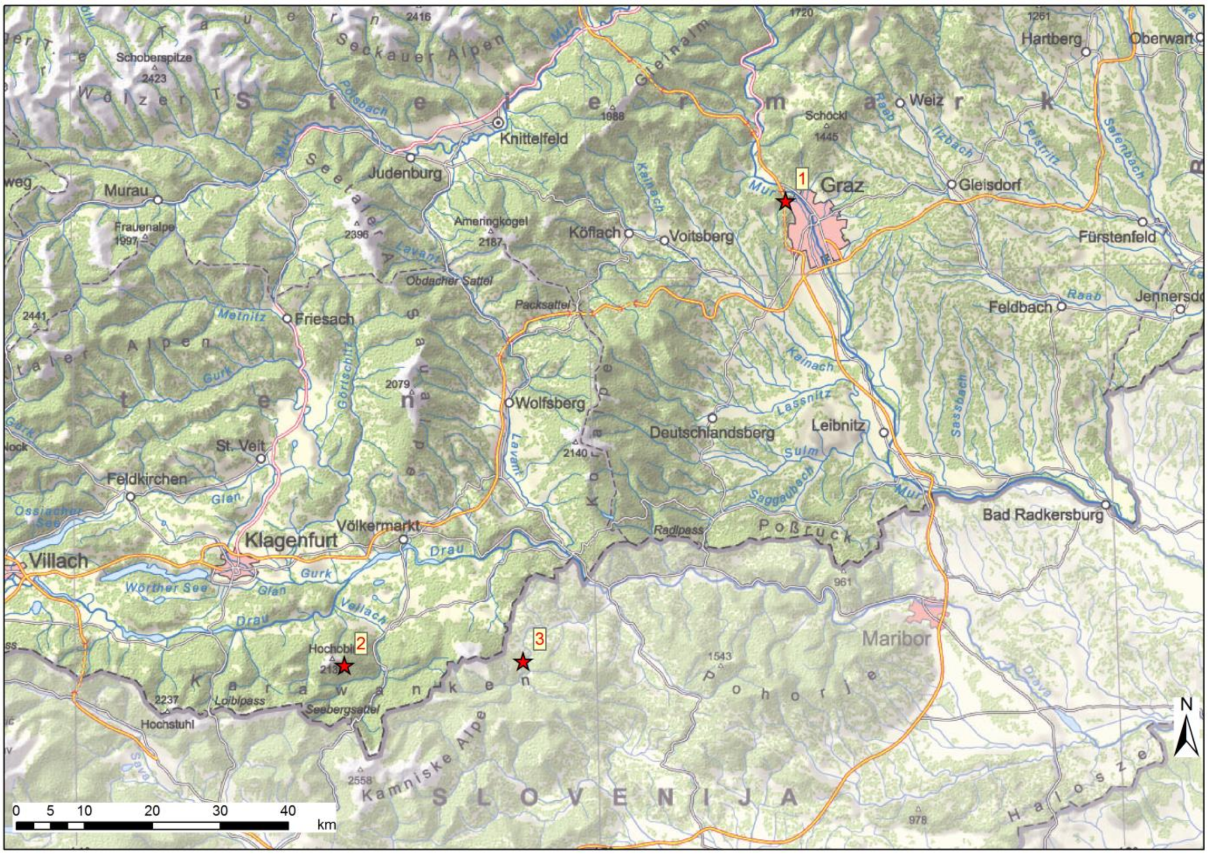
Geological Excursion

BASE-LiNE Earth

(Graz Paleozoic, Geopark Karavanke, Austria)

7.6. – 9.6. 2016



Route:

1. Day: Graz Paleozoic in the vicinity of Graz. Devonian Limestone with brachiopods. Bus transfer to Bad Eisenkappel.

2. Day: Visit of Geopark Center in Bad Eisenkappel. Walk on Hochobir (2.139 m) – Triassic carbonates.

3. Day: Bus transfer to Mezica (Slo) – visit of lead and zinc mine (Triassic carbonates). Transfer back to Graz.

CONTENT

Graz Paleozoic

Hubmann, B., Ebner, F., Ferretti, A., Kido, E., Krainer, K., Neubauer, F., Schönlaub, H.-P. & Suttner, T.J. (2014): The Paleozoic Era(them), 2nd edition. – In: Piller, W.E. [Ed.]: The lithostratigraphic units of the Austrian Stratigraphic Chart 2004 (sedimentary successions) – Vol. I – Abh. Geol. B.-A., 66, 9–133, Wien.

The Graz Paleozoic (GP) comprises an outcropping area of approximately 1,250 km^2 resting tectonically on metamorphic Austroalpine units. The GP itself represents a pile of nappes which is overlain unconformably by the Upper Cretaceous Kainach Gosau and by Neogene sediments of the "Styrian Basin" in the south. The nappes consist of different facial developments.

Fritz & Neubauer (1990) discerned a Basal, an Intermediate, and an Upper Nappe Group in which lithological similarities, the tectonic position, and metamorphic overprint of the nappes were considered. This concept of a tectonic tripartite arrangement in the sense of Fritz & Neubauer (1990) is the conceptual base for the lithostratigraphic arrangement shown in the ASC 2004:

1) The Basal Nappe Group (upper Silurian–Lower Devonian) comprises the Schöckel Nappe and the Anger Crystalline Complex. Besides the Alpine (Early to Late Cretaceous) deformation of the Graz Paleozoic in this basal nappe system minor Variscan deformation under upper greenschist facies condition (with rarely occurring amphibolite facies) is detected. The Schöckel Nappe is made up of pre-Devonian rocks (Passail Group, Taschen Formation) and the Devonian Peggau Group. Generally, volcaniclastics dominate the upper Silurian to Lower Devonian, and carbonates the Middle Devonian. Part of the Peggau Group is the Schönberg Formation with Meggen-type lead/zinc-barite Sedex mineralizations (Ebner et al., 2000).

2) The Intermediate Nappe Group (lower Silurian–Upper Devonian) includes the "Laufnitzdorf Nappe" and the "Kalkschiefer Nappe" (Lower to Upper Devonian). Both Nappes occur in different structural levels. The former development contains pelagic limestones, shales and volcaniclastics, the latter limestones and siliciclastics.

3) The Upper Nappe System (upper Silurian–upper Carboniferous) comprises the Rannach- and Hochlantsch Nappes. Both have a similar facial development, especially in the Emsian–Givetian. Successions of the Rannach Nappe are composed of volcaniclastic rocks (Silurian–Lower Devonian; Reinerspitz Group), siliciclastics and carbonates rich in fossils (Lower–Middle Devonian; Rannach Group) of a littoral environment followed by the pelagic Forstkogel Group (Upper Givetian–Serpukhovian) and the shallow marine Dult Group (Bashkirian/?Moskovian) (Hubmann & Messner, 2007; Ebner et al., 2008).

According to a paleogeographical interpretation of the entire Paleozoic succession, the formations of the Rannach and Hochlantsch Nappes are interpreted to have been deposite nearest to the shore, while the "Laufnitzdorf Facies" represents the most distant from shore. Successions of the Schöckel Nappe occupy an intermediate position in this conception (Hubmann, 1993).

The stratigraphic sequence indicates a sedimentation area changing from a passive continental margin with the continental breakup (alkaline volcanism) to shelf and platform geometries during the Silurian to Devonian time span. Sea-level changes and probably synsedimentary tectonics had affected both, the lithologic development (i.e., alternations of dolostones and limestones) and the formation of stratigraphic gaps and mixed conodont faunas (Ebner et al., 2000, 2008).

Recently, Gasser et al. (2010) published a new structural sketch of the Graz Paleozoic which gets along with only two nappes, a basal one characterized by intensely deformed units which show a penetrative foliation with a pronounced stretching lineation and an upper one comprising less metamorphic sequences. In this conception the lower nappe system consists of sequences of the Laufnitzdorf Facies, the Kalkschiefer Facies (partly) and the Schöckel Facies whereas the upper nappe system comprises the Kalkschiefer Facies (partly), the Rannach Facies and the Hochlantsch Facies.

Plabutsch-Formation / Plabutsch Formation

Bernhard Hubmann

Validity: Valid; first description by Penecke (1890: "Horizont des Heliolites Barrandei"); formalized by Hubmann (1993: Barrandeikalk-Formation), Flügel (2000: Barrandeikalk-Formation) and Hubmann (2003: Plabutsch-Formation).

Type area: ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Type section: The type section along the forest road (N 47°05'20" / E 15°22'12") at the southern slope of the Frauenkogel (near Thalwinkel) was described by Hubmann (1992, 1993).

Reference section(s): Reference sections within the Rannach Nappe, the Hochlantsch Nappe and the "transitional zone" are named by Hubmann (1993): the abandoned quarry at Kollerkogel (N 47°03'31" / E 15°22'29") from the Plabutsch-Buchkogel-Range, the section along the road south of St. Pankrazen (N 47°07'56" / E 15°11'04"), and in the Hochlantsch area the section along the forest road to Tyrnaueralm (N 47°20'10" / E 15°25'02") and the abandoned quarry in the vicinity of the hotel "Pierer" at Teichalm.

Remarks: Type area and eponym is the Plabutsch, a hill which supplied in several quarries huge amounts of building material for the city of Graz during the 19th century. Today, the ancient quarries are covered by vegetation and no persistent sections are known from that area. The formation occurs in the Rannach Nappe as well as in the Hochlantsch Nappe.

Derivation of name: After the hill Plabutsch (754 m) west of Graz (Hubmann, 2003).

Synonyms: During history of investigation the succession has been called "Barrandeikalk" (Penecke, 1890; derived from a heliolitid coral's species name) for more than 110 years. Attempts to subdivide the formation into a coral-dominated lower part and a brachiopod-rich upper part resulted in a subdivision of "Korallenkalk" and "Pentameruskalk" (Heritsch, 1935). Both terms and definitions are only applicable in some distinct regions and were therefore dismissed. Other older synonyms: Korallenbank des Plabutsch (Peters, 1867); Kalk des Gaisberges (Suess , 1868); Corallenkalk (Clar, 1874); Horizont des Heliolites Barrandei (Penecke, 1890); Barrandeikalk (H. Flügel, 1961, 1975); Barrandeikalk-Formation (Hubmann, 1993; Flügel et al., 2011). During evaluation of the conceptional content of the formation and re-definition (Hubmann, 2003: p. 285–287) the Draxler-Formation (sensu Flügel, 2000: p. 25; equivalent to “unterer Schweineggkalk” of Zier, 1982) was synonymised with the Plabutsch Formation.

Lithology: The succession represents a highly fossiliferous sequence dominated by dark marly bioclastic limestones. In the lower parts, especially at the boundary to the underlying Flösserkogel Formation yellow to brownish shales occasionally blotched with moulds of chonetid brachiopods are characteristic. In the upper parts of the formation intercalations of red marls and marly limestones are common.

Fossils: Coral and sponge taxa dominate the diverse fauna. Among tabulate corals most common are thamnoporids (Thamnopora reticulata, Th. vermicularis, “Striatopora” suessi), favositids (Favosites styriacus, F. alpinus), and heliolitids (Pachycanalicula barrandei). The rugose coral fauna is dominated by mostly fractured dendroid (phaceloid) taxa. A frequent and distinctive phillipsastreid taxon is Thamnophyllum (Th. stachei, Th. murchisoni). Stromatoporoids are mostly recrystallized and thus precluding precise determinations (common genera are Actinostroma and Clathrocoilona). Among brachiopods the thick valved Zdimir cf. hercynicus may occur in coquina horizons. For faunal list see H. Flügel (1975: p. 44–46).

Origin, facies: A deposition on a differentiated and gently inclined carbonate platform of some few (tens) meters is assumed (Hubmann, 1993). Conspicuous is the rarity of in situ organisms, the intermittently high supply of clayey sediments (marl-limestone intercalations) and high supply of lime mud, temporary influx of high amounts of continental phytoclasts and storm impacts (tempestites) (Hubmann, 1995).

Chronostratigraphic age: Eifelian; locally the sequence may range from Upper Emsian to Lower Givetian (Hubmann, 1993).

Thickness: 80–100 m, strong variation.

Lithostratigraphically higher rank unit: Rannach Group.

Lithostratigraphic subdivision: In some sections at the base of the unit less than 5 m thick brownish to yellow marly slates with moulds of chonetid brachiopods are named Gaisberg Bed (Flügel, 2000; Hubmann & Fritz, 2004; Hubmann & Messner, 2007).

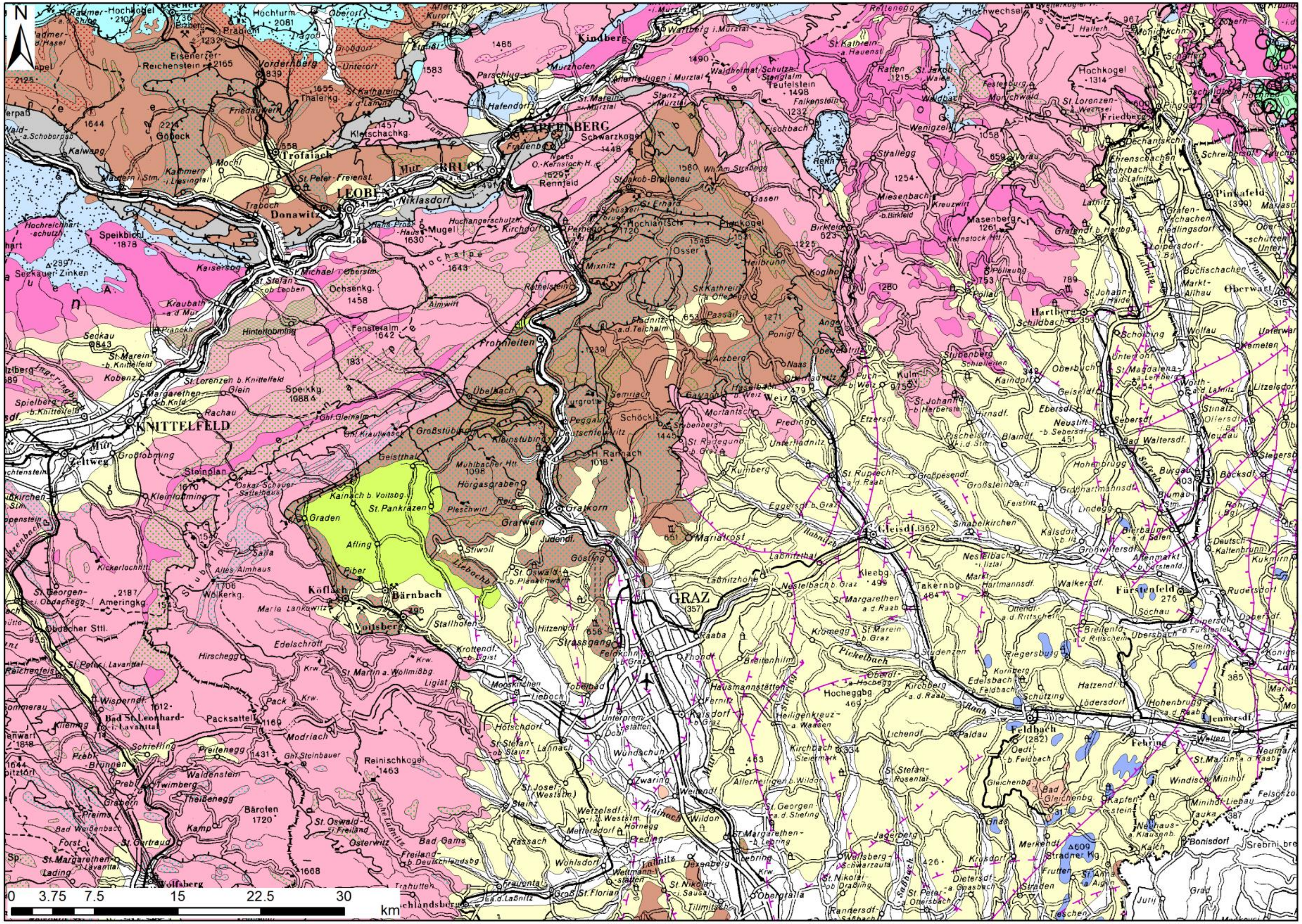
Underlying unit(s): Flösserkogel Formation (conformable contact, transgressive).

Overlying unit(s): Kollerkogel Formation (conformable contact).

Lateral unit(s): Flösserkogel Formation, Kollerkogel Formation, Tyrnaueralm Formation, Osser Formation.

Geographic distribution: Styria, highland in the surroundings of Graz; ÖK50-BMN, map sheets 134 Passail, 162 Köflach, 163 Voitsberg, 164 Graz.

Complementary references: Ebner & Hubmann (2012).


N
0 3.75 7.5 15 22.5 30
km
LEOBEN
BRUCK
KAPFENBERG
KNITTELFELD
GRAZ
Kindberg
Trofaiach
Donawitz
Niklasdorf
Frohnleiten
Gratkorn
Köflach
Bärnbach
Voitsberg
Weiz
Gleisdorf
Feldbach
Fürstenfeld
Hartberg
Pinkafeld
Friedberg
Zeltweg
Wolfsberg
Passail
Birkfeld
Pöllau
Kainach b. Voitsbg.
St. Pankrazen
Graden
Afling
Piber

Mesozoic of Northern Karavanke

Name of site: *Hochobir*

Short description: Wetterstein-limestone of Hochobir

Coordinate Y (UTM-33N): 460644 Coordinate X (UTM-33N): 5150081

Rating:

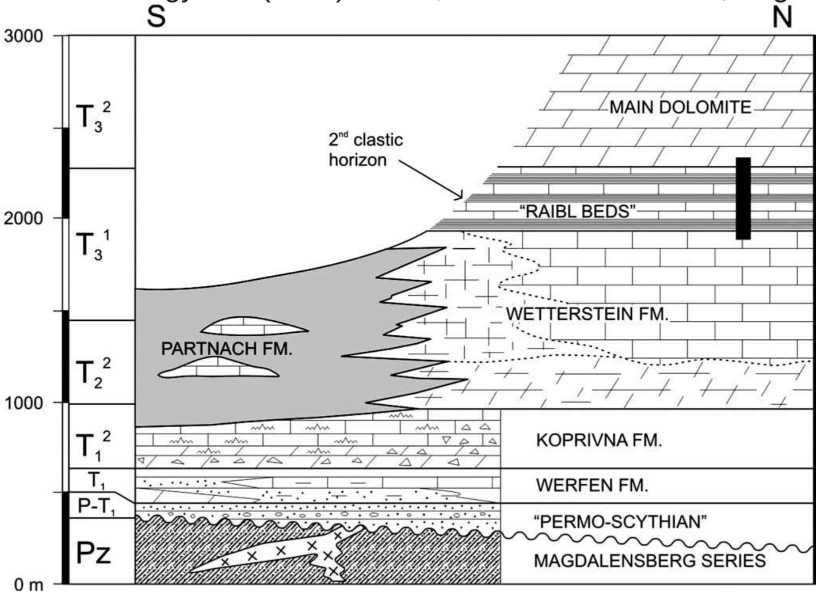
The Hochobir is at an altitude of 2139 m the highest mountain in the eastern North Karawanken. Because the summit region lies above the tree line, the Wetterstein-limestones are exposed here very well and the summit offers a beautiful view of the Karawanken and its northern foreland.

Description:

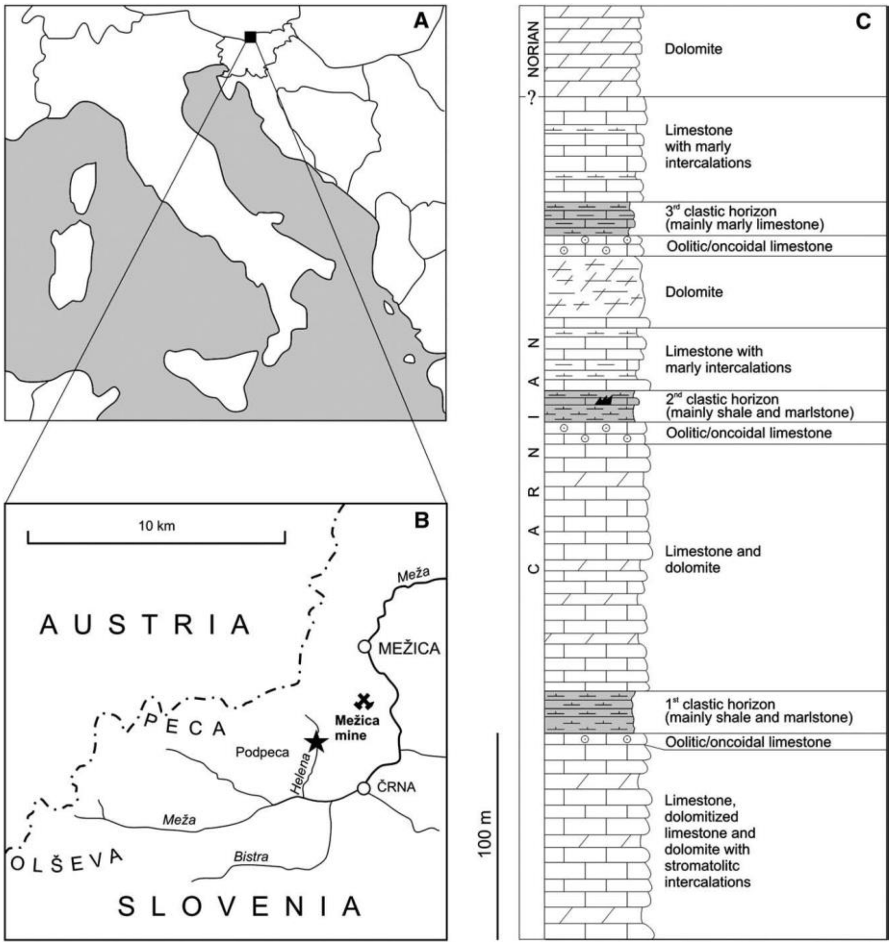
The middle triassic (ladinian) Wetterstein-limestone is the main cliff former of the Northern Karawanken. It is formed as bedded limestone of a lagoon facies or as massive limestone or dolomite of a reef facies. In the upper parts of the bedded lagoon facies in the area of Hochobir lead and zinc ores are found. On the hike to the summit there are many remnants of this former mining Accessibility: Several marked hiking trails at the Hochobir.

View from Hochobir to southwest. The foreground shows the bedded Wetterstein-limestone of the Hochobir massif. In the background you see the Koschuta, the border ridge to Slovenia. Foto: D. Zupanc

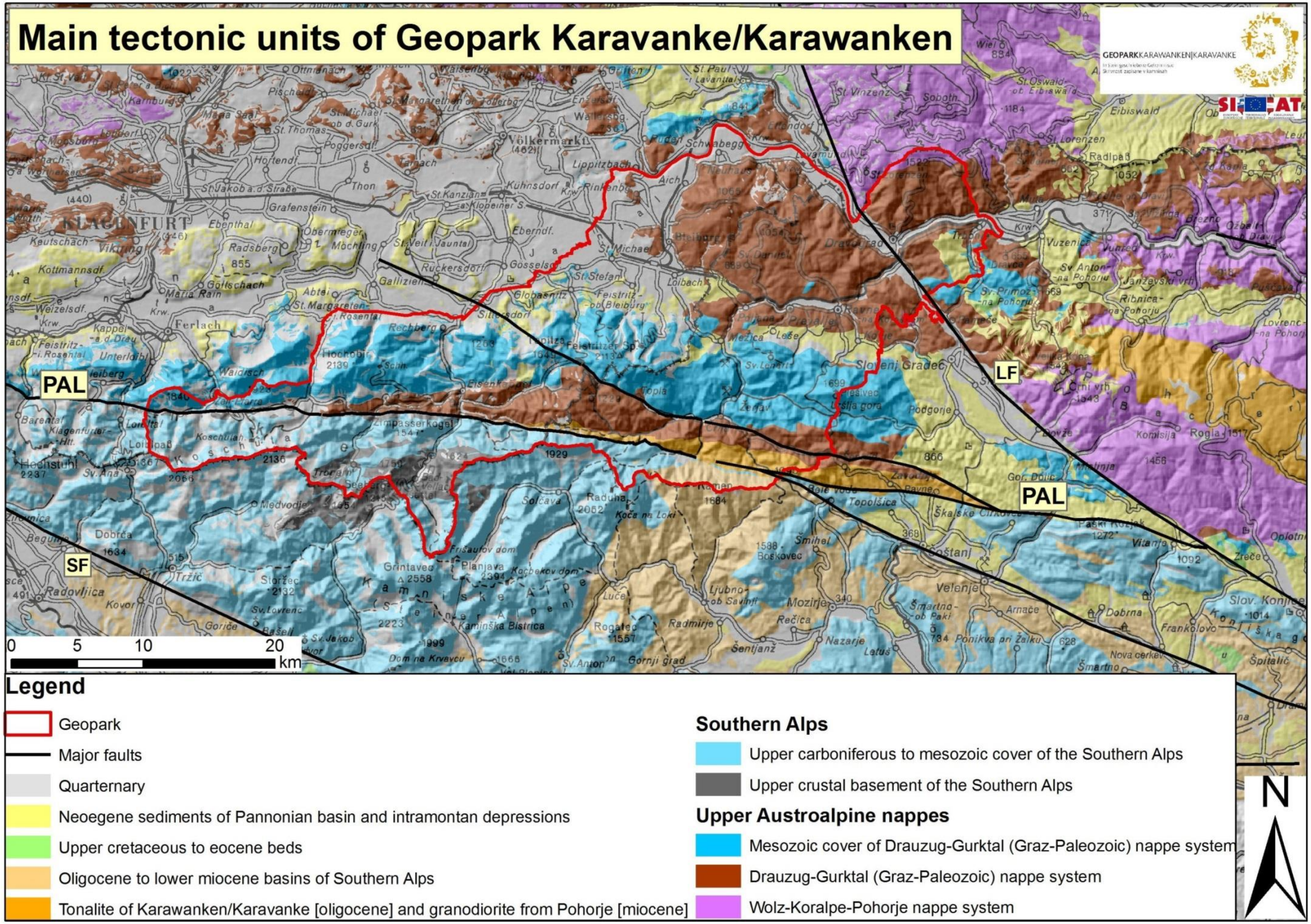
New paleontological evidence of the Carnian strata in the Mežica area (Karavanke Mts, Slovenia): Conodont data for the Carnian Pluvial Event - Palaeogeography, Palaeoclimatology, Palaeoecology 290 (2010) 81–88; Tea Kolar-Jurkovšek, Bogdan Jurkovšek



Generalized stratigraphic column of the northern Karavanke Mts with marked section of the Carnian strata in the Mežica area (modified after Mioč & Žnidarčič, 1977; Jurkovšek, 1978; Placer et al., 2002).



Geographic sketch map (A–B) and lithostratigraphic column of the Carnian strata (C) in the Mežica area, Karavanke Mts, Slovenia with position of conodont occurrence (modified after Kolar-Jurkovšek & Jurkovšek, 2009).


Main tectonic units of Geopark Karavanke/Karawanken
GEOPARK KARAWANKEN|KARAVANKE
PAL
LF
SF
0 5 10 20 km
Legend
Geopark
Major faults
Quarternary
Neoegene sediments of Pannonian basin and intramontan depressions
Upper cretaceous to eocene beds
Oligocene to lower miocene basins of Southern Alps
Tonalite of Karawanken/Karavanke [oligocene] and granodiorite from Pohorje [miocene]
Southern Alps
Upper carboniferous to mesozoic cover of the Southern Alps
Upper crustal basement of the Southern Alps
Upper Austroalpine nappes
Mesozoic cover of Drauzug-Gurktal (Graz-Paleozoic) nappe system
Drauzug-Gurktal (Graz-Paleozoic) nappe system
Wolz-Koralpe-Pohorje nappe system
N

Linking geology between the Geoparks Carnic and Karavanke Alps across the Periadriatic Line

Hans P. Schönlaub

Content

I: Introduction

The Carnic and Karavanke Alps of Southern Austria, Northern Italy and Slovenia represent one of the very few places in the world in which an almost continuous fossiliferous sequence of Paleozoic age has been preserved. The first extend in a W-E-direction for over 140 km from Sillian in Tyrol to Arnoldstein in central Carinthia. Continuing into the Western Karavanke Alps the Variscan sequence is almost completely covered by rocks of Triassic age. Further in the east, however, Lower Paleozoic rocks are excellently exposed in the Eisenkappel and Seeberg area of the Eastern Karavanke Alps south of Klagenfurt, the capital of Carinthia. Differing from the Carnic Alps, in this region the Lower Paleozoic strata are distributed on either side of the Periadriatic Fault (Gailtal Fault) which separates the Southern and the Central or Northern Alps. These rocks have been subdivided into a northern and a southern domain, respectively. The latter extends beyond the state border to northern Slovenia (fig.1).

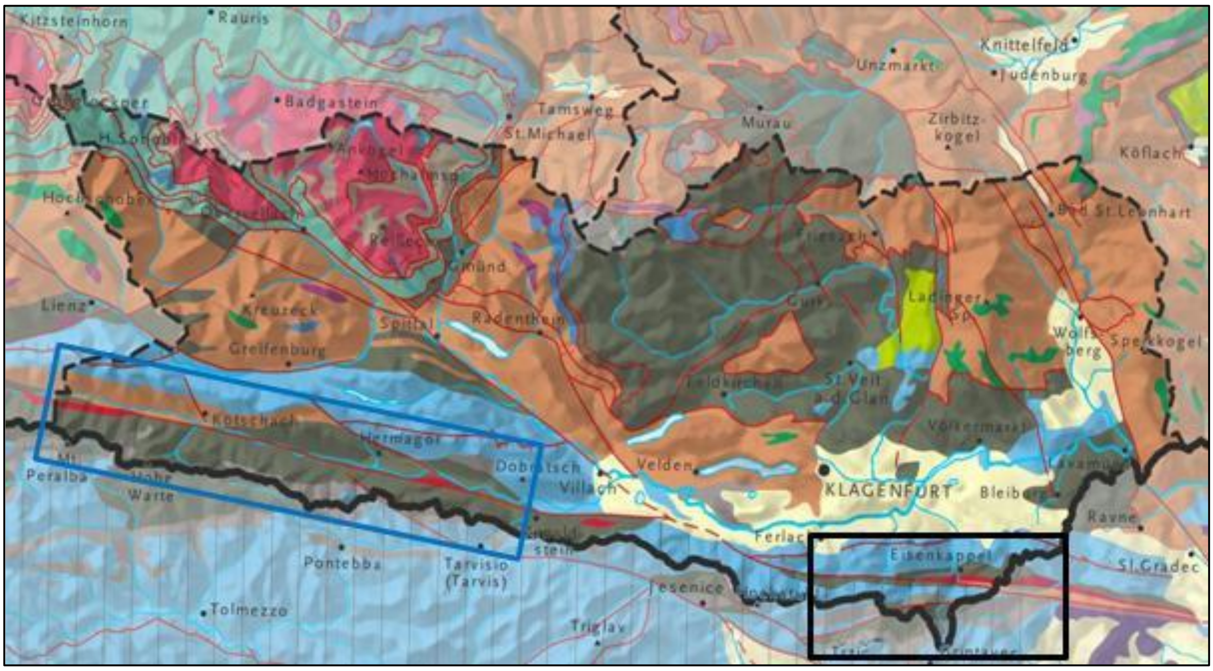


Fig. 1. Geological map of Carinthia, part of Friuli and northern Slovenia with indication of the Geoparks Carnic and Karavanke Alps, subdivided by the Periadriatic Line (red).

In both the Carnic and Karavanke Alps systematic research started soon after the foundation of the Geological Survey of Austria in the middle of the last century. The equivalents of the Lower Paleozoic were first found in the Karavanke Alps and not in the more fossiliferous Carnic Alps (SUESS, 1868; TIETZE, 1870). In this latter area main emphasis was drawn on marine Upper Carboniferous and Permian rocks. At the end of the 19th century this initial phase was followed by the second mapping campaign carried out by the Geological Survey of Austria and detailed studies by FRECH. During the first half of the 20th century HERITSCH and his research group from Graz University revised the stratigraphy on the Austrian side while GORTANI from Bologna University and others worked on the Italian part of the mountain range. One of the outstanding contributions of that time focusing on the Lower Paleozoic was provided by VON GAERTNER (1931). The detailed knowledge of Upper Carboniferous and Permian rocks resulted mainly from studies by KAHLER beginning in the early 1930s. Since that time many students of geology started to visit both regions including those from Tübingen University in Germany and of the University of Ljubljana in Slovenia. During this third campaign study of various microfossil groups began and other techniques were also applied.

This research culminated in the publication of detailed maps, a new stratigraphic framework, and revisions of old and discoveries of new faunas and floras.

Further reading: SCHÖNLAUB, 1971, 1979, 1980, 1985, 1998; SCHÖNLAUB & KREUTZER, 1994.

II. Tectonic subdivision and correlation

The Periadriatic Line divides the Karawanken Alps into a northern part (Northern Karavanke Alps) which belongs to the Eastern Alps and a southern part (Southern Karavanke Alps) belonging to the Southern Alps (fig. 2).

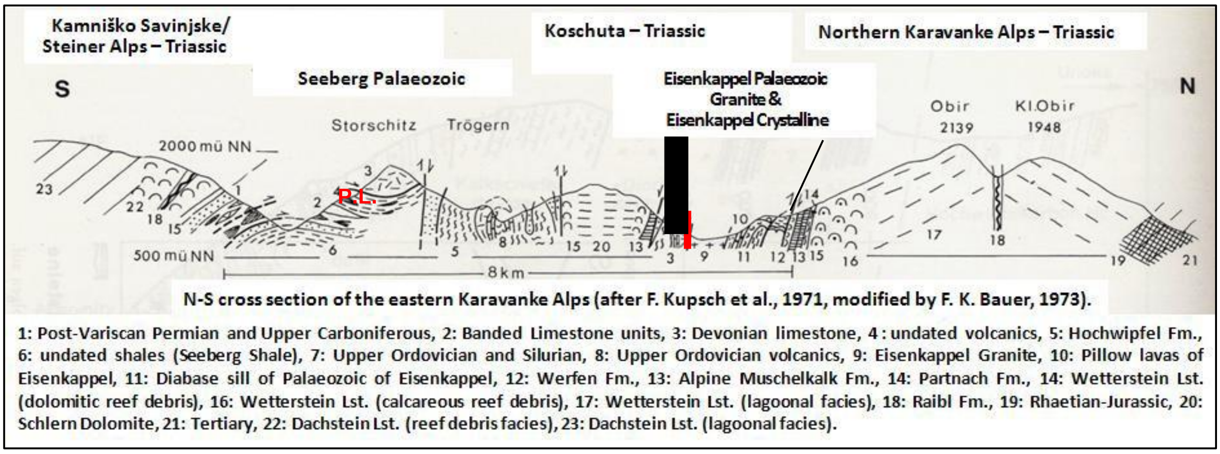


Fig. 2. North-south section of the eastern Karavanke Alps (after Kupsch et al., 1971, modified by Bauer, 1973, and Schönlaub).

In the Geopark Karavanke Alps there are additional structural elements which from north to south comprise the following units (fig. 3):

1) Northern Karavanke Foreland
2) Mesozoic of Northern Karavanke Alps
3) Paleozoic Diabase Unit of Eisenkappel
4) Karavanke Granite
5) Karavanke Crystalline Complex

6) Karavanke Tonalite
7) Seeberg Paleozoic
8) Mesozoic of Southern Karavanke Alps
9) Kamniško Savinjske/Steiner Alps

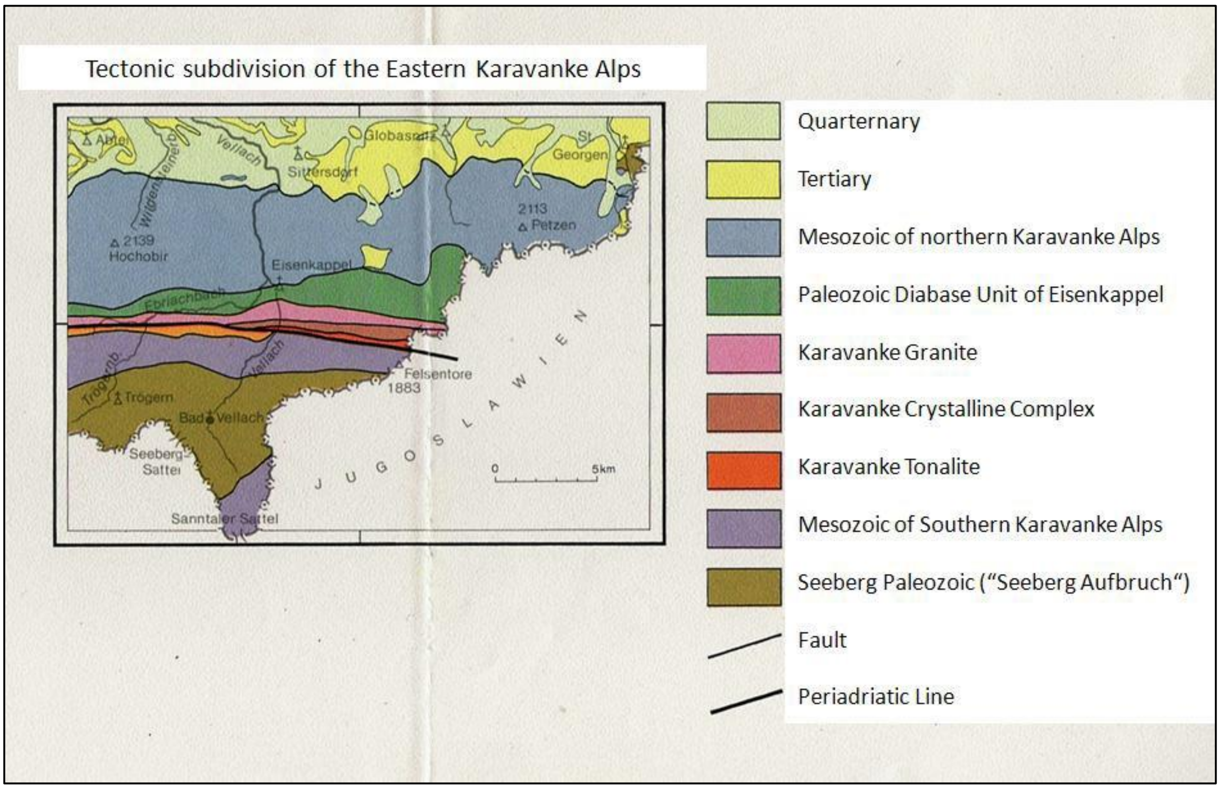


Fig. 3. Tectonic subdivision of the Eastern Karavanke Alps (from Bauer et al., 1983).

Suggested structural correlations between Carnic/Gailtal Alps and Eastern Karavanke Alps:

<u>**Carnic Alps Geopark**</u>	<u>**Karavanke Geopark**</u>
??	– Northern Karavanke Foreland
Mesozoic of Gailtal Alps ("Drauzug")	– Mesozoic of Northern Karavanke Alps
??	– Paleozoic Diabase Unit of Eisenkappel
Nötsch Granite	– Eisenkappel Granite
Gailtal Crystalline Complex	– Eisenkappel Crystalline Complex
Gailtal Tonalite	– Karavanke Tonalite
Carnic Alps Paleozoic	– Seeberg Paleozoic
Carnic Alps Mesozoic	– Southern Karavanke Mesozoic
--	– Kamniško Savinjske/Steiner Alps (Triassic)

1) Northern Karavanke Foreland

The Middle Miocene sequence starts with coal-bearing clays which are overlain by interbedded quartz-rich and carbonate-bearing gravel deposits. At the base crystalline pebbles occur as well as synsedimentary sliding deposits of Wetterstein Formation. Upwards pure carbonaceous gravels are dominating.

There are no occurrences of corresponding Tertiary deposits in the Geopark Carnic Alps.

2) Mesozoic of Northern Karavanke Alps

This unit represents the eastern continuation of the Gailtal Alps which are also known as "Drauzug". The sequence starts with the Werfen Fm. which overlies Permian clastics, followed by the Muschelkalk Fm., the marly Partnach Fm., Wetterstein Lst., Raibl Fm. and the Hautpdolomit Fm. The highest peaks like the mountains Petzen, Topitza, Oistra and Obir are composed of the Wetterstein Fm. Younger strata comprising, e.g., the Kössen Fm. and the equivalents of the Jurassic and Lower Cretaceous occur at the northern margin and are thrust-faulted by the Wetterstein Fm. The Northern Karawanken Alps are deformed by anti- and synclines and are strongly affected by faults. Their northern part is thrust upon Tertiary deposits.

The Gailtal Alps west of Villach represent the equivalents of the Northern Karavanke Alps.

Further reading: Bauer, 1983.

3) Paleozoic Diabase Unit of Eisenkappel

In the Eastern Karavanke Alps, north of the Periadriatic Line, rocks of Paleozoic age have long been known. They belong to the so-called „Diabaszug von Eisenkappel". This narrow belt extends in a 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, Loeschke et al. 1996) 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 min- eral composition in these rocks. The sedimentary rocks are monotonous grey shales and slates with intercalations of conglomeratic greywackes, 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.

The western continuation of the Diabase Unit of Eisenkappel is unknown. Parts of the Gailtal Crystalline, the Carboniferous of Nötsch or the southern quartzphyllite belt of the Goldeck Crystalline Complex in the Weißenbach Valley might correspond to this unit.

Further reading: Loeschke, 1983.

4) Karavanke Granite

The granite extends as a lamella-like intrusive body over some 46 km from east to west and by attaining a maximum width of 2 km. Based on radiometric dating a late Permian intrusion into the surrounding Karavanke Crystalline Complex is suggested. Due to processes of igneous differentiation the parent melt has undergone chemical alterations to form a series of olivinegabbros, diorites, granodiorites and coarse-grained granites. In addition, composite dikes of aplites and pegmatites occur rather abundantly in these rocks. Also, as a result of temperature increase contact metamorphism can be observed in the sediments of the Diabase Unit and the Crystalline Complex around the intrusive igneous rocks to form so-called "Cordierite-Knotenschiefer", hornfels and migmatites.

The 8 km long and 200 m wide Nötsch Granite most probably represents the analogue of the Karavanke Granite (Exner, 1976, 1984, Schönlaub, 1985).

Further reading: Exner, 1972, 1976, 1983.

5) Karavanke Crystalline Complex (“Altkristallin”)

The Crystalline Complex comprises a rich variety of paragneisses, phyllitic rocks, microcline-bearing gneisses and amphibolites which were intruded by the granitic and tonalitic magmas. Granite, crystalline rocks and the tonalite body show a general vergence towards north and thus reflect the alpine tectonic style of the Karavanke Alps. The distinct Periadriatic Line separates the granite body and the tonalite, respectively, to the south from the Seeberg Paleozoic and the Mesozoic of the southern Karavanke Alps, respectively the Gailtal Crystalline Complex represents the western continuation of the Karavanke Crystalline Complex.

Further reading: Exner, 1972, 1976, 1983.

6) Karavanke Tonalite

The main occurrence of the tonalite lamella extending over 43 km with a maximum width of 2.2 km is in Slovenia; in Austria it is reduced to some 8 km with a width of 650 m. The E-W to WNW striking tonalitic gneisses are dipping steep towards south, the northern margin is sharply pressed northvergent against the crystalline rocks forming the previous roof of the tonalitic body. Its southern boundary is characterized by cataclastic rocks along the Periadriatic Line. Based on radiometric dating techniques the Karavanke Tonalite was emplaced between 29.6 $\pm$ 6 and 28 $\pm$ 4 m.y., i. e., during the middle Oligocene. Originally it may have formed a body of considerable size which subsequently was compressed during the Alpine orogeny.

Spotted occurrences of small lamella of magmatites along the Periadriatic Line south of Villach and along the Gail and Lesach Valleys correspond to the Karavanke Tonalite.

Further reading: Exner, 1972, 1976, 1983, Exner & Schönlaub, 1973.

7) Seeberg Paleozoic (“Seeberg Aufbruch”)

In the Southern Karavanke Alps Paleozoic rocks are exposed in the Seeberg region extending over an area of approx. 40 x 20 km and as a small belt south of the Ebriach Valley west of Eisenkappel. The weakly metamorphosed fossiliferous sequence starts with acidic to intermediate pyroclastics and shallow marine flaser-limestones of presumably Katian (Upper Ordovician) age. The Lower Silurian strata are dominated by siliciclastics passing into Middle to Upper Silurian carbonate sequences. During the Devonian a carbonate platform developed with reefal structures resembling present-days atolls (Rantitsch 1990). Depending on adequate subsidence the location of the reef core shifted spatially and temporarily during the Devonian. Differing from the Carnic Alps with its 150 m thick reefs of Givetian age, in the Karavanke Alps there are no good records from the Middle Devonian. In both areas, however, the reef development ended in the Frasnian when the former shallow sea subsided being followed by a drowning and erosion of the reefs. Similar to the Carnic Alps in the Karavanke Alps these shallow water deposits were also replaced by uniform pelagic goniatite and clymeniid bearing limestones.

Upper Carboniferous and Permian molasse-type sediments also occur in the Seeberg area of the Eastern Karavanke 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 algal bearing limestones, arenaceous shales, sandstones and massive beds of quartz-rich deltaic conglomerates. Equivalents of the Permian are represented by the Trogkofel Limestone, its coeval detritic Trogkofel Formation and the Gröden Formation. The Bellerophon Formation is only locally preserved.

The tectonic style is characterized by alpidic north-vergent nappes and folds. The nappes form huge anticlinal structures which towards north became strongly folded (see fig.2). In the core of the nappes consisting of Devonian strata a tectonic window is exposed displaying the post-Variscan Auernig Fm.

Since the beginning of systematic research the Palaeozoic of the Eastern Karavanke Alps has been regarded as being equivalent to the Paleozoic of the Carnic Alps.

Further reading: Bauer et al. (1983), Tessensohn (1974a, b, 1983), Schönlaub, 1985.

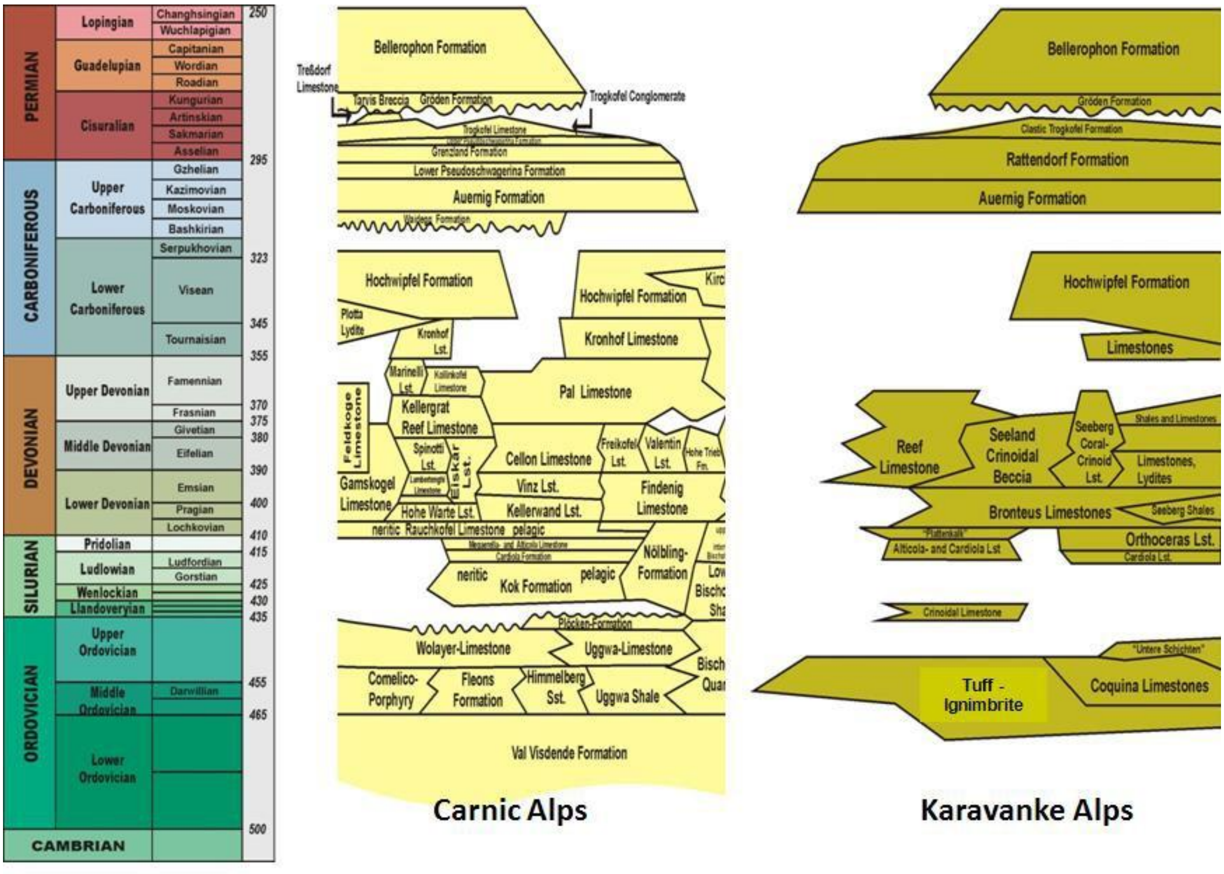


Fig. 4. Biostratigraphic scheme of the Palaeozoic sequence of the Carnic and Karavanke Alps (after Hubmann et al., 2003, modified from Schönlaub 1985).

8) Mesozoic of Southern Karavanke Alps

This unit is composed of rocks of Triassic age. It extends from the Koschuta cliff in the west to Zimpasserkogel and Uschowa in the east. Due to strong faulting there are no continuous sections in this area. The main rock type represents the Middle Triassic Schlern Dolomite Formation, while the Uschowa is composed of the late Triassic Dachstenkalk Fm. affected by faults, the Alpine Muschelkalk Fm. occurs in the Obojnik Creek; also the Werfen Fm. is folded. East of the Vellach Valley the Triassic rocks are overthrusting the cataclastic tonalite gneisses, while to the west they are thrust-faulted with the southalpine Seeberg Paleozoic south of the Ebriach Valley.

9) Kamniško Savinjske/Steiner Alps (Triassic)

Overlying the Seeberg Paleozoic are the south-dipping Triassic rocks of Kamniško Savinjske or Steiner Alps. Only a small part is located in Austria (Vellacher Kotschna), the majority belongs to Slovenia. The sequence comprises dolomites of Anisian age, followed by basinal strata of the Buchenstein Fm., Schlern Dolomite and the Dachsteinkalk-Formation. Due to tectonics, the equivalents of the Upper Triassic Raibl Fm. are missing. Comparable to the Northern Karawanken Alps which display a north-directed thrusting, the Kamniško Savinjske or Steiner Alps are overthrusting Neogene deposits to the south.

III. Geological evolution

Variscan history and orogeny Short overview

In modern literature the Variscan Orogeny is interpreted as a long lasting collision and subduction related process which affected several microcontinents in a time frame between 400 and some 300 Million years. During this orogenic event significant parts of the central European crust were formed, although it includes also remnants of older tectonometamorphic and magmatic fragments. In particular the Alps reflect a complex polymetamorphic history characterized by almost identical structural and metamorphic conditions during different orogenic disturbances. This is the reason why a detailed reconstruction of the geodynamic history during the early Phanerozoic is extremely difficult, although in the Alps there are clear evidences of Cadomic to Variscan events.

The geodynamic evolution of the Alps during the Lower Paleozoic has been subject of detailed studies by several authors in recent years (e.g. Frisch & Neubauer, 1989, Neubauer et al., 1999; Franke, 1989, 2006; v. Raumer et al., 2002, 2003; Stampfli & Borel, 2002, and Stampfli et al., 2002). It is generally accepted that several microcontinents accreted successively with Baltica and Laurentia, which split off from the northern margin of Gondwana ("Peri-Gondwana") during the Lower Ordovician to drift in northward direction.

Collision of the "Proto"-Alps with the accreted microcontinents in the north took place mainly during the Early Carboniferous. Finally, also Gondwana collided with Laurasia to assemble in the supercontinent Pangaea.

The Variscan Orogeny is characterized by widespread nappe tectonics, polyphase deformation, high-grade metamorphism and an intense magmatism. In addition, during the Carboniferous in the bordering zones synorogenic flysch-type sediments were deposited (Matte, 1986; Frank et al., 1987; Flügel, 1990, Läufer et al., 2001).

The Austroalpine basement varies with respect to the grade and timing of metamorphism ranging from greenschist-facies to granulites. In the Southern Alps the Variscan metamorphism reached greenschist-grade conditions.

During the Permian the Southern and Eastern Alps were affected by extensional tectonics giving rise to ascending basaltic magmas from the lithospheric mantle into the lower crust followed by plutonic and volcanic activities and accompanied by high-temperature/low-pressure metamorphism (Schuster et al., 2001). Some authors have proposed a westward drift of Gondwana during the Permian along a dextral megashear zone (Arthaud & Matte, 1977; Muttoni et al., 2003; Schaltegger & Brack, 2007). In the eastern part of the Southern Alps uplifting and transpressional tectonics (?) led to considerable erosion during the late Early Permian. This is indicated by the disconformably overlying Gröden Formation.

With regard to the paleobiography, the available faunal, floral and sedimentological data are derived from a continuous record of Middle to Upper Ordovician through end-Permian fossiliferous strata exposed in both the Carnic Alps and its eastward continuation in the Karavanke Mountains. These data, supplemented by paleomagnetic measurements (e.g., Tait et al., 2000), suggest a constant movement from more temperate regions of some 50° southern latitude in the late Ordovician to the equatorial belt during the Permian. Although direct evidence is missing it may be concluded that the Southern Alps, like other regions in Southern and Western Europe, belonged to the northern margin of the African part of eastern Gondwana during the Cambrian. Initiation of rifting, indicated by basic volcanism in certain regions of the Central Alps, may have occurred during the Lower Ordovician leading to fragmentation and northward drifting of several smaller and larger microplates. In fact, during the late Ordovician the supposed former close spatial relationship to northern Africa decreased.

Instead, the faunistic and lithic pattern suggests a warm water influx from Baltica and even

Siberia. The biota, in particular bivalves, nautiloids, trilobites and corals from the Silurian and Devonian show close affinities to coeval faunas and floras from southern, central and south-western Europe. However, the relationships to the “Atlantic” bordering continents and microplates in low latitude position such as Baltica, Avalonia and also Siberia were also remarkably close suggesting a setting of about 35°S for the Silurian and within the tropical belt of some 30° or less for the Devonian when huge masses of carbonates including reefal deposits accumulated in the Southern Alps (Schönlaub, 1992).

During the Visean Stage of the Lower Carboniferous the Lower Paleozoic sequence of the Southern Alps collided with the Central Alps and migration paths developed across the accreted Alpine terranes. Both, Lower and Upper Carboniferous faunas and floras appear of limited biogeographic significance as they exhibit either cosmopolitans, or represent a general humid equatorial setting. Nevertheless, they provide key elements for correlating continental deposits and shallow marine sequences.

Progressive northward drifting, assembly of the supercontinent Pangaea, and the deglaciation during the Lower Permian (Sakmarian/Artinskian) resulted in semi-arid and arid conditions, which started in the Central Alps in the Lower and in the Southern Alps during the Middle Permian.

Geodynamic evolution

During the last years, several geodynamic concepts have been developed for the Variscan orogeny in the Carnic Alps and Karavanke Mts. (Krainer, 1992, Vai, 1998, Läufer et al., 1993, 2001, Kutterolf, 2001, Diener et al., 2001, Diener, 2002). It is far beyond the scope of this paper to go into details of the different models.
We follow herein the scenario developed by Läufer et al., (1993) and Schönlaub & Histon (1999). Based on the geological data, the Variscan orogeny between the Eastern and Southern Alps can be briefly summarized as follows:

- During the Lower Carboniferous a former passive margin was transformed into an active margin setting of a collisional zone. North directed subduction led to a slab pull effect leading to an extensional regime S of the subduction zone and uplifting of a peripheral bulge where locally karstification and erosion took place. (Schönlaub et al., 1991). Extensional tectonics was probably connected with the volcanic activity in the Dimon Formation.
- The transformation also affected shelf areas with fossiliferous peritidal carbonates surrounding the northern active margin (fore-arc basin?) which were incorporated into an accretionary wedge and finally completely destroyed (Flügel & Schönlaub, 1990).
- In the Middle Visean to the south of the collision zone the deep-water trough was sup- plied from a northern source area with more than 1500 m thick flysch-type sediments of the Hochwipfel Fm. These siliciclastic deposits comprise varying lithologies including bedded sandstones, shales, chert-bearing conglomerates to pebbly siltstones, and bedded greywackes. During phases of decreased clastic sedimentation the deep-water Kirchbach Limestone was formed.
- To date, no detailed age data about the youngest sediments of the Hochwipfel Fm. are available. Most probably, however, sedimentation ceased during the middle, or upper Bashkirian.

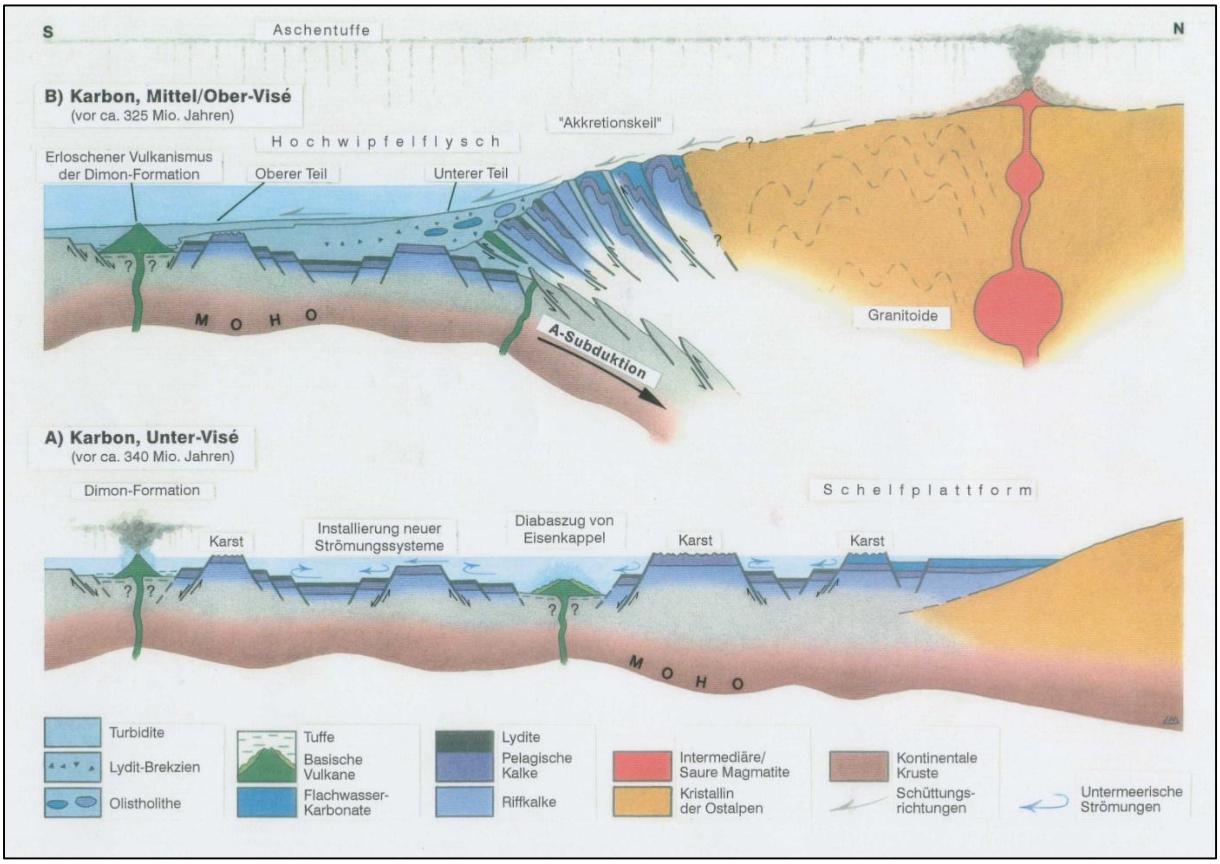


Fig. 4. The Variscan Orogeny at the boundary between the central and southern Alps during the Lower Carboniferous (modified from Läufer et al., 1993, 2001, Schönlaub & Histon, 1999).

Due to ongoing collision and subduction the Carnic and Karavanke basin completely closed during the Upper Bashkirian or Lower Moscovian. This event was succeeded by uplifting.

For the main deformation of the pre-Variscan basement sequences a rather short duration is envisaged which may correspond to less than the duration of the Bashkirian and Moscovian Stages. Depending on the timescale this means less than 11 and 15 m.y., re- spectively.

The outcrops east of the Auernig Alm in the Naßfeld area suggest that the actual sedimentary and time gap between the pre-Variscan Hochwipfel Fm. and the post-Variscan Auernig Fm. was rather short.

In conclusion, the Variscan Orogeny was a long-lasting process that started at the begin- ning of the Visean and reached its climax during the late Bashkirian or early Moscovian. At this time in the Carnic Alps and probably also in the Karavanke Alps the main deformation has taken place.

Further reading: Schönlaub & Forke, 2007.

Alpine history in eight steps

1. The Triassic Period (251 – 199.6 m. y.) – growing reefs

This interval of time was characterized by growing reefs due to increasing production of lime in association with rich and diverse organisms (corals, bivalves, brachiopods, ammonoids, porifera, algae etc.) living on a shallow marine shelf where extended reefs developed partic- ularly in the Middle and Upper Triassic, as well as lagoons and deep water realms. Continu- ous subsidence over some 50 m.y. resulted in more than 3000 m thick sediment accumula- tion.

Paleogeographically, sedimentation occurred on a passive continental margin with wide shelf area extending across the Apulian Promontory as part of African Plate.

2. The Jurassic Period (199.6 m. – 145.5 m.y.) – a new ocean is forming

During this Period the Penninic Ocean newly formed between Africa and Europe. At the same time marine sedimentary basins subsided differently due to a highly mobile crust. Limestone sedimentation was restricted to submarine swells, clayish and marly sediments deposited in deeper parts.

The paleogeography was characterized by the breakup of Pangaea and the opening of the Atlantic Ocean and subsequently of the Penninic Ocean some 165 m.y. ago. The sedimenta- tion of the later Limestone Alps took place on the northern part of the Apulian Promontory which was separated from the Helvetic Shelf on the other coast (= European Plate) by the Penninic Ocean. At the same time the Tethys Ocean started shortening.

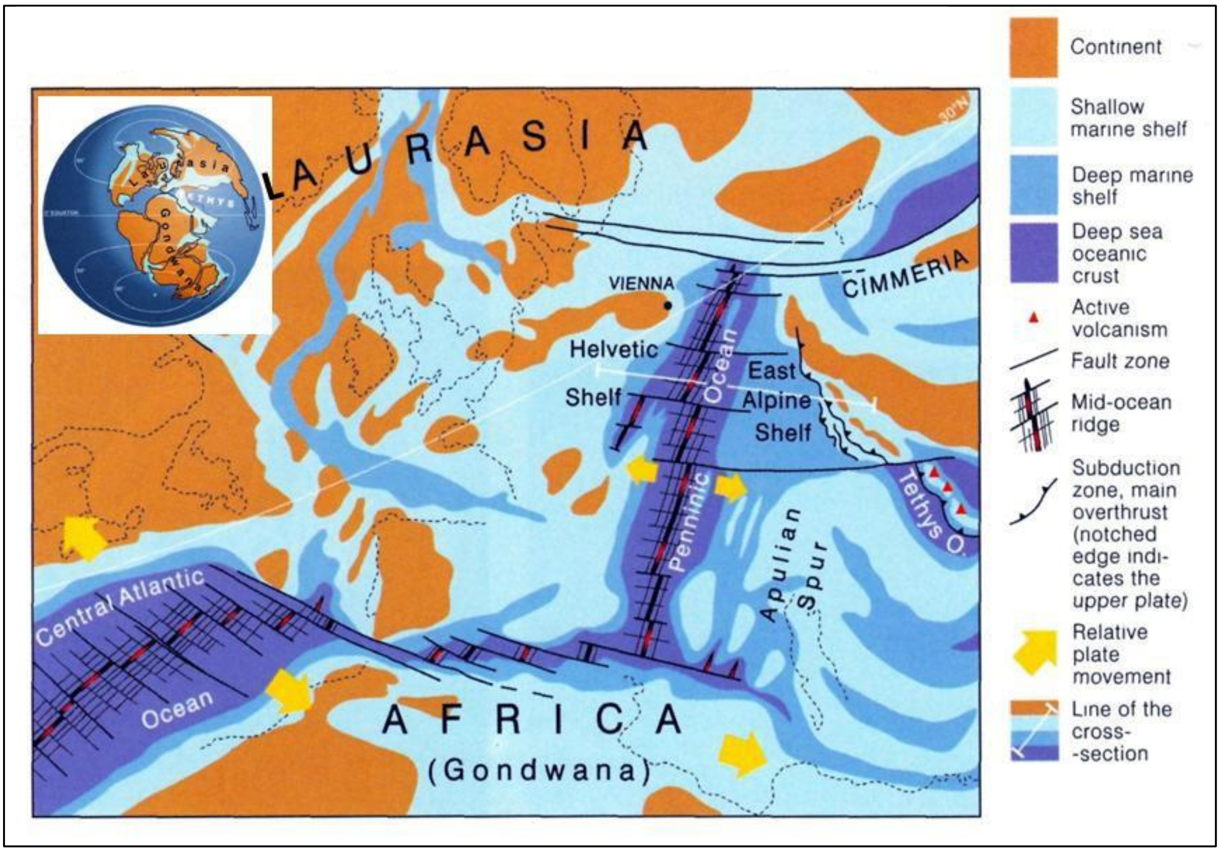


Fig. 5. **Upper Jurassic paleogeography**: Pangaea fragmented, Penninic Ocean opened. Sedimentation of the later Limestone Alps occurred on the northern part of the Apulian Promontory which is separated from the Helvetic Shelf on the other coast (= European Plate) by the Penninic Ocean. Tethys Ocean started closing.

3. The Lower Cretaceous Period (145.5 – 100 m.y.) – birth of the Alps

This time was characterized by the widening of the Penninic Ocean through production of new oceanic crust, upon which the "Bündner Schiefer" (schistes lustrès) were deposited. The intracontinental subduction within the Austroalpine (Eastalpine) tectonic unit some 135 m.y. ago caused shortening and tectonic subdivision of the Austroalpine into a lower and upper tectonic unit with formation of the Austroalpine nappes – the birth of the Alps!

Paleogeographically the breakup of Pangaea continued and the Adriatic Promontory sepa- rated from African Plate. As a consequence the Adriatic Microplate started an independent drift. Following the opening of the North Atlantic Ocean also the South and Central Atlantic Ocean opened.

4. The Upper Cretaceous Period (100 – 65.5 m.y.) – start of the Alpine Orogeny

While the Adriatic Microplate approached Europe, the Penninic Ocean started closing. The consumption of the ocean was responsible for the simultaneous formation of an accretionary wedge and the change from the former passive to an active continental margin. In the Penninic Ocean oceanic lithosphere and its sediment cover (= flysch-type Bündner Schiefer/“schistes lustrés“) deformed into Penninic nappes. Around 90 m.y. deeper crustal levels were affected by Eo-alpine high p/t metamorphism which, however, affected less distinctly the upper tectonic units including the areas covered by limestones. This event was the onset of the Alpine Orogeny.The upper nappes formed shallow Austroalpine sedimentary basins which were subdivided by islands with deposition of Gosau sediments.

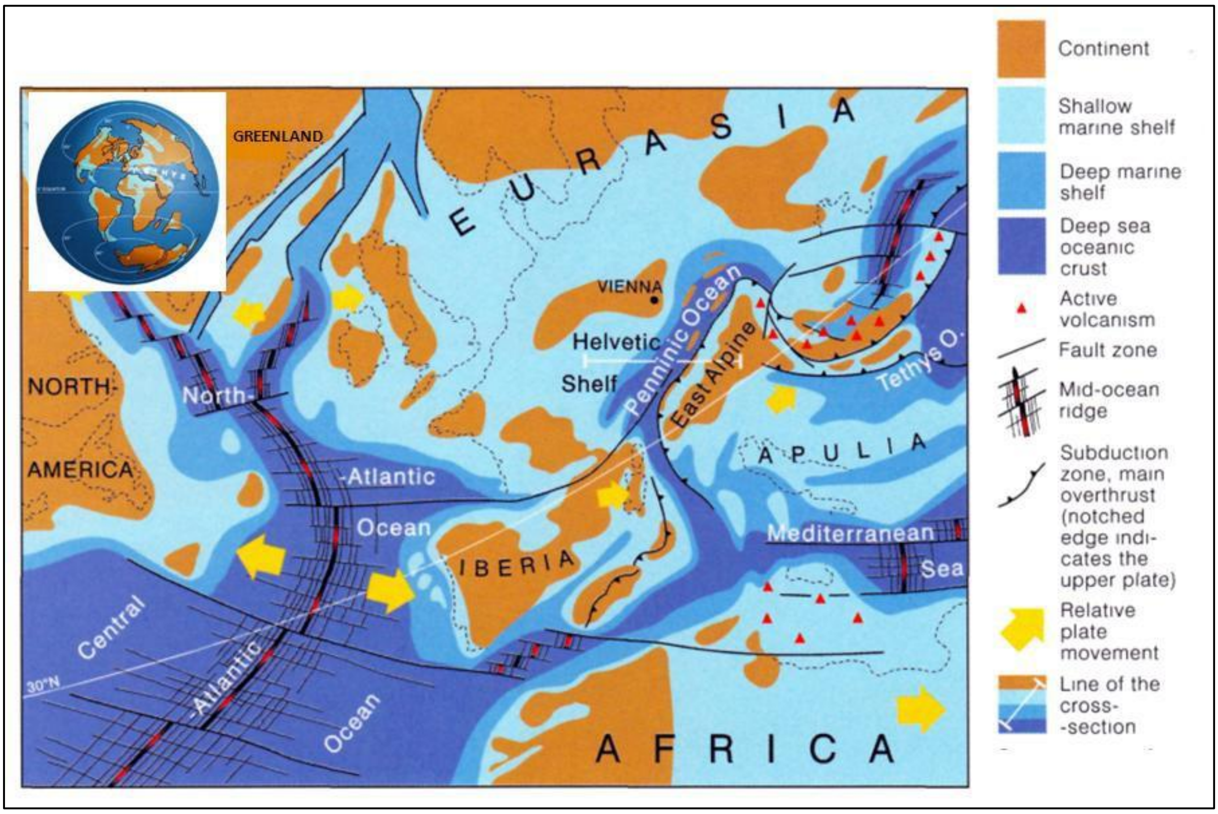


Fig. 6. **Upper Cretaceous paleogeography**: Apulia approached Europe, Penninic Ocean started closing with deposition of thick flysch deposits which subsequently were transformed into Penninic nappes. Shelf subdivided by islands with Gosau sedimentation. Eo-alpine high p/t metamorphism occurred in deeper crust.

5. The Paleogene Period (65.5 – 23 m.y.) – end of the Penninic Ocean

Approx. 50 m.y. ago the Penninic Ocean was completely closed. Until some 40 m.y. ago the southern margin of European Plate was subducted under the Austroalpine orogenic wedge forming the Helvetic and Subpenninic nappes, respectively. During this process the Variscan granites transformed to orthogneisses and a temperature-controlled “young-alpine“ meta- morphism known as “Tauernkristallisation“ occurred. Between 40 and 30 m.y. ago the slab break-off of lithospheric plate resulted in the ascent of hot melts between Austro- and Southalpine units, i.e. along the Periadriatic Line, which crys- tallized to granites and tonalites in the crust and volcanoes on the surface, respectively. Also, the

Adriatic Plate started south-directed thrusting while the crust underneath the central Alps thickened. As a consequence, some 30 m.y. ago isostatic adjustment movements started in the central Alps with slow uplift. Paleogeographically, the Austroalpine changed to a landscape with hills east of Brenner and low mountains to the west.

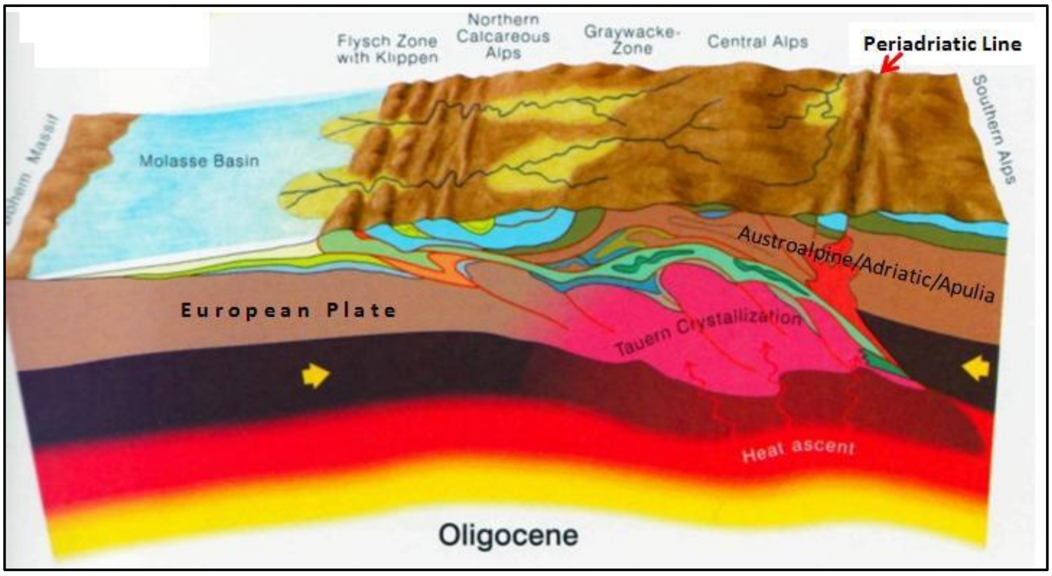


Fig. 7. Sketch from the Bohemian Massif in the North across the Molasse Basin to the northward thrusting Alpine nappes during Oligocene times.

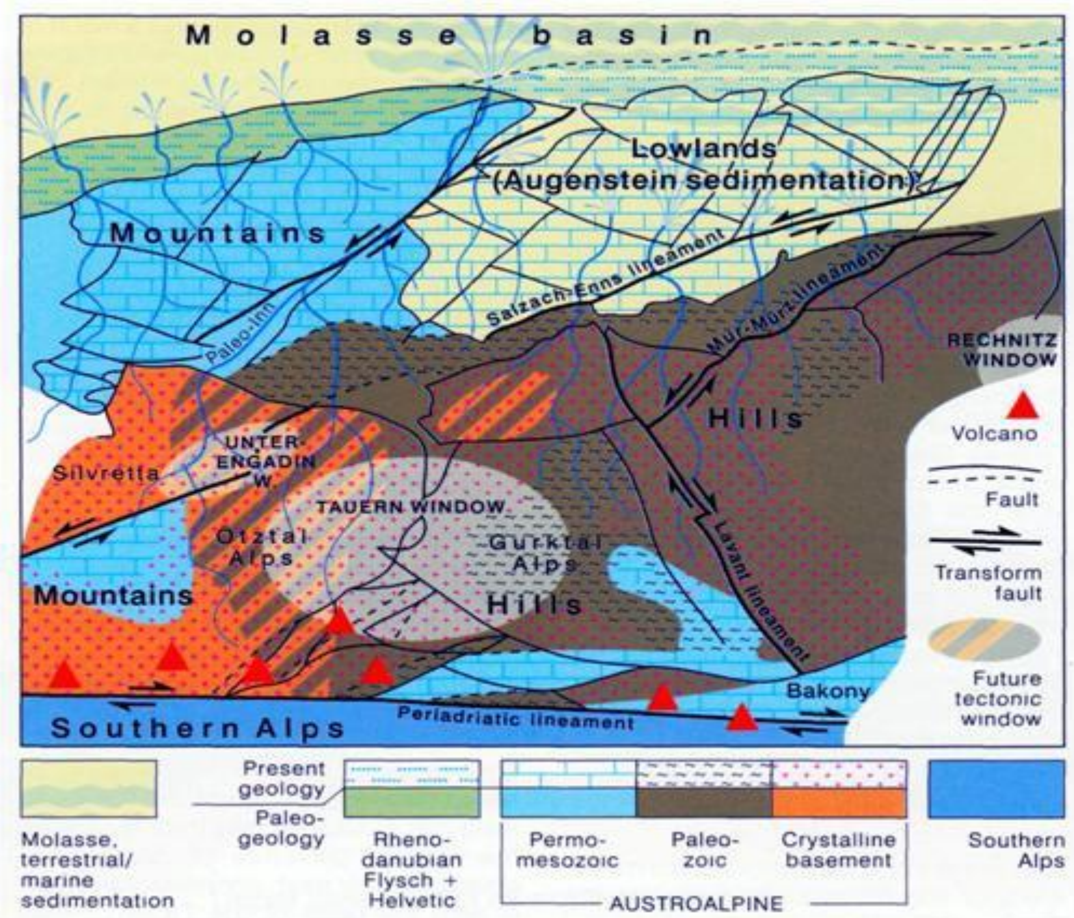


Fig. 8. Reconstruction of the Eastern Alps during the „Augenstein-landscape“ in the late Oligocene when the Northern Limestone Alps were not yet fully exhumed.

6. The Paleogene Period (65.5 – 23 m.y.) – Molasse Basin is formed

Beginning in the Eocene a foreland basin ("Paratethys") gradually subsided due to the superimposed load of the overriding Alps on the European Plate. It was gradually filled until some 15 m.y. with debris from the rising Alps and the Bohemian Massif. The basin contains a rich animal and floral heritage.

The paleogeographic situation is characterized by the shallow marine sedimentary Molasse Basin of the Paratethys surrounding the rising Alps.

7. The Neogene Period (23 – 2.4 m.y.) – the rise of the Alps to an orogen

The general North-South shortening resulted in an indenter of the Southern Alps some 20 m.y ago into the Central Alps. Simultaneously a rapid East-West lithospheric extension and stretching in Pannonian Basin occurred. The extension was accompanied by the development of a system of lateral displacements north and south of the Alpine chain which resulted in a lateral extrusion of the Eastern Alps against the Pannonian Basin.

Due to normal slip faulting the central part of Eastern Alps thinned and exhumation of Hohe Tauern started 15-13 m.y. ago. However, internal deformation continued and Alpine fissures formed. Within the Alps several intra-Alpine Molasse Basins formed.

The uplift of the Alps occurred approx. since 10 m.y. ago with rates of some 5 mm/y, later slowing down to 0.5 mm/y. In the Molasse Basin sedimentation continued until 4 m.y. when fresh water lake dried up.

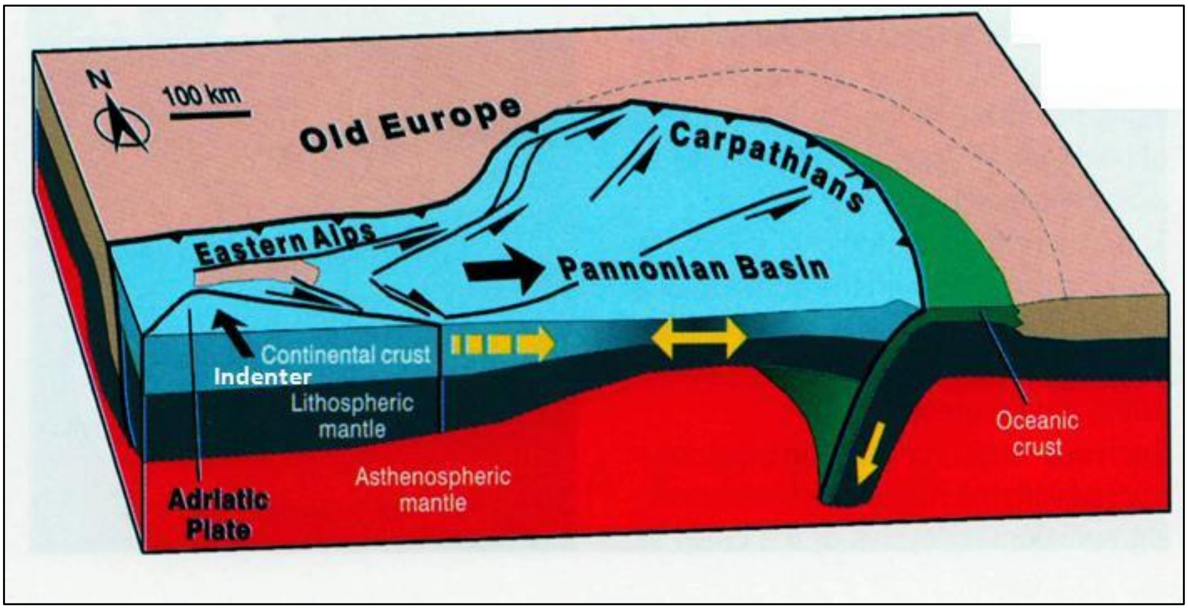


Fig. 9. Sketch of the Alpine-Carpathian area during the middle Miocene: large crustal wedges of the Austroalpine Unit were squeezed out towards the east due to a south-north directed compression (after Peresson & Decker, 1997, modified).

8. Present-day surface and subsurface geology

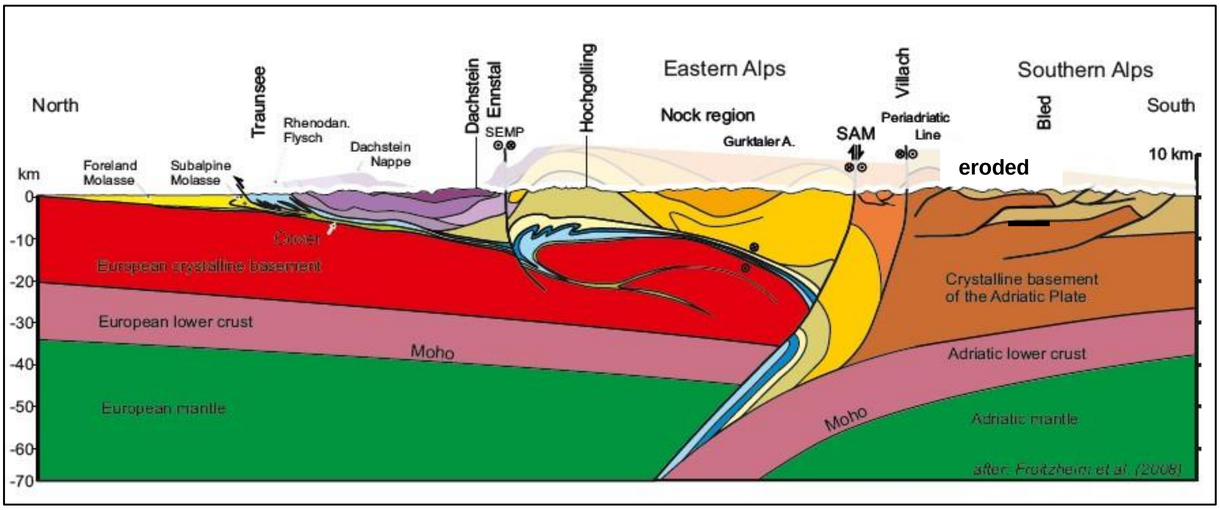


Fig. 10. Present day geological N – S section of the Eastern and Southern Alps from Traunsee in Upper Austria to Bohinjsko jezero in Slovenia (after Froitzheim et al. 2008, Schuster & Stuewe, 2010, Stuewe & Homberger, 2011, mod.).

Conclusions

The major steps of Alpine plate tectonic evolution can be summarized as follows:

- The Adriatic Plate was part of the African Plate until the Cretaceous ("Adriatic or Apulian Promontory")
- subsequently the Adriatic Plate broke up and started to drift independently
- while the Austroalpine unit was detached from the Adriatic Plate during the Lower Cretaceous, the Southalpine was sheared off in southern direction during the Paleogene
- today the Austroalpine and Southalpine units are part of the Alpine orogenic wedge which is overlying the plate boundary of the European and Adriatic Plate in the subsurface
- anticlockwise rotation of the Adriatic Plate continues today with movements of some mm/y triggering seismicity in Friuli-Venezia Giulia.

Further reading: Rocky Austria © Geol. B.-A., 2000 (Krenmayr, red.), Froitzheim et al., 2008, Schuster & Stuewe, 2010, Stuewe & Homberger, 2011.

Acknowledgments

The graphics used in this review are mainly based on the English version of Rocky Austria and were compiled by Monika Brüggemann-Ledolter (Geological Survey of Austria). Fig. 10 is from the English edition of "Geology of the Alps from the air" by K. Stuewe and Ruedi Homberger (Weishaupt Verl. Gams, 2012). Other figures are referenced in the captions.

IV. References

ARTHAUD, F. & MATTE, P. H. (1977): Late Paleozoic strike-slip faulting in southern Europe and northern Africa: result of a right lateral shear zone between the Appalachians and the Urals. – Geol. Soc. Am. Bull, 88, 1305-1320.

BAUER, F. K. (1973): Ein Beitrag zur Geologie der Ostkarawanken. – Veröff. Univ. Innsbruck, Heißel-Festschrift, 86, 1-23.

BAUER, F. K. (1983): Mesozoikum der Nordkarawanken. In: BAUER, F. K., CERNY, I., EXNER, C., HOLZER, H.-L., HUSEN, van D., LOESCHKE, J., SUETTE, G. & TESSENSOHN, F. (1983) Erläuterungen zur Geologischen Karte der Karawanken 1:25.000, Ostteil. – Geol. B.-A., 47-58.

BAUER, F. K., CERNY, I., EXNER, C., HOLZER, H.-L., HUSEN, VAN D., LOESCHKE, J., SUETTE, G. & TESSENSOHN, F. (1983): Erläuterungen zur Geologischen Karte der Karawanken 1:25.000, Ostteil. – Geol. B.-A., 1-86.

DIENER, R., KUTTEROLF, S. & KRAWINKEL, H. (2001): Petzrographie, Geochemie und Provenanz der Hochwipfel- Formation, Karawanken (Österreich/Slowenien). – Berichte des Institutes für Geologie und Paläontologie der Karl-Franzens-Universität Graz, "Paläozoikumforschung in Österreich": Workshop 19.-20. Oktober 2001, 8-9, St. Pankrazen/Stmk.

DIENER, R. (2002): Die siliziklastischen Sedimente der synorogenen Hochwipfel-Formation im Karbon der West- Karawanken (Österreich/Slowenien/Italien). – Unveröffentl. Diss. Univ. Stuttgart, 1-366.

EXNER, C. (1972): Geologie der Karawankenplutone östlich Eisenkappel. – Mitt. Geol. Ges., 64, 1-108.

EXNER, C. (1976): Die geologische Position der Magmatite des periadriatischen Lineamentes. – Verh. Geol. B.- A., 1976, 3-64.

EXNER, C. (1983): Altkristallin und Plutonite mit deren kontaktmetamorphen Hüllgesteinen. In: BAUER, F. K., CERNY, I., EXNER, C., HOLZER, H.-L., HUSEN, VAN D., LOESCHKE, J., SUETTE, G. & TESSENSOHN, F. (1983): Erläuterungen zur Geologischen Karte der Karawanken 1:25.000, Ostteil. – Geol. B.-A., 8-24.

EXNER, C. & SCHÖNLAUB, H. P. (1973): Neue Beobachtungen an der Periadriatischen Narbe im Gailtal und im Karbon von Nötsch. – Verh. Geol. B.-A., 1973, 357-365.

FLÜGEL, H. W. (1990): Das voralpine Basement im Alpin-Mediterranen-Belt – Überblick und Problematik. – Jb. Geol. B.-A., 133, 181-222.

FRANK, W., KRALIK, M., SCHARBERT, S. & THÖNI, M. (1987): 4. Geochronological Data from the Eastern Alps. -In: FLÜGEL, H. W. & FAUPL, P. (eds.) Geodynamics of the Eastern Alps: 72-281. – Deuticke Wien. FRANKE, W. (1989): Tectonostratigraphic units in the Variscan belt of central Europe. – Geol. Soc. America, Spec. Pap. 290: 67-89.

FRANKE, W. (2006): The Variscan Orogen in Central Europe: construction and collapse. In: Gee, D. & Stephenson, R. A. (eds), European Lithosphere Dynamics. – Geol. Soc. London, Mem, 32, 333-343.

FRISCH, W. & NEUBAUER, F. (1989): Pre-Alpine terranes and tectonic zoning in the eastern Alps. – Geol. Soc. Am., Spec. Pub., 230: 91-100.

FROITZHEIM, N., PLASIENKA, D. & SCHUSTER, R. (2008): Alpine tectonics of the Alps and Western Carpathians. In: McCANN, T. (ed.), The Geology of Central Europe, vol. 2: Mesozoic and Cenozoic, 1141-1232. GAERTNER, H. R. von (1931): Geologie der zentralkarnischen Alpen. – Denkschr. Österr. Akad. Wiss. Wien, math.- naturw. Kl., 102: 113-199, Wien.

HUSEN, van, D. (1983): Tertiär. In: BAUER, F. K., CERNY, I., EXNER, C., HOLZER, H.-L., HUSEN, VAN D., LOESCHKE, J., SUETTE, G. & TESSENSOHN, F. (1983) Erläuterungen zur Geologischen Karte der Karawanken 1:25.000, Ostteil. – Geol. B.-A., 64-71.

KRAINER, K. (1992): Fazies, Sedimentationsprozesse und Paläogeographie im Karbon der Ost- und Südalpen. – Jb. Geol. B.-A., 135/1, 99-193.

KRENMAYR, H. G., Red.(2002): Rocky Austria. Eine bunte Erdgeschichte von Österreich. – Geol. B.-A., 1-64. KUPSCH, F., ROLSER, J. & SCHÖNENBERG, R. (1971): Das Altpaläozoikum der Ostkarawaken. – Z. dt. Geol. Ges., 122, 89-96.

KUTTEROLF, S. (2001): Die klastischen Sedimente der karbonen Hochwipfel- und Auernig-Formation der Ostkarawanken (Österreich/Slowenien). Sedimentologie und Provenienz. – Unveröffentl. Diss. Univ. Stuttgart, 1-182.

LÄUFER , A., LOESCHKE, J. & VIANDEN, B. (1993): Die Dimon-Serie der Karnischen Alpen (Italien) – Stratigraphie, Petrographie und geodynamische Interpretation. – Jb. Geol. B.-A., 136, 137-162.

LÄUFER, A. L., HUBICH, D., LOESCHKE, J. (2001): Variscan geodynamic evolution of the Carnic Alps (Austria/Italy). – Int. J. Earth Sciences (Geol. Rundschau), 90, 855-870.

LOESCHKE, J. (1983): Diabaszug von Eisenkappel westlich der Vellach. In: BAUER, F. K., CERNY, I., EXNER, C., HOLZER, H.-L., HUSEN, VAN D., LOESCHKE, J., SUETTE, G. & TESSENSOHN, F. (1983): Erläuterungen zur Geo- logischen Karte der Karawanken 1:25.000, Ostteil. – Geol. B.-A., 24-30.

MATTE, P. (1986): Tectonic and plate tectonics model fort the Variscan belt of Europe. – Tectonophysics, 126, 329-374.

MUTTONI, G., KENT, D.V., GARZANTI, E., BRACK, P., ABRAHAMSEN, N., GAETANI, M. (2003): Early Permian Pangea 'B' to Late Permian Pangea 'A'. – Earth and Planetary Science Letters, 215, 379-394.

NEUBAUER, F., HOINKES, G., SASSI, F. P., HANDLER, R., HÖCK, V., KOLLER, F. & FRANK, W., 1999: Pre-Alpine metamorphism in the Eastern Alps. – Schweiz. Mineral. Petrogr. Mitt., 79, 41-62.

PERESSON, H. & DECKER, K. (1997): From extension to compression: Late Miocene stress inversion in the Alpine-Carpathian-Pannonian area. – Mitt. Ges. Geol. Bergbaustudenten Österr., 41, 75-86.

RANTITSCH, G. (1990): Fazies und Diagense devonischer Riffkalke des Seeberger Aufbruches (Kärnten, Österreich). – Jb. Geol. B.-A., 135, 273-285.

RAUMER, von, J., STAMPFLI, G. M., BOREL, G. D. & BUSSY, F. (2002): Organization of pre-Variscan basement areas at the north-Gondwanan margin. – Int. J. Earth Sciences (Geol. Rundsch.), 91, 35-52.

RAUMER von, J. F., STAMPFLI, G. M., & BUSSY, F. (2003): Gondwana-derived microcontinents – the constituents of the Variscan and Alpine collisional orogens. – Tectonophysics, 365, 7-22.

SCHALTEGGER, U. & BRACK, P. (2007): Crustal-scale magmatic systems during intracontinental strike-slip tec- tonics: U, Pb and Hf isotopic constraints from Permian magmatic rocks of the Southern Alps. – I. J. Earth Sci. (Geol Rdsch), (2007), 96, 1131-1151.

SCHÖNLAUB, H. P. (1971): Zur Problematik der Conodontenchronologie an der Wende Ordoviz/Silur mit besonderer Berücksichtigung der Verhältnisse im Llandovery. – Geologica et Palaeontologica, 5, 35-57.

SCHÖNLAUB, H. P. (1979): Das Paläozoikum in Österreich. – Abh. Geol. B.-A., 33, 1-124.

SCHÖNLAUB, H. P. (1980): Carnic Alps. Field Trip A. In: SCHÖNLAUB, H. P. (ed.): Second European Conodont Symposium, ECOS II, Guidebook, Abstracts. – Abh. Geol. B.-A., 35, 5-57.

SCHÖNLAUB, H. P. (1985): Das Paläozoikum der Karnischen Alpen. In: Arbeitstagung der Geologischen Bundesanstalt 1985, 34-52.

SCHÖNLAUB, H. P. (1992): Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its Impli cations for Plate Movements. – Jb. Geol. B.-A., 135, 381-418.

SCHÖNLAUB, H. P. (1998): Review of the Paleozoic Paleogeography of the Southern Alps – The Perspective from the Austrian Side. – Giorn. Geol., 60, Spec. Issue ECOS VII, Southern Alps Field Trip Guidebook, 59-68.

SCHÖNLAUB, H.P. & KREUTZER, L. (1993): Lower Carboniferous conodonts from the Cima di

Plotta Section (Carnic Alps, Italy). – Jb. Geol. B.-A., 136: 247269, Wien.

SCHÖNLAUB, H. P. & KREUTZER, L. (1994, eds.): IUGS Subcommission on Silurian Stratigraphy. Field Meeting Eastern & Southern Alps, Austria 1994. Guidebook + Abstracts. In memoriam H. JAEGER. – Ber. Geol. B.-A., 30, 1-156.

SCHÖNLAUB, H. P. & HISTON, K. (1999): The Palaeozoic of the Southern Alps. In: V. Intern. Symp. on Cephalopods – Present and Past, Guidebook Carnic Alps. – Ber. Geol. B.-A., 47, 6-30, Wien.

SCHÖNLAUB, H. P. & FORKE, H. C. (2007): Die post-variszische Schichtfolge der Karnischen Alpen - Erläuterungen zur Geologischen Karte des Jungpaläozoikums der Karnischen Alpen 1:12500. – Abh. Geol. B.-A., 61, 3-157.

SCHÖNLAUB, H. P., KLEIN, P., MAGARITZ, M., RANTITSCH, G. & SCHARBERT, S. (1991): Lower Carboniferous Paleokarst in the Carnic Alps (Austria, Italy). – Facies, 25, 91-118, Erlangen.

SCHUSTER, R., SCHARBERT, S., ABART, R. & FRANK, W. (2001): Permo-Triassic extension and related HT/LP metamorphism in the Austroalpine – Southalpine realm. – Mitt. Geol. Bergbau Stud. Österr., 44, 111-141.

SCHUSTER, R. & STÜWE, K. (2010): Die Geologie der Alpen im Zeitraffer. – Mitt. Naturw. Ver. Steiermark, 140, 5-21.

STAMPFLI, G. M. & BOREL, G. D. (2002): A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones. – Earth and Planetary Science Letters, 196, 17-33.

STAMPFLI, G. M., RAUMER, von, J. F. & BOREL, G. D. (2002): Paleozoic evolution of pre-Variscan terranes: From Gondwana to the Variscan collision. - In: MARTINEZ CATALAN, J. R., HATCHER, R. D., JR., ARENAS, R. & DIAZ GARCIA, F. (eds), Variscan-Appalachian dynamics: The building of the late Paleozoic basement. – Geol. Soc. America, Spec. Paper 364, 263-280.

STUEWE, K. & HOMBERGER, R. (2011): Die Geologie der Alpen aus der Luft. – Weishaupt Verlag Gams, pp. 1-288.

SUESS, E. (1858): Mitteilungen über kärntnerische Petrefakten. – Jb. Geol. R.-A., 9, 59.

SUESS, E. (1868): Über die Äquivalente des Rothliegenden in den Südalpen. – Sitzber. k. k. Akad. Wiss. Wien, math.-naturw. Kl., 57.

TAIT, J., SCHÄTZ, M., BACHTADSE, V. & SOFFEL, H. (2000): Palaeomagnetism and Palaeozoic palaeogeography of Gondwana and European terranes, in Orogenic Processes: Quantification and Modelling in the Variscan Belt, pp. 21-34. – Geol. Soc. London, Publ. House, Bath.

TESSENSOHN, F. (1974b): Schichtlücken, Diskordanzen, Mischfaunen. Neue stratigraphische Ergebnisse zu einer Faziesanalyse im Devon der Karawanken. – Carinthia II, 164, 137-160.

TESSENSOHN, F. (1983): Eisenkappler und Seeberger Paläozoikum. In: BAUER, F. K., CERNY, I., EXNER, C., HOLZER, H.-L., HUSEN, VAN D., LOESCHKE, J., SUETTE, G. & TESSENSOHN, F. (1983): Erläuterungen zur Geologischen Karte der Karawanken 1:25.000, Ostteil. – Geol. B.-A., 32-45.

TIETZE, E. (1870): Beiträge zur Kenntnis der älteren Schichtgebilde Kärntens. – Jb. Geol. R.-A., 20, 259-272. TES SENSOHN, F. (1974a): Zur Fazies paläozoischer Kalke in den Karawanken. – Verh. Geol. B.-A., 1974, 89-124.

VAI, G. B. (1998): Field trip through the Southern Alps: an introduction with geologic settings, palaeogeography and Palaeozoic stratigraphy. – Giorn. Geol., Spec. Issue ECOS VII, Southern Alps Field Trip Guidebook , 60, 1-38.

Author’s address: Kötschach 350, A-9640 Kötschach-Mauthen.