Carboniferous–Permian sequence of the Nassfeld area (Carnic Alps, Austria-Italy)

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Abstract: *In the Nassfeld area the post-Variscan sequences of the Carnic Alps is well preserved and consists of Late Palaeozoic to Early Mesozoic units which were deposited in equatorial realms. Of them the lithological and stratigraphical characteristics of the Carboniferous to Permian sediments are briefly described.*

Introduction

The Nassfeld area (= *ital.* Pramollo area) is located close to the border between Austria and Italy in the Carnic Alps (Fig. 1). It represents one of the most important localities in the Carnic Alps where the post-Variscan sedimentary sequence crops out (VENTURINI, 1990; KRAINER, 1990, 1995; SCHÖNLAUB & FORKE, 2007). According to VENTURINI (1983, 1990), the Carboniferous to Permian post-Variscan sequence at Nassfeld developed inside a narrow N120°E elongated tectonic basin (Pramollo Basin) which is separated from other basins in that region (Forni Avoltri and Tarvisio basins) by tectonically uplifted low elevations of the Hercynian basement. Since the tectonic evolution of the Nassfeld area is very complex, several hypotheses are published on the basinal development of that area (for different interpretations compare e.g., LÄUFER et al., 1993; VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007).

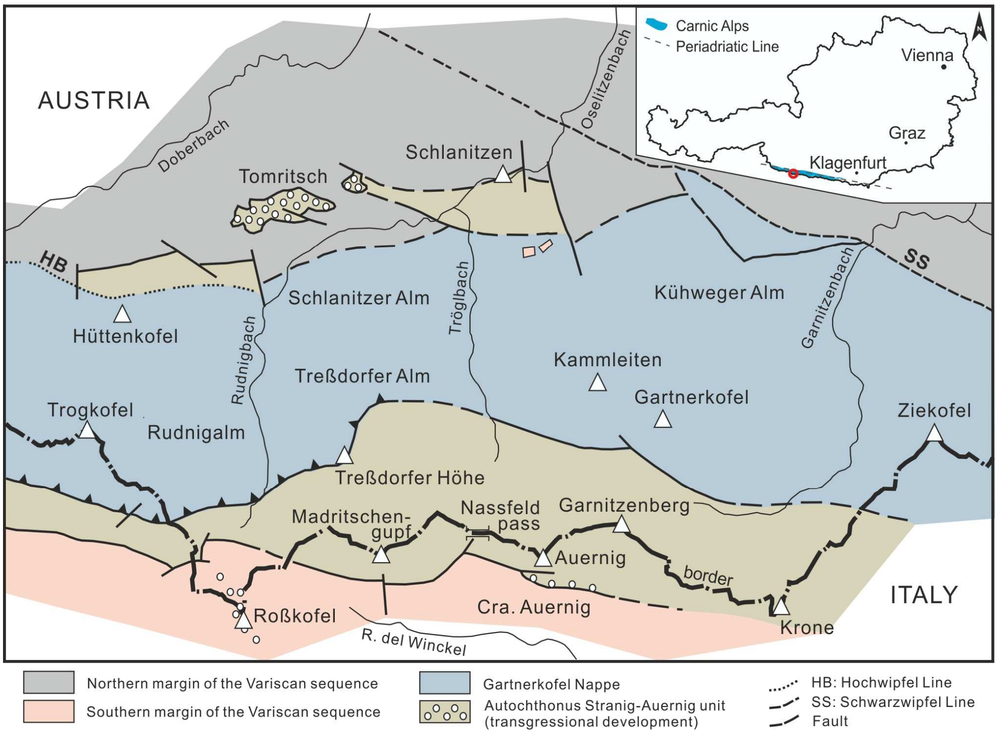

Fig. 1: Map of the Nassfeld area (Carnic Alps); modified after SCHÖNLAUB & FORKE (2007).

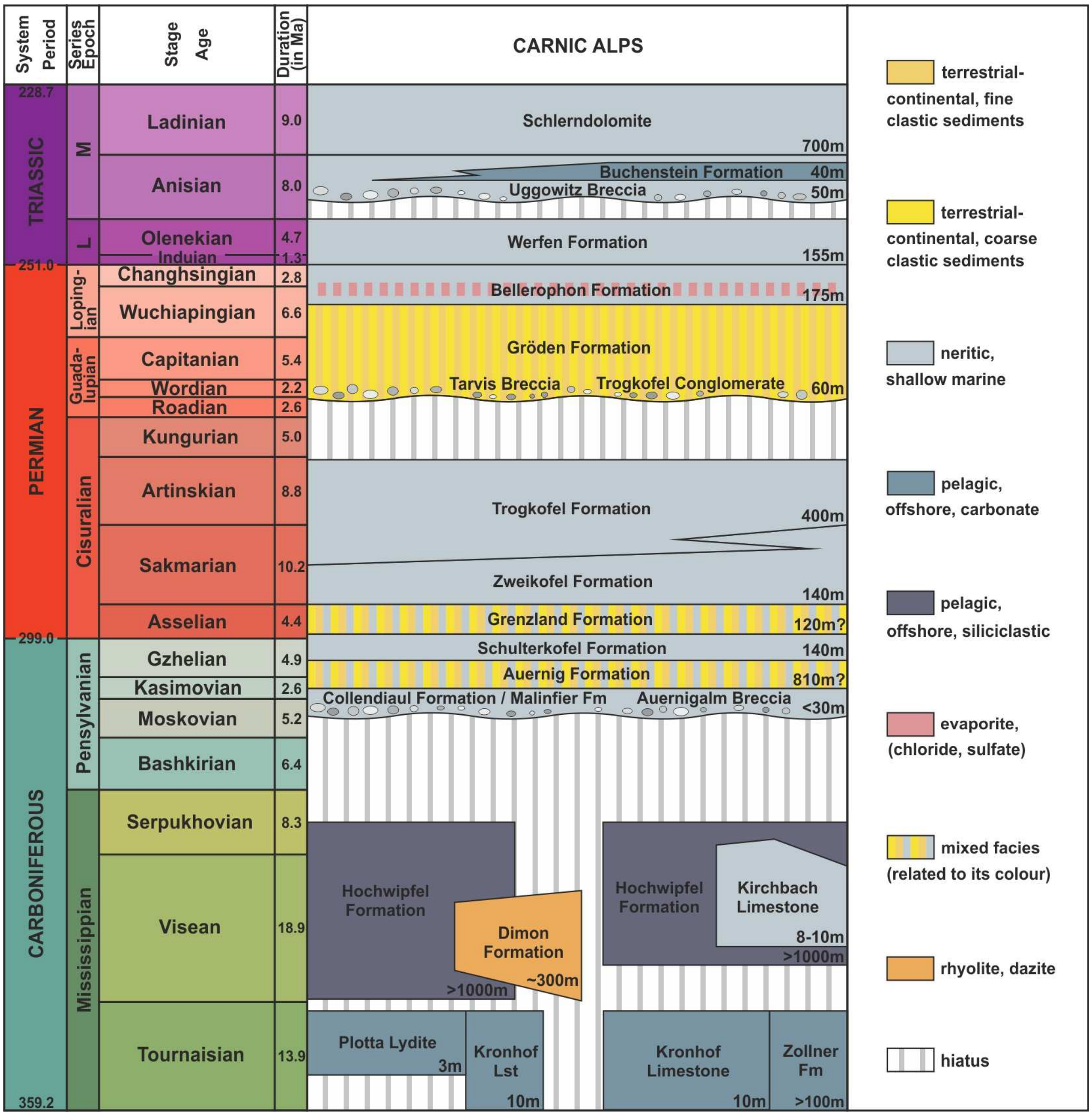

Fig. 2: Stratigraphic chart of Early Carboniferous (pre-Variscan sequence; after PILLER et al., 2004) and Late Carboniferous–Middle Triassic (post-Variscan sequence; after SCHÖNLAUB & FORKE, 2007) units in the Carnic Alps. The hiatus between the Serpukhovian–Moskovian stages demarcates the Variscan orogeny.

In general, the entire succession can be discriminated into three transgressive phases which rest unconformably upon each other and start with breccia-levels or conglomerates at the base (Fig. 2). The first transgressive phase covers the Late Carboniferous to Early Permian interval (Collendiaul Formation, Auernig Formation, Schulterkofel Formation, Grenzland Formation, Zweikofel Formation and Trogkofel Limestone) and reaches a thickness of about 1600 m. The second phase lasted from Middle Permian into Early Triassic (Tarvis Breccia, Gröden Formation, *Bellerophon* Formation and Werfen Formation) with a thickness of ca. 400 m. And the third transgressive phase covers the Middle Triassic time interval (Uggowitz Breccia, Buchenstein Formation and Schlerndolomite) with a thickness of approx. 800 m.

The sediments of this sequence are characterized by both, terrigenous and carbonatic deposits, which correspond to continental, deltaic, marginal marine, shelf and, but seldom, slope environments (VENTURINI, 1990). Here we briefly summarize the lithological character and fossil content of Upper Carboniferous to Permian deposits of Mount Krone (Carboniferous), Auernig (Carboniferous), Trogkofel (Permian) and Gartnerkofel (P/T boundary).

Post-Variscan sequence in the Nassfeld area

Upper Carboniferous

At Nassfeld, the basal units of the post-Variscan sequence are represented by the Collendiaul Formation (SCHÖNLAUB & FORKE, 2005), Malinfier Formation (VENTURINI, 1982) and the Auernig Breccia (SCHÖNLAUB & FORKE, 2005) resting unconformably upon the Hochwipfel Formation (Tournaisian–Visean). These deposits are composed of breccia and conglomerate horizons (max. 30 m in thickness). The upper part is marked by coarse clastic layers which are intercalated by silty and sandy shale. Based on conodonts (*Idiognathodus* sp. cf. *I*. *expansus* and *Swadelina*? sp. cf. *S*. *makhlinae*) and foraminiferans like *Fusulina* (*Quasifusulinoides)* sp., obtained from the uppermost part of the Auernig Breccia, an early Kasimovian age is proposed (SCHÖNLAUB & FORKE, 2007).

The overlying Auernig Formation (FRECH, 1894; KRAINER, 1992) is characterized by quartz conglomerates, cross-bedded sandstones, bioturbated siltstones, and bedded, massive or nodular limestones comprising a total thickness of about 600 to 800 m. A summary on further subdivision into six distinctive members (“Meledis” Mb, “Pizzul” Mb, Watschig Mb, Corona Mb, Gugga Mb and Carnizza Mb) is provided by FORKE et al. (2006) and SCHÖNLAUB & FORKE (2007). The fossil content of this unit is highly diverse and includes calcareous algae, foraminiferans (e.g., fusulinids), coralline sponges, gastropods, ostracods, brachiopods, bryozoans, echinoderms, conodonts and plants (e.g., DAVYDOV & KRAINER, 1999; FOHRER, 1991; FORKE & SAMANKASSOU, 2000). The age of the formation is based on different fossils groups and refers to the Kasimovian–Gzhelian (KRAINER & DAVYDOV, 1998; DAVYDOV & KRAINER, 1999; FORKE, 2007; FORKE & SAMANKASSOU, 2000; GAURI, 1965; KAHLER, 1983a, b, 1986, 1992; for summary see SCHÖNLAUB & FORKE, 2007).

Fig. 3: Panoramic view of Mount Krone (= *ital.* Mt. Corona); upper right corner: outcrop of plant-rich deposits.

At Mount Krone (type locality of the Corona Member; Fig. 3) and Mount Garnitzen (type locality of the Carnizza Member), less well bedded to massive limestone horizons consisting mainly of dasycladacean-boundstones reach a thickness of up to 22 m (*Anthracoporella* mounds; KRAINER, 1992 and SAMANKASSOU, 1998). These are alternating with realtively thick siliciclastic deposits of which especially the silt to fine grained sandstones near the middle part of the Mount Krone section (approx. 1730 m altitude) are rich in plants (Fig. 4). Since the first plant fossils were collected by HÖFER from and around Mount Krone in 1869 (FRITZ & BOERSMA, 1982), about 93 different taxa are described from more than 40 localities of this area (FRITZ et al., 1990; FRITZ & KRAINER, 2006, 2007). Taxa of following groups occur: Equisetophyta, Lycophyta, Filicophyta, Pteridospermae, Pteridophylla and Cordaitospermae.

Fig. 4: (a)-(g) Plant fossils of the section at Mt. Krone. (a) *Annularia* sp. (b) *Aphlebia* sp. (c) ?*Pecopteris* sp. (d) ?*Callipteridium* sp. (e) ?*Odontopteris* sp. (f) right: *Annularia* sp. (g) undetermined plant remains, and (h) casts of crinoid stem plates and brachiopods.

Fig. 5: Panoramic view of Mount Garnitzen (= *ital.* Carnizza).

At the western and southern slopes of Mount Auernig (Fig. 5) conglomerate levels alternating with sandstones, shales and limestones can be found. A more prominent interval of limestone beds occur in the uppermost part of the section (Carnizza Mb) which is well-known as "bed s" (SCHELLWIEN, 1892). This limestone produced abundant and exceptionally well-preserved silicified fossils (Figs. 6-8). Comprehensive palaeontological studies on bed g (= bed 15 of GEYER, 1896, and bed 116 of SCHÖNLAUB & FORKE, 2007) and bed s (= bed 30 of GEYER, 1896, and bed 148 of SCHÖNLAUB & FORKE, 2007) of the Auernig Formation at the Garnitzen and Auernig sections have been done for the i.e., fusulinids, ostracods, algae and bryozoans (SCHELLWIEN, 1898; FOHRER, 1991; LEPPIG et al., 2005). Additional fossil material of contemporaneous beds has been collected from the area around Lake Zollner and limestone hills in southeastern direction (DAVYDOV & KRAINER, 1999; FORKE & SAMANKASSOU, 2000) including foraminiferans (e.g., *Staffella*, *Schubertella*, *Fusiella*, *Protriticites*, *Quasifusulinoides*, *Beedeina*, *Fusulinilla*, *Montiparus* and *Praeobsoletes*), algae (e.g., *Herakella* sp., *Archaeolithophyllum* sp., *Euflugelia* sp.), coralline sponge (*Peronidella*), *Tubiphytes* and conodonts (e.g., *Hindeodus minutus*, *Idiognathodus* sp. cf. *I*. *expansus* and *Streptognathodus neverovensis*).

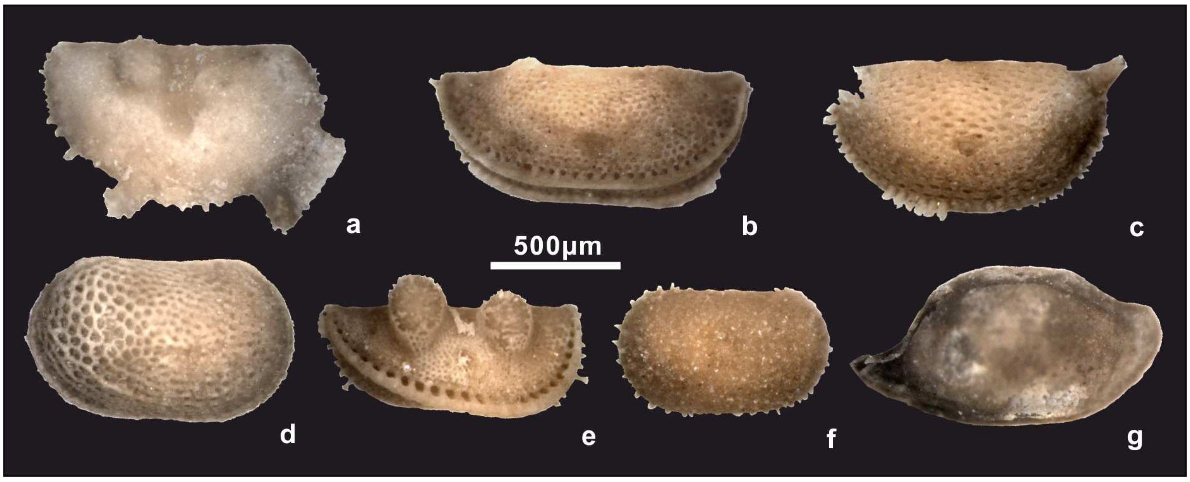

Fig. 6: Silicified ostracods of "bed s". (a) *Gortanella* sp. (b) *Aurikirkbya* sp. (c) *Coronakirkbya* sp. (d) *Shleesha* sp. (e) *Kellettina* sp. (f) *Roundyella* sp. (g) *Bairdia* sp.

Fig. 7: Silicified foraminiferans of "bed s". (a) *Palaeotextularia* sp. (b) *Climacammina* sp. (c) *Cribrogeneria* sp. (d)-(e) *Deckerella* sp. (f) encrusting specimen of *Calcitornella*, right specimen 250 µm. (g)-(i) *Tetrataxis* sp. (j) *Bradyina* sp. (k) cross-section of a fusulinid specimen.

The overlying Schulterkofel Formation (type locality: Mount Schulterkofel) is ca. 140 m in thickness and consists of bedded and massive limestones with subordinate siliciclastic rocks such as siltstone and fine-grained sandstone (KRAINER, 1995; SCHÖNLAUB & FORKE, 2007). Fossils occur in calcareous sandstones to sandy limestone horizons. The fauna consists mainly of foraminiferans, echinoderms, brachiopods and gastropods. Massive limestones are represented by *Anthracoporella* mounds (thickness: 2 - 3 m; max. 20 m), of which a mound and intermound facies can be discriminated (SAMANKASSOU, 1998, 1999). Based on the biostratigraphical study of fusulinids (*communis* to *versabilis* zones) the formation is Gzhelian in age (e.g. FORKE et al., 1998; KRAINER & DAVYDOV, 1998).

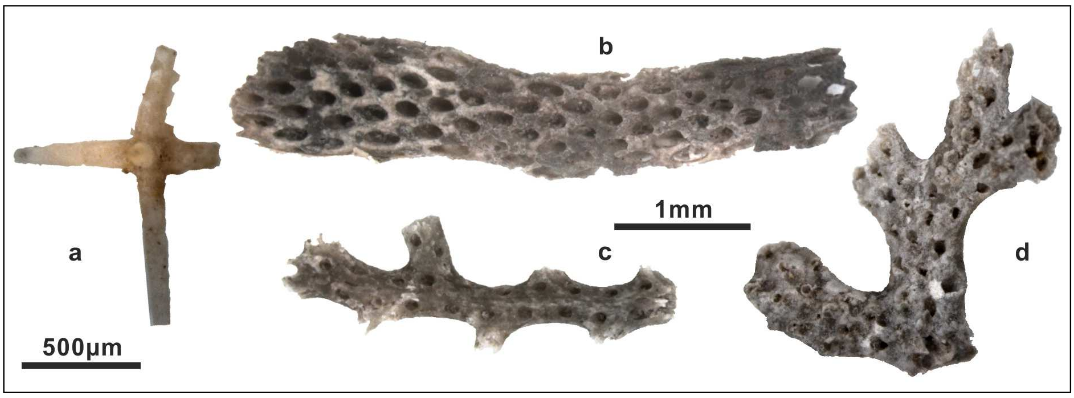

Fig. 8: Silicified fossils of "bed s". (a) sponge spiculae. (b)-(d) bryozoans.

Depositional environments and cyclic patterns of the Auernig and Schulterkofel formations

The sedimentation of the post-Variscan sequence of the Pramollo Basin is related to marine transgressive and regressive cycles which conform to single cyclothems of about 10 to 40 m in thickness (VENTURINI, 1990; KRAINER, 1992; SCHÖNLAUB & FORKE, 2007). That cyclicity is recognized in field by repetitive alternations of marine carbonates (Fig. 9; fossil content: fusulinids, algae, ostracodes, bryozoans, and brachiopods) and siliciclastic deposits bearing fossil mega-plants. The specific depositional pattern of the Auernig Formation has been intensively studied by e.g., FRECH (1894), GEYER (1896), HERITSCH et al. (1934), KAHLER (1955), BUTTERSACK & BOECKELMANN (1984), MASSARI & VENTURINI (1990), MASSARI et al. (1991), VENTURINI (1990), KRAINER (1991, 1992), SAMANKASSOU (1997a, b, 2002) and SCHÖNLAUB & FORKE (2007).

VENTURINI (1990) proposed that the close cyclicity developed in the Auernig deposits, which reflects sudden sea level fluctuations, is due to glacio-eustatic control with tectonic interferences. Accordingly he suggested that the Upper Carboniferous of "Auernig Group" (redefined as Auernig Formation by SCHÖNLAUB & FORKE, 2007) could be subdivided into two sets based on the sedimentation rate: A_1 - A_{2pp} (Kasimovian to lower Gzhelian) and A_{2pp} – A_3 – A_4 – A_5 (upper Gzhelian). Whereas the former set, indicates evidence of partial or generalized uplifts inside the Pramollo Basin, the latter one, conforms to lowering of large areas in the basin.

A similar cyclic pattern is documented from the overlying Schulterkofel Formation (HOMANN, 1969; SAMANKASSOU, 1997a, 1999). Here, four cyclothems which are related to sea level rise and fall are recognized within the *bosbytauensis-robusta* fusulinid zones. According to HOMANN (1969) and SAMANKASSOU (1997a), each of the cycles starts with siliciclastic deposition that grades into bedded and massive algal limestones.

Based on the palaeoenvironmental preferences of the distinctive association of heterozoan and photozoan communities within the Auernig cyclothems, temporary coastal upwelling is suggested for the Nassfeld area which was located in humid, tropical realms of the low latitudes during the Late Carboniferous (SAMANKASSOU, 2002).

Fig. 9: (a) Limestone interval within the Auernig Fm cropping out at the top of Mount Garnitzen. (b) in situ calcareous algae. (c) silicified fusulinids.

Permian

The Carboniferous Schulterkofel Formation is succeeded by the Grenzland Formation which is considered to be Permian in age, but due to uncertain correlation with the fusulinids biostratigraphy the position of the Carboniferous/Permian boundary remains unclear (e.g., KAHLER, 1983a, b: KAHLER & KRAINER, 1993; FORKE, 1995; FORKE et al., 1998; KRAINER & DAVYDOV, 1998; SCHÖNLAUB & FORKE, 2007). Although the contact with underlying and/or overlying strata is observed in the section of the Schulterkofel (FORKE et al., 1998; FORKE, 2000), at the Rudnigalm (FORKE, 2002), the Trogkar (FORKE, 2002) and at the Zweikofel (KRAINER, unpublished; SCHÖNLAUB & FORKE, 2007), the entire thickness of the formation is not known (estimated thickness is ca. 120 m; SCHÖNLAUB & FORKE, 2007). The formation is mainly composed of beds of clastic rocks such as conglomerate, sandstone and siltstone. Limestone beds are intercalated within the above mentioned beds, which consist of oncoidal limestones that yield foraminiferans (fusulinids), bioclastic limestones with a diversified fossil fauna and red limestone. The calcareous sandstone beds are observed in the transition to the limestone beds, and are characterized by brecciation on the top of the beds in which red matrix fills the space between brecciated components. Siltstone beds are commonly bioturbated. Sediments that indicate subaerial exposure of the deposits (recognized by the formation of palaeosols, fracture fillings, and collapse breccias) are outcropping in the section at the Zweikofel (Fig. 10). Within the sequence slumping, convolute bedding and load casts as well as ichnofossils are observed (SCHÖNLAUB & FORKE, 2007). The Grenzland Formation yields fusulinids like *Sphaeroschwagerina carniolica* and *Pseudoschwagerina extense* which are indicating a lower? to middle Asselian age. Additionally other fusulinids such as *Zellia*, *Robustoschwagerina* and species that belong to the *Paraschwagerina nitida* group are observed (FORKE, 2002).

The late Sakmarian to early Artinskian of the Zweikofel Formation is characterized by oncoidal and foraminiferal – algal limestones and siliciclastic deposits (conglomerate and sandstone). The thickness of the formation at the Zweikofel (type section) is 135 m (SCHÖNLAUB & FORKE, 2007). The fossil content of the Zweikofel Formation includes fusulinids such as *Zellia heritschi*, *Robustoschwagerina geyeri*, *Paraschwagerina nitida*, *Pseudofusulina* sp., *Pseudofusulinoides* sp. and conodonts like *Sweetognathus* sp. aff. *S. whitei*, *Mesogondolella bisselli* and species of *Diplognathodus* (FORKE, 2000; SCHÖNLAUB & FORKE, 2007).

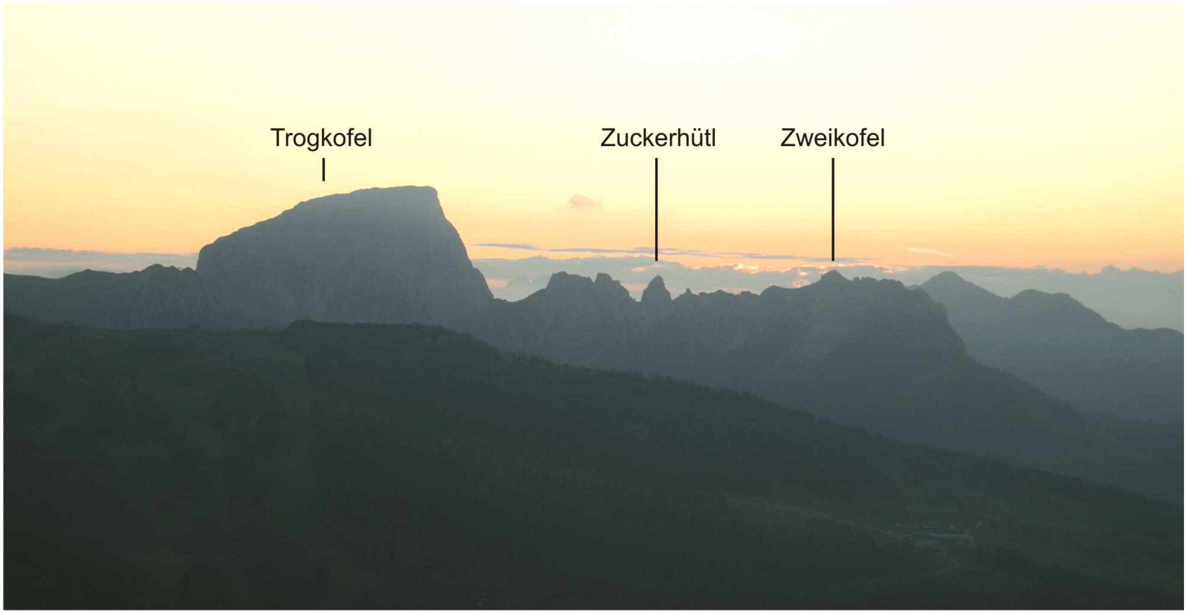

Fig. 10: Panoramic view of Mount Trogkofel and Zweikofel.

The Trogkofel Limestone is composed of mainly massive limestone which is partly reddish in color. In the section also shale beds and limestone breccia layers occur (SCHÖNLAUB & FORKE, 2007). The limestones are often dolomitized. According to VENTURINI (1990) the thickness is at maximum 400 m and decreases towards southeast. The formation is cropping out at the Trogkofel (Fig. 10) and the Reppwand. Within the massive limestone, *Archaeolithoporella* (encrusting algae) and *Tubiphytes* (microploblematica) which play role for cementation constructing boundstone, as well as bryozoans and echinoderms are observed (VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007). Additionally, wacke- and grainstones are observed in the unit (FORKE, 2000). Foraminiferans are low in diversity and occur in dasycladacean wack- and grainstones. The age of the Trogkofel Limestone is the late Artinskian which is based on the co-occurrence of the conodont *Neostreptognathodus* sp. cf. *N. pequopensis* and the fusulinid taxon *Robustoschwagerina spatopsa* (FORKE, 2000).

The Gröden Formation is unconformably overlain by metamorphic rocks and Late Palaeozoic marine deposits which are exposed north and south of the Periadriatic Lineament (SCHÖNLAUB & FORKE, 2007). The formation consists of breccia levels and conglomerates at the base, followed by the pelites which are red and partly greenish-grey in color. The deposits at the base of the Gröden Formation are assigned to the Tarvis Breccia when these cover the Auernig Formation and to the Trogkofel Conglomerate when deposits are accumulated on the Trogkofel Limestone (revised assignment follows SCHÖNLAUB & FORKE, 2007). The lithological features between the Tarvis Breccia and the Trogkofel Conglomerate differ. In the Straniger area, the Tarvis Breccia (thickness ca. 10 m) is composed of massive dolomite, rauwacke and red siltstones, whereas the Trogkofel Conglomerate consists of limestone pebbles which derived from the Trogkofel Limestone and from siliciclastic deposits. The beds composed of the pelites within the remaining part of the formation include alternating series of dolomitic shales and siltstones which are intercalated by nodular dolomitic marls or dolomites. The thickness of the Gröden Formation is approximately 60 m. The unit contents plant debris, stromatolithic algae, foraminiferans, ostracods, and gastropods (KAHLER & PREY, 1963; BUGGISCH, 1978).
As a high resolution biostratigraphy could not be established yet, the age of this unit is constrained to the interval from Guadalupian to Lopingian by the underlying Trogkofel Formation and the overlying *Bellerophon* Formation (SCHÖNLAUB & FORKE, 2007).

The Late Permian *Bellerophon* Formation is composed of dolomite, dolomitic marl and rauwacke in the lower part and platy to coarse bedded dolomitic limestones in upper part (SCHÖNLAUB & FORKE, 2007). The thickness is about 175 m. Within deposits of this unit small sized foraminiferans, dasycladacean, algae, ostracods, and radiolarians are found. The age of the formation is dated by foraminiferans belonging to the genus of *Paraglobivalvulina* and *Paradagmarita* (BOECKELMANN, 1988).

Depositional environments and cyclic patterns of Permian units
It is assumed that the Grenzland Formation (= *ital. syn.* Val Dolce Formation) was deposited at high-energy nearshore settings (FLÜGEL, 1975). Continued from the underlying Schulterkofel Formation, the unit remains a cyclic sedimentation. The individual cycles which are up to 10 m in thickness are characterized by siliciclastic deposits (conglomerates and sandstone at the base), covered by calcareous clastic beds which finally are overlain by oncoidal limestones.
Compared to the Grenzland Formation, the Zweikofel Formation comprises well developed limestones whereas siliciclastic input is reduced. In the Zweikofel, Zottachkopf and Trogkar areas, ooid barriers, oncoid limestone, and small mounds have been observed respectively. Based on facies analysis of the formation, these sediments are interpreted as deposits that accumulated on a carbonate platform under high energy to subtidal environments (SCHÖNLAUB & FORKE, 2007). In the formation, cyclic patterns show lateral variations. It is considered that they reflect morphological feature in the deposition at the shelf and sea-bottom as well as high-frequent sea-level fluctuations during the Sakmarian to Artinskian (SAMANKASSOU, 1997a).

The Trogkofel Limestone is characterized by massive limestone yielding algae and fusulinids and limestone breccia levels. Based on the lithological character of the unit a depositional environment on the shelf margin, platform and slope is assumed (VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007). The stratigraphically younger Gröden Formation shows a disconformable contact with the Trogkofel Limestone and the Auernig Formation. It is not clear yet whether the Gröden Formation was deposited under marine or continental conditions. Following BUGGISCH (1978), it is considered that the formation represents marine deposits based on fossils and the geochemical signal. The sediments of the *Bellerophon* Formation are interpreted as shelf environment with shallow water conditions that mostly referred to the open sea (VENTURINI, 1990).

Permian–Triassic boundary

In the Carnic Alps, the Permian/Triassic boundary can be observed in the surroundings of Nassfeld area. It is well documented from the drilling core in the Gartnerkofel region (Fig. 11) and the sequence exposed at the western Reppwand cliff. The scientific drilling was performed within an international project in 1986 at the Kammleiten peak (see publications in HOLSER & SCHÖNLAUB, 1991).

Fig. 11: Panoramic view of Mount Gartnerkofel.

At Kammleiten (summit height: 1998 m), a core of 331 m length was drilled with the position of the P/T boundary at the depth of 225 m. According to SCHÖNLAUB & FORKE (2007: p. 137) no sedimentary gap between the Permian and Triassic beds is found. The sediments across the boundary consist of dolomites which belong to the Permian *Bellerophon* Formation and also to the Triassic Werfen Formation. Although the dolomites show similar lithological character on both side of the boundary, the Permian and Triassic beds are distinguished by its fossil content and the distribution of quartz. In the outcrop section at the western Reppwand cliff, the P/T boundary is located between the *Bellerophon* and Werfen formations and is documented by the first occurrence of *Hindeodus parvus* in the Tesero Horizon of the Werfen Formation (SCHÖNLAUB, 1991).

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