomerates of the Roßfeld Formation and the Grabenwald Subformation (own data). Our findings of Paleocene rocks in the Weitenau area indicate that during the deposition of these carbonate arenites no movements of Mount Gollinger Schwarzenberg had taken place. The lack of components from Mount Gollinger Schwarzenberg in the resedimented Paleocene rocks is one indication for that. This implies that the Eocene age of the tectonic movements (northward thrusting and southward backthrusting) as proposed by Frisch and Gawlick (2003) and Missoni and Gawlick (2011) for the Dachstein and Berchtesgaden blocks can also be confirmed for the thrusting of parts of the Lammer unit onto the Weitenau area (compare Schorn and Neubauer, 2011). The new results limit the thrusting of Mount Gollinger Schwarzenberg (e. g., Gawlick et al., 1990) over the block puzzle of the Weitenau area to a maximum age of Late Eocene or Oligocene (Palaeogene orogeny: Frisch and Gawlick 2003). These thrusting processes deformed the weak, incompetent clay and gypsum unit of the Alpine Haselgebirge Mélange in front of, or below the nappe to its overall shape. In addition, the older fault systems and former nappe boundaries were overprinted.

Miocene tectonics affected the area only subordinately by minor reactivation and overprint of older structures. The presence of a prominent strike-slip fault system, sinistrally offsetting the southern ridges of Mount Gollinger Schwarzenberg by several kilometres (Decker et al., 1994), was excluded by Gawlick and Gawlick (1999). Miocene, strike-slip related northeastward thrusting of Mount Gollinger Schwarzenberg (Decker et al., 1994) onto the Weitenau area was of less importance

with an offset of only several 100 m. Also the shape of the Alpine Haselgebirge Mélange at Grubach-Moosegg was only marginally modified by these younger tectonic movements.

The investigation of the Weitenau Alpine Haselgebirge Mélange occurrence with its surrounding sedimentary rocks shows clearly that the application of a combination of lithological, biostratigraphical, microfacies, palaeontological and structural methods allows explaining most of the observed geological features.

5. Conclusions

1. Resedimented Thanetian shallow-water material from the Kambühel Formation is for the first time described from the Weitenau area. Microfacies and fauna are more or less identical with descriptions from other Kambühel Formation locations.
2. In the Weitenau area, a sedimentation gap exists between the Lower Cretaceous Rossfeld Formation and the Paleocene carbonate arenites of the Gosau Group.
3. The Thanetian carbonate arenite rocks are the key for a refinement of the sedimentary history in the younger parts of the Gosau basins, the evolution of the Northern Calcareous Alps in Paleocene times, and the reconstruction of the today widely eroded shallow-water carbonate shelf areas.
4. The occurrence of Gosau Group rocks northwest of Mount Gollinger Schwarzenberg sets the lower time limit of the northward thrusting of the Lammer unit onto the Weitenau block puzzle to the Late Eocene/Oligocene. The Weitenau Alpine Haselgebirge Mélange occurrence received its major shape in the course of this thrusting and deformation phase. In comparison to Late Eocene/Oligocene tectonics, the influence of Miocene tectonics on the Weitenau area was less significant.

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