Biostratigraphy and sedimentology of Campanian deep-water sections (Nierental Formation, Gosau Group) in Lower Austria

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Abstract

Two Campanian (Upper Cretaceous) sections of the Nierental Formation, Gosau Group, were investigated in the northeastern part of the Northern Calcareous Alps. The 220 m thick Groisbach section, situated in the Lunz nappe (Bajuvaric tectonic unit) within the Gießhübl syncline, ranges from the Santonian/Campanian boundary to Upper Campanian. The Tasshof section, on top of the Reisalpen nappe (Tirolic tectonic unit), exposes c. 70 m sediments of late Early to early Late Campanian age. Both sections are characterized by bathyal marlstone background sedimentation with intercalations of coarse-grained breccia and conglomerate intervals, and some turbidite sandstone beds. Conglomerate and breccia petrology shows a predominance of carbonate clasts from the surrounding Triassic to Jurassic rocks. At Groisbach, the lower to middle part of the sections contains also a significant amount of quartz porphyry clasts and reworked Upper Cretaceous sandstone clasts, indicating major erosion of Cretaceous rocks. At Tasshof, a conspicuous amount of serpentinite clasts points to erosion of ophiolite remnants in the source area to the south. Heavy minerals corroborate this interpretation with high amounts of chrome spinel at Tasshof and moderate amounts of chrome spinel at Groisbach. The facies assemblages of the sections indicate depositional systems within slope environments such as slope aprons and slope fans. Large-scale slumping in the Tasshof section also indicates an unstable slope environment. Normal faults control the deposition of clastic slope and slope-apron systems of the Campanian in this area.

Zwei Profile des Campaniums (Oberkreide) der Nierental-Formation, Gosau-Gruppe, wurden in Nordostteil der Nördlichen Kalkalpen untersucht. Das 220 m mächtige Groisbach-Profil der Gießhübler Mulde der Lunzer Decke (Bajuvarikum) reicht vom Santonium/Campanium-Grenzintervall bis ins Obere Campanium. Das Tasshof-Profil auf der Reisalpendecke (Tirolikum) schließt ca. 70 m einer Abfolge mit spätem Früh- bis frühem Spät-Campanium auf. Beide Profile sind durch eine bathyale mergelig-kalkige Hintergrundsedimentation mit Einschaltungen von grobkörnigen Breccien- und Konglomeratpaketen und einigen turbiditischen Sandsteinlagen gekennzeichnet. Die Petrologie der Konglomerate und Breccien zeigt eine Dominanz von karbonatischen Komponenten der umgebenden Trias- und Juragesteine. Der untere und mittlere Abschnitt des Groisbachprofils beinhaltet darüber hinaus auch signifikante Anteile von Quarzporphyr- und aufgearbeitete Oberkreidesandsteingeröllen, was auf eine bedeutende Erosion von Kreidegesteinen hinweist. In Tasshof tritt ein deutlicher Gehalt an Serpentinitklasten auf, der auf eine Erosion von Ophiolithresten im südlich gelegenen Liefergebiet hinweist. Schwermineraldaten unterstützen diese Interpretation mit hohen Chromspinellgehalten in Tasshof und mittleren Gehalten in Groisbach. Die Faziesvergesellschaftungen der Profile weist auf Ablagerungssysteme in einem Hangbereich, etwa Slope-Aprons und Hangfächer hin. Großräumige submarine Rutschfalten in Tasshof sind ebenfalls Hinweise auf einen unruhigen Hangbereich. Abschiebungen werden als Ursache für die Ablagerungen in diesen klastischen Hang- und Slope-Apron Systemen des Campaniums des Untersuchungsgebietes gesehen.

1. Introduction

The Gosau Group of the Northern Calcareous Alps (NCA) records sedimentation during and after a major orogenic phase of the Eastern Alps („eo-alpine phase", e.g. Faupl and Wagreich 2000). The Gosau Group comprises a terrestrial – shallow-marine lower interval (Lower Gosau Subgroup, Upper Turonian to Campanian; Wagreich and Faupl, 1994; Wagreich and Decker, 2001) followed by deep-water deposits (Upper Gosau Subgroup, mainly Campanian to Eocene; Wagreich and Faupl, 1994; Krenmayr, 1999; Wagreich and Krenmayr, 2005). The Campanian of the eastern part of the NCA records the transition from the Lower to the Upper Gosau Subgroup, characterized by an unconformity and a major subsidence phase (Wagreich, 1993a, 1995), coarse syntectonic deposits (Wessely, 1974, 2006; Wagreich, 1986) and a general rearrangement of basin structures (Wagreich, 1995; Wagreich and Marschalko, 1995). Basin formation of the Lower Gosau Subgroup was attributed to more localized strike-slip and pull-apart basins (Wagreich and Decker, 2001), whereas the subsidence in the Upper Gosau Subgroup records a NCA-wide event (Wagreich and Faupl, 1994) and was interpreted as a result of tectonic erosion due to subduction processes to the north of the NCA (Wagreich, 1993a, 1995).

This paper describes the geology, stratigraphy and sedimentology of two contrasting Campanian sections in the northeastern part of the NCA, at Groisbach/Alland and Tasshof/Altenmarkt an der Triesting (Figs. 1, 2), which were deposited in the critical time interval of renewed rapid subsidence and rearrangement of basin structures. Data for these investigated sections are based on four bachelor theses (Steinbrener, 2008; Porpaczy, 2009; Ilickovic, 2011; Popovic, in prep). Biostratigraphy of the sections is based on calcareous nannofossils and planktonic foraminifera. The two sections are described and interpreted in respect to their sedimentary structures and depositional environment. Provenance of the clastic material is inferred based on sandstone and conglomerate petrography and heavy mineral data to reconstruct the paleogeography of this part of the NCA during the time interval of deposition. Interpretations for the geodynamic evolution of the eastern NCA during the Late Cretaceous are discussed.

2. Geological setting

Both investigated sections are situated at the northeastern part of the NCA (Fig. 1), southwest of Vienna. The Groisbach section near Alland (coordinates WGS84 016° 03´ 11” E / 48° 02' 46” N to 016° 03´ 02” E / 48° 02' 45” N, 420 m above sea level) is exposed at a bend along the road from Alland to Nöstach, NE of the village Groisbach (Fig. 2). Due to road reconstructions and repair, the outcrop changes constantly, but recently got more and more covered by vegetation after construction of a wooden protection wall between the outcrop and the road. The outcrop is ca. 300 m long and covers about 220 m of stratigraphy (main dip direction towards ESE with dip angles around 30° in the west and around 10-20° in the east). The stratigraphically oldest part is situated in the west and the youngest part in the east.

The Groisbach section is situated in the western continuation of the Gießhübl Syncline, a syncline of Upper Cretaceous sediments (Fig. 1) that extends from the basement below the Vienna Basin to the Gießhübl area in the southern part of the Wienerwald (Plöchinger, 1964; Wessely, 1974, 2006, 2008) to Lilienfeld in the west (Wagreich, 1986; Plöchinger and Salaj, 1991). Tectonically, the Gießhübl Syncline is part of the northernmost tectonic thrust system of the NCA, the Frankenfels-Lunz Nappe System (Bajuvaric thrust units) and is positioned within the Lunz nappe (Wessely, 2006).

The Tasshof section is exposed within an abandoned quarry to the south of Altenmarkt an der Triesting, at the southeastern slopes of the Gemeindeberg (Fig. 2). The so-called „Zementmergel“ quarry is situated on a hiking path from Tasshof to Kienberg and Hocheck mountain (coordinates WGS84 016° 00´ 52” E / 48° 00' 09” N to 016° 00´ 42” E / 48° 00' 08” N, 480 m above sea level). Exposures are present at two quarry levels. Beds within the quarry are steeply dipping to vertical and in large parts of the quarry beds are exposed in overturned position. Generally, the strike directions of the beds are SE-NW in the lower and NE-SW in the upper part, with dip angles around 70-80°. The quarry succession is dissected by numerous strike-slip faults with calcite slickensides, probably of Miocene age, and therefore only a tentative composite section of c. 70 m of stratigraphy with some gaps can be logged in this quarry.

The Tasshof section can be attributed to a Gosau Group succession which has been deposited on a thrust unit belonging to higher tectonic position within the thrust stack of the eastern NCA, i.e. the Tirolic thrust system. In the local area this Tirolic

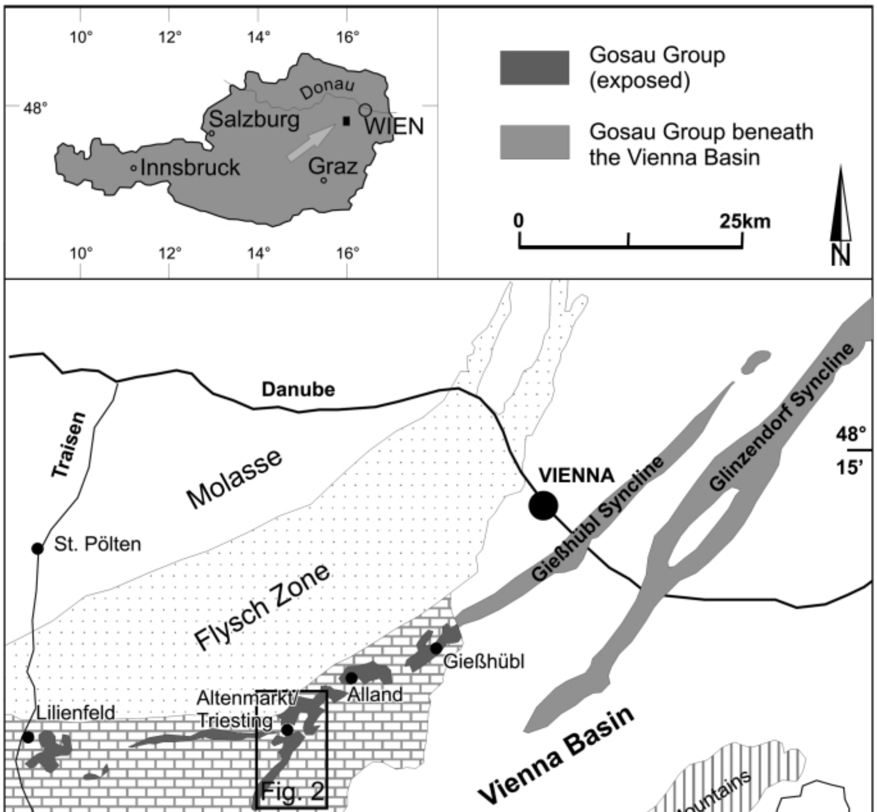

Figure 1: Geological sketch map of the eastern margin of the Eastern Alps indicating major outcrop belts of the Gosau Group discussed in the text. Inset at upper left corner shows the position of the study area within Austria.

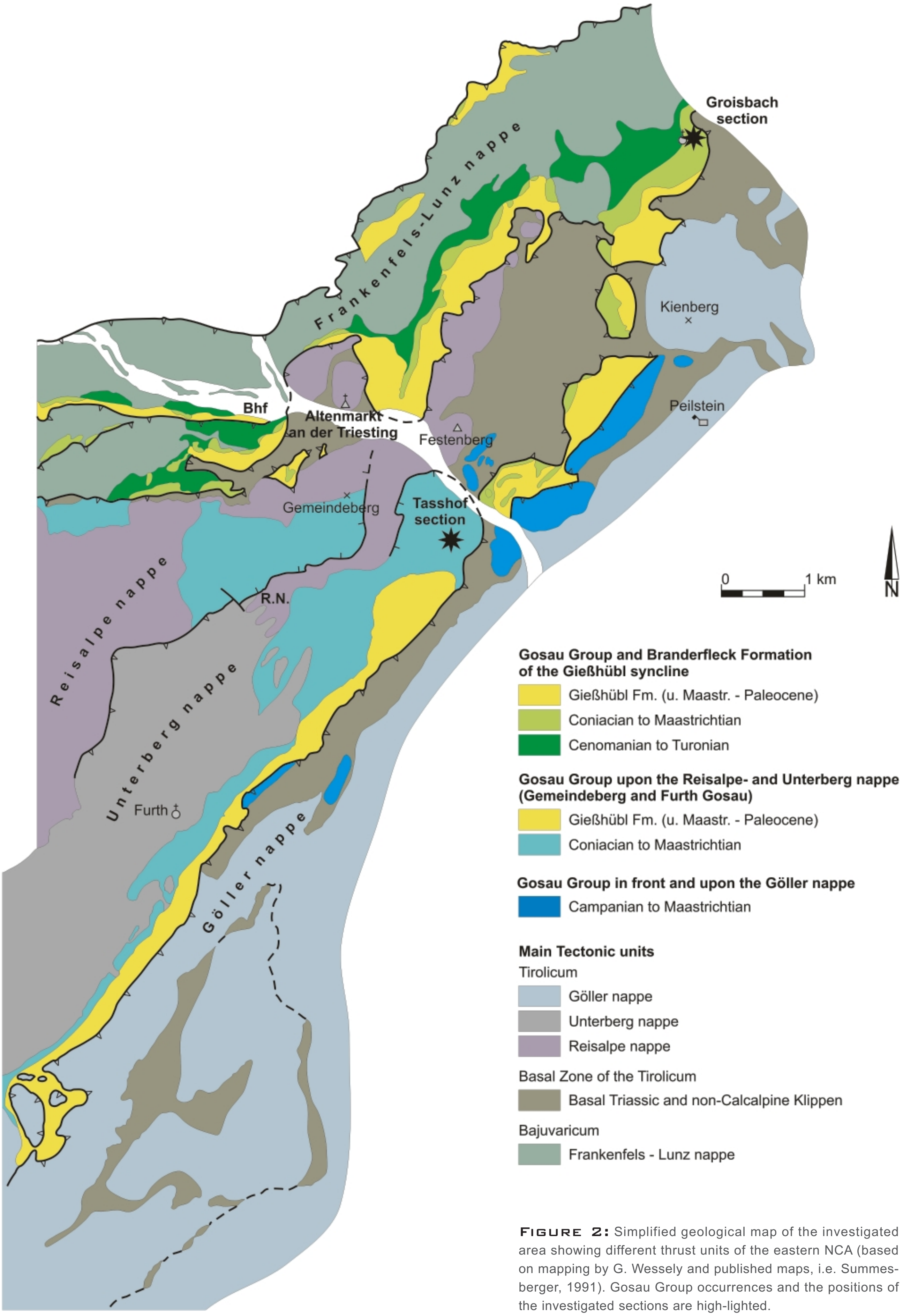

Figure 2: Simplified geological map of the investigated area showing different thrust units of the eastern NCA (based on mapping by G. Wessely and published maps, i.e. Summesberger, 1991). Gosau Group occurrences and the positions of the investigated sections are high-lighted.

thrust system consists of the Reisalpe nappe, the Unterberg nappe and the Göller nappe and is thrust upon the Lunz nappe which has the Gießhübl syncline on its top (Fig. 2). The Reisalpe nappe and the Unterberg nappe initiate in the area of Altenmarkt an der Triesting, where they are thinnest, and get thicker toward SW. The investigated section is situated on top of the Reisalpe nappe, just near the point where the Untersberg nappe thrusted above the Reisalpe nappe. According to Wessely (2006) the initiation of this overthrust seems to be caused by a postgosauic (post-Paleocene) reactivation of an existing normal fault (Fig. 2), which former affected the sedimentation of the local Gosau Group. The Gosau Group also continues toward SW, on top of the Unterberg nappe. The Gosau Group of the Reisalpe nappe and the Unterberg nappe is subsumed as the Gosau Group of Gemeindeberg/Furth (see geological map sheet Puchberg, Summesberger, 1991: "Further Gosau"). It is interpreted as a tectonically transported southern part of the Gießhübl syncline continuing into the Tirolic domain, characterized by a kind of slope sedimentation according to Wessely (2006).

3. Methods

Standard field techniques including bed-by-bed logging, recording of sedimentary structures and the recognition of grain size and clast lithologies were applied to the outcrops. The successions were sampled for thin section analysis and biostratigraphic evaluation. Foraminifera were analysed both from washed samples and thin-sections (for taxonomy see Caron, 1985). Nannofossils were investigated under the light microscope (magnification 1000x) using smear slides of unprocessed fine-grained samples (for taxonomy see Burnett, 1998). For mineral and texture analysis, thin-sections were investigated from representative field samples of sandstones, marls and breccias samples from the Groisbach and the Tasshof section. The thin sections were stained for calcite-dolomite separation using Alizarin S and Potassium ferrocyanide. Standard procedures (e.g. Wagreich and Marschalko, 1995) were applied for heavy mineral analysis using acetatic acid for decarbonatisation, tetrabromethan as heavy liquid for separation of the 0.063 to 0.4 mm size fraction.

4. Lithostatigraphy

The lithostratigraphic subdivision of the Gosau Group of the NCA comprises a complex system of formations due to sedimentation in largely separated basins especially during the deposition of the Lower Gosau Subgroup (e.g. Wagreich and Decker, 2001, Piller et al., 2004). The Upper Gosau Subgroup, to which the investigated Campanian sections belong to, shows laterally a more uniform development due to NCA-wide subsidence and a northward tilting of the NCA (Wagreich, 1993a, 1995). In general, the Upper Gosau Subgroup comprises pelagic to hemipelagic marls and limestones of the Nierental Formation (Krenmayr, 1999; Wagreich and Krenmayr, 2005) and various mass-flow, mainly turbidite-dominated deep-water formations such as the Zwieselalm Formation and the Gießhübl Formation (Wagreich and Faupl, 1994). The term Nierental Formation („Nierentaler Schichten“) dates back to Gümbel (1861) and denotes predominantly red and grey marls and marly limestones. Major refinements of the lithostratigraphic definition of the Nierental Formation including the original type section of the Nierental (Bavaria, Germany) and the hypostratotype in the Lattengebirge were provided by Herm (1962) and Krenmayr (1999).

Based on the presence of significant marl-dominated intervals, both sections of this study are included into the Nierental Formation (Krenmayr, 1999; Krenmayr in Hofmann, 2007). However, in both sections, a significant portion is made up of quite coarse sediments, i.e. conglomerates, breccias and sandstones. Therefore, the attribution to the Nierental Formation was discussed and questioned, and special names were considered for the sediments at Tasshof/Altenmarkt an der Triesting, such as Tasshof Formation („Taßhofer Schichten“, see Wessely, in Summesberger, 1991). However, Krenmayr (1999), in his renewed definition of the Nierental Formation, discussed this problem and concluded to attribute those sections still into the definition of the Nierental Formation. In contrast, sections where coarse carbonate clastics, i.e. breccias, dominate strongly were defined as separate formations, e.g. the Spitzenbach Formation in the Enns Valley area (Faupl, 1983).

In the investigated section at Groisbach (Fig. 3), the Campanian Nierental Formation is underlain by some meters of variegated Santonian marls and up to several tens of meters thick shallow-water sediments, grey Coniacian-Santonian carbonatic sandstones (“Karbonatsandstein des Mitterwäldchen” of Wessely, 2006), and is overlain by breccias attributed to the Spitzenbach Formation and a several hundred meters thick turbidite-dominated unit, the Gießhübl Formation (Plöchinger, 1964; Wessely, 1974, 2006) of Maastrichtian to Paleocene age (Fig. 2).

In the area of Tasshof-Gemeindeberg, the Campanian marls and marly limestones of the Nierental Formation are underlain by shallow-water sandstones (calcarenites and bioclastic sandstones) and sandy marls of Coniacian-Santonian age (see Fig. 3 and Summesberger, 1991). There, the base of the Gosau Group succession is formed by dolomite conglomerate. Campanian sediments are overlain by blocky conglomerates of the Spitzenbach Formation of Maastrichtian age and by the Gießhübl Formation (Upper Maastrichtian – Middle Paleocene, Wessely, 1984).

5. Biostratigraphy

In both sections, the biostratigraphy is based on calcareous nannofossils and planktonic foraminifera (Figs. 4, 5). Due to diagenesis and tectonic deformation leading to strong recrystallisation both nannofossils and foraminifera are poorly preserved and data are therefore scarce and incomplete. Nevertheless, biostratigraphic data clearly indicate coeval sedimentation of the sections during the Campanian in general (see also Krenmayr, 1999).

Planktonic foraminifera data of the Groisbach section (Fig. 6) are based on a few washed samples and some thin sections of sandstone layers. The presence of *Globotruncanita elevata* in samples at 6 and 121 m and the absence of the *Dicarinella*-group indicate an Early Campanian age already in the deepest part of the Groisbach section as logged in 2008-2010 (Fig. 6). During rebuilding of the road variegated marls below today's outcrop limits yielded *Dicarinella concavata*, a Coniacian-Santonian marker which ranges up into the lowermost Campanian. The uppermost part of the Groisbach section still belongs to the (Late) Campanian indicated by the absence of typical Maastrichtian foraminifera like *Rosita contusa* and *Gansserina gansseri*. However, *Globotruncanita calcarata*, a Late Campanian marker, was not found so far in the section. Between the dated lower and the upper Campanian interval a red colored conglomerate with exotic components can be regionally traced by mapping.

Planktonic foraminifera data from the Tasshof section are scarce. From sandstone thin-sections and washed sample A6-10 an assemblage including *Rosita fornicata*, *Rosita patelliformis*, *Globotruncana linneiana*, *Globotruncana arca*, *Globotruncana* cf. *ventricosa* (Fig. 4A) and *Globotruncanita elevata* (Fig. 4B) were identified. This assemblage hints to the *G. ventricosa* Zone of Late Campanian age (e.g. Caron, 1985). In general, this attributes to a Late Campanian age of the greater part of the Tasshof section. This is corroborated by data from similar grey marlstones and overlying red marlstones from the

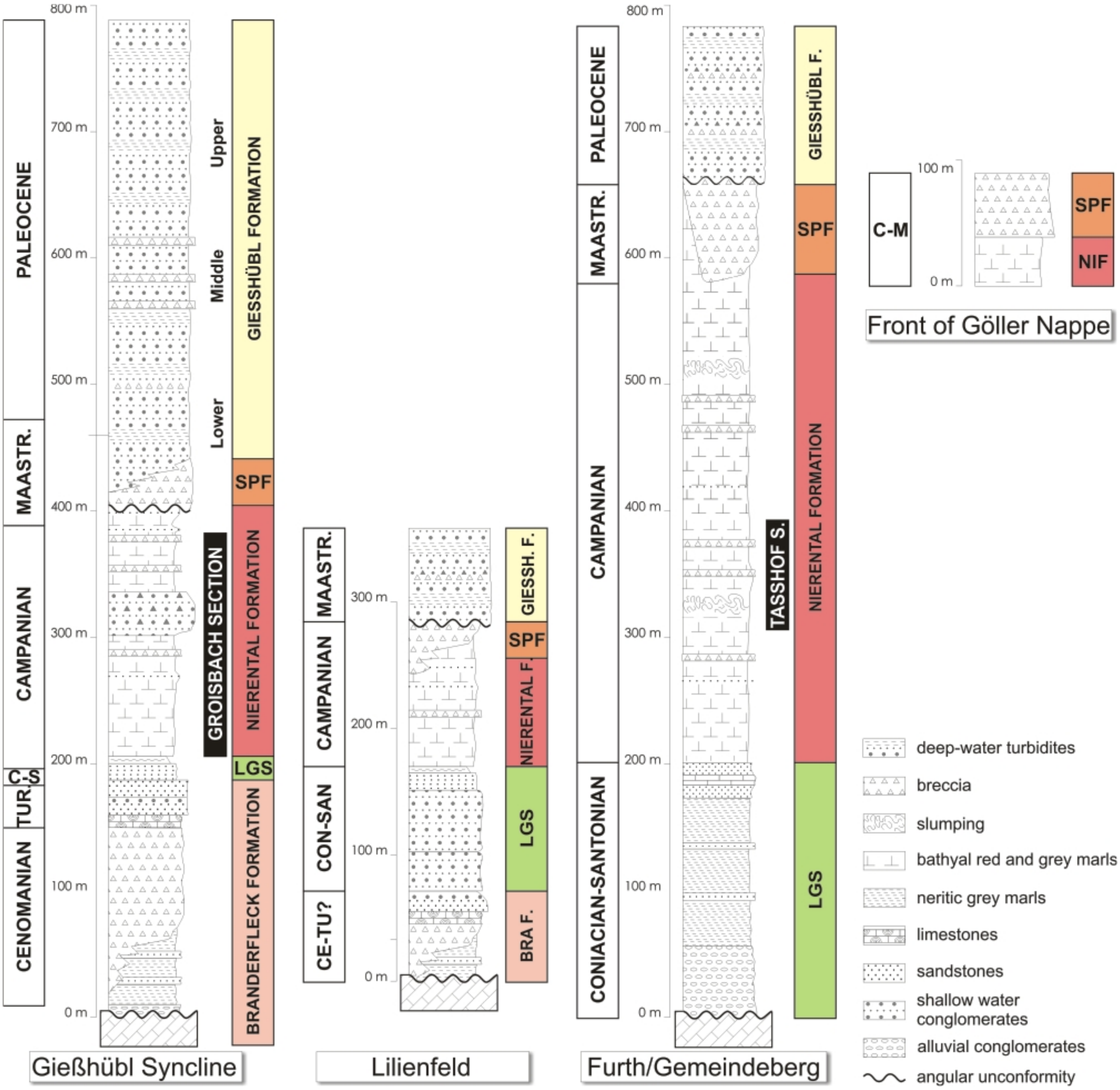

Figure 3: Schematic stratigraphic logs of the Branderfleck Formation and the Gosau Group of the Gießhübl syncline including the Groisbach section and the Gosau Group of Gemeindeberg/Furth including the Tasshof section, and surrounding sections at Lilienfeld to the and the front of the Göller nappe to the east of the investigated sections. Abbreviations: C-M: Campanian-Maastrichtian; C-S: Coniacian-Santonian; MAASTR: Maastrichtian; LGS: Lower Gosau Subgroup; NIF: Nierental Formation; SPF: Spitzenbach Formation; TUR: Turonian.

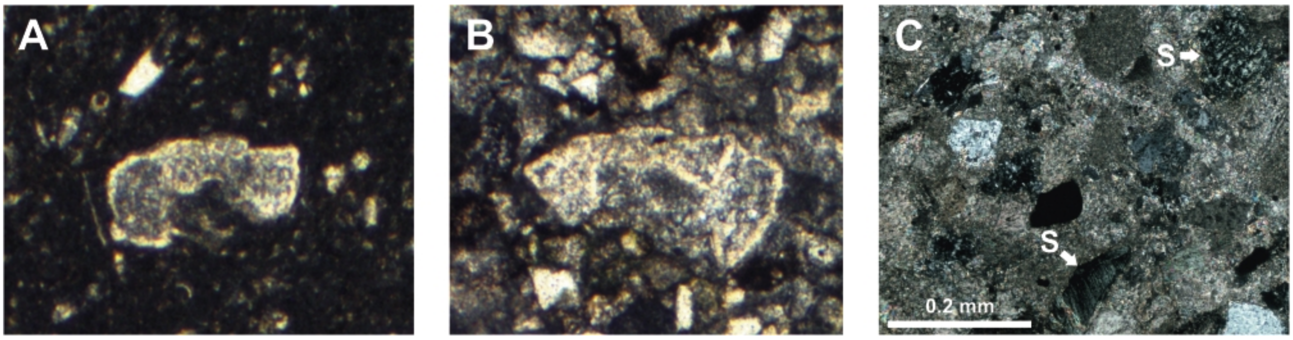

Figure 4: Planktonic foraminifera and serpentinite fragments from sandstone thin sections of the Tasshof quarry: (A) *Globotruncana* cf. *ventricosa* (sample A17, lower quarry level, Tp2; long side of photograph 0,5 mm). (B) *Globotruncanita elevata* (sample A17, lower quarry level, Tp2; long side of photograph 0,5 mm). (C) serpentinite fragments (S) in turbidite sandstone, (crossed nicols; sample O.2.1, upper quarry level, Tp 2).

frontal Gosau Group of the Göller nappe near Preinsfeld towards the east, in which *Globotruncanita calcarata*, a marker for the Late Campanian, has been found (Wessely, 1984). Additionally, some reworked benthic foraminifera in sandstone layers, such as *Orbitoides* sp., *Lepidorbitoides* sp. and *Stensioeina pommerana* (sample O.9), also indicate a (Late) Campanian age.

Calcareous nannofossils from the Groisbach section indicate also a Campanian age. *Broinsonia parca parca* is present in most of the samples. At the base, the sample P6 at section meter 6 (Fig. 6) contains curved *Lucianorhabdus cayeuxii*, a (regional) marker for the uppermost Santonian to lowermost Campanian (Wagreich, 1992). Thus, the section may start near the Santonian/Campanian boundary. At section meter 90, a comparable well preserved nannofossil sample included the following marker species:

Arkhangelskiella cymbiformis
Broinsonia parca parca
Broinsonia parca constricta
Calculites obscurus
Ceratolithoides aculeus
Lithastrinus grillii
Lucianorhabdus cayeuxii
Micula decussata
Reinhardtites cf. *anthophorus*

These markers indicate nannofossil zone CC20/UC15b^{TP} of late Early Campanian age (Burnett, 1998) for the middle part of the Groisbach section. In the upper part of the section, *Eiffellithus eximius* is still present, even in the topmost sample P220 at section meter 220, indicating that the section does not reach the Campanian/Maastrichtian boundary (see Wagreich et al., 2003). However, due to the bad preservation, no detailed zonation can be applied, and thus the exact age of the top of the section within the Upper Campanian is still unclear.

Calcareous nannofossils from the Tasshof section give evidence for a "middle" Campanian age of the section. Strong diagenetic overgrowth hinders a detailed nannofossil zonation in the section. The best preserved sample (Fig. 8, A6-10, Fig. 5) contains the following nannofossil markers:

Arkhangelskiella cymbiformis
Broinsonia parca parca
Broinsonia parca constricta
Calculites obscurus
Lucianorhabdus cayeuxii
Micula decussata
Quadrum gothicum
Quadrum (Uniplanarius) cf. *sissinghii*
Reinhardtites levis

These markers indicate nannofossil standard zone CC 21 of Sissingh (1977), defined by the first occurrence of *Quadrum (Uniplanarius) sissinghii*, a marker for the Late Campanian (Perch-Nielsen, 1985). According to the zonation of Burnett (1998), this assemblage without *Quadrum (Uniplanarius) trifidum* indicates subzone UC15c^{TP} of early Late Campanian age. *Ceratolithoides aculeus*, whose first occurrence marks the base of the preceding nannofossil zone CC20, seems to be generally rare in the section due to poor preservation, and was not found in this sample. However, this marker species is present in two other samples from Tasshof, indicating also the presence of nannofossil zone CC20/UC15b^{TP} of late Early Campanian age (Burnett, 1998). In general, samples with *Arkhangelskiella cymbiformis*, *Broinsonia parca parca*, *Broinsonia parca constricta* are typical for the Tasshof quarry. *Reinhardtites anthophorus*, a marker that disappears generally below the Campanian/Maastrichtian boundary (Wagreich et al., 2003), is present in one sample from the upper quarry level.

Based on the nannofossil results (see also Krenmayr, 1999), the Tasshof section can be ranged into nannofossil zones CC20/UC15b^{TP} to CC21/ UC15c^{TP} of late Early to early Late

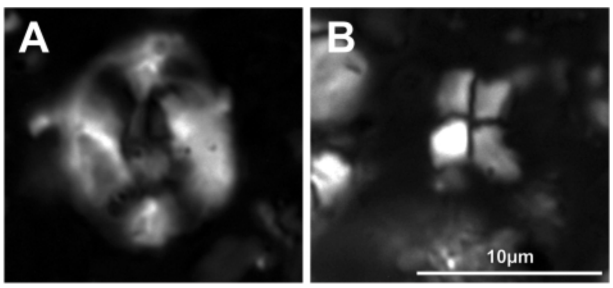

Figure 5: Nannofossils from the Tasshof quarry: (A) *Broinsonia parca constricta*, crossed nicols, sample A6-10. (B) *Quadrum (Uniplanarius)* cf. *sissinghii*, crossed nicols, sample A6-10.

Campanian age (Burnett, 1998). No indications for a Santonian or Maastrichtian age have been found, although the bad preservation of most of the samples hinders a detailed nannofossil zonation.

6. Sedimentology

6.1 Groisbach section

The Groisbach section (Figs. 6, 7) shows a succession of grey and reddish marlstones and red conglomerates in the lower 100 m interval (Fig. 7a). At the base, a c. 15.5 m thick grey to ochre, rarely reddish marlstone interval is present (Fig. 7b). The marlstones show a mottled appearance due to bioturbation. The microfacies can be classified as mud- to wackestones with mainly planktonic foraminifera. Carbonate contents of the marlstones range between 28 and 73%, with lower values predominating in silty red marlstones of the lower part of the section. Conglomerates start at 15.5 m of the section with a 3.5 m thick conglomerate bed (mean particle size ca. 6 cm). In the following interval, four conglomerate beds (Fig. 7c) with a composite thickness up to 14 m (i.e., section meter 15.5-29) are separated by thin, 10-30 cm thick layers of predominantly red marlstone. Above, from section meter 29 to 93, c. 10 m thick marly intervals, both red and grey, are interbedded with 4 conglomerate-breccia packages up to 5.7 m in thickness. Both matrix- and clast-support conglomerates are present. At 67.5 m, an 8 cm thick graded turbiditic sandstone bed is present within a marly interval. The topmost part of this interval, between section meters 90-93, is partly covered, but seems to consist again of a thicker conglomerate-dominated package. From 120 to 160 m, a succession of red, ochre and grey marlstones with three 30-50 cm thick graded turbidite sandstone beds is overlain by a 15 m thick grey carbonate breccia. One of the sandstones layers shows a prominent current ripple interval (Fig. 7d). In the following uppermost part of the section, from section meter 156 upwards, grey marlstones predominate with very rare beds of dolomitic breccia/ conglomerate and a few sandstone beds with a thickness up to 1 m. However, this part of the sections is poorly exposed and partly covered by dense vegetation. At the present top of the exposed section, at section meter 220, grey marlstone is present.

6.2 Tasshof section

The Tasshof section (Fig. 8), exposed at the two levels of an abandoned quarry (see inset in Fig. 8), displays mainly grey marlstone, thin-bedded sandstone and breccia. Grey marlstone and marly limestone show varying silt content. Fragments of inoceramid bivalves are present in the marls (Fig. 9d). Thin-bedded (several centimetre) marls interbedded with silt- to fine-grained sandstone are present predominantly in the upper quarry level (Fig. 9a) and form distinct intervals within coarser-grained intervals up to more than 1 m in thickness. In general, sandstone shows a distinct grading, especially above basal breccia layers where grading from coarse- to fine-grained sandstone is evident (Fig. 9b). Sandstones beds at quarry level 1 are up to 30 cm thick, intervening grey marlstone layers are up to 1 m thick. *Zoophycos*, *Chondrites* and *Planolites* Lebensspuren are present in this lower part of the quarry (Fig. 9c). In the upper level, sandstone beds up to 139 cm, are thicker than in the lower level, except sandstones of the thin-bedded facies. Massive to graded breccia beds are up to 3 m thick, and form amalgamated packages of more than 4 m thickness (Tp7.1 in Fig. 8). Breccia layers are mostly massive, but normal grading is also present, whereas inverse grading was only found at the base of one bed. Breccias are clast-supported but matrix-supported intervals do exist probably due to the presence of reworked marl rip-up clasts as a secondary matrix. Mean clast sizes are around a few centimeters, but outsized clasts up to 40 cm do occur.

7. Sedimentary petrography

7.1 Conglomerates and Breccias

Coarse sediments of the Groisbach section are dominated by dolomite clasts of the surrounding NCA, mainly Triassic succession. A more mixed calcitic-dolomitic pebble composition has been observed in the lower part and a strong predominance of grey dolomites in the upper part of the section. Well rounded quartz porphyry pebbles are present in conglomerates of the first 100 m and give the conglomerates a more polymictic appearance. They are especially concentrated in a distinct horizon in the middle part of the section of the Campanian. Reworked clasts of Coniacian-Santonian sandstones of the Gosau Group are present. The sandy matrix of the conglomerates consists of carbonate grains and poly- and monomictic quartz grains including some chert fragments. Large rip-up clasts of marls and marlstones within the conglomerates and breccias have also been found. Coarse-grained beds in the upper part of the section are largely monomictic dolomite breccias, derived mainly from Upper Triassic Hauptdolomit. Chert fragments, sandy-silty grains (presumably from Werfen beds) and reworked sandstones of the underlying Gosau succession have been documented. One grain of bauxite was also found.

Breccias of the Tasshof section are also dominated by dolomite clasts but in addition contain clasts of the Werfen Formation and various Triassic and Jurassic limestones. A conspicuous amount of biogenic clasts is present, e.g. *Inoceramus* shells and echinoderms and rare rudist shell fragments.

7.2 Sandstones

Sandstones of both sections can be generally classified as carbonate-rich lithic arenites. In the Groisbach section, carbonate rock fragments, both limestones and dolomites, form the major constituents. Only about 20 % of the grains comprise siliciclastics, mainly poly- and monocrystalline quartz. Feldspar is only present in a few percent. Layers rich in coalified plant fragments are present, as well as biogenic clasts, such as some tests of planktonic foraminifera and fragments of or-

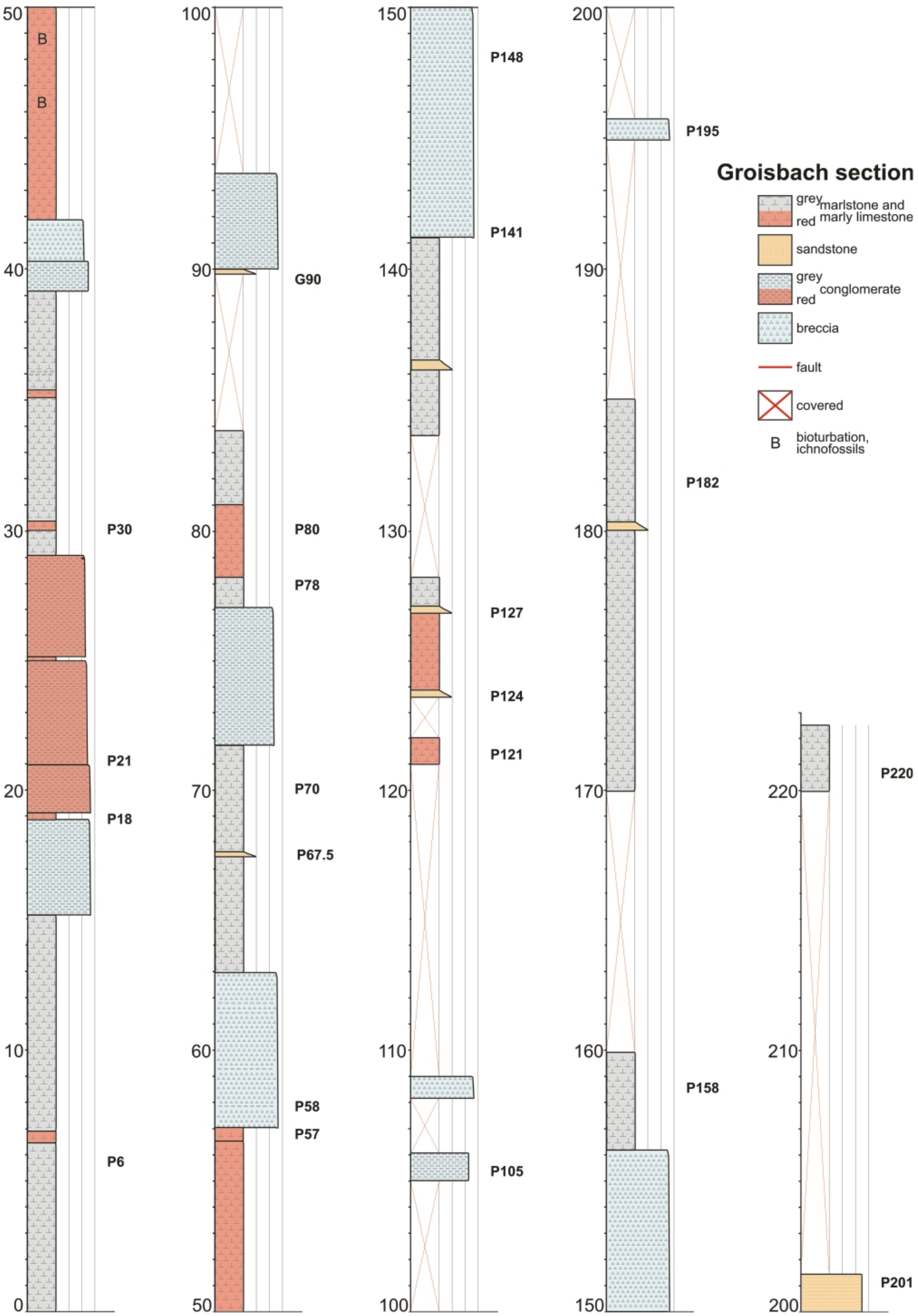

FIGURE 6: Sedimentological log of the Groisbach section (based on Steinbrener, 2008, and Porpaczy, 2009). P-numbers are sample numbers.

bitoidal foraminifers, and fragments of corallinacean algae.

Most grains have an angular to only subrounded shape and the sorting of the sandstones is only moderate to poor. Cements are mainly calcitic and have a blocky spar appearance.

Sandstones of the Tasshof section have a high amount of biogenic detritus besides the dominating calcite and limestone grains. Poly- and monocrystalline quartz is present. Biogenic particles include foraminifera, bivalves and other molluscs, echinodermal fragments, bryozoans, inoceramid shell fragments and radiolaria. Sorting is good in fine-grained parts but poor in coarse-grained sandstone. Angular to sub-rounded grains are present. Besides ubiquitous planktonic foraminifera, benthic foraminifera can be observed, e.g. *Orbitoides* sp., *Textularia* sp., thick-walled rotaliids and miliolids. A small but conspicuous amount of serpentinite fragments is present in most of the sandstones (Fig. 4c). Accessory minerals include chrome spinel grains and some opaque minerals. At transitions from sandstones to silt- and marlstones, a micritic matrix gives the sandstones a wacke-like appearance.

7.3 Heavy minerals

Heavy mineral data from both sections have already been reported by Krenmayr (1999, Tab. 3). Our results from Groisbach and Tasshof are in accordance with these data. Samples from Groisbach show a predominance of chrome spinels (33-44%), followed by stable minerals like zircon (22%), tourmaline (5-11%) and rutile (up to 4%) as well as minor amounts of hornblende, garnet, epidote and staurolite. Results from Tasshof show a significantly higher proportion of chrome spinels (ca. 77-87%) together with tourmaline (8-11%), and a few percent of zircon, garnet and chloritoide (see also Krenmayr, 1999: Tab. 3).

8. Interpretation and Discussion

8.1 Sedimentary Environment and Facies

The facies characteristics of the Groisbach section include a fine-grained background sedimentation of grey and red-colored marlstones and marly limestones. The predominance of planktonic foraminifera, the fine-grained micritic mudstone to wackestone, and the presence of bioturbation are indicative of a bathyal, well oxygenated slope environment, probably in the upper to middle bathyal with water depths from 200 to 1500 m which are typical values for the Nierental Formation (Butt, 1981; Krenmayr, 1996, 1999; Wagreich and Krenmayr, 2005).

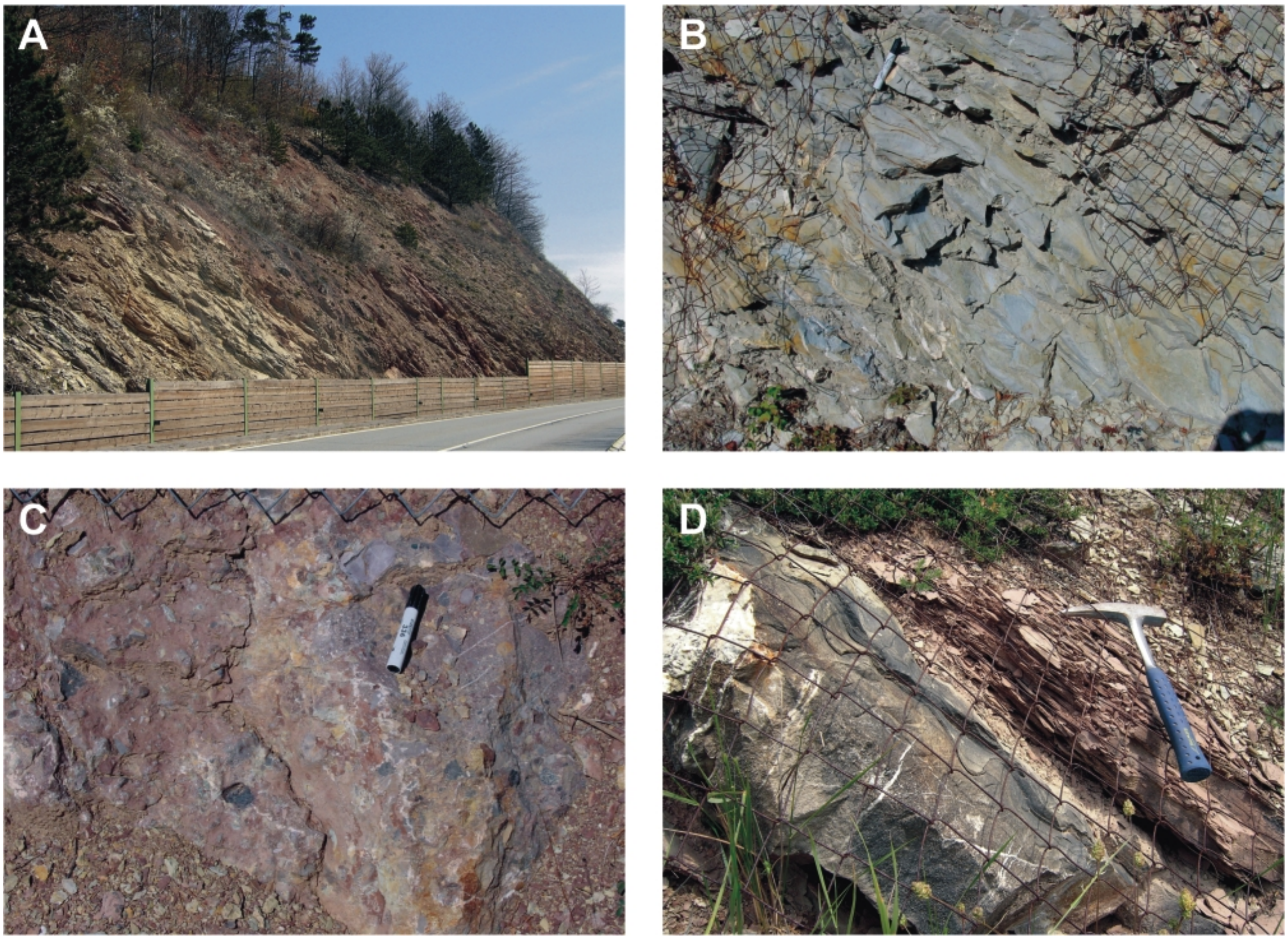

Figure 7: Outcrop photographs of the Groisbach section: (A) Overview picture of the outcrop situation (towards the SE) showing the lower part of the section in year 2008. (B) Grey marls, at section meter 3. (C) Red polymict conglomerate, section meter 26. (D) Graded turbidite sandstone layer with ripple lamination overlain by grey to reddish marls, section meter 124.

Within these fine-grained background sediments, various types of mass-flow deposits are intercalated. Especially in the lower to middle part of the Groisbach section, several intervals of partly graded conglomerate or breccia are present. The 3D-geometries of these coarse-grained sediments are not exposed, but sharp bases and graditional tops as well as lateral thickness changes within a few meters likely point to lense-like geometry, probably coarse-grained channels within the fine-grained background sedimentation. The internal sedimentary structures, i.e. partly matrix-support, massive appearance and upright clast orientations, indicate submarine debris-flow transport processes. These coarse-grained sediments can be classified as mass-transport complexes (MCTs) in the sense of Pickering and Corregidor (2005). Turbidites are nearly absent within this lower part of the section. This conglomerate interval of the Groisbach section can be mapped for several kilometers along strike of the outcrop belt (unpublished maps of G. Wessely), indicating a regional significance for this coarse-grained interval in the middle Campanian, most probably representing a deep-marine channel-fill system. In the upper part of the Groisbach section, a few classical medium to thick (30-50 cm) graded turbidite sandstone beds appear, together with thick massive carbonate (dolomite) breccia. Some of these breccia beds build the bases of sandstone beds and can be classified as breccia-turbidite-couplets. Due to the bad outcrop situation the geometry of these beds is hardly recognizable. However, a lens-like geometry can be inferred from scoured sharp bases and lateral thickness changes.

The Tasshof sections with its breccia layers can be correlated with the coarse-grained intervals of the Groisbach section. Depositional water depths may have been largely similar to the Groisbach area as indicated by predominance of planktonic foraminifera and the presence of a deeper-water ichnofauna including *Zoophycus*. The presence of thin-bedded, fine-grained sandstone-siltstone-marlstone packages within coarse-grained breccia bodies is typical of channel and interchannel areas on a more slope fan-like depositional system. Breccia beds show lense-like geometries based on frequent thickness-changes and pinching-out of breccia layers. Large slumps are present and indicate an unstable slope environment with frequent reworking.

The depositional systems recorded in the Groisbach and the Tasshof sections are interpreted as slope-type deep-water mass-flow systems in general (e.g. Prather, 2003; Hodgson and Flint, 2005). The absence of distinct fining- or coarsening-upward cycles and the rarity of classical turbidites excludes typical fan environments. Coarse-grained channel-fills within fine-grained bathyal slope background sedimentation are typical for the Nierental Formation. Slump deposits, as known from Tasshof, were not observed in the Groisbach section. These features point to

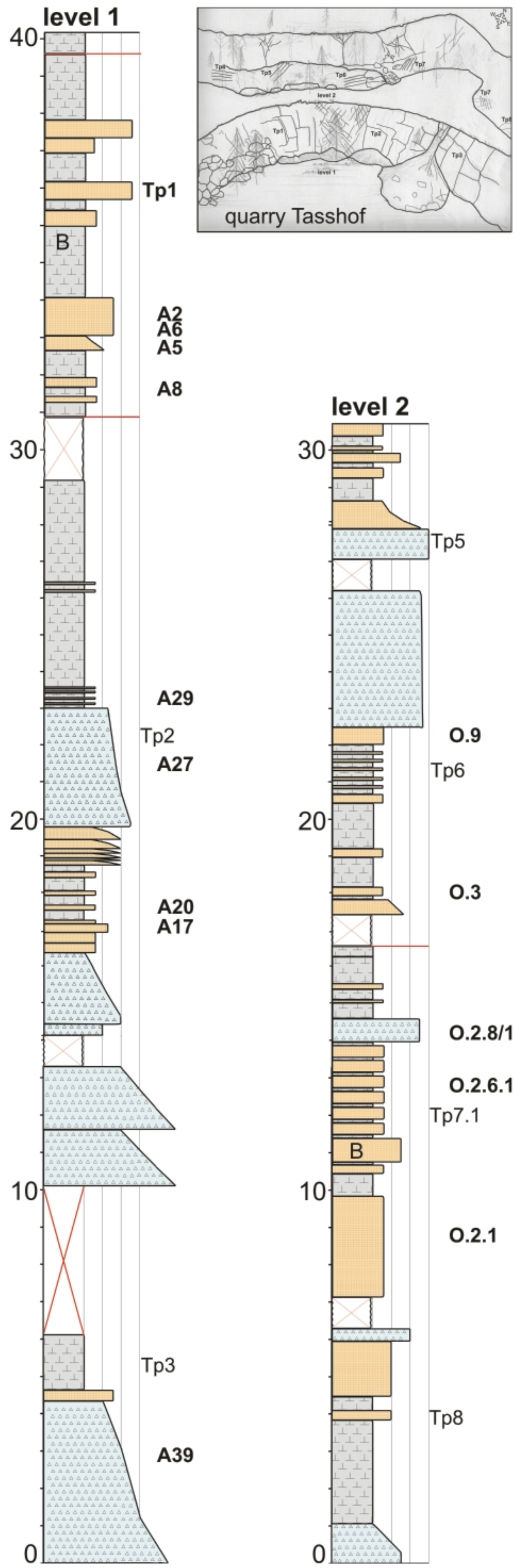

Figure 8: Sedimentological log of the Tasshof section (based on Ilickovic, 2011); for legend see Figure 6. A and O numbers are sample numbers. Inset shows sketch plan of the two quarry levels and the positions of section parts Tp1 to Tp7 within the quarry.

a slope-apron type depositional system (e.g. Wagreich, 2003) with a more linear source and a largely unorganized channel- and debris-flow depositional system at Groisbach. The more organized channel-interchannel successions at Tasshof may also point to the existence of small, coarse grained slope fans.

8.2 Provenance

In principle, both sections show a rather similar provenance of most of the clastic material. The lower part of the Groisbach section is outstanding in its content of quartz porphyry clasts ("exotic clasts" in the sense of e.g. Ampferer, 1918) besides a normal NCA clast suite from the surrounding older NCA rocks, including clasts of Werfen Formation, Middle Triassic limestones and Triassic dolomites. However, the presence of reworked Upper Cretaceous sandstones together with the quartz porphyry clasts indicates the reworking of older Cretaceous deposits, i.e. Branderfleck Formation, including well-known exotic conglomerates, and Coniacian-Santonian Gosau Group conglomerates and sandstones (Wessely, 1974, 2006). Reworking of older Cretaceous sediments may also be the reason for the predominance of chrome spinel in heavy mineral assemblages. The well known change from chrome spinel- to garnet-dominated heavy mineral assemblages (Woletz, 1967; Faupl, 1983) is not recorded in the section, as garnet is largely missing. The general evolution of the source area during the Campanian as recorded in the clast variations within the Groisbach section indicates a compareable mixed provenance in the lower part followed by a strong predominance of dolomites from the Upper Triassic Hauptdolomite in the upper part of the section. This may indicate further down-stepping of erosion into deeper units and/or an expansion of provenance into higher thrust units further to the south. Contemporaneous faulting along normal faults or coeval northward thrusting of southern, higher tectonic units may be involved.

The Tasshof section, on the other hand, is characterized, besides the predominance of local NCA clasts (mainly dolomites), by the presence of serpentinite clasts in the sandstone and breccia. Serpentinite clasts are a conspicuous feature of several Gosau Group litho-units, especially well known from more southern outcrop belts, from Grünbach to Gams/Hieflau up to the western NCA, at Brandenberg, Tyrol where a southern provenance was inferred from paleotransport directions and clast size distribution (Wagreich, 1993b; Wagreich et al., 2009). Together with high amounts of chrome spinel in heavy mineral assemblages, the serpentinite clasts of Tasshof point to the additional presence of a primary ophiolitic source to the south

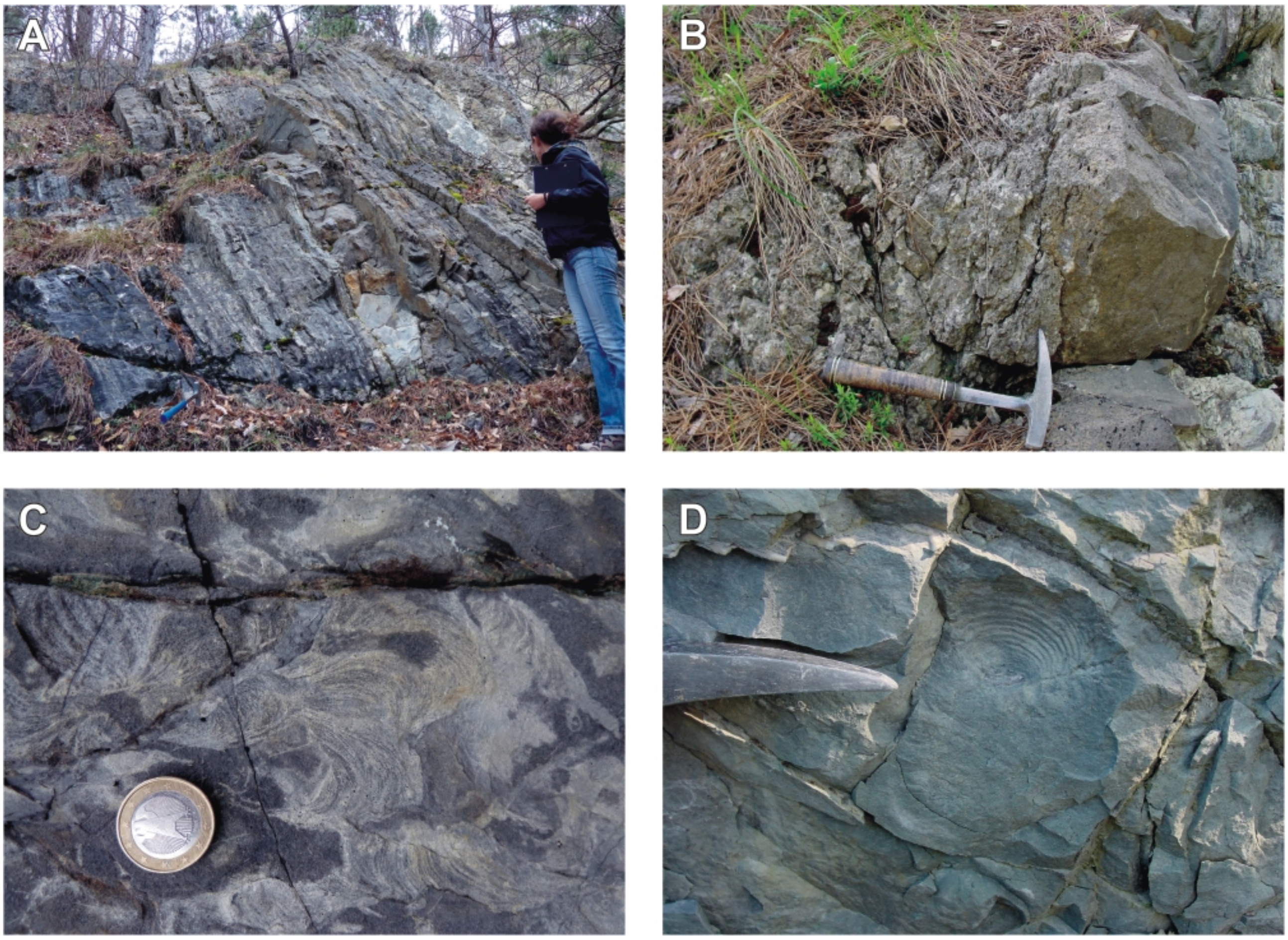

Figure 9: Outcrop photographs of the Tasshof section: (A) Thin-bedded marl-siltstone-sandstone succession, upper quarry level, Tp7. (B) Graded breccia-sandstone bed in overturned position, upper quarry level, Tp7. (C) Turbidite sandstone base with ichnofossils, i.e. *Zoophycos*, lower quarry level, Tp1. (D) Grey silty marl with *Inoceramus* cast, lower quarry level, Tp7.

of the investigated area still in late Early to early Late Campanian times. Remnants of a higher ophiolitic thrust unit on top of the NCA nappe stack, nowadays totally eroded, may have been the source for this ophiolitic detritus (see also Schuster et al., 2007; Wagreich et al., 2009) which may have been derived from a southern suture zone (“Hallstatt-Vardar suture”, Pober and Faupl, 1988; Faupl and Wagreich, 2000). Today, only small remnants of these ophiolitic bodies are present within tectonic melange zones (e.g. Summesberger, 1991, Gruber et al., 1992).

8.3 Campanian Palaeogeography

In general, the palaeogeographic evolution of the investigated area is characterized by its position along the active northern margin of the Austroalpine plate, to the south of the subducting Penninic Ocean (e.g. Faupl and Wagreich, 2000). During the Campanian, in the eastern part of the NCA, the transition from an originally mixed source originating from the north of the NCA to a later metamorphic provenance from the south took place. This implies a major palaeogeographic change to a rising metamorphic Austroalpine hinterland in the south in general (e.g. Woletz, 1967; Faupl, 1983; Pober and Faupl, 1988). However, in detail, the changes during the Campanian are more variable and influenced by regional and local geology. For the eastern part of the NCA in the Early Campanian a northward deepening, tectonically active slope can be reconstructed. Marginal marine – shallow-water to limnic sediments prevailed in Grünbach and Miesenbach to the south (e.g. Plöchinger, 1961; Gruber et al., 1992) in contrast to the Tasshof-Groisbach area, where bathyal slope environments predominated. Paleoflow directions of clastic fans and channels is generally from south to north as evidenced by reworked Gosau material and ophiolitic detritus from the south.

8.4 Geodynamic implications

The Campanian sections of Groisbach and Tasshof record a time of changing depositional systems in the Gosau Group due to the evolution from small-scaled extensional basins of the Lower Gosau Subgroup (Wagreich and Decker, 2001) to a large-scale tilting and deepening depositional area of the Northern Calcareous Alps as recorded by the Upper Gosau Subgroup (Wagreich, 1993a; Wagreich and Marschalko, 1995). This change, generally also recorded in the sedimentary detritus, i.e. the change in heavy mineral assemblages from chrome spinel- to garnet-dominated (Woletz, 1967; Faupl, 1983), led to the deposition of Campanian deep-water slope clastics from the Weyerer Arc-Grossraming area (Faupl, 1983: Hieselberg Formation and Spitzenbach Formation) to Lilienfeld (Wagreich, 1986) and the Gießhübl syncline (Wessely, 1974, 2006). We therefore infer a primarily tectonic control on the deposition of these carbonate clastics and no direct sea-level control (e.g. Eberli, 1991). The sections at Tasshof and Groisbach fit into this belt of slope clastics of mostly regional provenance. Both large-scale normal faulting and northward thrusting of higher tectonic units may control the development of these clastics giving rise to local relief and erosion into older rocks. As no clear-cut evidence for Campanian thrusting geometries in the mapped areas could be found and the Gosau Group successions continue without breaks into the thick siliciclastic Gießhübl Formation up to Upper Paleocene, we favor a model of active normal faults as the cause for the clastic slope basin and slope-apron system of the Campanian of this area (compare Faupl, 1983).

9. Conclusions

Based on the investigation of two Campanian Gosau Group sections in the northeastern Northern Calcareous Alps, we find evidence for a major rearrangement of the Gosau Group palaeogeography during this time interval. Coarse clastics, both breccias and conglomerates, within a bathyal marly background sedimentation indicate a deepening of the depositional area into bathyal depths. Synsedimentary active faulting attributes for the formation of slope basins and results in coarse-grained slope depositional systems like slope aprons and clastic fans along a steep submarine topography due to faulting. The presence of serpentinite clasts and high amounts of chrome spinel in heavy mineral assemblages point to erosion of ophiolite remnants in the south besides local clasts of the NCA and significant erosion of Upper Cretaceous rocks in the Groisbach section.

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