The Classic Fossiliferous Palaeozoic Units of the Eastern and Southern Alps[1]

with 18 figures

by

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Summary

In this report we review the present knowledge about the stratigraphy, the development of facies and the tectonic evolution of the Variscan sequences of the Eastern and Southern Alps. In the Eastern Alps outcrops of fossiliferous rocks of Lower Palaeozoic age are irregularly distributed. They form a mosaic-like pattern of dismembered units incorporated into the Alpine nappe system. Such areas include the Gurktal Nappe of Middle Carinthia and parts of Styria, the surroundings of Graz, a small area in southern Burgenland and the Graywacke Zone of Styria, Salzburg and Tyrol. South of the Periadriatic Line Variscan sequences are represented in the Carnic and Karawanken Alps where they form the basement of the Southern Alps. As regards the regions occupied by quartzphyllitic rocks of presumably Palaeozoic age the reader is referred to the article by Neubauer and Sassi (this volume).

Based on a comprehensive set of data a distinct geological history on either side of the Periadriatic Line is inferred. Main differences concern the distribution of fossils, the development of facies, rates of subsidence, supply area, amount of volcanism and the spatial and temporal relationship of climate sensitive rocks from north and south of the Periadriatic Line (H.P.Schönlaub 1992).

The Ordovician of the Southern Alps is characterized by mainly clastic rocks with minor participation of volcanics. This facies agrees well with other areas in the Mediterranean. Also, the widespread glacial event at or close to the Ordovician/Silurian boundary can be recognized. It is followed by different Silurian deposits ranging from shallow water carbonates to graptolitic shales. Thicknesses are overall similar and do not exceed some 60 m. Due to extensional tectonics and highly different rates of subsidence the facies pattern changed considerably during the Devonian. This is documented by more than 1200 m of shallow water limestones which are time equivalent to some 100 m of condensed cephalopod limestones. After the drowning of the reefs uniform limestones were deposited in the Famennian and early Dinantian followed by an emersion and a widespread karstification phase near the end of the

[1] Extended version of a paper published in: RAUMER, J.F. v. & NEUBAUER, F. (Eds., 1993): Pre-Mesozoic Geology in the Alps.- Springer Verl., 395-422; Heidelberg

Tournaisian. The final collapse of the Variscan basin started in the Visean and resulted in more than 1000 m of flysch deposits indicating an active margin regime at the northern edge of the Southern Alps plate, which culminated in the main deformation of the Southern Alps in the Westphalian. The transgressive cover comprisis Late Carboniferous and Lower Permian sediments at the end of the Variscan sedimentary cycle.

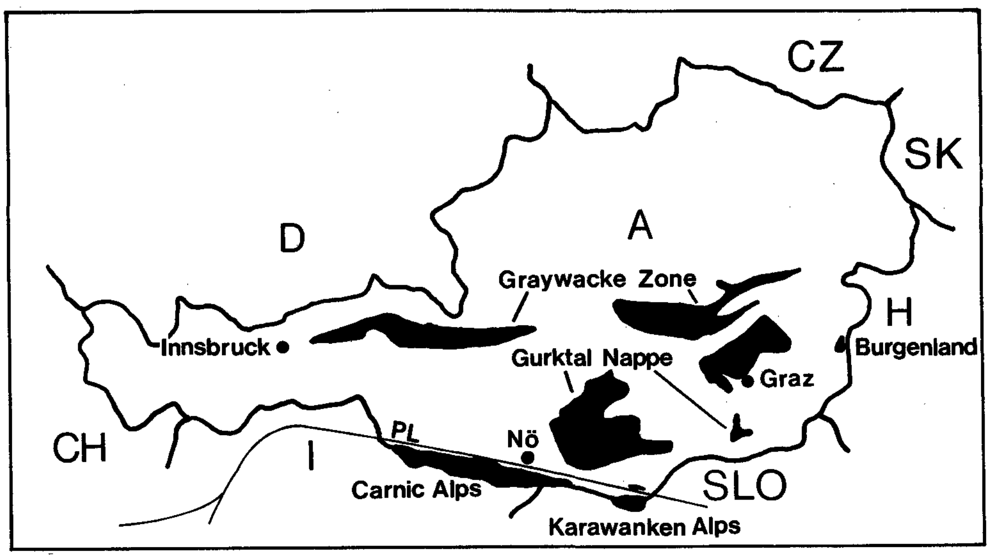


Fig. 1: Main regions with fossiliferous Paleozoic strata in the Eastern and Southern Alps (PL = Periadriatic Line, Nö = Nötsch)

The area north of the Periadriatic Line has only few rocks in common with the Southern Alps. In short, its geological history is significantly different. This concerns thick piles of siliciclastic rocks in the interval from the Ordovician to the Devonian, a contemporaneous local reef and warm water development during the Silurian and the Devonian, basic magmatism in the Middle (?) Ordovician, Lower Silurian and in the Middle Devonian (s.l.). The increased input of clastic material suggests a close proximity to a land area; the intense volcanism may be related to crustal extension starting already in the Ordovician. For some degree volcanism may also be responsible for the variation of facies which occurred in most areas north of the Periadriatic Line during the Silurian and particularly in the Lower and Middle Devonian.

In the Graywacke Zone the oldest sediments are of Tremadocian age; the second oldest fossils occur north of Klagenfurt and correspond to the Llandeillan Stage of the Middle Ordovician. They are underlain by basic volcanics and several hundred meters of metapelitic rocks of presumably Lower Ordovician age. Consequently, a continuous sedimentation from the base of the Ordovician to the top of the Variscan sequence is suggested, for example, in the surroundings of Graz, the Graywacke Zone and in Middle Carinthia until the Namurian or Westphalian. Thus, in the Alps a Caledonian orogenetic event as proposed by other authors, seems highly speculative. On the other side motion of individual areas ("microplates", "terranes") may have played a significant role and may help unravelling and explaining the observed differences between the Southern and the Northern Alps during the Palaeozoic.

Introduction

The term 'classic Palaeozoic' has generally been applied to those areas of the Eastern Alps in which fossiliferous strata of Palaeozoic age have been well known since the last century. They were recognized soon after foundation and designation of the individual Palaeozoic Periods in Great Britain following the pioneering phase of geology. For example, the world famous Carboniferous deposits of Nötsch (Carinthia) have been known since Mohs (1807) and were later visited by the highly reputated L v Buch in 1824; the equivalents of the Devonian Period were found in the surroundings of Graz as early as 1843, i.e., 4 years after the erection of the system by Murchison & Sedgwick in Devonshire; the discovery of Silurian strata date back to 1847 when F.v.Hauer found cardiolids of this age near the village of Dienten in the Graywacke Zone of Salzburg. Finally, Permian and Ordovician fossils were first described from the Carnic Alps by Stache in 1872 and 1884, respectively.

Accordingly, until about the year 1955 dating of sedimentary rocks of Palaeozoic age was mainly based upon macrofossils. The majority of fossils were derived from the Southern Alps, i.e, the Carnic and Karawanken Alps, yielding abundant and well preserved representatives of various faunal and floral groups for each period. The Palaeozoic of Graz too, furnished rich collections of corals, stromatoporoids and brachiopds mainly from the Middle Devonian. In the Graywacke Zone, Middle Carinthia and Burgenland, however, most macrofossils are badly preserved and generally occur less abundantly due to greenschist grade metamorphism and foliation.

Since the introduction of microfossil research methods in the mid-1950s, in particular conodont biostratigraphy, the knowledge about sedimentary sequences considerably increased. In fact the high-resolution biostratigraphy of conodonts in spite of lack of other fossils provided the basis for accurate dating and interregional correlation of poorly known almost 'unfossiliferous' sequences. In the meantime many reference sections in the Carnic Alps, the Graywacke Zone and the Palaeozoic of Graz have been studied which confirmed the conodont zonations from other parts of the world and/or supplied additional informations. Thus, together with sedimentological, microfacies, geochemical and structural data a very detailed subdivision of the geological record of the Eastern Alps has been established. Based on this multi-lined framework the Palaeozoic history of the Alps can be better inferred than ever before and hence, seems well constrained in today's geology of the Alps.

The occurrences of fossiliferous Palaeozoic outcrops represent different tectonic units. South of the Gailtal Fault they form the Variscan basement of the Southern Alps; to the north they belong to a huge thrust sheet named Upper Austroalpine Nappe. As far as their original palaeolatitudinal settings are concerned analysis of faunas and climate sensitive rock data has revealed fundamental differences between both major occurrences (Schönlaub, this volume). In addition, the intra-Alpine facies development varies to a certain degree. For example, the Palaeozoic record from Middle Carinthia is lithologically more close related to certain areas occupied by quartzphyllites than to any other region; the Graywacke Zone of Styria shows more similarities with the Carnic Alps than to the nearby Palaeozoic of Graz; this development reflects its own distinct setting suggesting an intermediate position between the Southern and Central Alps. Finally, in the Palaeozoic sequences of the Alps the participation of volcanic rocks varies considerably. They have been assigned to different geotectonic settings that characterized the Ordovician, Silurian and Devonian Periods (Loeschke & Heinisch, this volume).

The Carnic and Karawanken Alps

The Carnic Alps of Southern Austria and Northern Italy represent one of the very few places in the world in which an almost continuous fossiliferous sequence of Palaeozoic age has been preserved. They extend in West-East direction over 140 km from Sillian to Arnoldstein. In the following Western Karawanken Alps the Variscan sequence is almost completely covered by Triassic rocks. To the east Lower Palaeozoic rocks are excellently exposed in the Seeberg area of the Eastern Karawanken Alps south of Klagenfurt. Different from the Carnic Alps in this region Lower Palaeozoic rocks are distributed on either side of the Periadriatic Line (Gailtal Fault). They were subdivided into a northern and a southern domain, respectively. The latter extends beyond the state border to Northern Slovenia.

Historical Notes

In both regions systematic research started after foundation of the Geological Survey of Austria in the middle of the last century. Interestingly, the equivalents of the Lower Palaeozoic were first found in the Karawanken Alps and not in the Carnic Alps (Suess 1868, Tietze 1870). In this latter area main emphasis was laid on marine Upper

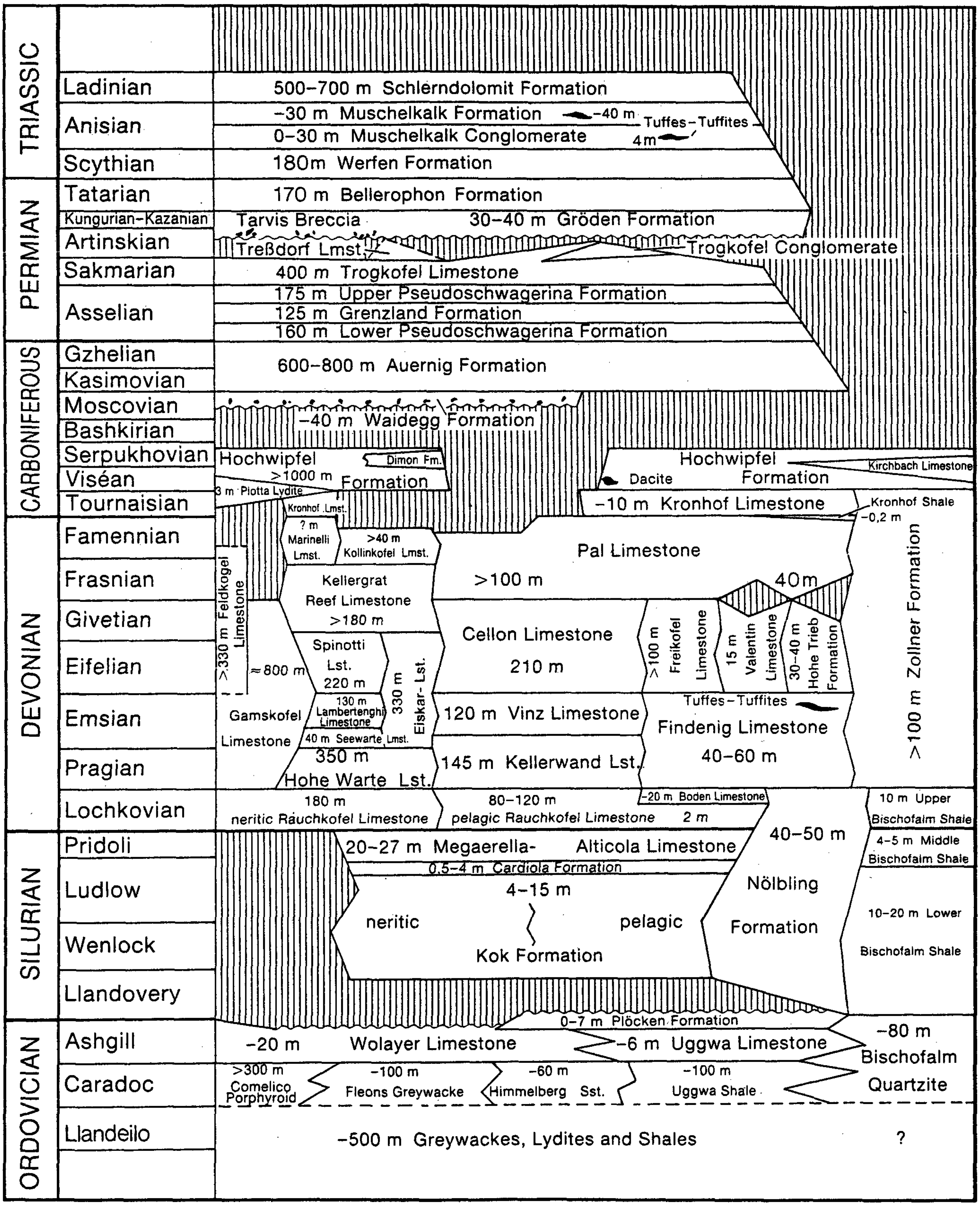


Fig. 2: Biostratigraphic scheme of the Palaeozoic sequence of the Carnic Alps. With only minor modifications this subdivision can also be applied in the Karawanken Alps (after Schönlaub 1985, amended by KREUTZER 1992a, 1992b).

Palaeozoic rocks. At the end of the 19th century this initial phase was followed by a second mapping campaign carried out mostly by Geyer and detailed studies of the Devonian by Frech. During the first half of this century Heritsch and his co-workers from Graz University refined the stratigraphy on the Austrian side while Gortani from Bologna University and others worked on the Italian side of the mountain range. One of the outstanding contributions of that time from the Lower Palaeozoic was provided by Gaertner (1931). The detailed knowledge of Upper Carboniferous and Permian rocks resulted mainly from studies by Kahler beginning in the early 1930s. Since then many students of geology started visiting both areas. During this third campaign after World War II study of different microfossil groups began and other techniques were as well introduced. It culminated in the publication of detailed maps, the refinement of the stratigraphy, and revisions of old and discoveries of new faunas and floras (see Schönlaub 1979, 1980, 1985a).

Review of Stratigraphy

Figure 2 summarizes the stratigraphy and facies relationship of various rocks of the Carnic Alps. With minor modifications this scheme is also valid for the Karawanken Alps (Schönlaub 1980, Moshammer 1989). Traditionally the sequence is subdivided into the Variscan basement rocks and its post-Variscan cover. The oldest fossiliferous rocks are Caradocian in age (Upper Ordovician) and comprise thick acid volcanics named Comelico Porphyroid and volcaniclastics of the Fleons Formation which laterally and vertically grade into the Uggwa Shale and the Himmelberg Sandstone. According to Dallmeyer & Neubauer (1994) detrital muscovites from the sandstones are characterized by apparent ages ($^{40}Ar/^{39}Ar$) of c. 600 to 620 Ma and may thus be derived from a source area affected by late Precambrian (Cadomian) metamorphism. They are succeeded by bioclastic limestones, i. e. the massive Wolayer Lst. and the corresponding quiet-water Uggwa Lst., respectively. The global regression during the Hirnantian Stage (Late Ashgillian) is documented by arenaceous limestones of the Plöcken Formation. It resulted in channeling, erosion and local non-deposition. Thus basal Silurian strata generally disconformably overlie the Late Ordovician sequence.

Ordovician fossil groups include rich collections of bryozoans, brachiopods, trilobites, pelmatozoans and hyolithes occurring with varying abundances in the Uggwa Shale, and abundant conodonts in the limestones (Schönlaub, see summary in this volume).

In the Carnic Alps the Silurian transgression began at the very base of the Llandovery, i.e., in the graptolite zone of *Akidograptus acuminatus*. Its forerunner from the latest Ordovician, *Gl.persculptus*, was reported from the Western Karawanken Alps. Due to the unconformity separating the Ordovician from the Silurian a varying thick pile of sediments is locally missing, which correspond to several conodont zones in the Llandovery and Wenlock in both the Carnic and Karawanken Alps. At some places even basal Lochkovian strata may disconformably rest upon Upper Ordovician limestones.

Silurian lithofacies is split up into four major facies reflecting different depth of deposition and hydraulic conditions. A shallow marine environment represents the Plöcken Facies characterized in succeeding order by the pelagic Kok Formation, the Cardiola Fm. and the Megaerella-Alticola Limestones. The typical section is the 60 m thick Cellonetta profile well known for its merits for the Silurian conodont zonation established by Walliser in 1964.

The Wolayer Facies represents an even shallower environment. It is characterized by fossiliferous limestones with abundant orthoconic nautiloids, trilobites, small brachiopods and crinoids. Due to a period of non-deposition at the base this facies is represented by only 10 to 15 m thick limestones. The main occurrences are in the Lake Wolayer region of the Central Carnic Alps.

The Findenig Facies represents an intermediate facies between the shallow water and the starving basinal environment. It comprises interbedded black graptolite shales, marls and limestone beds. At its base a quartzose sandstone may locally occur.

The stagnant water graptolite facies is named the Bischofalm Facies. It is represented by 60 to 80 m thick black siliceous shales, black cherty beds ("lydite") and clayish shales which contain abundant graptolites. Their distribution has been clearly outlined by the thorough work of Jaeger in the past 25 years (see Jaeger 1975, Flügel et al 1977, Jaeger & Schönlaub 1980, Schönlaub 1985).

The four Silurian lithofacies reflect different rates of subsidence. During the Llandovery to the beginning of the Ludlow sedimentation suggests a steadily subsiding basin and a transgressional regime. This tendency decreased and perhaps stopped during the Pridoli to form balanced conditions with uniform limestones being widespread deposited. Simultaneously, in the Bischofalm Facies black graptolite shales were replaced by greenish and grayish shales ("Middle Bischofalm Shale").

At the base of the Devonian in the Bischofalm Facies the deep-water graptolite environment was restored until the end of the Lochkovian Stage. The succeeding strata named Zollner Formation, also represent a deep-water off-shore setting that lasted to the end of the Devonian or early Carboniferous.

In comparison with the Late Ordovician and the Silurian subsidence and mobility of the sea-bottom significantly increased in the Devonian. This is documented in a Lower Devonian transgressional sequence including the up to 180 m thick Rauchkofel Limestone which corresponds to some 20 m of pelagic limestones ("Boden Lst."). During the Pragian and Emsian Stages the differences even increased. Within short distances of less than 10 kilometers (Kreutzer 1992a, b) a strongly varying facies pattern developed indicating a progressive but not uniform deepening of the basin. It was filled with thick reef and near-reef organodetritic limestones including different intertidal lagoonal deposits of more than 1000 m thickness in the Carnic Alps and some 300 m in the Karawanken Alps. They are time equivalent to some 100 m of pelagic cephalopod limestones and the pelitic Zollner Formation.

In the Carnic and Karawanken Alps reef growth started in the Lower Emsian. Main reef builders were stromatoporoids, tabulate corals and calcareous algae like *Renalcis*. For the Karawanken Alps Rantitsch 1990 concluded an arrangement of reefs resembling present-days atolls as opposed to the Carnic Alps with its barriere-type reefs (Kreutzer 1990, 1992a, b). Depending on adequate subsidence the location of the reef belt shifted spatially and temporarily during the Devonian. Different from the Carnic Alps with its 150 m thick reefs of Givetian age in the Karawanken Alps there are no good records from the Middle Devonian. In both areas the reef development ended in the Frasnian when the former shallow sea subsided and the reefs drowned and were partly eroded (Bandel 1972, Tessensohn 1974,1983, Pohler 1982 and Kreutzer 1990). Subsequently, with few exceptions, e.g., the Kollinkofel Lst., uniform pelagic goniatite and clymeniid limestones were deposited lasting from the Frasnian/Famennian boundary to the Late Tournaisian Stage. They were named Pal and Kronhof Lst., respectively. Generally, these wackestones contain abundant cephalopods, trilobites, radiolarians, foraminifera, ostracods, conodonts and even fish teeth.

The nature of the transition from the above mentioned limestones to the following clastics of the Hochwipfel Formation raised a long lasting controversy about the significance of tectonic events in the Lower Carboniferous. It now has been settled after recognizing a wide variety of distinct palaeokarst features in the Karawanken Alps (Tessensohn 1974) and in the Carnic Alps (Schönlaub et al 1991) including an extensive palaeorelief with related collapse breccias, fissures, strata-bound ore deposits and a silcrete regolith at the surface ("Plotta Lydite"), and caves with cave sediments, formation of speleothems and palaeokarst-related cements in the subsurface. The palaeokarst was caused by a drop in sea-level during the Late Tournaisian. Rise of sea-level and/or collapse of the carbonate basin promoted the transgression of the Hochwipfel Formation which presumably started as early as the Tournaisian/Visean boundary.

On account of its characteristic lithology and sedimentology Tessensohn 1971, 1983, Spalletta et al. 1980, v Amerom et al. 1984, Spalletta & Venturini 1988 and others interpreted the 600 to more than 1000 m thick Hochwipfel Formation as a flysch sequence. In modern terminology the Kulm sediments indicate a Variscan active plate margin in a collisional regime following extensional tectonics during the Devonian Period. The main lithology comprises arenaceous to pelitic turbidites with intercalations of several tens of metres thick pebbly mudstones, disorganized debris flows and chert and limestone breccias in its lower part. They may represent submarine canyon fillings or inner fans. Widespread although less abundantly are up to 10 m thick massive sandstone beds. Vertically, and locally also laterally, the flysch grades into volcaniclastites and volcanics of the Dimon Formation.

Except for trace fossils the palaeontological content of the flysch series is very poor. According to v Amerom et al 1984 and v Amerom & Schönlaub (in prep.) plant remains are fairly common suggesting a Middle Visean to Namurian age for the formation of parts of the flysch. Other stratigraphic data are derived from the underlying limestone beds and a few scattered limestone intercalations, i.e., the Kirchbach Limestone which provided index conodonts of the Visean/Namurian boundary (Flügel & Schönlaub 1990). Moreover, of great interest are limestone clasts within the debrites. They comprise a broad spectrum of shallow water carbonate shelf types with stratigraphically important fossils like the coral *Hexaphyllia mirabilis*, the algae *Pseudodonezella tenuissima*, the foraminifera *Howchinia bradyana* and the early fusulinids. Apparently, these clasts together with the turbidites were supplied from a source area located originally to the north of the present Southern Alps.

In the Southern Alps the Variscan orogeny reached the climax between the Late Namurian and the Late Westphalian Stages. This time corresponds to the interval from the Early Bashkirian to the Middle or Late Moscovian Stages. According to Kahler (1983) the oldest post-Variscan transgressive sediments are Late Middle Carboniferous in age and, more precisely, correspond to the *Fusulinella bocki* Zone of the Upper Miatchkovo Substage of the Moscovian Stage (Moscow Basin). In particular between Straniger Alm and Lake Zollner they rest with a spectacular angular unconformity upon strongly deformed basement rocks including the Hochwipfel Formation, the Silurian-Devonian Bischofalm Formation or different Devonian limestones. This basal part named Waidegg Formation consists of mainly basal conglomerates, disorganised pebbly siltstones and arenaceous and silty shales with thin limestone intercalations. Even meter-sized limestone boulders reworked from the basement were recognized at the base of the transgressive sequence (Fenninger et al 1976) and named Malinfier Horizon by Italian geologists. The Bombaso Formation of the Naßfeld region, i.e., the Pramollo Member, has also long been regarded as the base of the Auernig Group in this area (Venturini et al 1982, Venturini 1990). Based on new field evidence, however, for this member a clear relationship with the Variscan Hochwipfel Formation is suggested.

South of Naßfeld its transgressive molasse-type cover comprises the 600 to 800 m thick fossiliferous Auernig Group. Although the oldest part biostratigraphically may well correspond to the Late Moscovian Stage (Pasini 1963) the majority of sediments belong to the Kasimovian and Ghzelian Stages.

In the Lower Permian the Auernig Group is followed by a series of almost 900 m thick shelf and shelf edge deposits (see HOLSER et al 1991, Krainer, this volume). They characterize a differentially subsiding carbonate platform and outer shelf settings which from the Westphalian to the Artinskian Stages were affected by transgressive-regressive cycles. This cyclicity may be explained as the response to the continental glaciation in the Southern Hemisphere (see Schönlaub, this volume).

Upper Permian sediments rest disconformably upon the marine Lower Permian or its equivalents, and farther to the west, on quartzphyllites of the Variscan basement. They indicate a transgressive sequence beginning with the Gröden Formation and followed by the Bellerophon Formation of Late Permian age (Boeckelmann 1991, Holser et al 1991).

Upper Carboniferous and Permian molasse-type sediments also occur in the Seeberg area of the Eastern Karawanken Alps (Tessensohn 1983, Bauer 1983). Although strongly affected by faults the general lithology and the fossil content resemble that of the Auernig Group of the Carnic Alps being dominated by interbedded fusulinid and other fossil bearing marine limestones, arenaceous shales, sandstones and massive beds of quartz-rich deltaic conglomerates. Equivalents of the Permian are represented by the Trogkofel Lst., the coeval detritic Trogkofel Beds and the Gröden Formation. The Bellerophon Dolomite is only locally preserved.

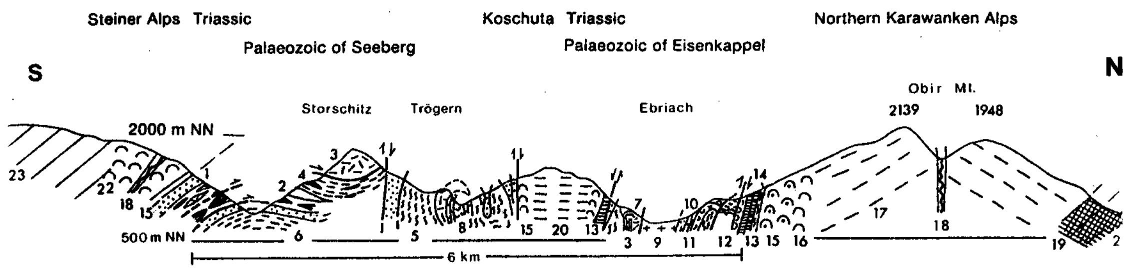


Fig. 3: N-S directed section through the Eastern Karawanken Alps. Numbers indicate (1) post Variscan Permian and Late Carboniferous, (2) banded limestone slices, (3) Devonian limestones, (4) undated volcanics, (5) Hochwipfel Fm., (6) Seeberg Shale, (7) Upper Ordovician and Silurian rocks, (8) volcanics of the Upper Ordovician, (9) granite of Eisenkappel, (10) pillow lava of the "Diabaszug of Eisenkappel", (11) sills, (12) Werfen Fm., (13) Muschelkalk Fm., (14) Partnach Fm., (15, 16, 17) Wetterstein Lst., (18) Raibl Fm., (19) Rhätian to Jurassic deposits, (20) Schlern Dolomite, (21) Tertiary, (22, 23) Dachstein Lst. (from Schönlaub 1979).

In the Eastern Karawanken Alps north of the Periadriatic Line rocks of Palaeozoic age have long been known. They belong to the so-called "Diabaszug von Eisenkappel" (Fig. 3). This narrow belt extends in W-E direction from Zell Pfarre via Schaidasattel to east of Eisenkappel and continues further east to Slovenia. In Austria this zone has a length of more than 25 km and a maximum width of 3,5 km. The 650 m thick Palaeozoic sequence comprises up to 350 m of volcanic and volcaniclastic rocks and sediments. According to Loeschke (1970-1977, 1983) the first group is dominated by basic tuffs and tuffitic rocks, massive pillow lavas and basic sills of hawaiitic composition with ultrabasic layers. Sills and pillow lavas represent spilites which differentiated from alkali olivine basalts, the original geotectonic setting of which is yet not known. Subsequent low-temperature metamorphism associated with devitrification and metasomatic replacement processes caused the spilitic mineral composition in these rocks. The sedimentary rocks are monotonous gray shales and slates with intercalations of conglomeratic graywackes, quartzitic and graphitic sandstones and thin limestone beds. The definite age of this succession is yet not exactly known although some poorly preserved single cone conodonts recovered from the limestone intercalations are rather in favour of an Ordovician than any younger age (Neubauer, pers. comm.).

Tectonic Remarks

The Palaeozoic sequence of the Carnic and Karawanken Alps represent a strongly compressed WNW-ESE running thrust sheet complex composed of isoclinally folded anchi-to epimetamorphic Palaeozoic rocks. This style of deformation developed during the Variscan orogeny in the Late Namurian or Early Westphalian. It is sealed by the post-Variscan cover overlying the deformed basement with a distinct angular unconformity. Paraconformities occur at different levels within the Palaeozoic sequence, for example, at the end of the Ordovician, in the late Middle and early Upper Devonian and in the Lower Carboniferous. Supposedly, they were caused by sea-level changes related to the glaciation of parts of Gondwana at the end of the Ordovician, to seismic shock events, and to a palaeokarstic event, respectively. Lowering of sea-level and/or block faulting may also have acted at the end of the Trogkofel Stage being responsible for extensive erosion and accumulation of reworked limestones, stratigraphic gaps, formation of fissures and local karstification.

For many years the complicated tectonics of the Carnic Alps was explained in terms of 9 nappes produced during the Variscan orogeny. Each north verging nappe consisted of a more or less continuous Ordovician to Devonian sequence and was separated from the next by the clastics of the Hochwipfel Formation. The extent of Alpine overprints on this pile of nappes was difficult to decide. With respect to the less deformed post-Variscan cover, however, it was concluded that the intensity of the Variscan tectonics was much stronger than the Alpine deformation. Nevertheless, the latter resulted in interferences between both and was responsible for a complex deformative pattern in the Southern Alps (Castellarin & Vai 1981)

According to Vai 1979 the horizontal shortening of the Carnic Alps during the Variscan deformation is estimated to 75-80% of its original width. This value does not consider the assumed detachment from pre-Ordovician basement rocks.

Based on new field data from mainly the Naßfeld area the old concept was challenged by Venturini (1990, 1991) who proposed a new structural model. He speculated on three distinct and interacting phases that resulted in different systems of asymmetric folds and faults distributed along N 120° - 140° E direction (Fig. 4):

1. Middle or early Upper Carboniferous compressional tectonics caused a huge SSW-verging fold that affected the whole belt. Syncinematically a back fold system with clear northern vergence developed on its back side. Such smaller-scale syn-and anticlinales can be recognized, for example, on Roßkofel, at Hoher Trieb, at Plöckenpaß-Kleiner Pal-Piz Timau. Perhaps even the fold structure separating the Cellon subnappe from the Kellerwand-subnappe (Kreutzer 1990) can be attributed to this deformation.

2. In response to uplifting brittle deformation occurred with development of flat fault planes along shale horizons. As a result the huge asymmetrical fold was cut into smaller tectonic slices.

3. The third phase occurred during further uplift. It produced huge open antiforms following new thrust planes and older folded structures. They were later reactivated during the Alpine compression.

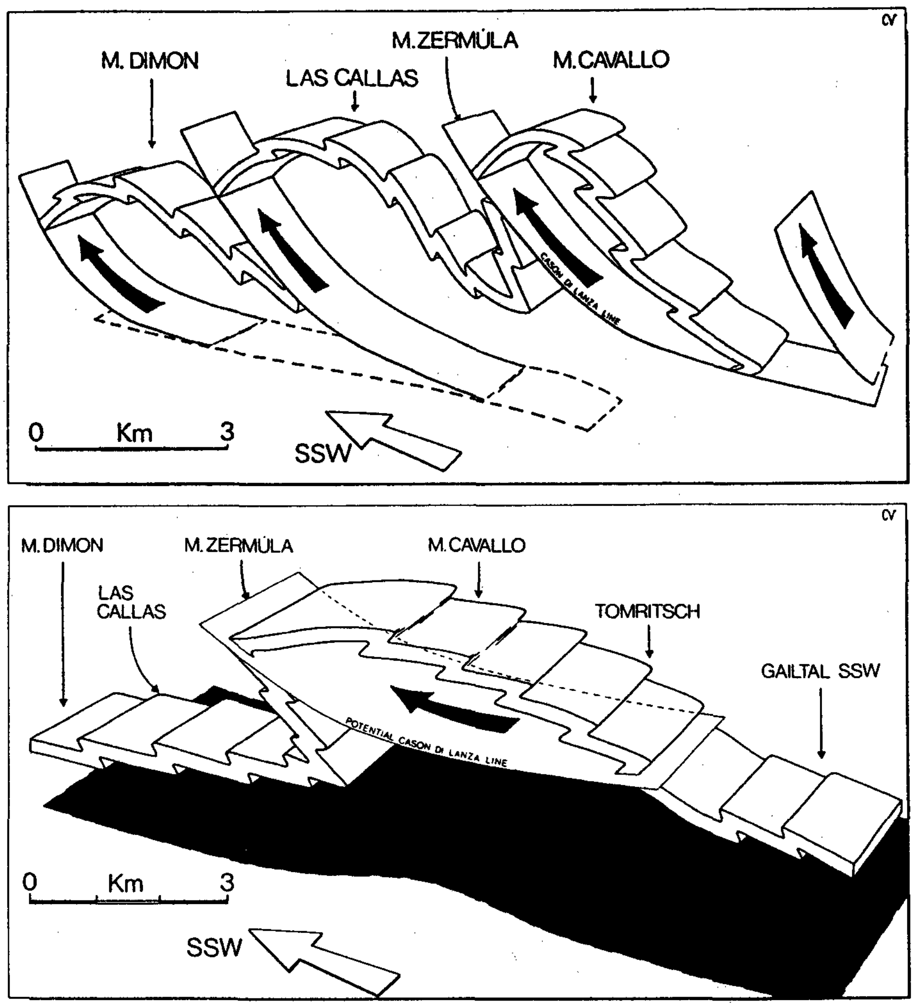


Fig 4: Hercynian deformation of the Carnic Alps. Figured are the 1st and 3rd (Figure above) deformative phases. The huge asymmteric fold affected the whole Palaeozoic belt. The 3rd phase formed thrusts with open folds which re-folded the older structures of the 1st and 2nd deformative stages (from Venturini 1990).

The formation of sedimentary basins in the Upper Carboniferous was governed by extensional tectonics (Venturini 1990). They were related to 120° to 130° directed fault zones forming thus an elongated trough with an original width of not more than 15 km shortened today to a narrow zone of some 10 km.

According to Venturini (1990) three different stress directions controlled the Alpine deformation pattern. An early NE-SW directed stressfield produced N 120°E trending thrust which, for the Carnic Alps, have mainly been destroyed by the younger N-S compression. The main structures are running in E-W direction. They include close folds, steep thrust planes, vertical faults and conjugate faults. Also, older faults were rejuvenated, for example the Bordaglia Line and the But-Chiarso-Line along which sinistral movements probably occurred during the Neogene. The third phase acted during the Plio to Quaternary time and had a stress direction from NW to SE. During this event older fault zones were reactivated.

As noted already by Heritsch (1936) the post-Variscan cover was affected by strong Alpine deformation which even produced nappes composed of flat lying Upper Carboniferous to Lower Permian limestones thrust upon the Gröden Formation. In the region west of Naßfeld Eichhübl (1988) distinguished two tectonic units, i.e., the allochthonous Trogkofel Unit and the autochthonous Stranig Unit. Evidently, thrusting of the Trogkofel Unit occurred towards southeast. This direction has clearly been inferred from numerous southeast verging folds, fold axes, kinkfolds with rounded hinges and conjugate folds recognized along the thrust plane. Thrusting is estimated to have a magnitude of more than 3 km. The NW-SE directed orientation of the maximum stress resulted from the interaction between Alpine N-S directed shortening within the Southern Alps and the developing dextral wrench fault of the Periadriatic (Gailtal) Line. After stress release a system of shear zones developed during the Oligocene (Schwarzwipfel Fault, Hochwipfel Fault, Mölltal Line and other) followed by repeated NW-SE directed shortening in the Middle Miocene during which folds en échelon facing mostly to southeast and reverse faults of the same polarity were established. At this shear faults (flower structures) large vertical displacements and uplifting occurred. Subsequently the stress field changed to N-S direction leading to the final overthrust of the Karawanken Alps over the foreland during the Pannonian and Pontian, and to the southward thrusting of the Steiner Alps in Slovenia.

The tectonic framework of the Eastern Karawanken Alps is characterized by the north verging anticlinal structure of the central and southern part (Fig. 5). Its axis dips gently towards southwest. The whole area may be subdivided into two superposed allochthonous units. In addition, north of the Seeberg anticline the folded Trögern area further complicates the deformation style.

1. In the area around the Seeberg Pass the uppermost unit is represented by the Reef Unit. Near the Pass rocks of the core are well exposed. They comprise reef and near-reef limestones, e.g., north of Plasnik (P.1257), at Rapold, Pasterk, Storschitz and at the Grintoutz localities. Laterally this facies grades into forereef and pelagic deposits. Generally, the sequence within this unit consists of different limestone of Devonian age, followed locally by the Carboniferous Hochwipfel Formation and transgressive sediments of Late Carboniferous and Permian age..At the the southern limb the well known localities of Paulitschwand, Leßnik and Sadnikar are occurring, while on the northern side such famaous outcrops as Sadonighöhe, Stanwiese, Grintoutz and Hirschfelsen are located. The lateral movement of the Reef Unit is estimated to be some 4,5 km.

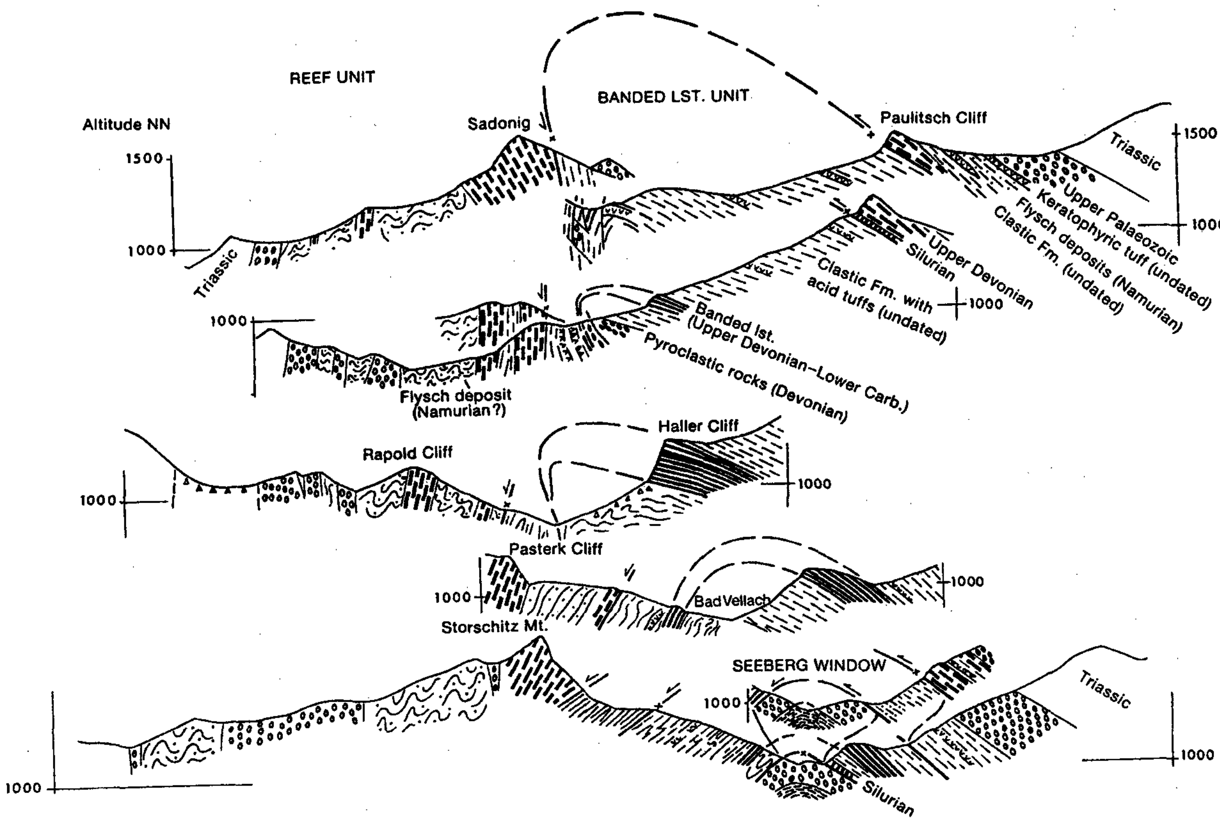


Fig. 5: N-S running sections through the Palaeozoic of the Seeberg area of the Eastern Karawanken Alps (after Rolser & Tessensohn 1974)

2. The above mentioned uppermost unit is underlain by the Bänderkalk Unit ("Striated banded limestone Unit"). It is dominated by banded limestones and over and underlying clastics. Locally, at its base nautiloid bearing Silurian limestones and Lower Devonian tentaculite bearing limestones occur. The amount of thrusting in this unit does not exceed 1,5 km.

3. The Basal Unit is well distributed between the village of Bad Vellach und the locality "Steiner". Structurally, this unit can be regarded as a tectonic window (Fig. 6). Its sequence consists of the so-called "Seeberg Shale" the age of which has yet not been ascertained and its transgressive cover formed by the equivalents of the Auernig Group, i.e., fusulinid bearing limestones, shales, sandstones and quartz-rich conglomerates.

To unravel the complicated tectonic deformation of the Eastern Karawanken Alps the above mentioned Late Carboniferous sediments are of critical importance as they provide clear evidence of the age of nappe-forming processes. Due to the fact that the post-Variscan molasse-type sediments are also involved in the nappe pile the main deformation in this are must be assigned to the Alpine tectonism.

North of the anticline formed by the above mentioned nappes the folded zone of Trögern occurs. It is characterized by steep to vertical dipping of the sequence dominated by clastic rocks of the Hochwipfel Formation. Locally also the Devonian substratum and the post-Variscan cover is exposed showing a mushroom and drop-like appearance due to squeezing of competent rocks between clastic layers. This zone may locally attain a width of more than 3 km.

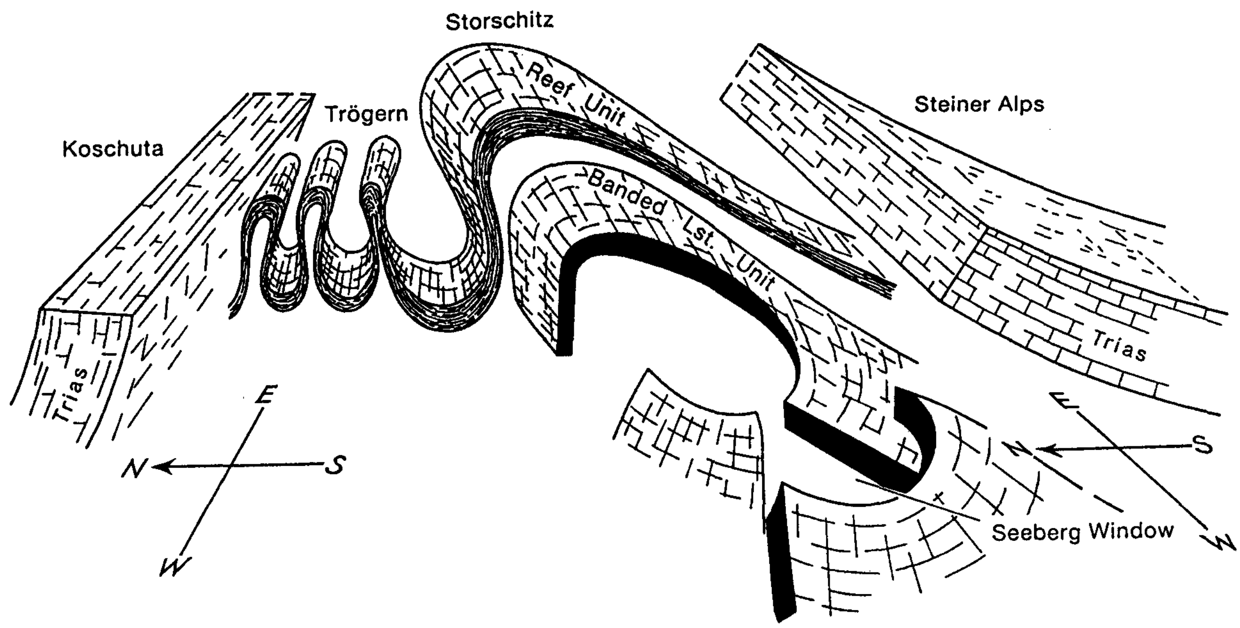


Fig. 6: Diagram showing the main tectonic units of the Seeberg area of the Estern Karawanken Alps (from Rolser & Tessensohn 1974).

In addition to the huge fold structures with amplitudes of several hundreds of meters small-scale folding is very common in the Seeberg area. It mainly affects those regions which are occupied by shales, i.e. the Seeberg Shale and the Hochwipfel Formation. Finally, steep faults have further subdivided the whole area into numerous small blocks. During the uplift of the whole area the Triassic cover of the Koschuta belt and the Steiner Alps detached from the underlying Late Carboniferous and Permian rocks.

The narrow belt of the "Diabaszug of Eisenkappel" from north of the Periadriatic Line is fault bounded to the north and the south (Fig. 3). It represents a highly compressed folded and faulted north verging zone showing several repetitions. To the north this belt of Palaeozoic rocks is thrust upon Late Permian and Triassic rocks. Most probably they formed the original cover of the Lower Palaeozoic volcaniclastic sequence suggesting thus a Variscan deformation for this Palaeozoic series. The southern boundary is formed by the north thrusting Karawanken Granite. According to radiometric dating it was formed during Late Variscan times (Cliff et al. 1975). During intrusion the Diabase of Eisenkappel and its accompanying rocks were marginally affected by contact metamorphism (Exner 1972).

The Carboniferous of Nötsch

The famous fossiliferous outcrops of Carboniferous age are located in the Gail Valley between Windische Höhe and the Villacher Alpe. It culminates in the peak called Badstube (1369 m) and is crossed by the Nötsch River. The name-bearing village of Nötsch, however, is situated in the Gailtal Crystalline Complex follwing to the south of the Carboniferous deposits (Fig. 7).

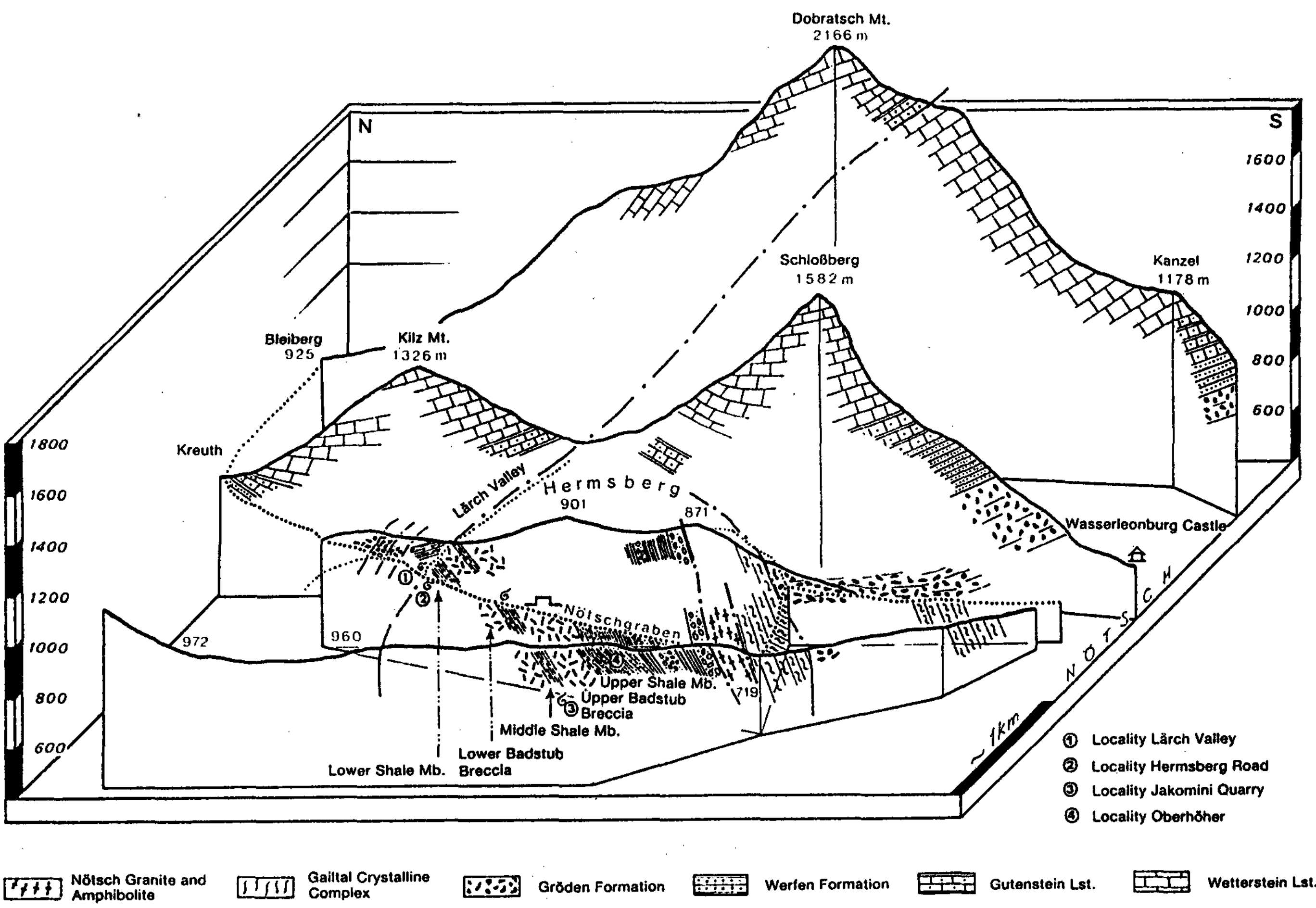


Fig. 7: Diagrammatic sketch of the eastern part of the Carboniferous of Nötsch showing the south dipping succession along the river Nötsch bounded to the north and south by faults. To the east the Carboniferous deposits are overlain by Permian and Triassic rocks of the mountain Dobratsch (=Villacher Alpe). From Schönlaub 1985.

Since the beginning of the last century the Carboniferous of Nötsch has been famous for its abundance of fossils and thus has attracted many geologists and palaeontologists. The east-west directed exposures extend as narrow fault-bounded wedge over a distance of 8 km the maximum width of which is 2 km in the east. Further to the west the Carboniferous rocks are squeezed out between the above mentioned rocks and are also covered by Quaternary deposits, respectively.

The tectonic significance of these Carboniferous rocks has raised many controversial statements in the past. In fact the true relationship between the Carboniferous sediments and the surrounding units of the Gailtal Crystalline Complex and the Drauzug has long been a matter of debate and has yet not been solved satisfactorily. One of the main problem concerns the northern boundary of the Carboniferous deposits (see Fig. 7): Some authors consider it as a distinct fault zone separating the Carboniferous from the Permian and Triassic while some others assume an originally transgressive relationship between Upper Carboniferous rocks and the overlying Permian clastics. A conclusive decision about one of the two options has significant implications for the tectonic framework of the greater part of the Eastern Alps.

Based on a revised map and additional palaeontological work carried out in the last few years knowledge about most rocks and fossils considerably increased. In the south dipping sequence which was affected by several NNE-SSW trending distinct faults the oldest part occurs in the north and is named Erlachgraben Formation. Towards south it is followed by the Badstub Breccia and the Nötsch Formation. Erlachgraben and Nötsch Formation display similar lithologies such as grayish blackish shales, micaceous siltstones, sandstones and quartz-rich conglomerates. Locally, fossils occur very abundantly. The disorganized Badstub Breccia is composed of mainly subrounded and rounded crystalline clasts such as amphibolites, ortho- and paragneisses, schists, micaschists, quartz, quartzites, marbles and few limestone clasts embedded in a dense green matrix of tholeiitic composition. From sedimentological evidence Schönlaub (1985b) and subsequently Krainer & Mogessie (1991) inferred a sedimentary origin of the breccia. Previously a volcanic source was favoured for the explanation of this rock. Conodonts recovered from limestone clasts indicate a formation after the *Paragnathodus nodosus* Zone. In terms of the presently used chronostratigraphical subdivision of the Carboniferous this time correpsonds to the latest Visean or more probably, to the early Serpukhovian.

New and revised fossil data (see Schönlaub, this volume) suggest an overall Late Visean to Early Westphalian age for the molasse-type Carboniferous sediments. The dominating fossil groups are brachiopods, followed by bivalves, trilobites, gastropods, corals, crinoids, bryozoans, very few cephalopods and plants; microfossils include foraminifera, ostracods and few conodonts. In addition in the clastics trace fossils are fairly common.

Yet the basement of the transgressive Carboniferous sequence has not been found. It may either be formed by an amphibolite-grade crystalline complex or less probably, by the Gailtal Quartzphyllite. Interestingly, at several places north of the village of

Nötsch there is clear evidence of a transgressive relationship between the latter and overlying Permian clastics (Schönlaub 1985b). It may thus be concluded that the present outline of the Carbonifeous basin was formed during the Alpine orogeny which affected and rejuvenated older faults and created new ones parallel to the Periadriatic Line. Extensive N-S shortening was mainly responsible for the closely neighbouring different tectonic units observed today; additionally vertical movements promoted the preservation of Carboniferous deposits distributed today in an apparently distinct and almost exotic setting.

The Palaeozoic of the Gurktal Nappe

Since the first half of this century fossils of Lower Palaeozoic age have been known from Middle Carinthia. They were first recognized by Petraschek (1927) who recorded *Orthoceras* sp. from the area between Feldkirchen and Lake Ossiach. According to Haberfelner (1936) who studied the Aich quarry near Althofen and north of St.Veit an der Glan, the clastic part of the section tentatively was subdivided into Ordovician and Silurian cherts, siliceous slates and quartzites. They are overlain by platy stromotoporoid bearing limestones which he assigned to the Lower Devonian. A few years later Seelmeier (1938, 1940) and Murban (1938) discovered even older fossils at the locality Bruchnig on Christofberg from north of Klagenfurt. They occurred in tuffaceous rocks at the top of a thick volcanic series studied later by Riehl-Herwirsch (1970) and Loeschke (1989) in great detail. Yet the brachiopods from this locality represent the oldest macrofauna ever been recorded from the Alps; according to Havlicek et al (1987) the fauna is equivalent to the Llandeilo Stage of the British succession and thus represents a Middle Ordovician age. Below the volcanics badly preserved conodonts may also indicate this age (Neubauer & Pistotnik 1984, Pistotnik 1989).

For a long time these few fossil localities were the only database in this region. It changed after introduction of research methods for microfossils, in particular conodonts. Since then many new data have been obtained:

-- A conodont based subdivision of the Magdalensberg Group of Kahler (1953) was first established by Strehl (1962) on the western margin of the Saualpe between Eberstein and Klein St.Paul. He recognized a 400 m thick clastic sequence with intercalations of limestones ranging from almost the base of the Silurian to the Upper Devonian. It succeeds basic volcanics and pyroclastic rocks assigned to the Upper Ordovician. Interestingly, one of the lowermost limestone lenses of the Silurian contains abundant tabulate corals and other fossil debris (crinoids, brachiopods) suggesting a bioclastic or patch-reef origin. Buchroithner (1979) confirmed this conclusion and extended the biostratigraphic information to the Upper Ordovician (Ashgillian). From the same area of Klein St. Paul Neubauer and Pistotnik (1984) recorded basic volcanics of Lower Silurian age.

-- Clar et al (1963) supplemented these data and provided additional biostratigraphic evidence from the area between Althofen-Mölbling and the Magdalensberg region including the western part of the Saualpe.

-- From limestone intercalations within phyllitic slates of the southeastern part of the Saualpe Kleinschmidt & Wurm (1966) recorded Upper Silurian (Ludlowian) conodonts.

-- Neugebauer (1970) discovered spiriferid brachiopods from marbles within the "Phyllit Group" of the Saualpe region suggesting a Devonian age.

-- The Aich quarry near Althofen was further subdivided by Schönlaub (1971). It displays a 50 m thick limestone succession ranging from the Lower Emsin to the early Famennian. Parts of the Middle Devonian, however, are missing. The limestone sequence is overlain by shales and cherts which yielded conodonts assignable to the Late Tournaisian or the Tournaisian/Visean boundary (Neubauer & Herzog 1985).

-- At Mölbling some 5 to 10 m thick limestones and dolomites provided conodonts of Late Silurian age. According to Buchroithner (1979) these carbonate rocks may well represent the extended base of the nearby Aich quarry section. In addition, Upper Ordovician conodonts were found near Mölbling (Neubauer & Pistotnik 1984) suggesting an overall continous long ranging Ordovician to Carboniferous section in this region.

-- Additional biostratigraphic information was derived from Drasenberg near the village of Meiselding and from Schelmberg east of Guttaring (v Gosen et al 1982, Neubauer & Herzog 1985). Based on conodonts some limestone lenses were assigned to the Lower and Upper Devonian, respectively. They occcur within a siliciclastic sequence which according to Neubauer & Herzog (1985) suggests similarities with the flysch-type Hochwipfel Formation of the Southern Alps.

In conclusion, the facies development of the Gurktal nappe system varies between a carbonate dominated and a carbonate-poor facies (Tollmann 1977, Buchroithner 1979 and Ebner et al 1990, see Fig.8). The first represents the pelagic "Facies of Althofen" and corresponds to the Pridolian, the whole Devonian and the Lower Carboniferous. It is opposed by the "Facies of Magdalensberg" representing a more than 500 m thick clastic-volcanic sequence with intercalations of 2 to 8 m thick limestone horizons. It spans the interval from Middle (?) Ordovician to the Middle Devonian (Buchroithner 1979, Pistotnik 1989).

The above mentioned facies variation has also been documented from the north and northwest of Middle Carinthia, i.e., the Murau and Turrach areas (Höll 1970, Ebner et al 1977, Buchroithner 1978, 1979, Neubauer 1979, Neubauer & Pistotnik 1984, Ebner et al 1990, Neubauer & Sassi, this volume). In these regions the oldest part of the sequence (?) is formed by the "Metadiabase Formation" of presumably Lower or Middle Ordovician age (according to Schnepf 1989 they may be assigned to the Silurian). This thick mafic volcanics are overlain by the more than 100 m thick Golzeck Sandstone containing conodont bearing Upper Ordovician limestone lenses, the 7 m thick Golzeck Quartzporphyry and the 6 m thick Lower Auen Dolomite indicating most probably an Ashgillian age. After a sedimentary break lasting from the Lower to the Middle Silurian the following part of the sequence is represented by the 20 m thick Middle Auen

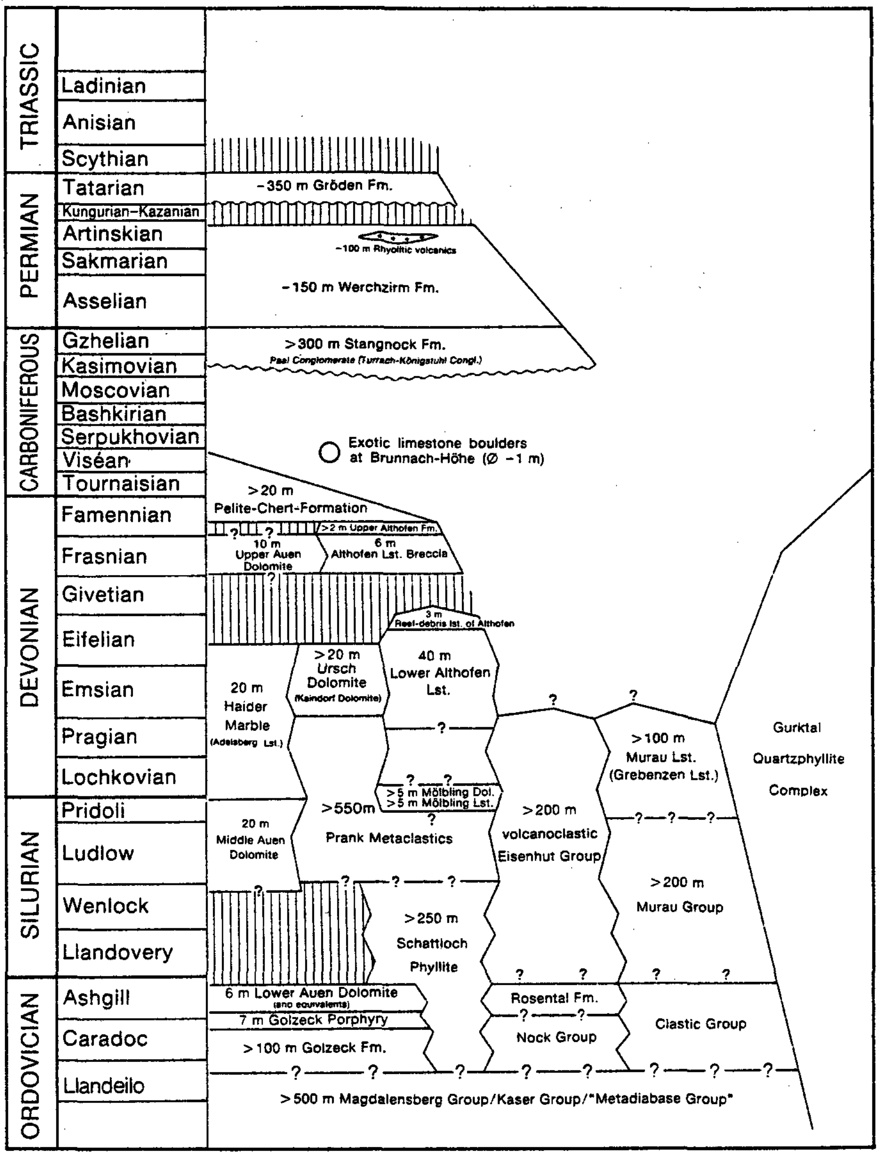


Fig. 8: Stratigraphy of the Variscan sequence of the Gurktal Nappe of Middle Carinthia and the surroundings of Murau (SW Styria). Modified from Buchroithner (1979) and Neubauer & Pistotnik 1984.

Dolomite in the Upper Silurian and the 20 m thick Haider Marble of Lower to Middle Devonian age. The 10 m thick Upper Auen Dolomite represents the uppermost portion of the sequence indicating a Frasne age.

The concurrent clastic facies displays marked differences (Neubauer 1979, Neubauer & Pistotnik 1984). For example, at locality Prankerhöhe distinct lithologies comprise more than 500 m of sandstones, quartz wackes and quartz arenites underlying the Emsian to Eifelian Ursch Dolomite. Also, in the surroundings of Turrach similar lithologies are distributed.

In addition, the Lower Palaeozoic sequences of the Gurktal nappe system are characterized by volcanic activities. Volcanism occurred at different times, varying intensity and differing geochemical behaviour depending grossly on its paleotectonic setting. For further details the reader is referred to the respective articles of this book (Loeschke and Heinisch; Neubauer and Sassi).

The Palaeozoic of Graz

Introduction

The Palaeozoic sequence in the surroundings of Graz has long been famous for its varied lithology and its abundance of fossils of mainly Devonian age. The Palaeozoic outcrops cover an area of approx. 50 x 25 km to the east and the west of the Mur river (Fig. 9). Even within the city of Graz Silurian and Devonian oucrops are widely distributed. Close to the southwestern edge the "Gosau of Kainach" transgressively overlies the Lower Palaeozoic sequence. Its eastern and northern frame is formed by crystalline rocks attributed to the Middle Austroalpine tectonic complex. To the south the Palaeozoic is covered by Tertiary rocks and thus mask the assumed continuation to the Sausal and Remschnig counterparts of southwestern Styria.

Shortly after Anker (1828) recognized the "Übergangsgebirge" in the vicinity of Graz the equivalents of the Devonian Period were discovered by Unger (1843). Although the first subdivision of the rock sequence was presented by Suess as early as 1868 a stratigraphic scheme based on fossils was not established till Stache (1884) and Pennecke (1894). This latter work constituted the base for all future studies, in particular that of Heritsch who published the first comprehensive monographs about the Palaeozoic of Graz in 1915 and 1917.

For a long time in the Palaeozoic of Graz the existence of nappes was not realized. Schwinner (1925) was the first who assumed lateral movements which explained some of the problems in stratigraphy raised by the old concepts. Following the newly proposed tectonic framework and additional field data provided by Heritsch, Clar, Waagen and others Heritsch (1943) and Flügel (1953) further improved the stratigraphic database. In the 1950s a new study campaign started. Preliminary it was completed in 1960 when Flügel (1960, 1961) presented a new map and explanatory notes based on revised and supplemented data on fossils and rocks. Since that time research in different fields has continued and the knowledge about the facies development, the macro and microfauna content, distribution of ores and the deformation features have considerably increased. For recently published summaries we refer to Flügel (1975), Schönlaub (1979), Ebner et al (1981, 1990), Flügel and Neubauer (1984) and Weber (1990).

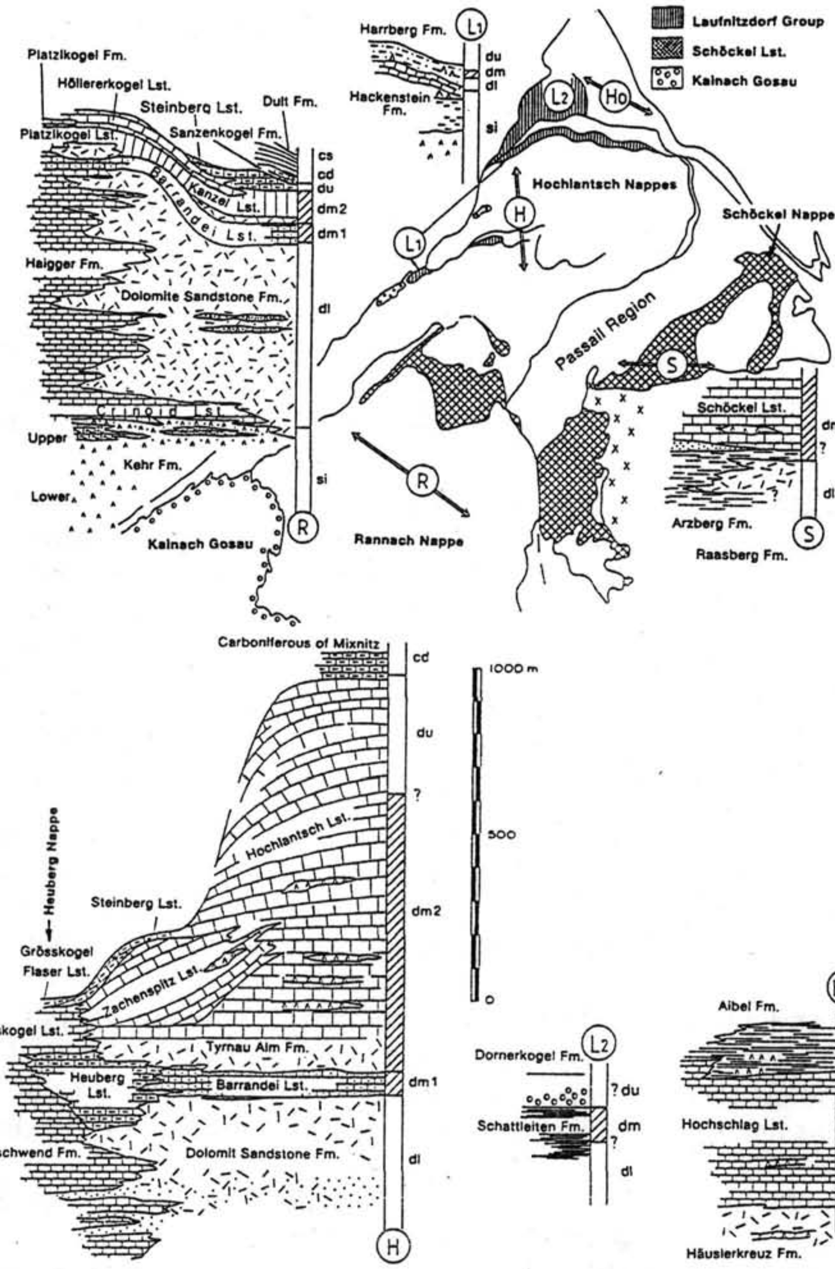


Fig. 9: Stratigraphy of the thrust system of the Palaeozoic of Graz. Letters of the stratigraphic colums indicate: R=Rannach Group, L_1, L_2=Laufnitzdorf Group, H=Hochlantsch Group, Ho=Hochschlag Group, S=Schöckel Group (from Flügel and Neubauer 1985).

Recently Fritz et al (1986, 1991) subdivided the nappe system into lower and upper nappes (Fig. 10). The first type is represented by the metamorphic Schöckel Nappe and the 'Angerkristallin', the latter by the anchi to epimetamorphic Hochlantsch, Rannach, Heuberg, Laufnitzdorf and Kalkschiefer Nappes. In comparison with the former these higher nappes lack a Variscan ductile structural imprint.

Fig.9 summarizes the lithology, stratigraphic range and regional distribution of the main facies developments of the Rannach and Hochlantsch Nappes supplemented by additional data from other units. This sketch clearly demonstrates that the individual nappes represent facies nappes.

Review of Stratigraphy

The Palaeozoic history of the Graz area is best displayed in the sequence of the Rannach Nappe. The oldest parts comprise basic metavolcanics of Ludlovian age followed by Upper Silurian to Lower Devonian clastics and limestones. Sedimentation of different carbonates dominated from the Middle Devonian to the beginning of the early Upper Carboniferous.

New field data from the Silurian Kehr Formation indicates a sedimentation pattern controlled mainly by volcanism (Fritz and Neubauer 1988, Neubauer 1989). The eastern area is characterized by a proximal shallow water setting with lavas and coarse lapilli tuffs while the western sections represent the distal facies displaying cinerites with intercalated lapilli-rich beds, agglomerates, shales and pelagic limestones. Beside other components the Kehr Agglomerate consists to 1-3% of quartzites, dolomites, cherts and reworked limestones. During the succeeding Lochkovian and Pragian Stages sedimentation of the 0 to 100 m thick Crinoid Beds and time-equivalent quartz-arenites followed the inherited topography. However, in the course of the Lower Devonian the clastic input progressively ceased in favour of carbonate sedimentation, and finally in the Emsian gave way to an almost uniform formation of dolomites, i.e, the 500 to 1000 m thick Dolomit-Sandstein Formation (Fenninger and Holzer 1978). Still, in its lower part a weak volcanic activity is indicated by the intercalation of pyroclastic rocks.

New field and biostratigraphic data obtained from other nappes suggest overall similar environmental conditions for the Upper Silurian portion of the respective sections of the Schöckel Nappe and the Laufnitzdorf Group. In the latter, however, pelagic nodular limestone sedimentation persisted during the Devonian (Gollner et al 1982).

The lower 300 m thick Sandstone Member of the Dolomit-Sandstein Formation comprises thick sandstone beds, dolomitic shales and bioclastic dolomites; the succeeding Dolomite Member consists of lower grayish and and upper blackish dolomites. In the gray dolomites Fenninger and Holzer (1978) recognized stromatolites, sheet cracks, fenestral fabrics, tepee structures, pseudomorphs of gypsum indicating a supra and subtidal environment; the black types are rich in amphiporids suggesting a setting in a protected lagoon. As far as these types and the extent of the basal sandstone member are concerned lateral and vertical variations are quite common (see Gollner and Zier 1985).

In the Eifelian the thick Dolomit-Sandstein Formation is succeded by the Barrandei and the Kanzel Limestone. The first are represented by 80 to 100 m thick grayish packstones and bioclastic limestones rich in corals, stromatoporoids, brachiopods and crinoids indicating a shallow water environment (Flügel 1975). Locally, they are interbedded with graphitic shales and brownish marls (e.g.,"Chonetenschiefer"). In the Heuberg Nappe the Heuberg Limestone represents a lateral equivalent of the Barrandei Lst. The main difference is its increased content of clastic detritus suggesting a more coastal setting.

The upper portion of the Barrandei Lst., represented by black *Amphipora*-bearing limestones is succeeded by the coarse-bedded and massive up to 100 m thick Kanzel Limestone. It comprises mudstones and wackestones with only few corals and other fossils indicating a middle or upper Givetian age. Presumably, they were formed in a protected and low agitated moderately deep environment. Time equivalent deposits are named Platzkogel Lst. and Größkogel Lst., respectively, which may also pass to platy limestones, thin bedded clayish limestones and even sandstones. Most probably they represent a near-shore shallow water environment close to or shortly after the Middle/Upper Devonian boundary.

In the Hochlantsch Nappe the 140 t0 500 m thick Tyrnau Alm Formation grossly corresponds to the Kanzel Lst. and its equivalents; previously it was named "Calceola Beds". This formation comprises dolomitic rocks, sandstones, dolomitic sandstones, limestones, shales and rauhwackes in the lower part followed by a volcanic horizon and an upper limestone member. This latter contains abundant corals and stromatoporoids forming small biostromal accumulations. For details see Gollner and Zier (1982, 1985), Zier (1982) and Gollner (1983).

The Tyrnau Alm Formation is overlain by the 350 m thick mostly well bedded Zachenspitz Limestone, previously named "Quadrigeminum Lst.". They are characterized by abundant fossils like tabulate and rugose corals, bioherms of stromatoporoids, amphiporids, crinoids and other fossil debris suggesting a subtidal quiet water environment with local reef growth. Locally, at the base volcaniclastic intercalations are common.

The lateral equivalent of this formation is the more than 800 m thick Hochlantsch Limestone. The lithology comprises massive grayish to reddish limestones which have been interpreted as shallow water back-reef deposits. They provided only few fossils like, for example, conodonts, tabulate corals and *Amphipora* indicating a Givetian to Frasnian age.

In the Hochlantsch Nappe the uppermost beds are represented by 15 m thick styliolinid limestones resembling the Steinberg Lst. of the Rannach Nappe. According to conodonts a Frasnian age of these limestones has been concluded. Disconformably they are succeeded by a limestone breccia forming the base of the cephalopod bearing "Carboniferous of Mixnitz". These pelagic deposits are up to 100 m thick and correspond to the Upper Tournaisian, Visean and basal Namurian B.

In the Rannach Nappe the Upper Devonian is represented by the grayish to yellowish or reddish and between 20 and 70 m thick Steinberg Limestone. The transition from the underlying Kanzel Lst. is gradational starting in the varcus conodont zone of the Late Givetian and ending at different time levels of the Famennian. In general, these limestones closely resemble cephalopod limestones distributed widely in the Variscan region, e.g, the Rhenish Slate Mts., the Carnic Alps or southern France. The fauna (cephalopods, trilobites, ostracods, foraminifera, conodonts) indicate a pelagic setting of moderate depths between 60 and 300 m. Corresponding units occur in the western part of the Rannach Nappe at Platzlkogel and at Höllererkogel (Höllererkogel Lst.) but also in southern slices of the Hochlantsch Nappe (Größkogel Lst.).

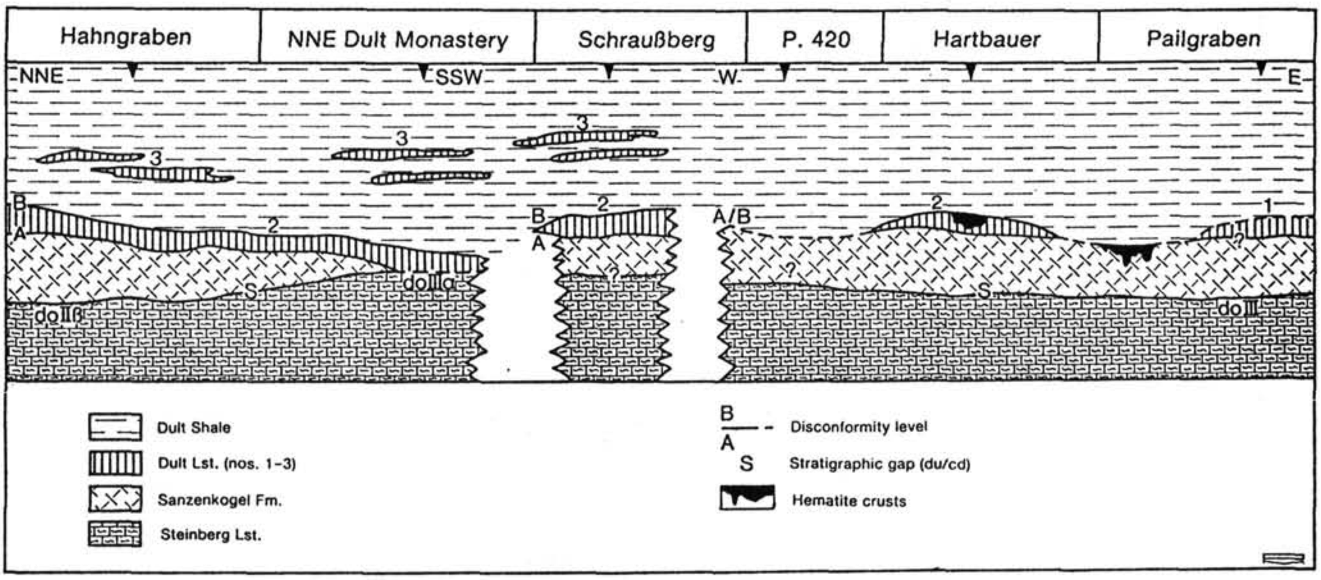


Fig. 10: Upper Devonian and Lower Carboniferous sediments of the Graz Palaeozoic. Note unconformity at the D/C boundary (letter S) and between the Sanzenkogel and the Dult Formations (A, B). From Ebner 1976.

The 20 to 25 m thick Sanzenkogel Formation represents the Lower Carboniferous part of the limestone succession of the Rannach Nappe (Fig. 10). This unit comprises grayish bedded limestones with intercalations of chert, phosphorite and shales in the lower part. They disconformably overly various levels of the Steinberg Lst. suggesting significant erosion and non-deposition in the Tournaisian. As a result the Lower Sanzenkogel Limestone ranging from the equivalents of the sulcata Zone to the Upper Tournaisian anchoralis-latus zone, does not exceed 2.20 m in thickness; frequently it is even completely missing. Formation of fissures, a distinct micro and macrorelief, internal sediment accumulations, hematite crusts, hardgrounds and mixed conodont faunas most probably indicate local emersion and karstification at the end of the

Tournaisian (Ebner 1978, Fig. 10). Subsequently, limestone sedimentation continued and the Upper Sanzenkogel Limestone was deposited.

In the Rannach Nappe the more than 70 m thick predominantly clastic Dult Formation represents the youngest rock. At its base the 10 to 15 m thick Dult Limestone is developed which disconformably overlies the Sanzenkogel Limestone (Fig. 10). Based on conodonts these basal parts represent shallow water limestones corresponding to the Namurian B. Due to the relief at the base these limestones only locally have been deposited and preserved (Ebner 1976a,b 1977a,b, 1978a,b, 1980a,b). Hence, these deposits too suggest local emersion which accords well with data from other parts of Central Europe (Schönlaub 1991). Yet the range of the Dult Formation is not precisely known; it may extend to the Westphalian as has been inferred from few conodonts and some plants.

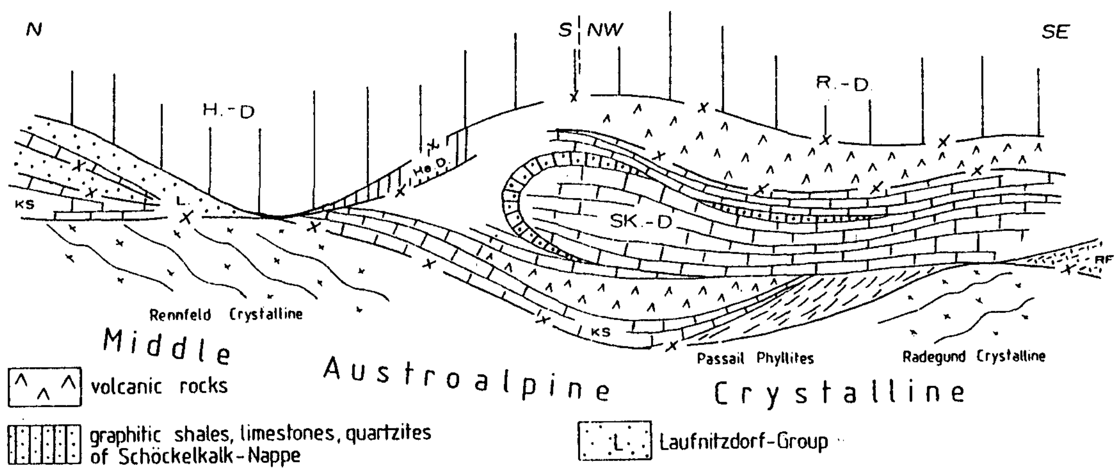


Fig. 11: Tectonic sketch of the Palaeozoic of Graz. Abbreviation: H.-D. Hochlantsch Nappe, He.D. Heuberg Nappe, R.-D. Rannach Nappe, KS Kalkschiefer unit, RF Raasberg Group (unknown age, underlying Silurian strata). From Ebner et al 1990.

In the surroundings of Graz the deepest tectonic unit is represented by the Hochschlag Group. However, the stratigraphy is only poorly known due to tectonic complications, metamorphic overprints and scarcity of fossils. It comprises the basal Häuslerkreuz Formation composed of arenites, marbles, dolomitic rocks and metavolcanics. Few conodonts indicate an Upper Silurian to Lower Devonian age. It is followed by the Hochschlag Formation composed of interbedded platy and shaly limestones, graphitic quartzites, black shales, dolomitic rocks and local occurrences of metavolcanics. Locally the limestones yielded Middle Devonian conodonts. The Hochschlag Fm. may be overlain by the Aibel Formation comprised mainly of siltstones and shales (Thalhammer 1982) with less abundantly occurring limestones, cherts, sandstones and basic metavolcanics of unknown age. Similar rocks are widely distributed near the western margin of the Palaeozoic of Graz and north of the Hochlantsch mountain. Generally they have been described as "Kalkschiefer". According to Thalhammer and Tschelaut (1983), Flügel (1984), Tschelaut (1984) and Hubauer (1983) this lithology includes interbedded mudstones to wackestones, bioclastic limestones, sandstones, arenaceous shales, marls and intercalations of volcaniclastic rocks. Thickness of these strata varies between several 100 metres and more than 800 metres. Based on conodonts the Kalkschiefer Group may range from the Upper Silurian (or Lower Devonian) to the late Middle Devonian.

Tectonic Remarks

The Palaeozoic of Graz is subdivided into a number of thrust sheets which are composed of Silurian to Carboniferous sequences of distinct facies (Figs. 9, 11). The metamorphic overprint varies from amphibolite facies at the tectonic base, i.e. the Anger Crystalline Complex, and greenschist facies of the Schöckel Nappe s.l. to nearly unmetamorphosed sequences in the Rannach and Hochlantsch trust sheets at the tectonic top of this pile. The middle portion of the nappe pile displays a multiple imbrication of the Laufnitzdorf Nappe with Kalkschiefer nappes in the northern part of the Palaeozoic of Graz. Age of metamorphic overprint is Cretaceous; Variscan metamorphism is restricted to the deepest thrust sheets. Ductile deformation along thrust surfaces and in the interior of sheets is related to Alpidic thrusting and subsequent low angle normal faulting, which reactivated thrust surfaces during exhumation (Fritz et al., 1991).

The Palaeozoic of Burgenland

In southern Burgenland rocks of Palaeozoic age have been known since the last century (Hoffmann 1877). The Devonian age was inferred from corals and crinoids which were found in massive limestones intercalated in a predominantly shaly sequence. Such occurrences ar located between the villages of Hannersdorf and Burg, near Kirchfidisch and in the surroundings of Güssing (see Pollak 1962, Schönlaub 1984, 1990).

According to Toula (1878) the small fossil collection comprises tabulate and rugose corals, badly preserved brachiopods and crinoid stems. Based on this fauna Toula concluded a Middle Devonian age. Recently new findings of tabulate corals, amphiporas, crinoids and few conodonts , i.e. icriodids, confirmed the old age assignment. Lithologically these carbonates suggested a close relationship to coeval formations in the nearby Palaeozoic of Graz. Such an affinity seems well founded by subsurface data from the area in between (Ebner 1978c, 1988, Flügel 1988).

According to new stratigraphic data interbedded shales and limestones of the Blumau Formation are dominating in the Silurian. The Lower Devonian Arnwiesen Group is characterized by dolomitic rocks which are mainly occurring in the subsurface of the Tertiary Basin of Eastern Styria. Its Middle Devonian part, however, is widely exposed in Southern Burgenland. Ebner (1988) and Flügel (1988) suggested a correlation of these carbonates with the Dolomit-Sandstein Formation of Graz. Less certain are other possible equivalents, for example, the parallelization with the Barrandei Formation or the Dult Formation. Other affinities may exist to to the Palaeozoic outcrops of North Hungary, i.e., the Szendrö-Uppony Mountains which show a very similar lithologic succession.

The Graywacke Zone

Introduction

The Graywacke Zone forms the Palaeozoic basement of the Northern Limestone Alps. The WSW-ENE directed belt of Palaeozoic rocks extends over a length of some 450 km and a maximum width of 23 km from the Rhätikon of Vorarlberg to the town of Ternitz east of the Semmering Pass. In the Vienna Basin the eastern continuation is covered by Tertiary rocks.

The Graywacke Zone and its transgressive cover, i.e. the Northern Limestone Alps, belong to the Upper Austroalpine Nappe system. It is thrust upon crystalline complexes of the Central Alps following to the south. Generally all rocks of the Graywacke Zone are moderately metamorphosed ranging as far as the upper greenschist grade, and display a certain degree of foliation. Consequently, most fossils have been either destroyed or are badly preserved.

In the eastern part the Lower Palaeozoic sequence locally starts with a conglomeratic horizon named Kalwang Gneiss Conglomerate (Daurer and Schönlaub 1979). Based on its position below fossil bearing strata for the conglomerate an age within the Ordovician can be inferred. In the surroundings of the town Bruck an der Mur it rests upon a crystalline basement complex (Neubauer 1985) which by some authors has been referred to an enigmatic intra-Ordovician collision-subduction process (Frisch et al 1984, Becker et al 1987, Neubauer and Frisch 1988, Neubauer et al 1989, Frisch et al 1990).

In the provinces of Styria and Lower Austria the Graywacke Zone is subdivided into two major tectonic units, i.e. the Veitsch Nappe below and the Noric Nappe System above (Figs.12, 15). The first comprises shallow water limestones and molasse-type clastics of Lower to Upper Carboniferous age (see article of Krainer, this volume) while the latter forms a series of strongly deformed nappes and smaller tectonic slices ranging from the Middle or Upper Ordovician to the Carboniferous. Overthrusting of the Noric and Veitsch nappes occurred during the Alpine orogeny; both nappes are separated by the so-called "Noric Thrust Line". For the Noric Nappe System, however, a strong Variscan deformation is indicated by the transgressive "sealing" redbeds of the Permian Präbichl Formation (Schönlaub 1982, Neubauer 1989).

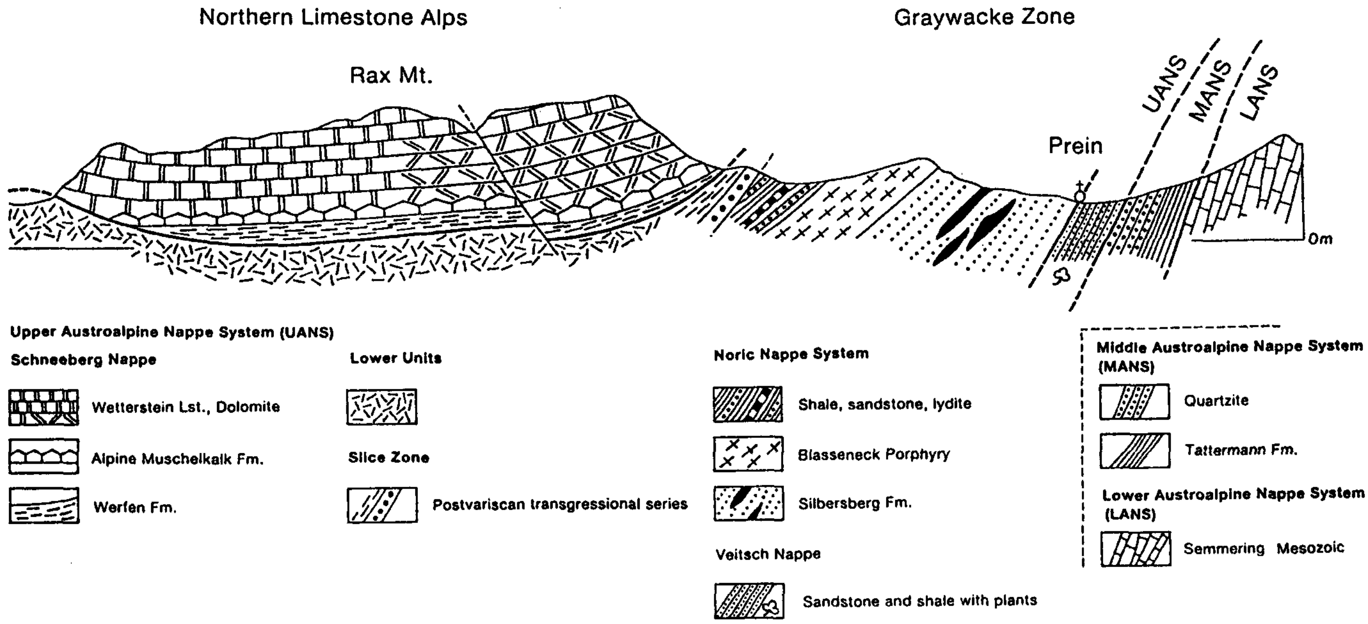


Fig. 12: NW-SE directed cross section of the Semmering area showing the tectonic relationship between the Lower, Middle and Upper Austroalpine Units. Note bipartation of the Graywacke Zone into the Veitsch Nappe below and the Noric Nappe System above. The latter is unconformably overlain by the Limestone Alps (from Tollmann).

Historical Notes

Prior to the discovery of fossils all schists of the Graywacke Zone collectively were named "graywacke". This term emphasized the separation from the "Urgebirge" of the Alps and designated as well the dominating rock type of this zone. Also it indicated the importance of mining in the Graywacke Zone during the 19th century; presently, however, only the siderite mine of Eisenerz is being mined. Following v Hauer's (1847) recognition of a Silurian fauna at Dienten the Graywacke Zone was generally regarded to represent a Lower Palaeozoic rock sequence.

For a long time knowledge of rocks and fossils of the Graywacke Zone of Styria and Salzburg was promoted by and benefited much from the mining industry. Research and progress of stratigraphy was equally concentrated in the Dienten-Mitterberg and the Eisenerz areas where a first subdivision of rocks was established by v Pantz and Atzl as early as 1814. Later, the first fossils were found including crinoids, bivalves, corals, trilobites, brachiopods and nautiloids from the localities Nagelschmiedpalfen near

Dienten and the Sauberg Limestone quarry of Eisenerz, the Polster region and a few more places (see Schönlaub 1979, 1982). At the beginning of this century subsequent work provided additional material from other regions near Kitzbühel and Fieberbrunn in Tyrol, the Entachenalm south of Hintertal in Salzburg and the Eisenerz area of Styria. As a result of the new and revised old collections Heritsch (1932, 1943) published a first biostratigraphically founded subdivision of the different lithologies of the Graywacke Zone. This scheme was further improved by correlating some of the rocks of the Graywacke Zone with coeval strata of the Southern Alps (HABERFELNER, K.METZ).

Yet, the main step towards the modern needs of a detailed biostratigraphic framework was not achieved until the early 1960s when conodont studies started in the Graywacke Zone. Such pioneering methods were first employed by Flajs for the Styrian part of the Graywacke Zone and by Mostler for the Salzburg and Tyrolian segment. Since then a great variety of new biostratigraphic data were recognized accompanied by analysis of facies, geochemistry work on volcanics and new maps (for more details the reader is referred to Schönlaub 1979, 1982, Heinisch 1986, 1988, Heinisch et al 1987, Schlaegel-Blaut 1990, Ebner et al 1990).

The Eastern Graywacke Zone of Styria

Review of Stratigraphy

The Eastern Graywacke Zone comprises a series of nappes and tectonic slices which display a certain variation of facies development of the Lower Palaeozoic rock sequence. A pre-Caradocian age is suggested for a more than 1000 m thick unfossiliferous sequence of greenschists, arenaceous shales, a thin marble bed, metaclastics and metapyroclastic rocks underlying the Blasseneck Quartzporphyry in the Southern Eisenerz Alps north of Kalwang (J.LOESCHKE et al. 1990, Fig. 13). Near the base the Kalwang Gneiss Conglomerate forms a distinct debris flow horizon interbedded in greenschists. Its age remains open.

The succeeding Blasseneck Quartzporphyry ("Blasseneck-Porphyroid") varies in thickness between a few meter or less and more than 1500 m (Heinisch 1981). In the Präbichl area the quartzporphyry is underlain by some up to 30 m thick limestone lenses which produced a rich conodont fauna of Late Caradocian or Early Ashgillian age (Flajs and Schönlaub 1976). The volcanics represent different types of recrystallized massive ignimbrites (pumice flow deposits), unwelded tuffs and other pyroclastics. According to its chemistry alcali-rhyolitic and rhyolitic compositions are dominating over rhyodacitic, dacitic and trachyandesitic rocks. These latter types mainly occur in the surroundings of Eisenerz. In this northern area the quartzporphyry is overlain by some 60 m thick quartzarenites named "Polster Quartzite" and the 13 m thick Cystoid Limestone both belonging to the Ashgillian Series (Fig. 13). In the southern part, however, the corresponding rocks may be represented by slates with intercalations of quartzarenites, greenschist and black shales comprising a thickness of a few hundred meters. Limestone intercalations in the upper part indicate a Late Llandovery or Early Wenlock age.

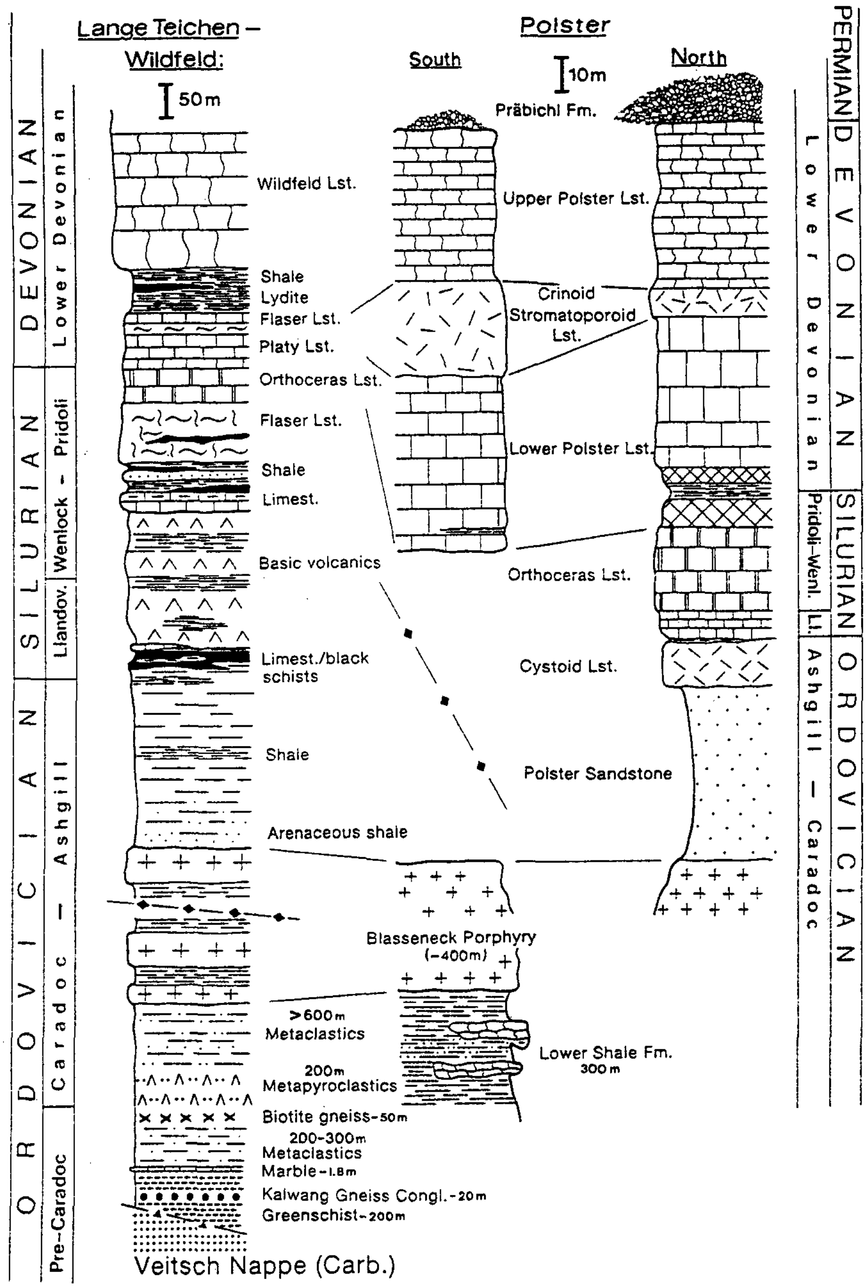


Fig. 13: Stratigraphy and facies variation of the Lower Palaeozoic sequence of the Graywacke Zone in the southern and northern Eisenerz Alps (from Schönlaub 1979, modified)

During the Silurian the facies pattern varied from some 50 m thick crinoid and nautiloid bearing limestones in the northernmost part to black graptolitic shales in a more southern area. Upwards and also laterally they grade into interbedded limestones and shales followed by a pure limestone development during the Late Ludlow and Pridoli. Thus far intercalations of basic volcanics of Llandovery age have only been found near the southern margin of the Graywacke Zone (Schönlaub 1976, 1982).

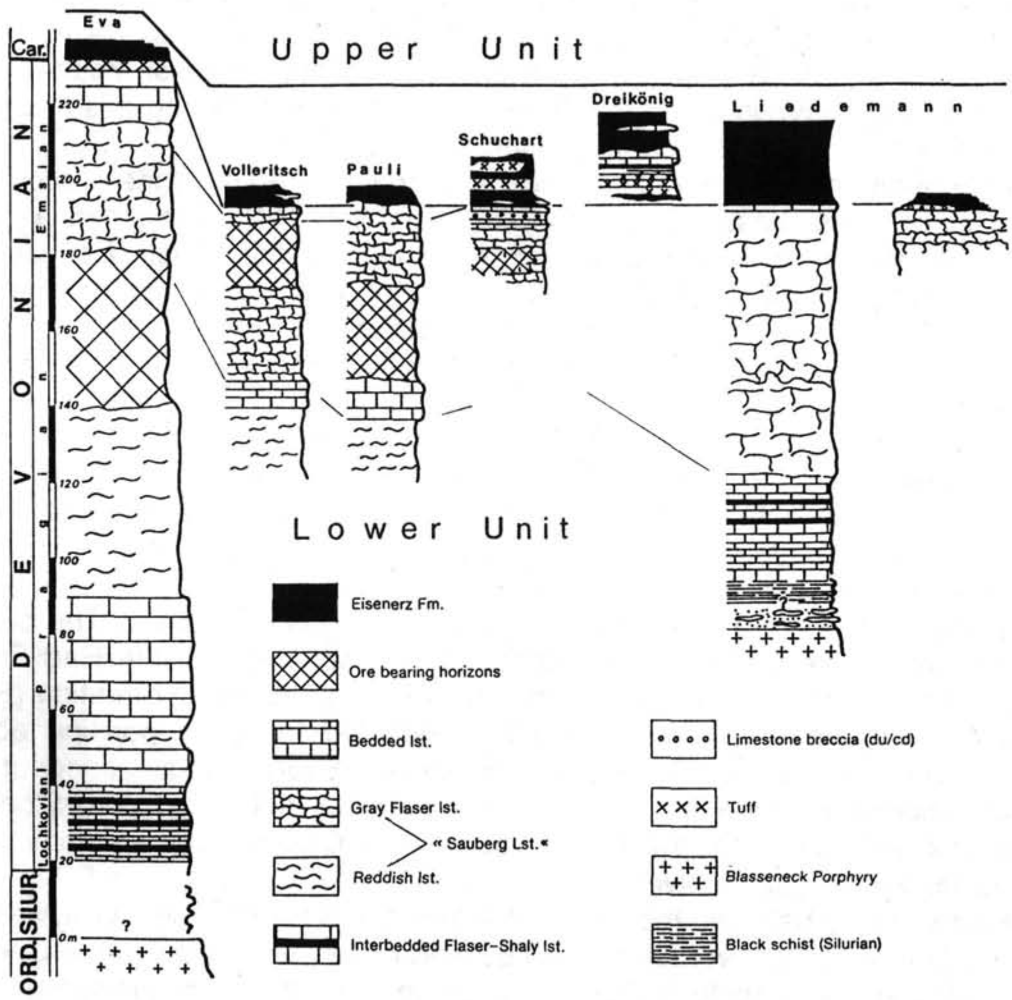


Fig. 14: Composite stratigraphic sections of the iron-mine at Erzberg/Eisenerz. Note unconformity relationship between the Devonian sequence and the overlying clastic Eisenerz Formation ("Zwischenschiefer") with a limestone breccia at the base (from Schönlaub 1979, modified).

In the Eastern Graywacke Zone limestone sedimentation continued during the Devonian. Different from other areas of the Alps, however, splitting of facies is less pronounced during this time. The Lochkovian Stage is characterized by platy limestones which may pass laterally into variegated limestones with intercalations of shales and organodetritic limestones. Locally they range into the Pragian and Emsian Stages (Fig. 13). Also, during this time nodular dacryoconarid bearing limestones and reddish limestones are very common.

In this part of the Graywacke Zone the majority of sections end at or close to the Lower/Middle Devonian boundary. At few places, however, some unfossiliferous limestones above may represent a Middle Devonian age as can be inferred from overlying rocks of Frasnian and even Famennian age. They demonstrate that limestone sedimentation may have lasted through the entire Devonian. During this time between 200 and 300 m of limestones were deposited.

Disconformably the Devonian sequence is overlain by a limestone breccia and the 100 to 150 m thick clastic Eisenerz Formation (Fig. 14). The breccia produced reworked and mixed conodonts spanning the time from the Middle Devonian to the Dinantian. Most probably the breccia was formed during a karstification event in the Visean (Schönlaub 1982). At the end of the Dinantian the paleokarst was covered by the clastic Eisenerz Formation ranging perhaps into the lower parts of the Upper Carboniferous.

A partly modified stratigraphic framework is inferred from more eastern areas of the Styrian Graywacke Zone. According to Nievoll (1983, 1987) the lowermost part is represented by the more than 300 m thick unfossiliferous Silbersberg Formation comprising metaclastites with intercalations of quartzarenites, metaquartz-conglomerates, greenschists, cherts and acid volcanics (Fig. 12). Analogous to the Eisenerz region they are overlain by the Blasseneck Quartzporphyry. The succession above is represented by the 300 to 1000 m thick metapelits of the Rad Formation. Although fossils are almost lacking for the lower part of the Rad Formation (Rad Unit) an Upper Ordovician and Silurian age is concluded from the position above the quartzporphyry and mainly below the occurrence of ferruginous conodont bearing Devonian limestones. Whether or not the overlying pelites of the Stocker Unit correspond to the clastic Eisenerz Formation of the Carboniferous or may represent tectonic repetitions is yet unsolved.

In the Enns valley between the towns of Admont and Radstadt the Graywacke Zone is tectonically reduced or even eliminated between crystalline rocks of the Central Alps to the south and the Limestone Alps to the north. The former continuation, however, has been confirmed by small outcrops near the village St.Martin south of Grimming (Böhm 1988) and from northeast of the town of Schladming (Schönlaub, unpubl.). At the first site black graphitic phyllites are associated with conodont bearing marbles of early Famennian age; previously, this sequence was regarded as part of the Veitsch Nappe. East of Schladming yellowish-brownish limestones overlying a metapelitic sequence produced conodonts of probably Upper Silurian age.

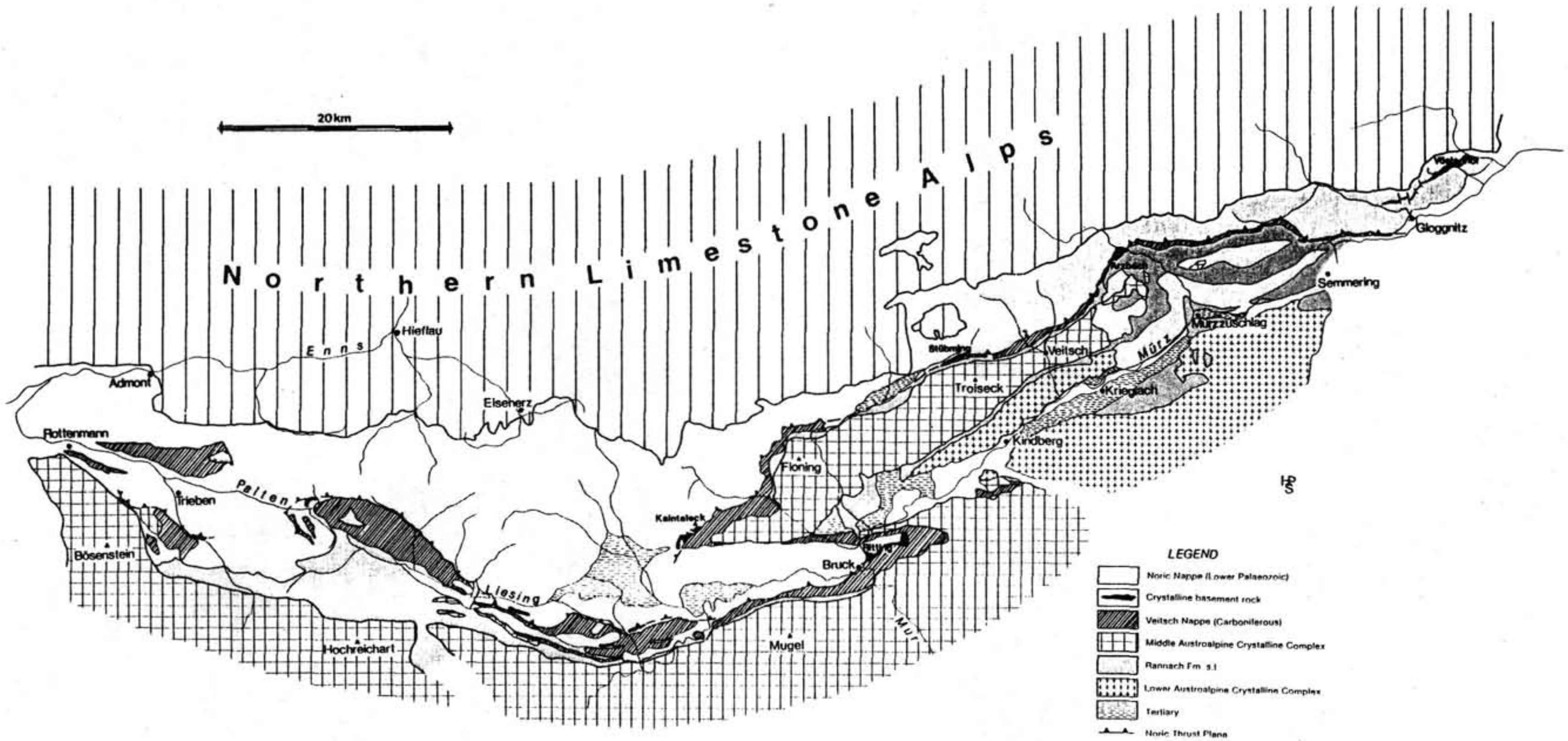


Fig. 15: Main subdivision of the eastern part of the Graywacke Zone of Styria and Lower Austria (from Schönlaub 1979, modified).

Tectonic Remarks

The main deformation of the Lower Paleozoic sequence of the Eastern Graywacke Zone occurred in the Upper Carboniferous. It resulted in southwest facing axial surface planes accompanied locally by a foliation at very low grade metamorphic conditions. During that time also an extensive system of nappes with flat lying thrust surfaces formed. This is documented by coarse clastic sediments of the Permian Präbichl Formation which unconformably overly different Variscan nappes, folds and faults (Flajs and Schönlaub 1976, Schönlaub 1982, Neubauer 1989).

In the Eisenerz Alps of the Eastern Graywacke Zone from south to north the following Variscan nappes and tectonic slices can be distinguished (Schönlaub 1982, Figs. 15, 16): Zeiritzkampl Nappe, Wildfeld Nappe, Reiting Nappe, Slice Zone and Northern Zone. Each nappe is composed of a rock sequence of mainly different stratigraphic extent and lithology. During the Alpine Orogeny this pile of basement rocks of the Northern Alps was thrust upon a lower unit comprised of the Carboniferous of the Veitsch Nappe. Both major tectonic units are separated by the Noric thrust plane.

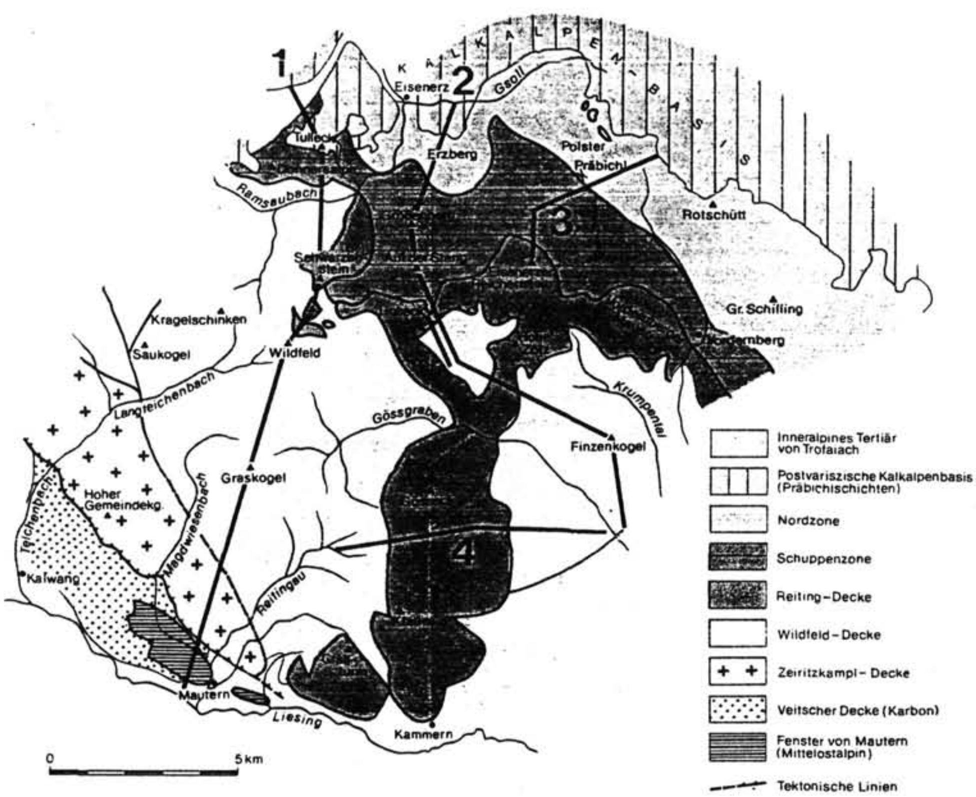


Fig. 16: Tectonic map of the Graywacke Zone of the Eisenerz Alps (from Schönlaub 1982).

The Veitsch Nappe represents the lowermost unit of the Upper Austroalpine thrust sheet. It is thrust upon the Middle Eastalpine thrust system exposed in the tectonic window of Mautern (Schönlaub 1982). The lithology within the window resembles the Rannach Formation and the Lower Triassic "Scythian Quartzite" well known from the Semmering area. In the region south of the Eisenerz Alps such clastics form the Permotriassic cover of the Variscan Seckau Crystalline Complex (Fig. 15).

The Western Graywacke Zone of Salzburg and Tyrol

Review of Stratigraphy

In the early sixties in the Western Graywacke Zone a team from Innsbruck University headed by Mostler started the re-examination of the stratigraphy and tectonic evolution of the Lower Palaeozoic sequences of Salzburg and Tyrol. The result was a well founded new biostratigraphic scheme based mainly on conodonts, supplemented by detailed sedimentological, petrographical and geochemical analysis (e.g. Mostler 1966, 1968, 1970, 1984, Al-Hasani and Mostler 1969, Mavridis and Mostler 1970, Emmanuilidis and Mostler 1970, Colins et al 1980, Fig. 17). Subsequently, detailed mapping of the Kitzbühel-Saalbach area was carried out by a working group of Munich University focusing on sedimentology, stratigraphy, volcanology, petrography and structural geology (Heinisch 1986, 1988, Heinisch et al 1987, Schlaegel 1988, Schlaegel-Blaut 1990).

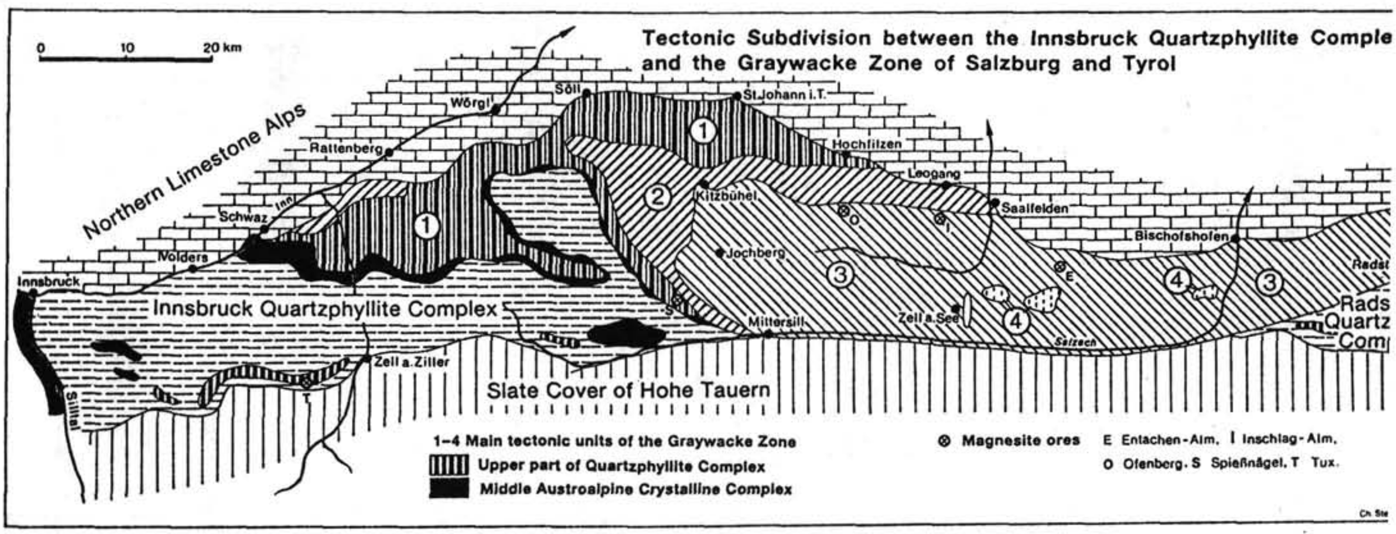
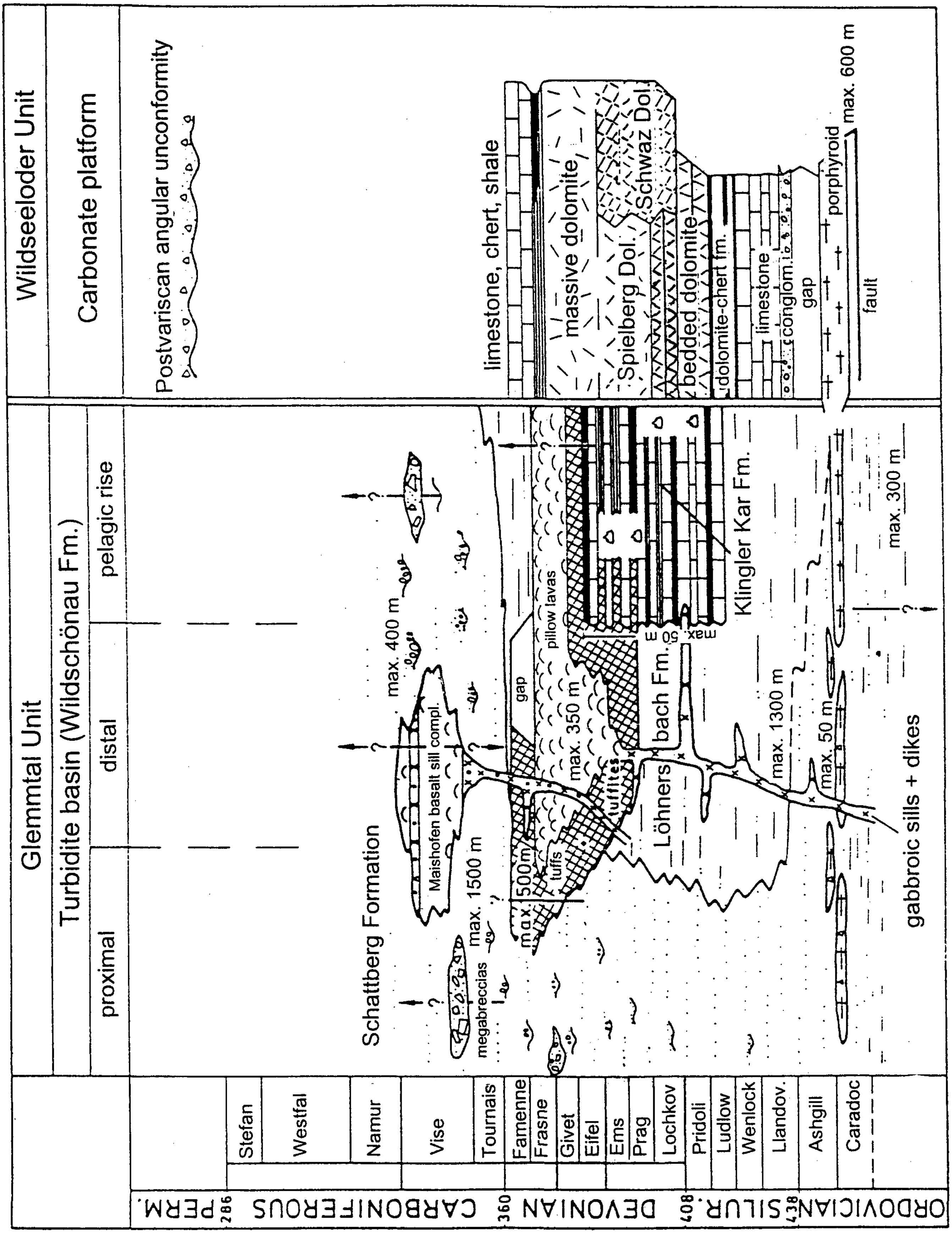


Fig. 17: Main structural subdivision of the Graywacke Zone of Salzburg and Tyrol (from Mostler 1973, modified).


Wildseeloder Unit
Carbonate platform
Postvariscan angular unconformity
limestone, chert, shale
massive dolomite
Schwaz Dol.
Spielberg Dol.
bedded dolomite
dolomite-chert fm.
limestone
conglom.
gap
porphyroid
max. 600 m
fault
Glemmtal Unit
Turbidite basin (Wildschönau Fm.)
proximal
distal
pelagic rise
Schattberg Formation
megabreccias
max. 1500 m
Maishofen basalt sill compl.
max. 400 m
gap
pillow lavas
max. 350 m
max. 500 m
tuffs
tuffites
Löhnersbach Fm.
max. 50 m
Klingler Kar Fm.
max. 1300 m
max. 50 m
max. 300 m
gabbroic sills + dikes
Stefan
Westfal
Namur
Vise
Tournais
Famenne
Frasne
Givet
Eifel
Ems
Prag
Lochkov
Pridoli
Ludlow
Wenlock
Llandov.
Ashgill
Caradoc
PERM.
286
CARBONIFEROUS
360
DEVONIAN
408
SILUR.
438
ORDOVICIAN

Based on the comprehensive set of new and refined old data from the two groups mentioned above between Kitzbühel and Zell am See an obvious heterogenity of facies of the Paleozoic rock record has been recognized. Within short distances two distinct facies can be distinguished (Heinisch 1988; Fig. 18). They are preserved in two nappes named Wildseeloder and Glemmtal Unit, respectively, which are separated by a polyphase composite shear zone.

The Wildseeloder Unit covers the northern part of the studied area. It is characterized by thick piles of Upper Ordovician Blasseneck Quartzporphyry and pelagic carbonates that developed during the Silurian and the Devonian (Fig. 18).

In this unit the oldest rocks are represented by the Blasseneck Quartzporphyry. Although in this part of the Graywacke Zone fossils are missing there are good reasons to assume the same Upper Ordovician age for these volcanics as in the Eastern Graywacke Zone. According to Mostler (1970, 1984) and Heinisch (1981, 1988) the up to 600 m thick rhyolitic ignimbrites extruded under subaerial to shallow marine conditions. Due to intense thrusting, any rocks older than the Blasseneck Quartzporphyry are not preserved.

Conglomeratic horizons at the top of the volcanics might mask a considerable gap in sedimentation. In addition, mudstones, debris flows and sandstones partly interfinger with volcaniclastic layers. At some places the Blasseneck Quartzporphyry is overlain by limestones of Llandovery age (Mostler 1967, 1970). During the Silurian facies differentiation was a common feature ranging from black shales with occasional occurrences of graptolites to cherts, siliceous pelagic limestones, condensed cephalopod limestones and even to dolomitic rocks. Starting in the Upper Silurian a carbonate platform developed until the early Upper Devonian. It comprises shallow water lagoonal dolomites, a local reef development and pelagic limestone of Frasnian age (Mostler 1970, Schönlaub 1979, 1980).

The Glemmtal Unit covers the southern part of the area. It comprises several thousand meters of siliciclastic sediments named Wildschönau Group. Locally intercalations of condensed pelagic limestones with interbedded cherts and siliceous shales are found. They are named Klingler Kar Formation. Of further importance are intercalations of basic magmatites ranging from a few meters to several 100 m thickness.

The monotonous siliciclastic rocks of the Wildschönau Group consist of interbedded shales, siltstones and sandstones, with locally occurring microconglomerates, conglomerates and breccias. Relics of sedimentary features (i.e., grading, cross laminations, plane parallel laminations, convolute bedding, Bouma sequences) demonstrate a turbidite origin. Within short distances two intergrading facies can be distingiushed (Heinisch 1986, Fig. 18):

-- the Schattberg Formation displays characteristics of proximal turbidites, e.g., coarse grained m-thick graded sandstones, channeling microconglomerates and breccias; and

-- the Löhnersbach Formation shows features indicating distal turbidites, e.g., dm-thick medium to fine grained sandstones with higher amounts of siltstones and shales.

In general facies relations are diachronous although a certain degree of coarsening upwards can be recognized. Following the basic volcanism in the Middle Devonian the Schattberg Formation was distributed over the entire Glemmtal Unit. Whether or not this formation extends into the Carboniferous is yet not known because of lack of fossils.

Olistholithic megabreccias of the Schattberg Formation comprise a varying spectrum of partly well rounded boulders of garnet or hornblendegneisses, amphibolites, quartzites, sericitic gneisses and granitoids. According to heavy mineral analysis the sandstone composition, i.e.subgraywackes, indicates a continental source area (Heinisch 1988).

In conclusion during the Lower Palaeozoic the Graywacke Zone of Kitzbühel and Saalbach may have acted as a marginal basin to a continent. It was supplied by turbidites connected with fan and channel deposits. The adjacent eroded continent was characterized by a metamorphic zoning and by intruded granitoids. This passive margin regime persisted from at least the Upper Ordovician to the Middle Devonian.

The up to 50 m thick Klingler Kar Formation represents a marine hemipelagic deeper water setting which lasted from the Upper Silurian to the Middle Devonian. It comprises condensed cephalopod limestones, marls, greenish and black shales, chert horizons ("lydites") and basaltic layers. The only fossils yet discovered are conodonts which indicate different levels within the Upper Silurian and the Lower to Middle Devonian. In addition they provide precise age assignments for some of the intercalated volcanic horizons (Heinisch et al 1987, Heinisch 1986, 1988).

Intercalated in the metasediments a huge amount of basic rocks occur (Schlaegel 1988, Schlaegel-Blaut 1990). During a short time span all facies zones except the carbonate platform were affected by strong magmatic events. According to conodonts volcanism apparently started in the late Lower Devonian Emsian Stage (Heinisch et al 1987); its end has not been dated yet. The volcanism produced lavas, pyroclastic rocks and tuffites described in great detail by Schlaegel-Blaut (1990). Based on trace elements the basaltic volcanism is of intraplate type (transitional basalts and alkali basalts) and may be linked to seamounts reaching temporary a subaerial stage (see Loeschke and Heinisch, this volume).

In the past the extensive basalt-sill complex of Maishofen has been interpreted as Ordovician ocean floor basalt (Colins et al 1980, Mostler 1984). It differs from the volcanics mentioned above by the tholeiitic pillow lavas and the sills which were generated within the deeper water. Yet the exact age has not been based on fossils.

Originally, the stratigraphic base of the clastic sedimentation was supposed to be in the Lower Ordovician (Mostler 1970). Recently, this idea was supported by acritarchs of Tremadocian age recovered from metapelites near Kitzbühel (Reitz and Höll 1989). Whether or not some of the basaltic volcanics are also Ordovician in age as suggested by Mostler (1970, 1984) is presently difficult to decide due to lack of fossil evidence.

In summary, during the Silurian and Devonian in the Western Graywacke Zone the shallow water platform facies of the Wildseeloder Unit existed contemporaneously with the turbiditic basin facies of the Glemmtal Unit. The connecting link between both facies is the Blasseneck Quartzporphyry although this rock too reflects two different settings: The Wildseeloder Unit is characterized by subaerial ignimbrites; in the Glemmtal Unit the dominating rock type is an epiclastic volcanic debris washed into the basin by sediment flows. Presently the distance between these two depositional areas is not known.

Conclusions

Based on the data from the classic fossiliferous Palaeozoic regions of the Eastern and Southern Alps in the authors opinion there is no unequivocal evidence for a Caledonian collision of parts of the early Alps as proposed by Frisch et al (1984), Frisch and Neubauer (1989) and Loeschke (1989). In fact, neither an angular unconformity has been recognized in the geological record of the Alps nor any significant hiatus in sedimentation. The widespread Upper Ordovician acid volcanism as documented by the Blasseneck Quartzporphyry needs not necessarily be related to a subduction process. Rather, its partly calc-alkaline chemistry can be interpreted as anatectic melts of a thick continental crust formed during the "Pan-African tectonothermal event" (Almond 1984, Sacchi 1989).

The angular unconformity advocated by Neubauer (1985) as evidence for a Caledonian event from the base of the Palaeozoic sequence of the Eastern Graywacke Zone is undoubtely older than Upper Ordovician. Furthermore, the basally occurring conglomerate corresponding perhaps to the Kalwang Gneiss Conglomerate has not been dated yet.

There is no true time relationship between these hypothetical events in the Alps and the Caledonian collision and closure of the lapetus ocean in Northern Europe during the Late Silurian followed by the Old Red sedimentation. Consequently, in the Alps the term "Pan-African" should be applied when describing Cambrian and/or Ordovician accretionary events. The affinities with Gondwana seem to justify such an approach.

Also, during the Ordovician to Devonian there is definitely no proof of a well developed ocean floor characterized by oceanic crust in the Alps. The majority of the basic rocks neither displays a relationship to an active plate margin nor to a mature oceanic ridge segment, but instead shows intraplate geochemistry. Any model dealing with the plate tectonic evolution of the early Alps must consider this fact.

Variation of facies is a widely occurring phenomenon and has been demonstrated for the Graywacke Zone and for other areas in the Alps characterized by Lower Palaeozoic strata. However, biostratigraphic data yet available are not always as sufficient as are required as base of a highly sophisticated evolutionary model. In particular this regards fossil data from the early Ordovician and in greenschist grade metamorphosed strata.

Crustal extension is the most common and distinct feature during the early Palaeozoic history of the Alps. It strongly controlled the sedimentation and the kind of volcanism from the Ordovician to the middle of the Dinantian. During the following time this changed in favour of subduction and collision related processes which mainly occurred in the Southern Alps.

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