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Geologic Frame of Palaeozoic Reefs in Austria with Special Emphasis on Devonian Reef-architecture of the Graz Palaeozoic

Geologischer Rahmen paläozoischer Riffe Österreichs mit besonderer Berücksichtigung der Riff-Architektur im Grazer Paläozoikum

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Abstract: The recognition of Palaeozoic reefs and reef-related deposition within Austria's borders has a long tradition. These developments are reviewed in stratigraphic schemes representing all non-metamorphic units of Austria. Generally all Palaeozoic strata suffered from various types of post-depositional loss, i. e. tectonic removal, dolomitization, metamorphic overprint, etc., during the Variscan and Alpidic orogenies, thus complicating or limiting their investigation.

Four phases in reefal development during the lower to middle/upper Devonian of the Graz Palaeozoic are outlined: flat mounds constructed by branching stromatoporoids, coral-stromatoporoid biostromes, patch-reefs, and bioherms built up by compound rugose corals.

Zusammenfassung: Paläozoische Riffablagerungen des alpinen Raumes sind schon lange bekannt und haben früh Eingang in die Literatur gefunden. Im folgenden wird eine Zusammenschau dieser Entwicklungen, sowie deren Einordnung in stratigraphische Schemata aller nichtmetamorphen Paläozoikumsvorkommen Österreichs geboten. Für die detaillierte Untersuchung von Riffen und riffassoziierten Ablagerungen muss generell bedacht werden, dass alle alpinen Paläozoikumsvorkommen verschiedenste Einschränkungen durch tektonische Zuschnitte, Dolomitisierung, metamorphe Überprägungen etc. während zweier orogener Phasen erlitten haben.

Im Grazer Paläozoikum lassen sich im Zeitbereich Unter- bis Mittel-/Oberdevon vier Phasen der Riffentwicklung unterscheiden: flachhügelige, durch ästige Stromatoporen aufgebaute Körper, Korallen-Stromatoporen-Biostrome, Flecken-Riffstrukturen und von massiven rugosen Korallen dominierte Riffkörper.

Key Words: Palaeozoic strata; Geologic frame; Development of reefs; Devonian of Graz.

Schlüsselworte: Paläozoikum; Geologischer Rahmen; Riffentwicklung; Grazer Devon.

Contents

1. Introduction

Austrian geologists discovered the Alpine Palaeozoic systems soon after their establishment in other countries. As early as 1843 – only 4 years after SEDGWICK & MURCHISON’s establishment (1839) of the Devonian System in southwestern England – the famous Austrian palaeobotanist Franz UNGER identified the Devonian age of fossiliferous strata in the vicinity of Graz (UNGER 1843). In 1847 Franz von HAUER recognized fossil-bearing Silurian rocks within the Greywacke Zone of the Central Alps. Between 1872 and 1884 Guido STACHE discovered Ordovician rocks, and fusulinids of Permian age, in the Southern Alps. Different authors mentioned Carboniferous strata early in the history of geological research in Austria. However, for several decades this system remained a vast bin for unidentified Palaeozoic rocks.

Knowledge on Palaeozoic corals and stromatoporoids in Austria dates back to the year 1843 when a list of Devonian fossils was published by Franz UNGER.

Four years later Adolphe MORLOT interpreted an interval of fossil-bearing strata as "reefs" (MORLOT 1847). In 1856, the presence of Carboniferous corals in the eastern Carnic Alps was mentioned in a letter by Eduard SUESS to Dionys STUR (STUR 1856); in 1868 SUESS noted the presence of rugose corals from the Nötsch Carboniferous. In 1870 Emil TIETZE recognized Devonian "reefal limestones" in the Karawanken Mountains containing corals which were subsequently described by FRECH (1887) and PENECKE (1887). Lower Palaeozoic corals of the central Carnic Alps were mentioned by Guido STACHE in 1884. One year later Karl HOFFMANN reported on solitary corals from the Greywacke Zone, which are Carboniferous in age (HOFFMANN 1885).

Austria's oldest sedimentary strata, pre-Ashgillian in age, are located in the Greywacke Zone, the Carnic Alps and Middle Carinthia. They consist of siliciclastic and volcanoclastic rocks containing only few fossils of Caradocian age. With the exception of a single poorly preserved steinkern of an Ashgillian streptelasmatid, the occurrence of corals and sponges starts in the Lower Silurian.

From the Graz Palaeozoic, the Carnic Alps and the Karawanken Mountains Mid-Palaeozoic reefs have been described for more than 130 years.

Although the term "reef" is part of our every-day language its correct use is far more problematic than it seems. This refers to the majority of Austrian Palaeozoic "reefs" since they are not mound-shaped (biohermal) but layered (biostromal). Throughout this paper we use the term "reef" for in situ accumulations of various kinds of calcium carbonate-secreting sessile organisms (mainly stromatoporoids, tabulates and rugose corals). These bio-constructions feature remarkably high mud portions and relatively unimportant cavity spaces. Therefore hydrodynamic conditions of the depositional environment were probably low to moderate although "reef-building" organisms are usually allochthonous due to frequent relocation through storm impacts. Architecturally comparable counterparts of these "reef bodies" may be modern coral carpets (cf. RIEGL & PILLER 2000).

The Mid-Palaeozoic was characterized by warm greenhouse climates as well as exceptionally high oscillating sea levels. Global tectonic plate movements arranged continents within equatorial belts, and oceanographic configuration allowed free circulation of warm ocean water. Consequently, favourable conditions for the creation of tropical carbonate factories were developed. At that time tropical platforms reached their largest areal and latitudinal extent, and metazoan reef development hit the Phanerozoic acme (COPPER 1994, 2002).

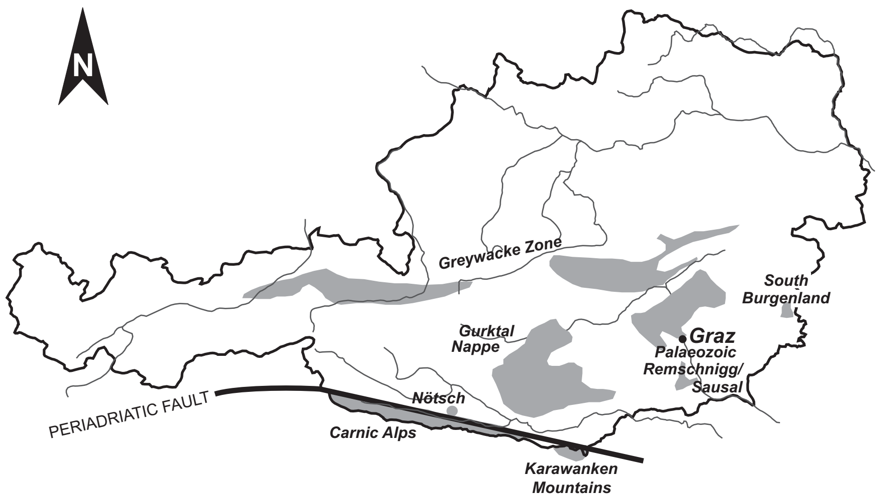
Mid-Palaeozoic shallow water deposits are exposed in some distinct regions within the alpine mountain belt, but the cnidarians, especially rugose corals (FLÜGEL & HUBMANN 1994), tabulates (HUBMANN 1995a, 2002), and other metazoan reef builders are limited. During the first prominent spreading of the Mid-Palaeozoic reef community, characterized by corals, stromatoporoid sponges and calcareous algae (WEBBY 1984; PONCET 1990), the depositional basins of the "Proto-Alps" suffered from cold to moderate water conditions due to high latitudinal position on a peri-Gondwanan terrane (SCHÖNLAUB 1992, 1997a).

In the Silurian the terrane (or several terranes?) on which the “alpine” sequences were deposited continued to shift from higher to lower latitudes. Palaeomagnetic data from northern Gondwana seem to support the assumption of rather rapid northward plate movements that brought the Alpine occurrences of Silurian deposits into an estimated position of approx. 30 to 40° southern latitude (Schönlaub 1997b). In the Lower Devonian (Emsian) some regions probably reached the equator (for instance the Graz Palaeozoic sediments; Fenninger et al. 1997), whereas other areas remained in higher latitudes (Schönlaub 1992). The northward shift with time is visible in facies patterns which were changing towards carbonate-rich sediments and an increasing biodiversity.

2. Geologic framework

2.1. Tectonic Zones

In Austria low grade metamorphic (precisely anchizonal to lower greenschist) Palaeozoic successions are irregularly distributed (Fig. 1). An unknown portion of sedimentary precursor sequences nowadays known as quartz-phyllites – but even amphibolite-grade metamorphic rocks – may also have originated during Palaeozoic times. Due to the incorporation of Palaeozoic successions as dismembered units into the rather complex Alpine Nappe System, their primary geographic position and their mutual bio-(geo)graphic relations are only poorly understood.



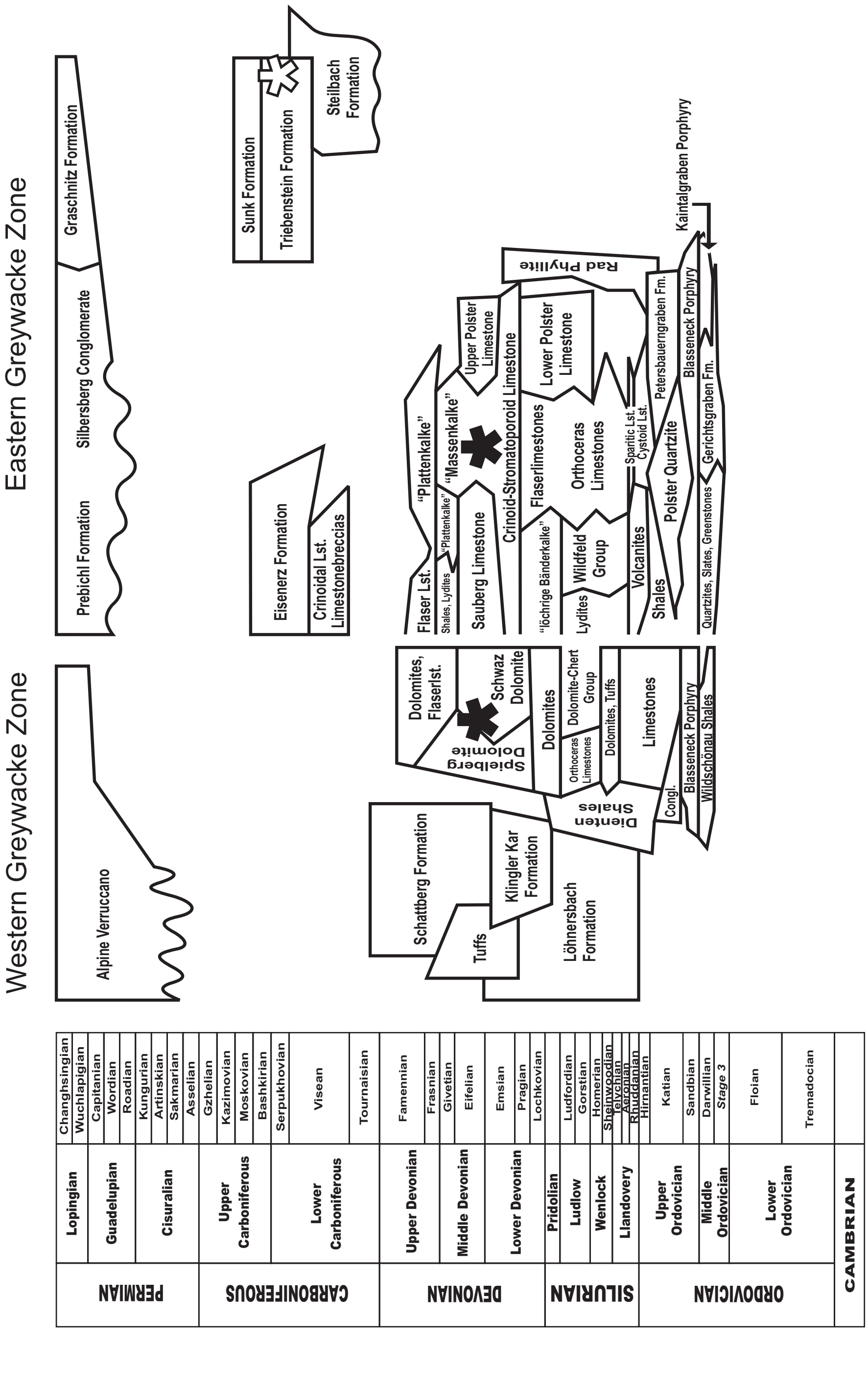
Generally two major regions of Palaeozoic developments separated by the Periadriatic Line, the most prominent Alpine fault system, are distinguished: the Upper Austroalpine Variscan sequences (i. e. the Greywacke Zone, the Nötsch Carboniferous, the Gurktal Nappe, the Graz Palaeozoic and some isolated outcrops in southern Styria and Burgenland) and the Southern Alpine sequences (i. e. the Carnic Alps and the Karawanken Mountains). Developmental differences of both areas are visible in different facies and biotic characters, as a result of independent histories of subsidence rates, amounts of volcanic activity and climatic impact.

Looking at the "bio-architecture" of the Upper Austroalpine sequences and the successions south of the Periadriatic Line, some regions developed reefs or coral-sponge bearing strata (Hubmann et al. 2003; compare synoptic view of Palaeozoic reefs and reef-related rocks drawn on revised stratigraphic columns of all Austrian non-metamorphic Palaeozoic remains in Fig. 2-7).

2.2. Greywacke Zone

This unit comprises moderately metamorphosed Ordovician to Carboniferous rocks, with fossils either poorly preserved or completely lacking. Parts outcropping in a belt between Salzburg and Tyrol belong to the Western Greywacke Zone (cf. Schönlaub & Heinisch 1993). Significant constituents of this unit are acidic volcanics of Upper Ordovician age which are probably related to plate disruption in northern parts of Gondwana. The volcanics are underlain by a thick sequence of schists, slates, marls, and pyroclastic fragmentites, the Wildschönau Slates, which demonstrate persistent volcanic activity until the Lower Carboniferous. Locally the slates represent turbiditic deepwater

Fig. 1: Distribution of "non-metamorphic" Palaeozoic units within Austria's borders. The bold line indicates the suture of the Periadriatic fault separating Austroalpine units in the north from Southalpine units. The area north of the Periadriatic fault has only few rock sequences in common with the Southern Alps, especially Ordovician to Devonian siliciclastics, contemporaneous local reef developments during the Devonian, and basal magmatism in the Ordovician, Lower Silurian and in the Middle Devonian (cf. Fig. 2). Intense intra-plate volcanism may be related to crustal extension probably responsible for different facies developments occurring in most areas north of the Periadriatic fault during the Silurian and parts of the Devonian.
Abb. 1: Verteilung nicht-metamorpher paläozoischer Einheiten Österreichs. Die verbreiterte Linie im Süden ("Periadriatic Fault") kennzeichnet den Verlauf der Periadriatischen Naht. Diese trennt die im Norden gelegenen Ostalpinen von den Südalpinen Einheiten. Gebiete nördlich der Periadriatischen Naht haben nur wenige vergleichbare Gesteinsabfolgen mit den Südalpen; im Besonderen sind dies siliziklastische Entwicklungen des Ordoviziums bis Devons, gleichzeitiges Riffwachstum während des Devons, und der basale Magmatismus (Ordovizium, Untersilur, Mitteldevon; cf. Fig. 2). Durch Ausdünnung der Kruste hervorgerufener Intraplattenvulkanismus ist vermutlich verantwortlich für die vielfältige Faziesentwicklung im Silur und Unterdevon nördlich der Periadriatischen Linie.


Western Greywacke Zone
Eastern Greywacke Zone
PERMIAN
CARBONIFEROUS
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
Lopingian
Guadelupian
Cisuralian
Upper Carboniferous
Lower Carboniferous
Upper Devonian
Middle Devonian
Lower Devonian
Pridolian
Ludlow
Wenlock
Llandovery
Upper Ordovician
Middle Ordovician
Lower Ordovician
Changhsingian
Wuchiapigian
Capitanian
Wordian
Roadian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kazimovian
Moskovian
Bashkirian
Serpukhovian
Visean
Tournaisian
Famennian
Frasnian
Givetian
Eifelian
Emsian
Pragian
Lochkovian
Ludfordian
Gorstian
Homerian
Sheinwoodian
Telychian
Aeronian
Rhuddanian
Hirnantian
Katian
Sandbian
Darwillian
Stage 3
Floian
Tremadocian
Alpine Verruccano
Schattberg Formation
Tuffs
Klingler Kar Formation
Löhnersbach Formation
Dienten Shales
Congl.
Dolomites, Flaserlst.
Spielberg Dolomite
Schwaz Dolomite
Dolomites
Orthoceras Limestones
Dolomite-Chert Group
Dolomites, Tuffs
Limestones
Blasseneck Porphyry
Wildschönau Shales
Prebichl Formation
Silbersberg Conglomerate
Graschnitz Formation
Eisenerz Formation
Crinoidal Lst. Limestonebreccias
Sunk Formation
Triebenstein Formation
Steilbach Formation
Flaser Lst.
Shales, Lydites
"Plattenkalke"
"Plattenkalke"
"Massenkalke"
Sauberg Limestone
Upper Polster Limestone
Crinoid-Stromatoporoid Limestone
"löchrige Bänderkalke"
Flaserlimestones
Lower Polster Limestone
Rad Phyllite
Lydites
Wildfeld Group
Orthoceras Limestones
Sparitic Lst.
Cystoid Lst.
Volcanites
Shales
Polster Quartzite
Petersbauerngraben Fm.
Quartzites, Slates, Greenstones
Gerichtsgraben Fm.
Blasseneck Porphyry
Kaintalgraben Porphyry

sediments interfingering with Upper Silurian to Devonian pelagic limestones, Devonian basaltic lavas and tuffs, as well as Lower Carboniferous basalts. A higher wedge is dominated by carbonates of Silurian to Devonian age. Dolomites prevail in this part.

The Lower Austrian and Styrian parts belong to the Eastern Greywacke Zone, which roughly can be subdivided into two nappe systems. The Noric Nappe together with the underlying Kaintaleck- and Silbersberg Nappe is dominated by Lower Palaeozoic rocks. Similar to the Western Greywacke Zone, a more than 1500 m thick lithostratigraphic unit comprising different types of massive ignimbrites and other pyroclastics (Blasseneck Quartz porphyry) is underlain by quartzites, slates and pyroclastic rocks which are compared with the Wildschönau Slates. The Quartz porphyry itself is overlain by Ashgillian quartzites and Cystoid Limestones. The Silurian and Devonian are characterized by sequences (up to 300 m) of limestones locally containing strongly recrystallized stromatoporoids. Parts of these limestones are metasomatically replaced by siderite and form the iron mine at Erzberg/Eisenerz.

The Devonian sequence is disconformably overlain by limestone breccias with conodonts spanning a time-interval from the Middle Devonian to Lower Carboniferous, and by the clastic Eisenerz Formation probably ranging from Visean to lowermost Upper Carboniferous. This sequence, ranging from Upper Ordovician to Upper Carboniferous age represents the primary base of the Permo-Mesozoic sequences of the Northern Calcareous Alps.

The Noric nappe-group is underlain by the Veitsch Nappe which is Carboniferous in age. The Lower Carboniferous (Visean) is characterized by shales, crinoidal limestones and dolomites (Steilbach and Triebenstein Formation; Fig. 2).

Fig. 2: Greywacke Zone. Explanation to Fig. 2-7: Stratigraphic columns of "non-metamorphic" Palaeozoic units within Austria's borders. The fundamental base for the schemes was provided by Schönlaub (1979). Lithostratigraphic revisions or re-designations of formations during the last two decades are mentioned (Pasini 1963; Neubauer & Pistotnik 1984; Ratschbacher 1984; Schönlaub 1985; Heinisch 1988; Kreutzer 1992a, b; Neubauer et al. 1994; Ebner et al. 2000, 2001; Flügel 2000; Kreutzer et al. 2000; Hubmann 2003). White stars indicate reef-development; black stars denote coral/sponge-rich strata which contain either poorly preserved fossils or do not comply with reef definitions. White star in brackets indicates reefal boulders found reworked in Neogene sediments (Arnfels Fm.; Schell 1994). Dating scale after the International Stratigraphic Chart of the IUGS (2004).

Abb. 2: Grauwacken-Zone. Erläuterungen zu Abb. 2-7: Stratigraphische Tabelle der nicht-metamorphen paläozoischen Einheiten in Österreich. Darstellungsgrundlage nach Schönlaub (1979) mit zahlreichen lithostratigraphischen Veränderungen (Pasini 1963; Neubauer & Pistotnik 1984; Ratschbacher 1984; Schönlaub 1985; Heinisch 1988; Kreutzer 1992a, b; Neubauer et al. 1994; Ebner et al. 2000, 2001; Flügel 2000; Kreutzer et al. 2000; Hubmann 2003). Weiße Sterne kennzeichnen Riffe; schwarze Sterne weisen auf Korallen/Stromatoporen-reiche Abfolgen, die entweder schlecht erhaltene Fossilien führen oder nur vereinzelte Anreicherungen von Korallen und Stromatoporen aufweisen und somit nicht als Riffe angesprochen werden können; in Klammer gesetzter weißer Stern kennzeichnet Riffschutt-Blockwerk, das in Sedimenten des Neogen wieder aufgearbeitet wurde (Arnfels-Fm.; Schell 1994). Die Zeitskala folgt der Internationalen Stratigraphischen Tabelle der IUGS (2004).

Within the 300 m thick Triebenstein Formation, RATSCHBACHER (1987) reported scattered rugose coral patch-reefs. The Upper Carboniferous consists of sequences with conglomerates, sandstones and slates containing plant fossils of Bashkirian to Moskovian age (Sunk Formation).

2.3. Gurktal Nappe System

The Gurktal Nappe System contains Ordovician to Early Carboniferous basement sequences and Late Carboniferous to Triassic covering sequences (NEUBAUER 1987, 1992). In general the nappe complex is subdivided into two major tectonic units, the lower Murau Nappe and the higher Stolzalpe Nappe. Both nappes contain Lower Palaeozoic successions showing similar stratigraphic trends, but striking differences in detail. The lower Murau Nappe consists of black shales and phyllites of unknown age overlain by Upper Silurian to Lower Devonian carbonates (Fig. 3).

The basal sequence (approx. 500 m) consists of phyllites and greenschists derived from lava flows, sills and tuffs which are overlain by a phyllite-rich unit (300 m). Carbonate phyllites, black phyllites, and quartzites with minor greenstones and orthoquartzites build up the next higher stratigraphic unit. At the southern border of the Gurktal Nappe Complex, widespread acidic volcanoclastics occur (LOESCHKE 1989). The overlying sequence is characterized by laterally differentiated carbonates of Late Silurian to Early Devonian age.

Basal parts of the Stolzalpe Nappe are similar to those of the Murau Nappe consisting of mafic volcanic sequences. These sequences are divided into the Middle to Late Ordovician Magdalensberg Group, the Late Ordovician Nock Group and the volcanic Early to Middle Silurian Eisenhut Group at the northern edge of the Gurktal Nappe System. These volcanic successions are overlain by sequences dominated by pelitic-psammitic rocks passing into pelagic limestones (Upper Devonian to Lower Carboniferous) at the top.

Corals and sponges are very rare in the Gurktal Nappe Area with an exception of a Silurian limestone lens within a 400 m tick clastic sequence near Klein St. Paul (Carinthia) containing fossil debris (crinoids, brachiopods) and tabulate corals (STREHL 1962).

2.4. Graz Palaeozoic

The Graz Palaeozoic consists of a pile of nappes thrusting upon a metamorphic basement; no undeformed basement is known. Each nappe unit comprises different facial developments. Lithologic similarities, tectonic position, and metamorphic superimposition allow discerning a basal, an intermediate, and an upper nappe group (Fig. 4).

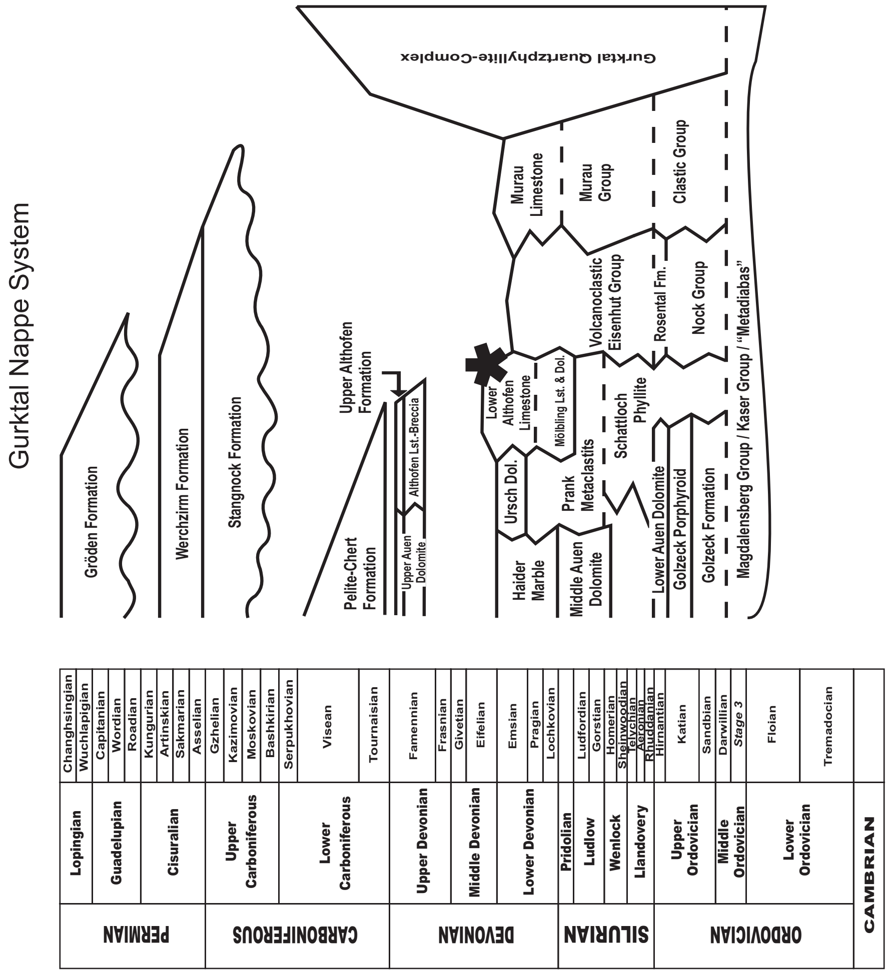


Fig. 3: Gurktal Nappe System. Explanations cf. Fig. 2.
Abb. 3: Gurktaler Deckensystem. Erläuterung vgl. Abb. 2.

The Basal Nappe System was deformed under upper greenschist facies conditions (with exceptionally amphibolite facies) in the Upper Silurian to Lower Devonian.

The Intermediate Nappe System (Early Silurian to Upper Devonian) includes two nappe groups in different structural levels. One contains pelagic limestones, shales and volcanoclastics, the other limestones and siliciclastics.

The Upper Nappe System (Upper Silurian to Upper Carboniferous) comprises the Rannach- and Hochlantsch-Nappes. Both have similar facies developments, especially in the Emsian to Givetian. Successions are composed of volcanoclastic rocks (Silurian to Early Devonian; Reinerspitz Group), siliciclastics and fossil-rich carbonates (Early to Middle Devonian; Rannach Group, Lantsch Group) of a near-shore environment followed by the pelagic Forstkogel Group (Late Givetian to Bashkirian) and the shallow marine Dult Group (Serpukovian, Bashkirian).

Using a palaeogeographic interpretation of the Palaeozoic succession, the formations of the Upper Nappe System are interpreted as having developed nearest to shore, and the Intermediate Nappe System in an off-shore setting. Successions of the Basal Nappe System occupied an intermediate position (Hubmann 1993). The stratigraphic sequence indicates a change from a passive continental margin with the continental breakup (alkaline volcanism) to shelf and platform during the Silurian to Devonian (Fritz et al. 1992). During this time, persistent subsidence is documented by increasing carbonate production in the Upper Nappe System. During Pragian to Givetian time deposition changed from near-shore facies to open platform environments. During that time interval sea-level changes and probably synsedimentary tectonics had affected both the lithology (i. e. alternations of dolostones and limestones within the succession; Hubmann 1993) and resulted in the formation of stratigraphic gaps and mixed conodont faunas (Ebner 1978). In the Frasnian the carbonate platform drowned and bedded cherts (lydites) and cephalopod limestones were deposited.

2.5. Remschnigg/Sausal areas

In South Styria, various Palaeozoic rocks are encountered as scattered isolated outcrops surrounded by sediments of the Neogene Styrian basin. Their affiliation to other Palaeozoic units, i. e. the Graz Palaeozoic or the Gurktal Nappe System is unclear. The lowermost strata in the Remschnigg area are composed of volcanoclastics overlain by slates and marly shales, flaser-limestones and marly crinoidal limestones of Llandoverian to Wenlockian age (cf. Žorž & Moser 2002). This succession is overlain by slates and sandstones of unknown age (Upper Palaeozoic?) and dolomites and/or detrital limestones of Triassic to Cretaceous age (Fig. 5).

A comparable sequence is known from the Sausal area where slates and sandstones alternate with greenschists and diabase volcanites (Schlamberger 1987). Platy limestones of Emsian age (as indicated by conodonts) are replaced by biodetritic limestones locally containing corals which are (presumably) of Lower to Middle Devonian age.

2.6. Southern Burgenland

In southern Burgenland, Palaeozoic outcrops similar to those of the Styrian Remschnigg/Sausal areas occur. Isolated occurrences are buried by Neogene sediments, thus complicating reliable comparisons with other Palaeozoic remnants in Austria (Fig. 5).

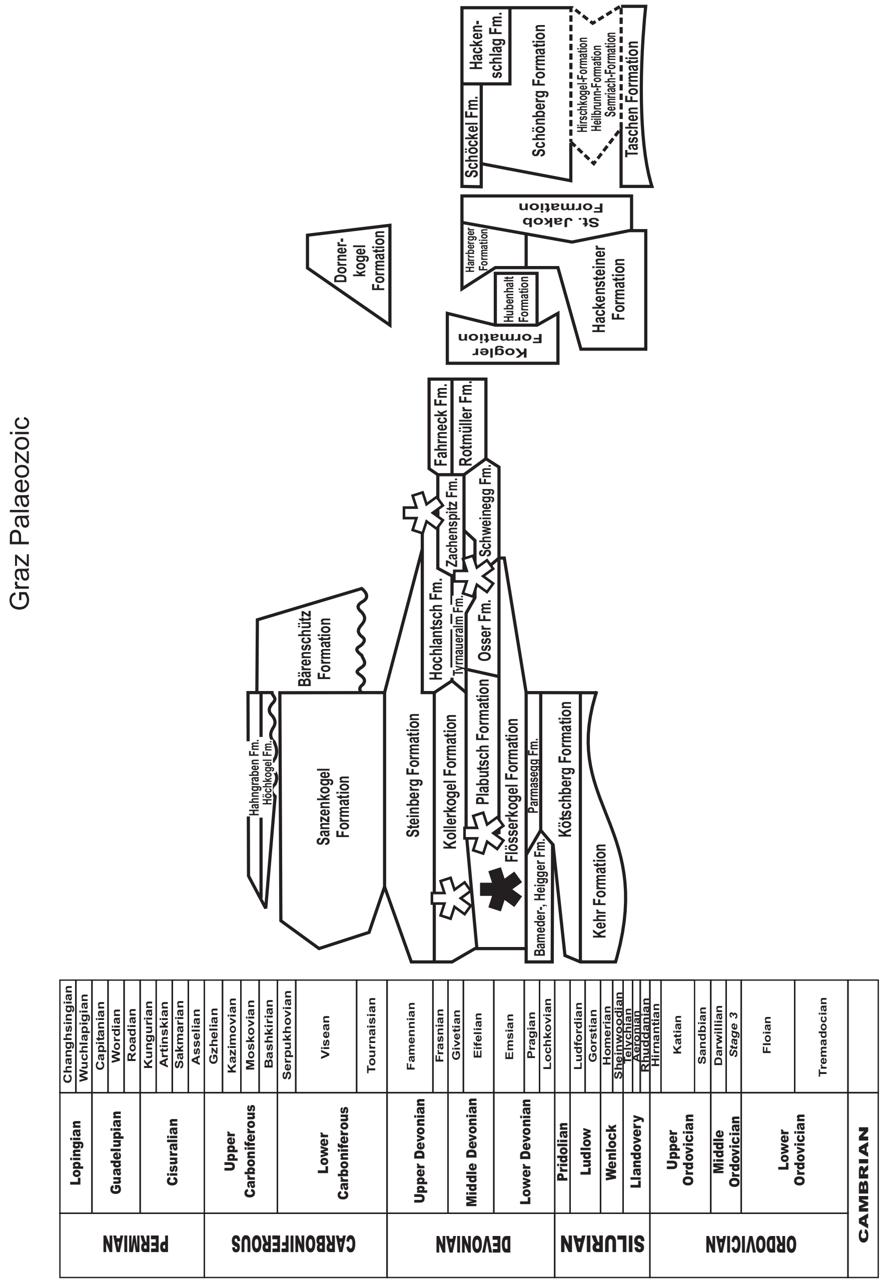


Fig. 4: Graz Palaeozoic. Explanations cf. Fig. 2.
Abb. 4: Grazer Paläozoikum. Erläuterung vgl. Abb. 2.

Rocks known from some scattered outcrops in that area comprise shales, limestones and dolomites of unknown cumulative thickness (Hoffmann 1877; Pollack 1962). A fossil assemblage of conodonts, rugose and tabulate corals and crinoid debris indicates Lower Devonian age for at least parts of the carbonate sequence (Schönlaub 2000a; Suttner & Lukeneder 2004). Biostratigraphic data together with similarities in facies developments suggest an originally close connection with fossiliferous sequences around Graz (Schönlaub 1994). This conclusion is supported by frequently occurring dolomitic rocks of Lower Devonian age in the subsurface of the Neogene Basin of eastern Styria (Ebner 1988).

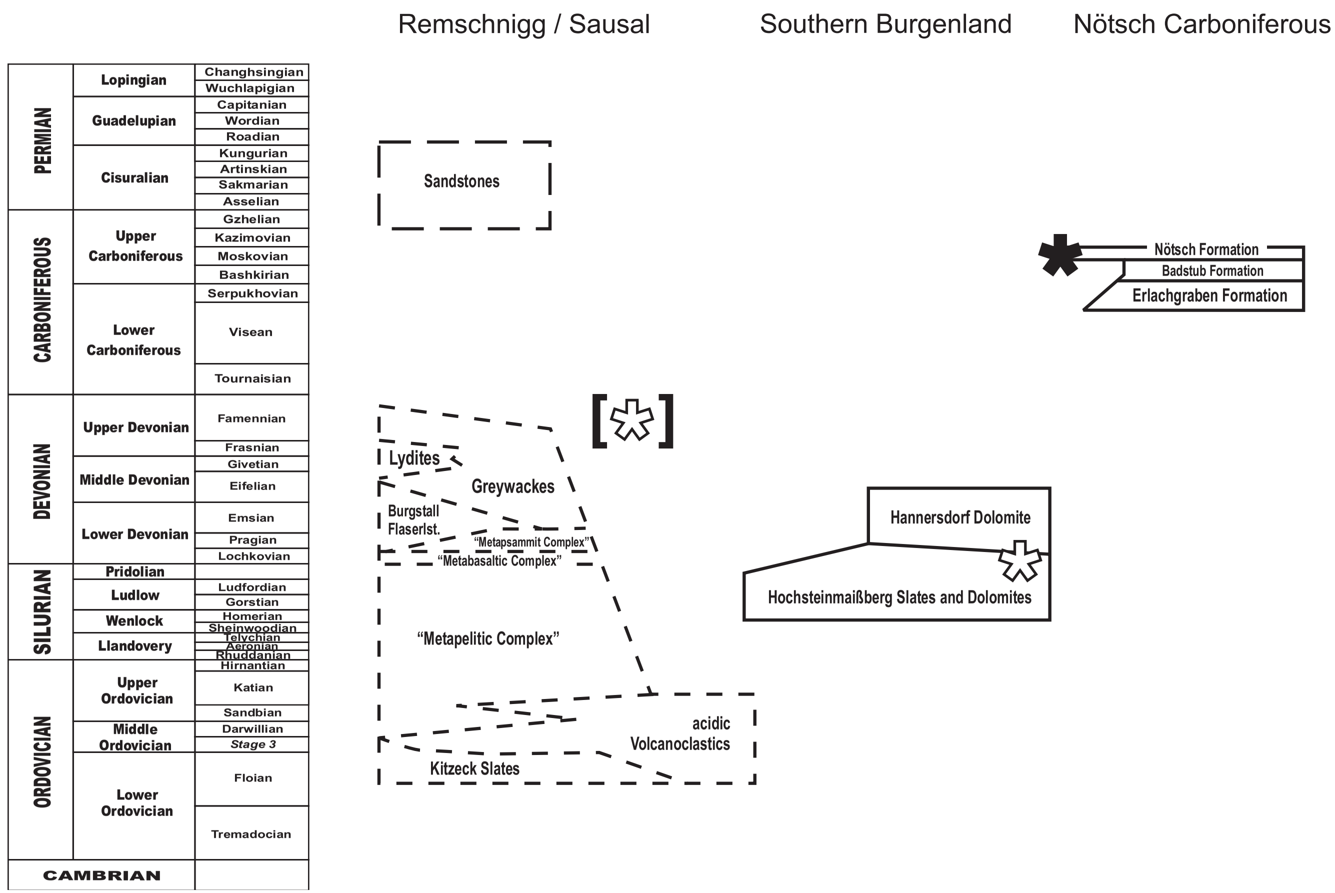
2.7. Nötsch Carboniferous

The Nötsch Carboniferous represents a tectonically isolated sequence occupying a small area of approximately 30 km^2, well known since the 1820ties because of its rich fauna (Schraut 1999; Fig. 5).

The area of the Nötsch Carboniferous was strongly affected by the last Quaternary glaciation event and hence major parts are covered by glacial deposits. Although outcrops are rare and isolated, the succession may be subdivided into three formations. The lower Erlachgraben Formation consists of basal polymict conglomerates, immature sandstones, siltstones and shales showing sedimentary features of both deep-sea and shallow marine depositional environments. The intermediate Badstub Formation comprises a succession of breccias and conglomerates with amphibolite, granite, gneiss, quartzite, and carbonate pebbles and intercalated sand- and siltstones. Approximately in the middle of the sequence a remarkable multi-meter thick shale unit is developed. This interlayer contains a rich fauna dominated by brachiopods and corals. The structural, textural and compositional features of the Badstub Formation (Krainer 1992, 1993) indicate that the sediments represent submarine re-sedimented deposits formed by gravity flows on a proximal fan or slope (fan delta, slope apron), along an active fault zone at a passive margin. Age indications for the deposit are provided by Upper Visean conodonts in grey limestone clasts and an Upper Visean trilobite fauna from shales overlying the Badstub Formation. Plant fossils point to a deposition of the breccia in a short time-interval during the Upper Visean.

The overlying Nötsch Formation shows some similarities with the upper part of the Erlachgraben Formation. A turbiditic setting for a 100 m thick sequence of shales and siltstones rich in fossils (brachiopods, bivalves, bryozoans, echinoderms, gastropods, trilobites, corals, nautiloids, plants, etc.) intercalated with sandstones and conglomerates was proposed by Krainer (1992, 1997).

Fig. 5: Remschnigg/Sausal, Southern Burgenland, Nötsch Carboniferous. Explanations cf. Fig. 2.
Abb. 5: Remschnigg/Sausal, Südburgenland, Karbon von Nötsch. Erläuterung vgl. Abb. 2.


Remschnigg / Sausal
Southern Burgenland
Nötsch Carboniferous
PERMIAN
Lopingian
Changhsingian
Wuchlapigian
Guadelupian
Capitanian
Wordian
Roadian
Cisuralian
Kungurian
Artinskian
Sakmarian
Asselian
CARBONIFEROUS
Upper Carboniferous
Gzhelian
Kazimovian
Moskovian
Bashkirian
Lower Carboniferous
Serpukhovian
Visean
Tournaisian
DEVONIAN
Upper Devonian
Famennian
Frasnian
Middle Devonian
Givetian
Eifelian
Lower Devonian
Emsian
Pragian
Lochkovian
SILURIAN
Pridolian
Ludlow
Ludfordian
Gorstian
Wenlock
Homerian
Sheinwoodian
Llandovery
Telychian
Aeronian
Rhuddanian
ORDOVICIAN
Upper Ordovician
Hirnantian
Katian
Sandbian
Middle Ordovician
Darwillian
Stage 3
Lower Ordovician
Floian
Tremadocian
CAMBRIAN
Sandstones
Lydites
Greywackes
Burgstall Flaserlst.
“Metapsammit Complex”
“Metabasaltic Complex”
“Metapelitic Complex”
acidic Volcanoclastics
Kitzeck Slates
Hannersdorf Dolomite
Hochsteinmaißberg Slates and Dolomites
Nötsch Formation
Badstub Formation
Erlachgraben Formation

2.8. Carnic Alps

The stratigraphic record of the Carnic Alps includes Ordovician to Middle Triassic strata (Fig. 6). The Ordovician Series are characterized by weakly metamorphosed fine to coarse clastic rocks (Val Visdende Group). They are overlain by acidic volcanoclastics (Comelico-Porphyroid, Fleons Formation), and their lateral equivalents comprising the Himmelberg Sandstone and the Uggwa Shale, the latter locally containing a rich fossil assemblage of bryozoans, trilobites, hyoliths, gastropods and cystoids of Caradocian age (SCHÖNLAUB 2000b). This basal sequence is capped by a fossiliferous limestone horizon of early Ashgillian age (Wolayer Limestone) composed of parautochthonous bioclasts (cystoids and bryozoans) which laterally grade into bedded wackestones (Uggwa Limestone) interpreted as basinal deposit. The global glacially-induced regression during the Hirnantian Stage is documented by marly intercalations and arenaceous bioclastic limestones of the Plöcken Formation.

Silurian deposits are subdivided into four lithologic facies representing different depths of deposition and hydraulic conditions suggestive of a steadily subsiding basin and an overall transgressional regime from the Llandoverian to Ludlovian. Uniform limestone sedimentation during the Pridolian suggests that more stable conditions were developed at this time (SCHÖNLAUB 1997b). Silurian deposits range from shallow water bioclastic limestones to nautiloid-bearing limestones, interbedded shales and limestones to black graptolite-bearing shales and cherts. Faunal affinities point to relationships with Baltica and Avalonia and minor connections with Africa and southern Europe. First occurrences of rugose and tabulate corals and stromatolitic biolaminations in the uppermost Silurian indicate a moderate climate suggesting an ongoing drift towards lower latitudes. In the central Alps rifting-related basic volcanism underpins these inferred plate movements (SCHÖNLAUB & HISTON 1999, 2000).

Due to extensional tectonics and highly different rates of subsidence which lasted until the early Lower Carboniferous, facies patterns changed significantly during the Devonian. This is documented by strata rich in shelly fossils, varying depositional thicknesses, reef developments and interfingering facies ranging from near-shore sediments to carbonate buildups, lagoonal and slope deposits, condensed nodular cephalopod limestones to deep oceanic shales. After the drowning of the shallow marine environments in the late Frasnian sedimentation was more uniform and continued during the Famennian and early Lower Carboniferous. Emersion and karstification at the end of the Tournaisian was followed by the collapse of the Variscan basin and its transformation to a flysch setting in the Visean to Westphalian (Hochwipfel Formation). The Variscan orogeny reached its climax between the Bashkirian and Late Westphalian. The transgressive Late Carboniferous to Middle Triassic cover comprises thick shelf deposits ranging from near-shore siliciclastics to fossiliferous phylloid and dasyclad algal and fusulinid limestones.

Within the transgressive molasse-type cover (Auernig Group) with its varied lithologies (conglomerates, pebbly sandstones, sandstones, mudstones, marls and lime-

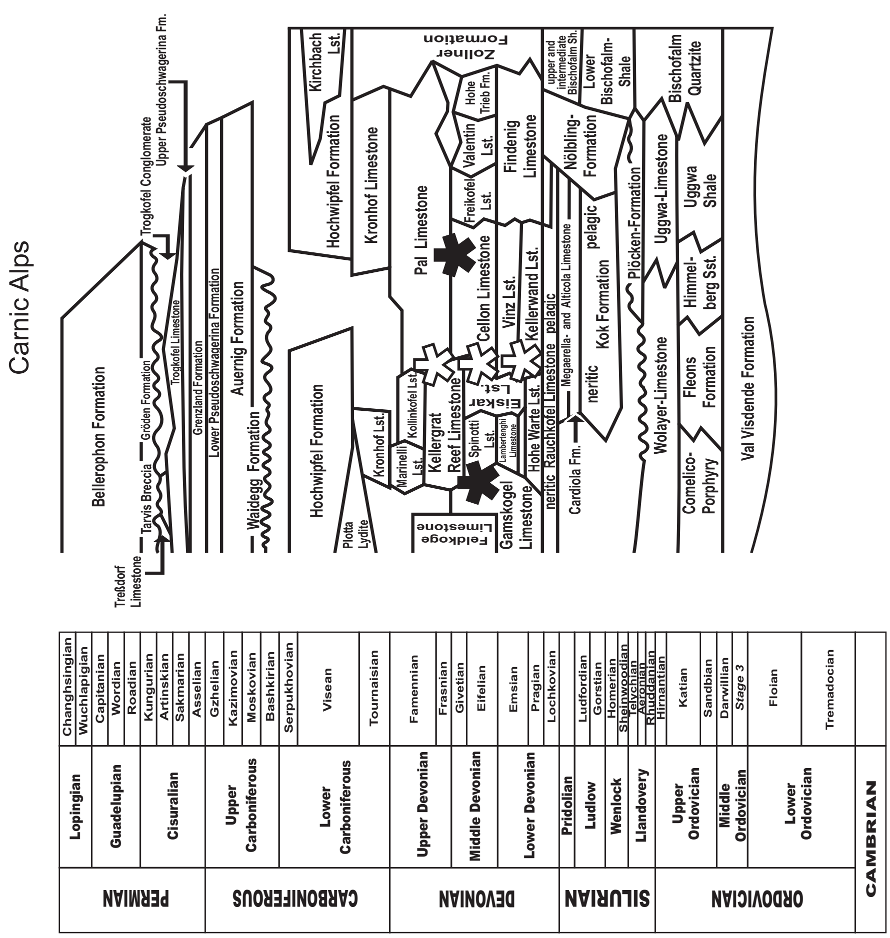


Fig. 6: Carnic Alps. Explanations cf. Fig. 2.
Abb. 6: Karnische Alpen. Erläuterung vgl. Abb. 2.

stones containing calcareous algae, plant fossils, foraminifera (especially fusulinids), ostracods, sphinctozoans, solitary rugose corals, bivalves, gastropods, conulariids, brachiopods and ichnofossils) algal mounds occur.

The Lower Permian Auernig Group is succeeded by a series of shelf and shelf edge limestones with mound structures and reefs (Trogkofel Limestone; Flügel 1980) and clastics, whereas Upper Permian sediments rest disconformably upon the marine Lower Permian or its equivalents. They indicate a transgressive sequence starting with the Gröden Formation and followed by the Bellerophon Formation of Late Permian age (Krainer 1993).

2.9. Karawanken Mountains

The Periadriatic Line divides the Karawanken Alps into a northern part (Northern Karawanken), which belongs to the Eastern Alps, and a southern part (Southern Karawanken) belonging to the Southern Alps (Fig. 7).

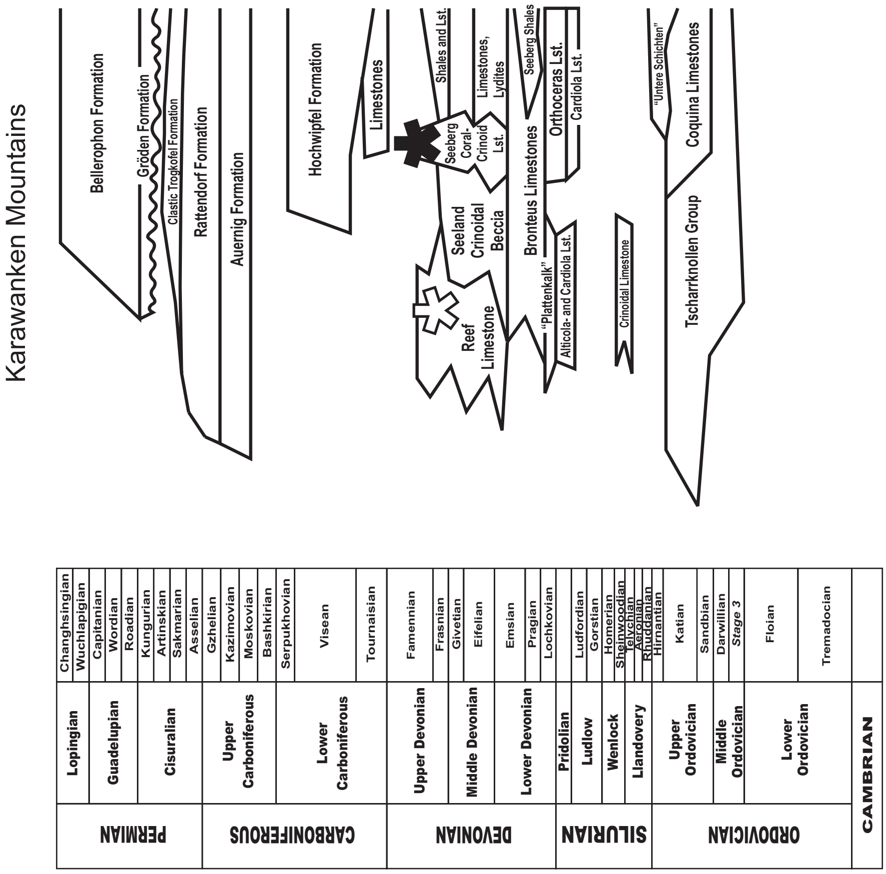


Fig. 7: Karawanken Mountains. Explanations cf. Fig. 2.
Abb. 7: Karawanken. Erläuterung vgl. Abb. 2.

In the Eastern Karawanken Mountains, north of the Periadriatic Line, rocks of Palaeozoic age form a narrow belt extending some 25 km in a W–E direction, continuing further east to Slovenia. The sequence comprises altered volcanic and volcanoclastic rocks, and sequences of monotonous grey shales and slates with intercalations of conglomeratic greywackes, quartzitic and graphitic sandstones, and thin limestone beds. A definite age for this succession is not known, although some poorly preserved simple cone conodonts recovered from the limestones suggest an Ordovician rather than younger age.

In the Southern Karawanken Mountains Palaeozoic rocks are exposed in the Seeberg region very close to the Austrian-Slovenian border. Here, the sequence starts with acidic to intermediate pyroclastics and shallow marine flaser-limestones of Late Caradocian age. Lower Silurian strata are dominated by siliciclastics passing into Middle to Upper Silurian carbonate sequences. During the Middle Devonian a carbonate platform developed with reefal structures resembling present-days atolls (RANTITSCH 1992). Depending on adequate subsidence, the location of the reef core shifted spatially and temporarily during the Devonian. In the Frasnian, reefal and adjacent environments subsided and shallow water deposits were replaced by uniform pelagic goniatite limestones. During Late Carboniferous and Permian molasse-type sediments occurred in the Seeberg area of the Eastern Karawanken Alps (TESSENSOHN 1983). Although strongly affected by faults, the general lithology and the fossil content resemble those of the Auernig Group of the Carnic Alps, both being dominated by interbedded fusulinid and dasyclad and phylloid algae bearing limestones, shales and sandstones, and massive beds of deltaic conglomerates. The Permian of the Trogkofel Limestone, its coeval detritic Trogkofel Formation and the Gröden Formation terminate the Paleozoic successions. Only locally is the Bellerophon Formation developed on top.

3. “Reef-architecture” of the Graz Palaeozoic

The Graz Palaeozoic reflects a geodynamic history starting with intraplate volcanism during the Early Silurian and passing to shelf and platform configuration during the Silurian and Devonian. Persistent subsidence in the uppermost nappe system during that time span is documented by increasing carbonate production until the Late Devonian. The general trend to increased water-depth of the basin is connected with progressive northward drift of the carbonate platform into subtropical to tropical areas (FRITZ & NEUBAUER 1988; FENNINGER et al. 1997).

Interaction of a favourable palaeo-latitude and the specific configuration of the basin is expressed by Emsian to Frasnian fossiliferous strata. Overall deepening is explained by the development of graben structures associated with the creation of a basin characterized by a south to north-oriented subsiding axis. Basin formation is thought to be connected with the hyperthermal anomalies (e.g. Silurian volcanoes; HASENHÜTTL 1994; HUBMANN & HASENHÜTTL 1995).

Detailed studies of the thermal history of the sedimentary inventory improved the knowledge about different stages of basin development (HASENHÜTTL 1994): The reconstructed outlines of Emsian and Eifelian limestones show a carbonate platform surrounding a wedge-shaped basin which, due to its rifting history, opened to the south.

Within this setting four phases of “reef-development” may be distinguished, showing a development starting with semilagoonal environments with benthic pioneer communities and ending with coral-stromatoporoid bioherms (Fig. 8).

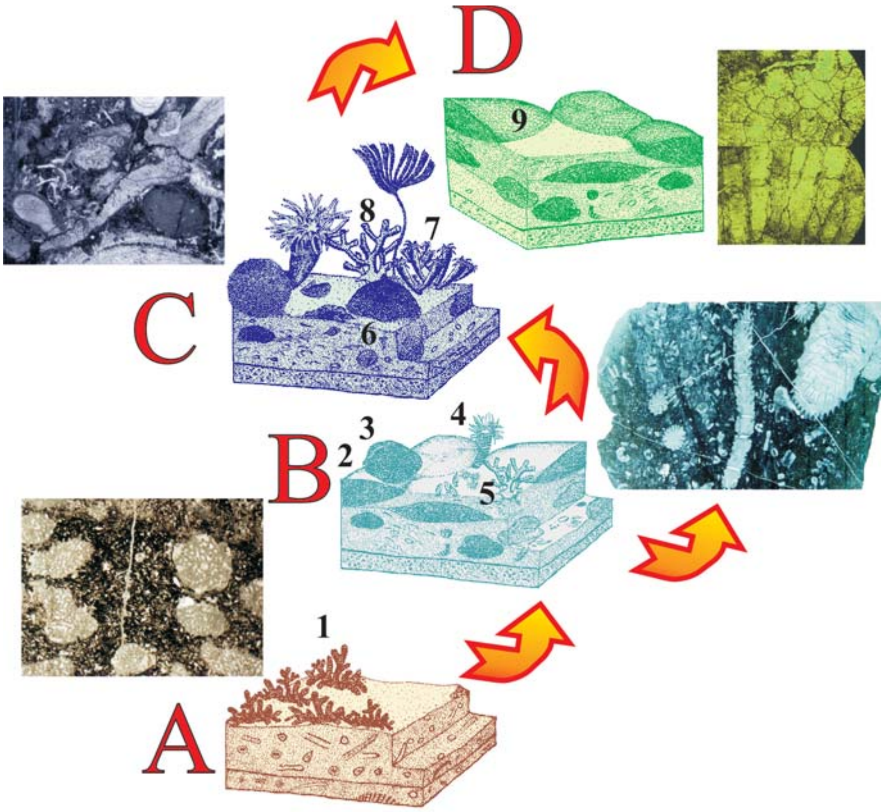


Fig. 8: Phases of reefal developments in the Upper Nappe Group of the Graz Palaeozoic.
A) Emsian *Amphipora*-mounds within the Flösserkogel Formation; B) Eifelian coral-stromatoporoid-carpets of the Plabutsch Formation; C) Givetian patch-reefs of the Kollerkogel Formation; D) Upper Givetian *Argustastrea*-Alveolitid-stromatoporoid-carpets of the Zachenspitz Formation. (1) *Amphipora ramosa*, (2) *Actinostroma* sp., (3) *Favosites styriacus*, (4) *Thamnophyllum stachei*, (5) *Thamnopora* sp., (6) *Favosites* sp., (7) *Sociophyllum* sp., (8) *Stachyodes* sp., (9) *Argutastrea darwini*.

Abb. 8: Phasen der Riffentwicklung der Oberen Decken Gruppe des Grazer Paläozoikum.
A) *Amphipora*-mounds aus der Flösserkogel Formation (Emsium); B) Korallen-Stromatoporen-Rasen aus der Plabutsch Formation (Eifelium); C) Flecken-Riffe aus der Kollerkogel Formation (Givetium); D) *Argustastrea*-Alveolitiden-Stromatoporen-Rasen aus der Zachenspitz Formation (Obergivetium). (1) *Amphipora ramosa*, (2) *Actinostroma* sp., (3) *Favosites styriacus*, (4) *Thamnophyllum stachei*, (5) *Thamnopora* sp., (6) *Favosites* sp., (7) *Sociophyllum* sp., (8) *Stachyodes* sp., (9) *Argutastrea darwini*.

First Phase: Emsian *Amphipora*-Mounds

Resting on basal volcanoclastics, the peritidal Flösserkogel Formation (less than 500 m) commenced in the Early Pragian. The formation consists of variegated dolostones, silt- to sandstones and lesser dolomitic limestones, that are interpreted as depositions of a supra- to shallow subtidal, barrier-surrounded lagoon, or tidal flat (Fenninger & Holzer 1978). In the vicinity of Graz, the lower parts of the succession are interpreted as sand bars, whereas the upper parts which are separated by volcanic tuffs contain meadows of *Amphipora ramosa desquamata*. Rare conodont finds indicate an Early Emsian age (cf. Ebner et al. 2000). The small hump-shaped bodies of the *Amphipora*-beds with abundant individuals, and lack of disarticulated coenostea are interpreted as mound structures. In constrast to other lithotypes of the Flösserkogel Formation the *Amphipora*-mounds show a black matrix due to dispersed pyrite probably associated with previously high organic carbon content.

Second Phase: Eifelian Coral-Stromatoporoid-Biostromes

Overlying or interfingering with the Flösserkogel Formation is the Plabutsch Formation (80 m thick). Predominance of typical "reefbuilding organisms" (Flügel 1975) is conspicuous in all outcrops (Fig. 9). Nevertheless, there is no exposure of a cemented reef whereas tabular coral-stromatoporoid-carpets are the dominant features. Facies studies indicate deposition on a differentiated and gently inclined carbonate platform (Hubmann 1993). The rarity of in situ organisms, the intermittent high supply of clays and lime mud (marl-limestone intercalations), along with a temporary influx of large amounts of continental phytoclasts and storm impacts (several tempestite sequences within the profiles) resulted in deposition of a substrate that was unsuitable for the creation of reef structures (Hubmann 1995b).

This phase is terminated by a repetition of tidal flat deposits similar to the Flösserkogel Formation, possibly caused by sea level fall.

Third Phase: Givetian Biostrome/Patch Reefs

Transgression resulted in a sequence with sharp (bio)facies contrasts between patch-reefs and monotonous (up to 150 m thick) limestones of Givetian age. In both upper nappes, the Rannach Nappe and the Hochlantsch Nappe, contemporaneous mudstones as well as small patch reefs or biostromal deposits coexisted. Reefal developments are variable due to local environmental constraints. Within the Kollerkogel Formation small-sized *Amphipora*-thickets pass into beds with scattered chaetetids, *Favosites*, *Thamnopora*, *Thamnophyllum*, *Sociophyllum* etc. (Weiße Wand, northern slope of Rannach Mountain).

In a transitional zone between Rannach- and Hochlantsch Group a succession consisting of *Amphipora*-beds, microbialitic lens-shaped bodies and cnidarian patch-reefs with *Stachyodes*, *Heliolites*, *Favosites*, *Alveolites*, disk-shaped stromatoporoids and solitary rugose corals are developed at Grabenwarterkogel and Höllererkogel near St. Pankrazen, 30 km NW of Graz (Ebner et al. 2000, 2001).

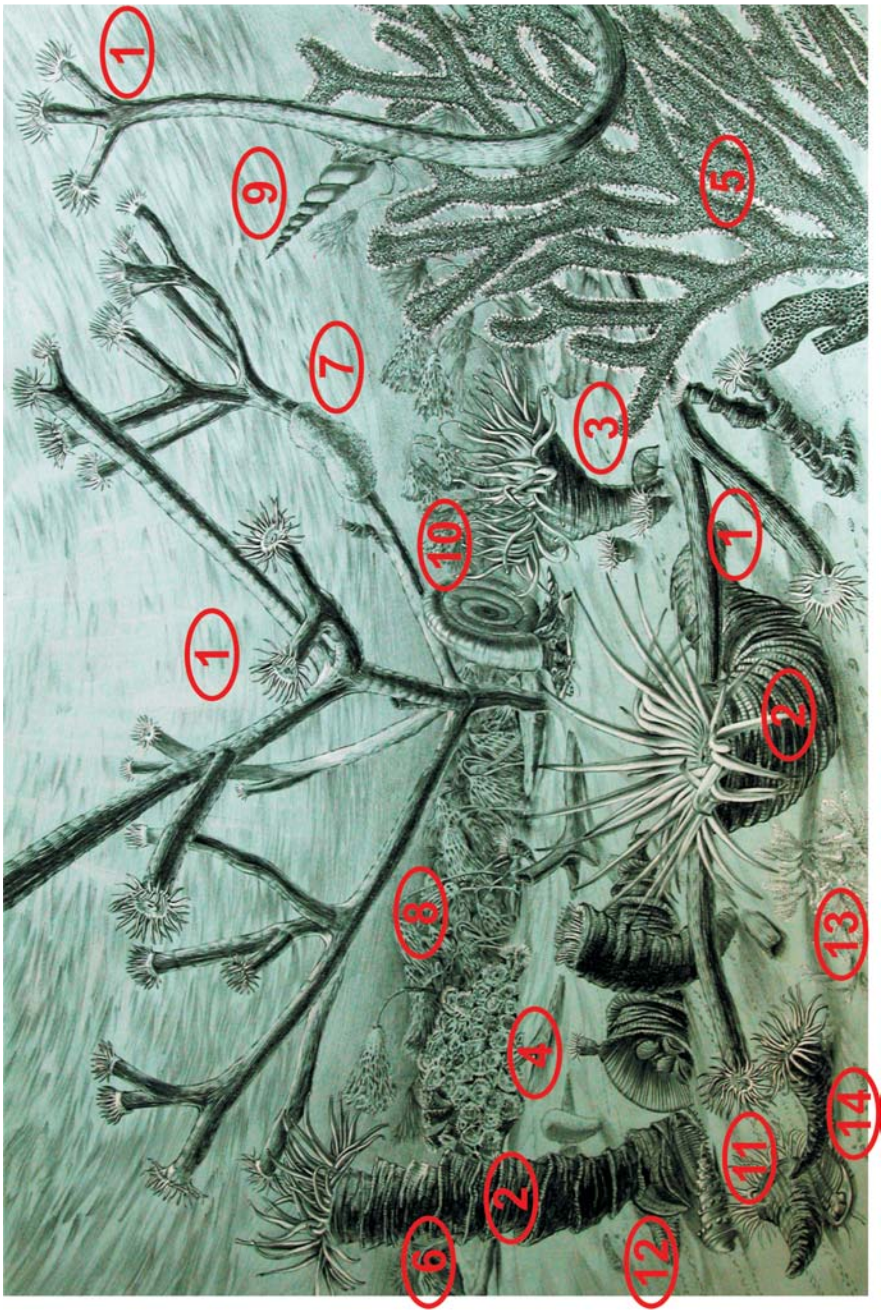

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Fig. 9: Artistic reconstruction of the Plabutsch Formation based on specimens collected from the Plabutsch hill (West of Graz).
(1) *Thamnophyllum stachei*, (2) "*Cyathophyllum*" sp., (3) "*Cyathophyllum*" *graecense*, (4) *Disphyllum* sp., (5) *Thamnopora reticulata*, (6) *Actinostroma* sp., (7) chaetetid, (8) *Cupresso-crinites* sp., (9) "*Holopella*", (10) *Straparollus* sp., (11) *Murchisonia* sp., (12) *Atrypa* sp., (13) *Zeapora gracilis*, (14) *Maladaia* sp.
Abb. 9: Künstlerische Rekonstruktion der Plabutsch-Formation basierend auf Fossilfundmaterial vom Plabutsch (Westlich von Graz).
(1) *Thamnophyllum stachei*, (2) „*Cyathophyllum*" sp., (3) „*Cyathophyllum*" *graecense*, (4) *Disphyllum* sp., (5) *Thamnopora reticulata*, (6) *Actinostroma* sp., (7) Chaetetide, (8) *Cupresso-crinites* sp., (9) „*Holopella*", (10) *Straparollus* sp., (11) *Murchisonia* sp., (12) *Atrypa* sp., (13) *Zeapora gracilis*, (14) *Maladaia* sp.

Biostromal bodies constructed by the organisms mentioned above also occur in the Tyrnaueralm Formation in the Hochlantsch Nappe (KRAMMER 2001) at the Zechnerhube locality. There, similar to the situation near St. Pankrazen, alveolitid corals supply great amounts of the "binder guild".

Fourth Phase: Upper Givetian to (?)Frasnian *Argutastrea*-Bioherms

Restricted only to the Hochlantsch area some 30 km N of Graz, the last reefs of the Graz Palaeozoic are developed within the Zachenspitz Formation. This Upper Givetian (probably continuing to the Lower Frasnian) formation contains several basal *Amphipora*-beds grading into biohermal *Argutastrea*-Alveolitid-Stromatoporoid baffle- to boundstones (northern slopes of the Hochlantsch Mountain). (Micro-)Facies investigations indicate a shallow, offshore, depositional environment with a pelagic fauna dominated by tentaculitids in the inter-bioherm facies (GOLLNER & ZIER 1985).

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