The Neogene of the Styrian Basin – Guide to Excursions

Das Neogen des Steirischen Beckens – Exkursionsführer

Martin GROSS, Ingomar FRITZ, Werner E. PILLER, Ali SOLIMAN, Mathias HARZHAUSER, Bernhard HUBMANN, Bernd MOSER, Robert SCHOLGER, Thomas J. SUTTNER & Hans-Peter BOJAR

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1. Introduction

The Styrian Basin is located at the south-eastern margin of the Alps. In the north, west and southwest it is encircled by crystalline Austroalpine units and the Graz Paleozoic. The north-eastern boundary is built by the Güns Mountains (Penninic unit). Extensive ranges of hills are characteristic for the basin landscape interrupted by valleys of gene-rally southeast draining rivers. Exposures of the basement (e. g., Sausal Mountains) and volcanic "cones" (e. g., Gleichenberg, Kapfenstein) highlight the scenery (Figs. 1-2).

Fig. 1: View at Kapfenstein from the south.
Abb. 1: Blick von Süden Richtung Kapfenstein.

Geological investigations date back into the early 19th century and are intimately connected with Arthur WINKLER-HERMADEN, who summarized the standard of knowledge in his "Geologisches Kräftespiel" [Geological dynamics] in 1957 (WINKLER-HERMADEN 1957; WINKLER 1913, 1927a).

Results of intensive explorations of the Rohöl-Aufsuchungs AG [Crude oil mining company] in the middle of the 20th century were published by Kurt KOLLMANN. The detailed paper "Jungtertiär im Steirischen Becken" [Younger Tertiary of the Styrian Basin] (KOLLMANN 1965) is still a standard work for this area. Geophysical data on the pre-Neogene basement (KRÖLL et al. 1988), deep boreholes, studies of coalification gradients and new geodynamic models were combined to the "Entwicklungsgeschichte des Steirischen Tertiärbeckens" [Developmental history of the Styrian Tertiary Basin] by Fritz EBNER and Reinhard F. SACHSENHOFER (EBNER & SACHSENHOFER 1991, 1995; SACHSENHOFER et al. 1997).

More detailed overviews offer the excursion-guides of WINKLER-HERMADEN (1939), FLÜGEL et al. (1964), FLÜGEL & HERITSCH (1968), FLÜGEL (1972), HOLZER (1994), SACHSENHOFER (1996), STINGL (1997), GROSS (2000), and GROSS et al. (2005).
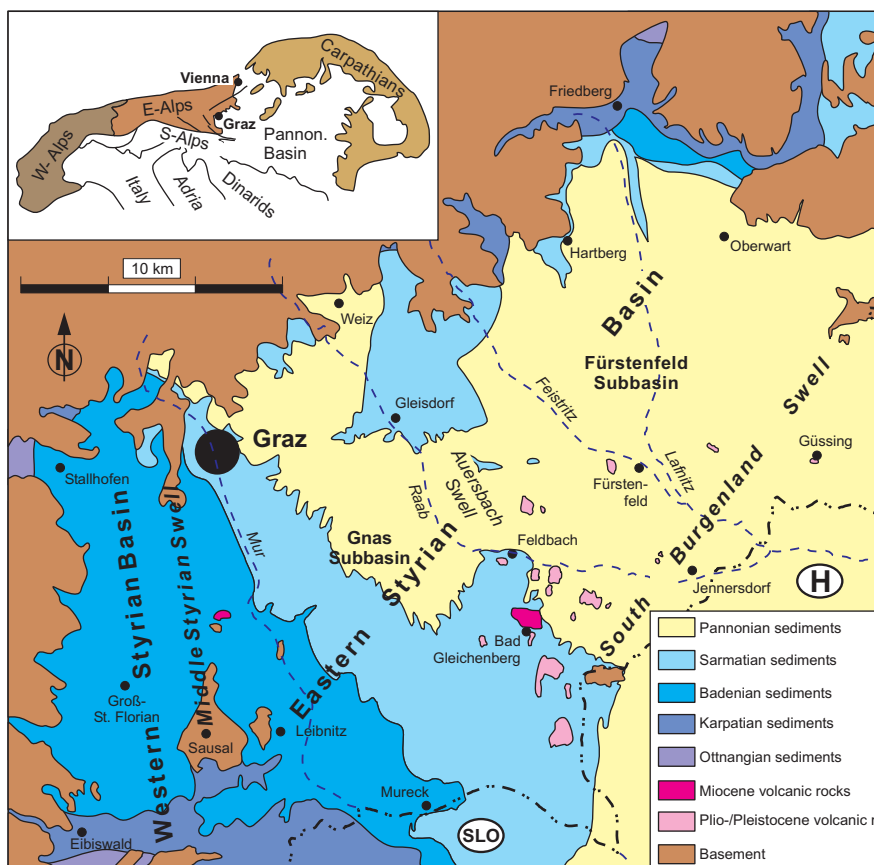

Fig. 2: Geological sketch of the Styrian Basin.
Abb. 2: Geologische Übersichtskarte des Steirischen Beckens.

2. The Styrian Basin

2.1. Structure, genesis and palaeogeography

The approximately 100 km long, 60 km wide and up to 4 km deep Styrian Basin belongs to the Pannonian Basin System, which is surrounded by the Alps, Dinarids and Carpathians (Fig. 2). It is detached by the NE–SW striking South Burgenland Swell from the Western Pannonian Basin and internally divided by the Middle Styrian Swell into a Western and an Eastern Styrian Basin. Basement spurs and subordinate swells cause further differentiation in bays and subbasins (KRÖLL et al. 1988; Fig. 2).

Initiation of basin formation is connected to continental escape tectonics of alpidic crustal wedges at the final collision stage (Late Oligocene to Miocene) of the Adriatic with the European plate (NEUBAUER & GENSER 1990; RATSCHBACHER et al. 1991). The tectonic evolution in the Carpathian-Pannonian region is accompanied by the generation of a wide variety of magmas. The Miocene development of the Carpathian chain and the Pannonian Basin System is discussed to be controlled by retreating subduction in front of the orogene and with back-arc extension associated with the diapiric upraise of astenosphere (KOVAC et al. 2000; KONECNY et al. 2002). Calc-alkaline and alkaline magmatism was closely related to subduction, rollback, collision and extension (SEGHEDI et al. 2004).

Lateral escape happened along large, E–W trending strike-slip faults generating small pull-apart basins (Noric Line). Simultaneously, isostatic uplift of thickened continental crust is associated with gravitative sliding of higher parts of the lithosphere along flat downthrown faults and led to the exposure of deeper units (Penninic). Downthrown faults are regarded responsible for horizontal block tilting, which caused asymmetric, N–S-striking extensional structures like the Styrian Basin (NEUBAUER & GENSER 1990; NEUBAUER et al. 1995). More information - including palaeomagnetic data and geochemical analyses of magmatic rocks - to the geodynamics of the Alpine/Carpathian/Pannonian region provide, e.g., KOVAC et al. (2000) or SEGHEDI et al. (2004).

Palaeogeographically, the Styrian Basin is part of the Central Paratethys. The Paratethys was born after the vanishing of the Tethys Ocean because of the collision of Eurasia, India and Africa around the Eocene/Oligocene boundary. South of the rising Alpine orogene, the (Proto-)Mediterranean developed, to the north the Paratethys. The Central Paratethys comprises the region from the Bavarian Molasse zone in the west, to the Carpathian arc in the east. Due to a different palaeobiological and palaeogeographical evolution regional chronostratigraphic stages were established. Discussions about correlations with the adjacent Mediterranean and the Eastern Paratethys are still ongoing (e.g., RÖGL & DAXNER-HÖCK 1996; RÖGL 1998, 1999; HARZHAUSER et al. 2002; POPOV et al. 2004). The subsequent overview attempts to explain the history of the basin fill interrelated with geodynamics and sea level fluctuations and the resulting lithological and palaeobiological changes (Fig. 3).
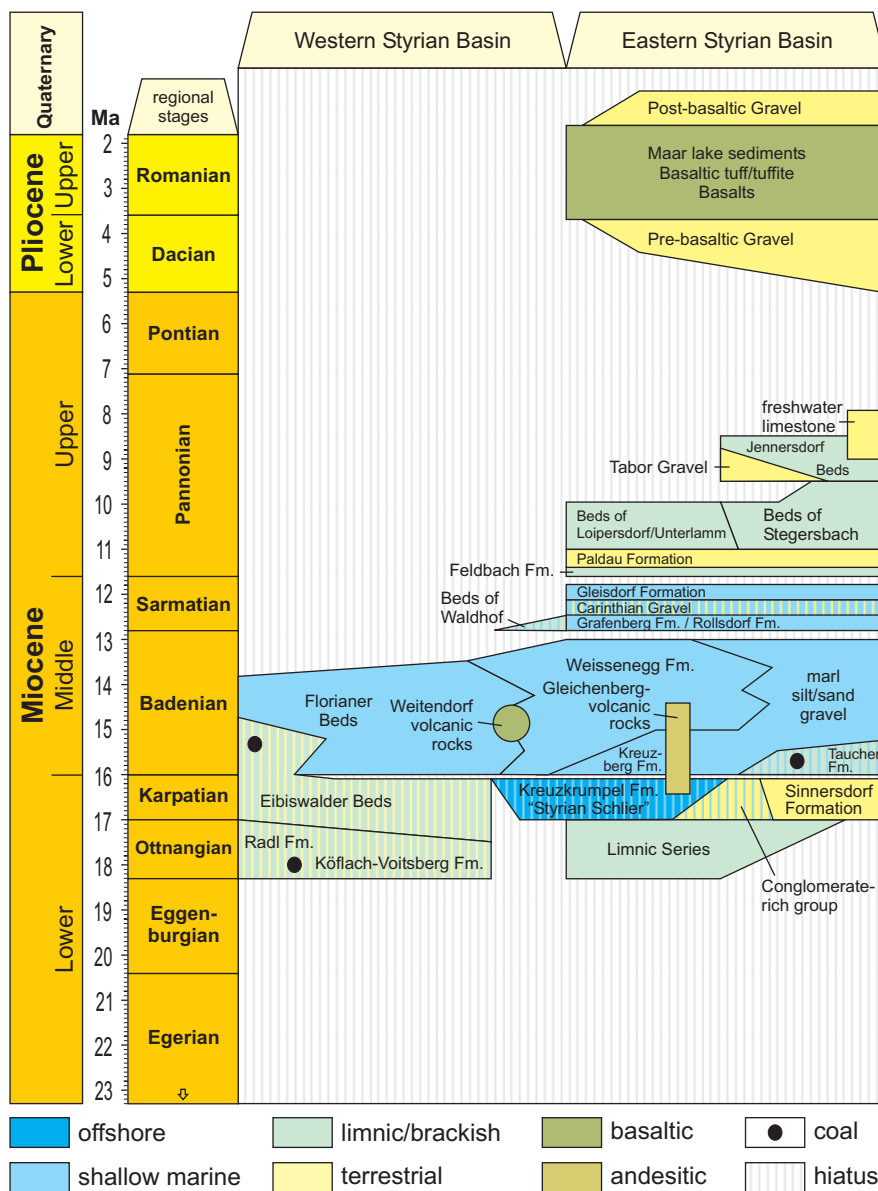
Western Styrian Basin | **Eastern Styrian Basin**

Eonothem/Era		Epoch	regional stages	Ma

Quaternary

Pliocene — Lower/Upper

Romanian
Dacian
Pontian
Pannonian
Sarmatian
Badenian
Karpatian
Ottnangian
Eggenburgian
Egerian

Miocene — Upper / Middle / Lower

Ma: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23

Eastern Styrian Basin units:
Post-basaltic Gravel
Maar lake sediments, Basaltic tuff/tuffite, Basalts
Pre-basaltic Gravel
freshwater limestone
Jennersdorf Beds
Tabor Gravel
Beds of Loipersdorf/Unterlamm
Beds of Stegersbach
Paldau Formation
Feldbach Fm.
Gleisdorf Formation
Carinthian Gravel
Grafenberg Fm. / Rollsdorf Fm.
Beds of Waldhof
Weissenegg Fm.
Gleichenberg-volcanic rocks
marl silt/sand gravel
Florianer Beds
Weitendorf volcanic rocks
Kreuzberg Fm.
Tauchen Fm.
Eibiswalder Beds
Kreuzkrumpel Fm. "Styrian Schlier"
Sinnersdorf Formation
Radl Fm.
Köflach-Voitsberg Fm.
Limnic Series
Conglomerate-rich group

Legend:
offshore | limnic/brackish | basaltic | ● coal
shallow marine | terrestrial | andesitic | hiatus

Fig. 3: Stratigraphic chart of the Neogene basin fill of the Styrian Basin (modified after PILLER et al. 2004).
Abb. 3: Stratigraphische Tabelle der neogenen Beckenfüllung des Steirischen Beckens (verändert nach PILLER et al. 2004).

2.2. The underground of the Styrian Basin and its upraises

According to the classical work of KOLLMANN (1965) the Styrian Basin is subdivided into three depocenters (Western Styrian Basin, Gnas Basin and Fürstenfeld Basin). The differences in elevation of the relief amounting to over 3000 m were obviously developed independent from the structure and composition of the basement itself and its pre-Neogene erosion (FLÜGEL 1988). The knowledge of the geological underground relies on approximately 35 drillings, which reached the subsurface, geophysical data, as well as isolated exposures. The underground upraises are linked to two distinctive swells, which also sedimentologically affected the depocenters considerably: the "Middle Styrian Swell" [Mittelsteirische Schwelle] (i. e., the upraises of Remschnigg and Poßruck, Sausal, Seggauberg and Kreuzkogel; cf. Stop 11 herein) and the "Southern Burgenland Swell" [Südburgenländische Schwelle] with its upraises at St. Anna am Aigen, Rotterberg/Stadelberg (southern Burgenland and northern Slovenia; cf. Stop 4) and Kohfidisch, Hannersdorf and Hohensteinmaisberg (Kirchfidisch). Outcrops on upraises would permit a direct view on the lithological composition of the underground, regrettably this is however impossible for various reasons. In the meagre surface outcrops complete successions are not known (HERITSCH 1963); this makes the affiliation of individual occurrences very difficult. Furthermore these isolated occurrences are tectonically cut and internally intensively fractured and folded. The monotonous, fossil-poor rocks suffered at least from green schist metamorphosis. Therefore the comparison with successions of areas known from the northern and/or northwestern edge of the basin is pretty difficult. Following the conceptions of KRÖLL et al. (1988), the underground can be subdivided into three large tectonic units: (A) Penninic Units, (B) Austroalpine Crystalline Units and (C) Upper-Austroalpine Units.

The Penninic successions, which upraise in the Rechnitz Window, might occur only in the subsurface of western Burgenland, however not in eastern Styria. The Austroalpine Crystalline successions capture an obviously large portion of the underground. They essentially represent the continuation of units cropping out in the northern and western margins of the basin (Fig. 4). The allocation of phyllitic, volcanoclastic and carbonatic successions, which are known from outcrops along the "Middle Styrian Swell" becomes difficult. They orographically represent the continuation of the Plabutsch-Buchkogel-Range of the Graz Paleozoic, but have however lithologically only few similarities in common.

In the Sausal area acidic volcanites (in analogy to the Greywacke Zone they are interpreted as Upper Ordovician), sandy to clayey slates with occasionally interbedded green schists and diabases (carbonate rocks are very subordinate) probably may have a Silurian to Devonian age. At Burgstall-Grillkogel flaser-limestones and crinoidal limestones of Lochkovian to Pragian age are tectonically overlaying (SCHLAMBERGER 1987).

In the Remschnigg and Poßruck areas at the Austrian border to Slovenia, although extremely bad excavated, a lithologically very variable sequence is known. Stratigraphically oldest rocks are volcanic tuffs, green schists, and diabases (south of Oberhaag).
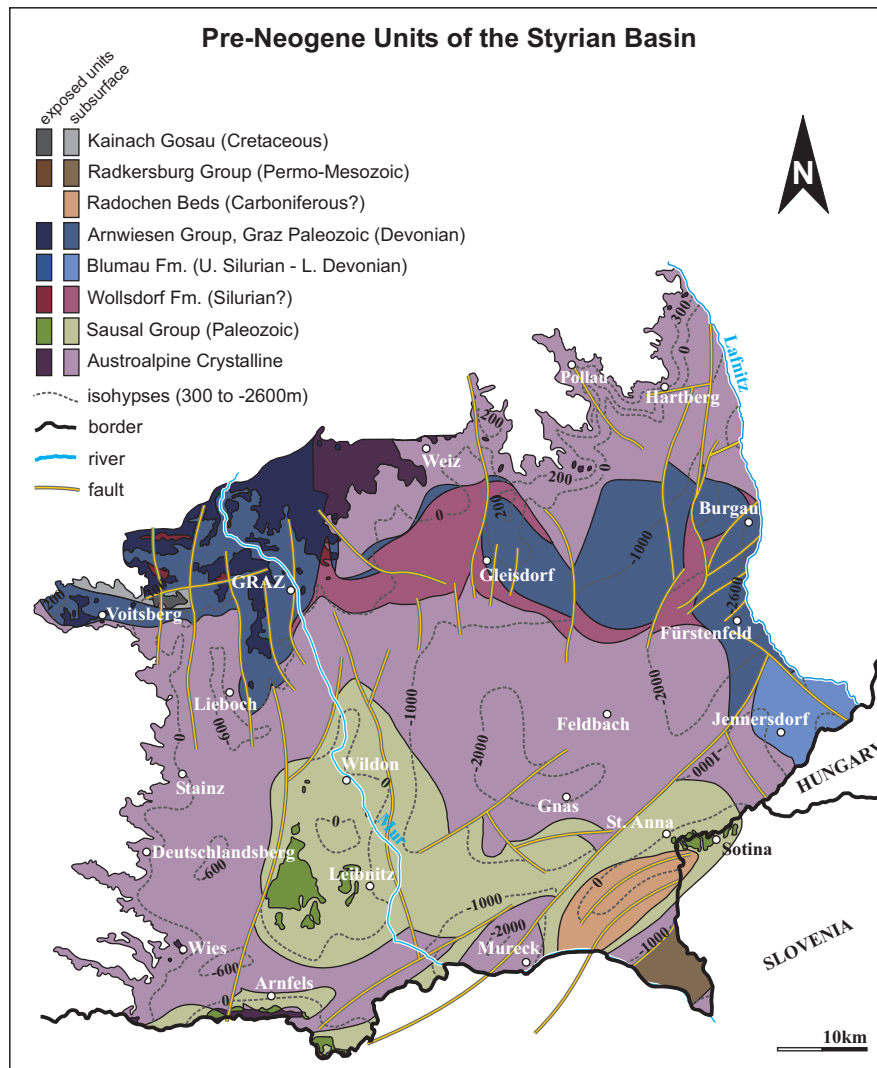
Pre-Neogene Units of the Styrian Basin

exposed units
subsurface

- Kainach Gosau (Cretaceous)
- Radkersburg Group (Permo-Mesozoic)
- Radochen Beds (Carboniferous?)
- Arnwiesen Group, Graz Paleozoic (Devonian)
- Blumau Fm. (U. Silurian - L. Devonian)
- Wollsdorf Fm. (Silurian?)
- Sausal Group (Paleozoic)
- Austroalpine Crystalline
- isohypses (300 to -2600m)
- border
- river
- fault

Fig. 4: Pre-Neogene units of the Styrian Basin.
Abb. 4: Prä-Neogene Einheiten des Steirschen Beckens.

They are overlain by argillaceous shales and schists, which are interbedded by platy limestones, flaser-limestones and crinoidal limestones. Conodonts indicate ages of the Llandoverian/Wenlockian transition as well as Emsian and Frasnian. Micaceous shales and sandstones, as well as red conglomerates and sandstones are developed above argillaceous shales and phyllitic schists, which might belong to the upper Paleozoic.

Exclusively from completely isolated locations, which lack contacts to other rocks, quartzitic sandstones and argillaceous shales, marls and platy limestones with remains of *Cidaris* are known. The former rocks are interpreted as possibly equivalent to the Werfen Formation (Lower Triassic) of the Northern Calcareous Alps; the latter are similar to the sediments deposited during the "Raibl level" (Karnian). The succeeding dolomites and cellular dolomites (reaching a maximum thickness of about 100 metres) possibly represent the Norian "Hauptdolomit". The succession is terminated by Upper Cretaceous brecciated limestones, containing rudists and marls with coccoliths (EBNER 1975; FLÜGEL 1984). Probably the eastern continuation of this succession was found resting on Paleozoic phyllitic schists in the drilling core at Radkersburg (FLÜGEL 1988). In the vicinity of St. Anna am Aigen (southern Styria) and Rotterberg/Stadelberg (southern Burgenland, Slovenia) phyllitic successions (quartzitic phyllites and carbonatic phyllites; Leinergraben), metatuffs (quarry Sotina) and pyrite-rich "banded limestones" (abandoned quarry at Kalch) occur in some isolated small outcrops (cf. Stop 4). WIN-KLER (1927a) already mentioned that these associations of rocks can impossibly be integrated into a stratigraphical sedimentary sequence due to the lack of coherent profiles. Possibly, the little less metamorphically over-printed rocks at Hohensteinmaisberg near Kirchfidisch (southern Burgenland) represent a comparable succession. Two main lithological complexes have been distinguished there (POLLAK 1962; SCHÖNLAUB 2000; SUTTNER & LUKENEDER 2004): a dolomite-limestone complex and a phyllite-limestone/shale-complex.

2.3. Lower Miocene

2.3.1. Ottnangian

The filling of the basin started – poorly dated – in the Early Miocene (syn-rift phase) when limnic-fluvial sediments (red soils, breccias, marls with coal seems and conglomeratic layers) were deposited ("Limnic Series", KOLLMANN 1965). For the western Gnas Subbasin a shallow marine environment is supposed for up to 1000 m thick beds (EBNER & SACHSENHOFER 1995; Fig. 5a).

Alluvial fan and delta sediments at proximal areas (Bay of Eibiswald, Weiz, Friedberg-Pinkafeld) are assigned to this stage (e.g., Radl Formation, "Lower Eibiswald Beds", STINGL 1994; "Beds of Naas", "Breccia of Zöbern"; KOLLMANN 1965). Only coal-bearing, limnic-fluvial sediments in the Bay of Stallhofen are well dated by combined bio-/magnetostratigraphic investigations (Köflach-Voitsberg Formation; HAAS et al. 1998; STEININGER et al. 1998). These strata also contain the oldest weathered tuffs within the Styrian Basin (EBNER et al. 2000).

2.3.2. Karpatian

The Middle Styrian and Leibnitz Swells established in Karpatian times beside the already existing South Burgenland Swell (Fig. 5b). High subsidence as a consequence of increasing tectonic activity and a transgression led to the deposition of several hundred metres thick offshore mud- and siltstones with sandy, turbiditic intercalations (Kreuzkrumpel Formation resp. "Styrian Schlier", type locality: Wagna/Leibnitz; cf. Stop 10; FRIEBE 1990; SCHELL 1994; RÖGL et al. 2002). Via Slovenia (Trans-Tethyan-Trench-Corridor) the Styrian Basin was in conjunction with the Mediterranean (RÖGL 1998).
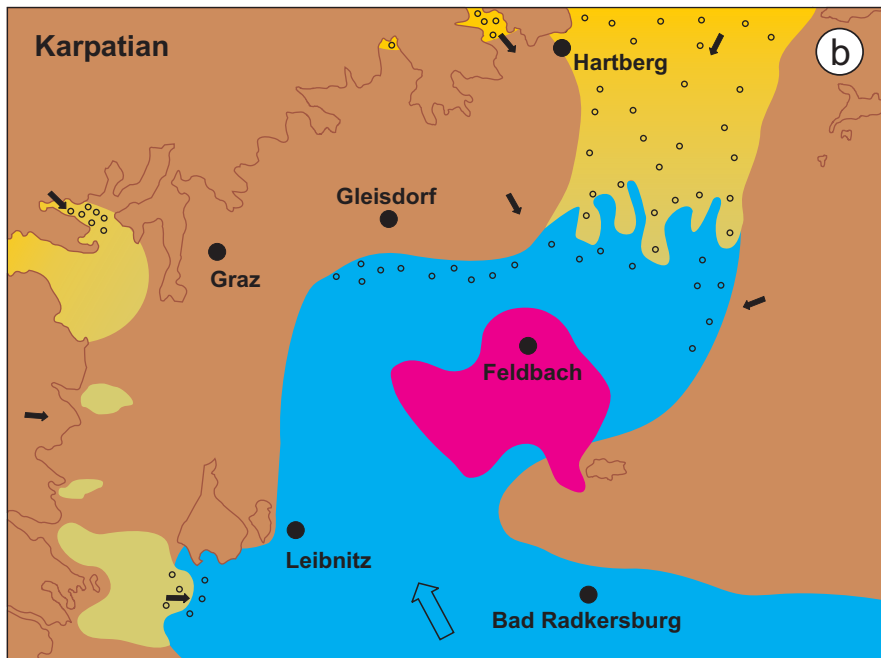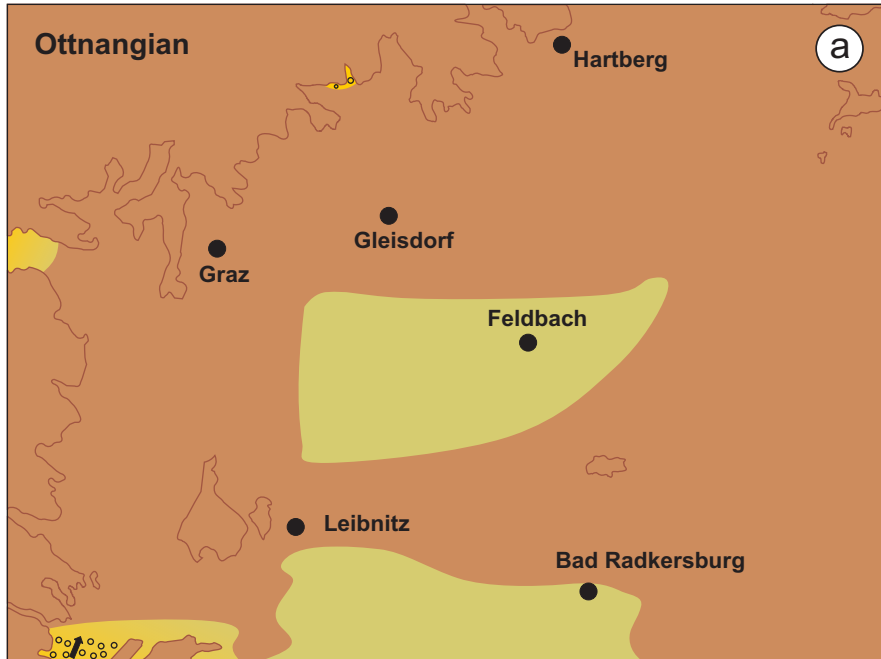
Marine environments close to the basin margin, expressed by subaquatic mass flows along a delta slope, are developed at the transition to the Western Styrian Basin (SW of the Middle Styrian Swell; "Arnfels Conglomerates", "Leutschach Sands"; WINKLER 1927b). Limnic-deltaic sediments north of the Bay of Stallhofen ("Conglomerate of Stiwoll"; FLÜGEL 1975) and fine clastics with bentonites in the Bay of St. Florian are questionably assigned to the Karpatian (KOLLMANN 1965; EBNER & SACHSENHOFER 1991). Fluvial fan sediments (Sinnersdorf Formation; NEBERT 1985) dominate the Bay of Friedberg-Pinkafeld and are supposed to continue into the Fürstenfeld Subbasin (GOLDBRUNNER 1988).

The strong crustal and subcrustal extension during the Karpatian was accompanied by volcanic activity, which continued until the end of the Early Badenian (HANDLER et al. 2006). Eruptions of acidic to intermediate (mainly latitic) volcanism occurred in the Gnas Subbasin.

EBNER and SACHSENHOFER (1991) speculated about a subduction-related origin of the K-rich subalkaline-alkaline magmas emphasizing the association of K-rich volcanics with areas of intense extensional and strike-slip tectonics during or after subduction processes (SACHSENHOFER 1996). Shallow magma chambers caused a remarkable increase of heat-flow in the vicinity of these huge shield volcanoes, which are nearly completely covered by younger sediments today (EBNER & SACHSENHOFER 1991). Several thermal springs used in a number of spas (e. g., Loipersdorf, Bad Gleichenberg, Bad Radkersburg; ZÖTL & GOLDBRUNNER 1993) are associated with the elevated geothermal gradient.

Weathered volcanic ash layers in fossil-free or -poor areas were linked in earlier papers with this volcanism, which was considered active up to the Badenian. New geochronological data offer a more complex view and indicate that tuffs/bentonites have a much longer range (Ottnangian to Pannonian?) and are not necessarily related with the "Gleichenberg Volcanism" (EBNER 1981; EBNER et al. 2000; HANDLER et al. 2005, 2006).

At the end of the Karpatian, tectonic movements increased and caused block rotations ("Styrian tectonic Phase"; cf. Stop 10) associated with erosion and unconformities (Wagna, Retznei, Katzengraben/Spielfeld).
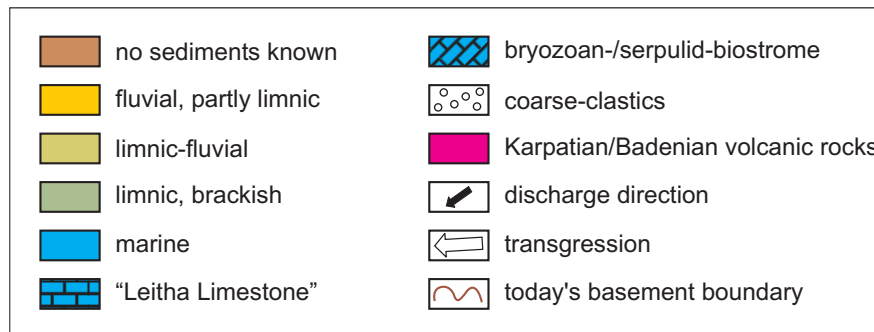
Ottnangian

Hartberg

Gleisdorf

Graz

Feldbach

Leibnitz

Bad Radkersburg

a

Karpatian

Hartberg

Gleisdorf

Graz

Feldbach

Leibnitz

Bad Radkersburg

b

▬ no sediments known		▨ bryozoan-/serpulid-biostrome	
▬ fluvial, partly limnic		▨ coarse-clastics	
▬ limnic-fluvial		▬ Karpatian/Badenian volcanic rocks	
▬ limnic, brackish		◥ discharge direction	
▬ marine		⇦ transgression	
▨ "Leitha Limestone"		∿ today's basement boundary	

Fig. 5: Facies maps for the Lower Miocene of the Styrian Basin (Legend above).
a) Ottnangian. b) Karpatian.
Abb. 5: Fazieskarten für das Unter-Miozän des Steirischen Beckens (Legende oberhalb).
a) Ottnangium. b) Karpatium.

A distinct hiatus is also observed in the Vienna Basin and the Molasse Zone (RÖGL et al. 2002) and is linked with the interplay of the "Styrian Phase" and a global sea level fall at the Early/Middle Miocene boundary (HUDACKOVA et al. 2000; KOVAC et al. 2004).

2.4. Middle Miocene

2.4.1. Badenian

In the Lower Badenian, marine sediments reached its largest extent despite reduced subsidence (post-rift phase). This was connected with a eustatic sea level rise (FRIEBE 1990; RÖGL 1998; KOVAC et al. 2004). A wide marine conjunction across Slovenia enabled the immigration of various tropical/subtropical taxa (HIDEN 1996; HARZHAUSER et al. 2003; BOJAR et al. 2004). Biostratigraphic subdivision traditionally follows the foraminiferan ecostratigraphy of the Vienna Basin (Lagenidae, *Spiroplectammina*, *Bulimina/Bolivina* Zone). Volcanism shifted to the north (Ilz-Walkersdorf), but also in the area of the Middle Styrian Swell eruptions took place (Weitendorf).

While marine sedimentation with pelitic, sometimes turbiditic rocks prevailed in the central Eastern Styrian Basin, thick conglomerates were brought in by fan-deltas in the northern Fürstenfeld Subbasin. Marin-deltaic environments with paralic coals and corallinacean limestones were established in the NE of the basin (Bay of Friedberg-Pinkafeld, Tauchen Formation; NEBERT 1985; Fig. 6a).

Around basement highs (Middle Styrian Swell, shield volcanoes, South Burgenland Swell) variegated corallinacean-coral patch reefs and rhodolith-platforms ("Leitha Limestone"; STEININGER & PAPP 1978; DULLO 1983) developed.

Lower Badenian

Hartberg

Graz

Gleisdorf

Feldbach

Leibnitz

Bad Radkersburg

a

Lower Sarmatian

Hartberg

Gleisdorf

Graz

Feldbach
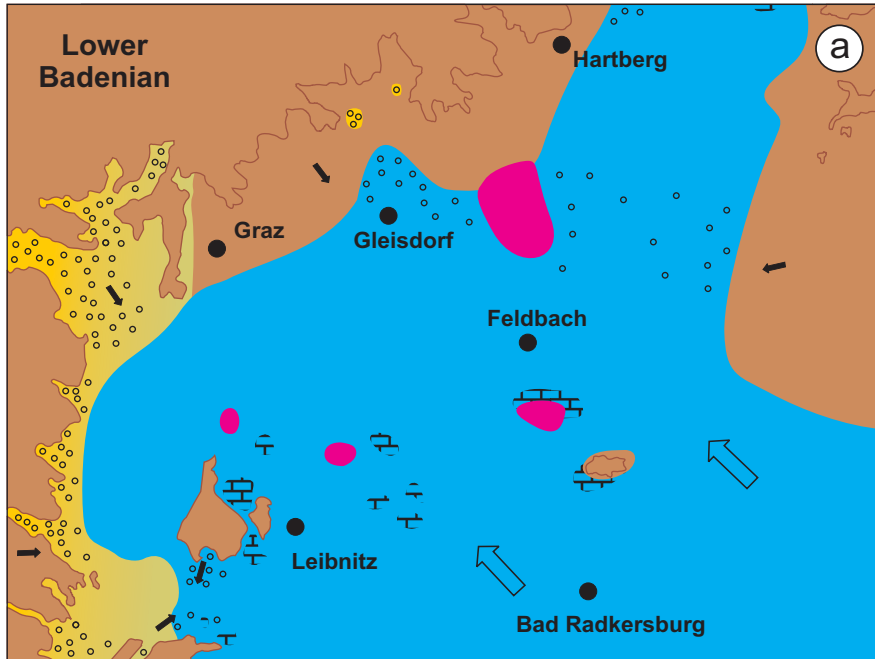
Leibnitz

Bad Radkersburg

b

Fig. 6: Facies maps for the Middle Miocene of the Styrian Basin (legend cf. Fig. 5).
a) Badenian. b) Sarmatian.
Abb. 6: Fazieskarten für das Mittel-Miozän des Steirischen Beckens (Legende vgl. Abb. 5).
a) Badenium. b) Sarmatium.

These carbonate rocks and the associated shallow marine siliciclastics are integrated in the Weissenegg Formation (FRIEBE 1990) and interfinger with coarse-clastic, deltaic deposits of the Ottenberg Member (Kreuzberg Formation). Since Roman times these *"Lithothamnium* Limestones" have been used as building stones or for cement production. Impressive quarries like Weissenegg and Retznei (cf. Stop 8), but also the subsurface "Roman Quarry" near Aflenz (cf. Stop 9) document the economic importance of this formation.

Lagoonal deposits dominate the Bay of St. Florian in the Western Styrian Basin ("Beds of St. Florian"), which are well known for a long time because of their rich mollusc fauna (e.g., ROLLE 1855; HILBER 1878). According to geochronological data the coal-bearing "Middle and Upper Eibiswald Beds" belong to the Early Badenian (HANDLER et al. 2005, 2006) and document the transition from the lagoon of St. Florian to the limnic-fluvial Bay of Eibiswald (HIDEN & STINGL 1998; GRUBER et al. 2003). Coarse castics ("Schwanberg Beds"; NEBERT 1989) at the western margin of the basin point to the uplift of the basement.

In the Bay of Stallhofen, the Lower Badenian limnic-fluvial Stallhofen Formation (EBNER & STINGL 1998; EBNER et al. 2000) with coarse-clastic (Eckwirt Member) and tuffitic intercalations (Lobmingberg Member) overly discordantly Lower Miocene deposits of the Köflach-Voitsberg Formation.

Most probably, the "Eckwirt Gravels" (FLÜGEL 1959) with typically weathered crystalline pebbles and "exotic" components (e.g., Eocene pebbles) are not only restricted to the Lower Badenian. They are supposed to be a heterochronous alluvial sediment (Badenian to Pannonian?) like the "Eggenberg Breccia", a talus deposit, possibly ranging from the Karpatian to the Badenian (FLÜGEL, 1975).

Lacustrine, pelitic to sandy rocks with coal seams and sometimes gastropod-bearing freshwater limestones at the northwestern margin ("Beds of Rein") are assigned to the Lower Badenian mainly according to the traditional "tephrastratigraphy" (EBNER & GRÄF 1979; HIDEN & ROTTENMANNER 2007).

Sea level fluctuations and diverging subsidence led to complex facies shifts in Badenian times (FRIEBE 1990). A compilation of all data, as recently achieved for the Vienna Basin (KOVAC et al. 2004), is still missing.

A regression at the Badenian/Sarmatian boundary corresponds with a global sea level fall (HARZHAUSER & PILLER 2004a, b) and caused erosion and the progradation of fluvial ("Eckwirt Gravels") and deltaic systems (Dillach Member of the Weissenegg Formation; FRIEBE 1990).

2.4.2. Sarmatian

The nearly complete isolation of the Paratethys from the Mediterranean and Indopacific (RÖGL 2001) caused serious environmental changes, which have been reviewed critically in the last years. The disappearance of euhaline taxa (e. g., radiolaria, planktonic foraminifera, corals, echinoids; RÖGL 1998) was regarded as indicative for reduced (brackish) salinity for a long time (PAPP 1956). HARZHAUSER & PILLER (2004a, b), however, provided palaeontological and microfacial evidence for fully marine, sometimes even hypersaline environments (PILLER & HARZHAUSER 2005). Furthermore, these authors evaluated the lithostratigraphy and provided a detailed sequence-stratigraphic scheme. Biostratigraphy follows that of the Vienna Basin based on foraminifera and molluscs (PAPP 1956).

After the sea level lowstand at the Badenian/Sarmatian boundary pelitic, *Mohrensternia*-bearing sediments were deposited at the basin margin in a polyhaline environment ("Waldhof Beds", Rollsdorf Formation). Overall normal marine conditions prevailed as indicated by bryozoan-serpulid-biostromes in the Bay of Friedberg-Pinkafeld (Grafenberg Formation) or close to the South Burgenland Swell (Klapping/St. Anna; Fig. 6b; cf. Stop 5). A regression at the top of the Lower Sarmatian initiated erosion and progradation of the "Carinthian Gravel" (WINKLER 1927a; SKALA 1967).

Upper Sarmatian, mixed siliciclastic-carbonate alternations give hints to repeatedly oscillating sea level and are subsumed in the Gleisdorf Formation (FRIEBE 1994). Within this formation the Waltra Member comprises cyclic successions of silts, sands and oolites (basal Upper Sarmatian) and the superimposed Löffelbach Member is predominately composed of marly limestones. Shallow, high-energetic, carbonate supersaturated, normal marine to hypersaline conditions within a subtropical environment are supposed for these sequences. This is indicated beyond the microfacies (oolites, cements) by foraminifera and gastropod faunas and by geochemical investigations too (PILLER & HARZHAUSER 2005).

Alluvial fan sediments (basal parts of the "Puch Gravels") and limnic-fluvial, partly coal-bearing deposits in the Bay of Weiz ("Lower coal-bearing Beds of Weiz") and north of Graz are assigned doubtfully to the Upper Sarmatian (FLÜGEL 1975; MOSER 1986; KRAINER 1987a; GROSS et al. 2007; cf. Stop 12).

2.5. Upper Miocene

2.5.1. Pannonian

An extensive regression at the Sarmatian/Pannonian boundary, which seems to be linked with a global sea-level fall, caused widespread erosion and the isolation of the Central from the Eastern Paratethys. This gave birth to the "Lake Pannon" (KAZMER 1990; MAGYAR et al. 1999; RÖGL 1999; SACCHI & HORVATH 2002; KOSI et al. 2003; HARZHAUSER et al. 2004).

Marine faunas vanished and some endemic taxa of molluscs (Dreissenidae, Lymnocardiidae) and ostracods (Cytherideidae, Hemicytheridae) evolved, which are used for a biostratigraphic zonation (Papp 1951; Kollmann 1960; Daxner-Höck 1996; Gross 2000, 2004).

A few hundreds of metres of Lower Pannonian sediments form the bulk of the exposed rocks in the Eastern Styrian Basin. Coarse clastics with some coaly strata ("Mühldorf Gravel", "Lignites of Feldbach", "Sandy bed with *Melanopsis impressa*"; Stiny 1918; Winkler 1927c; Winkler-Hermaden & Rittler 1949) are discordantly superimposed on the Sarmatian deposits. These beds are overlain by limnic-brackish, sometimes fossil-rich pelites (*"Congeria* Marls", "Ostracode Marls"; Eisengraben Member) and limnic-deltaic, pelite-sand-alternations with coal seams (Sieglegg Member) of the Feldbach Formation (Gross 2000, 2003; cf. Stop 3). At the northern basin margin alluvial ("Puch Gravel") and limnic-fluvial sedimentation continued ("Upper coal-bearing bed of Weiz"; Flügel 1975; Krainer 1987a; Fig. 7a).
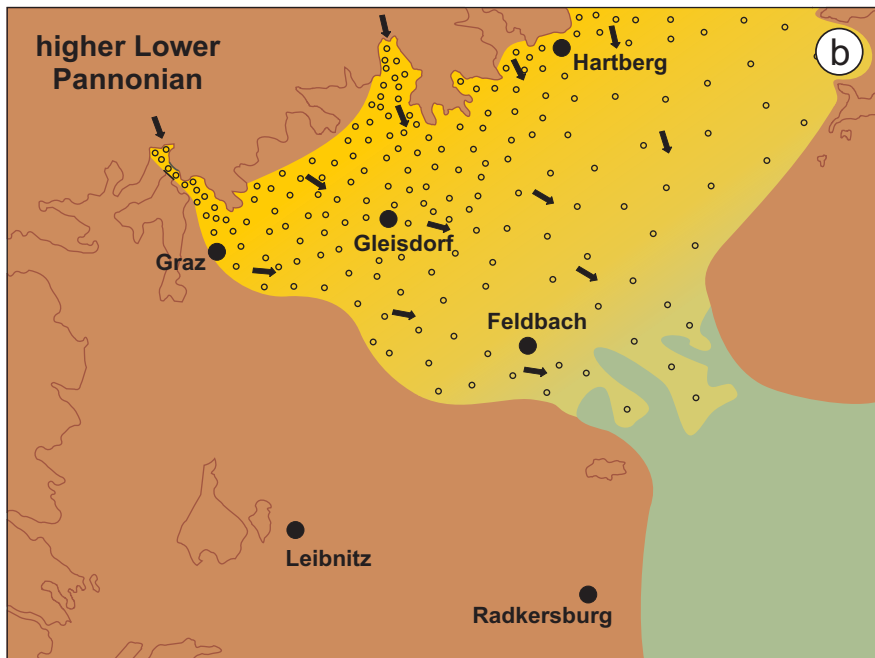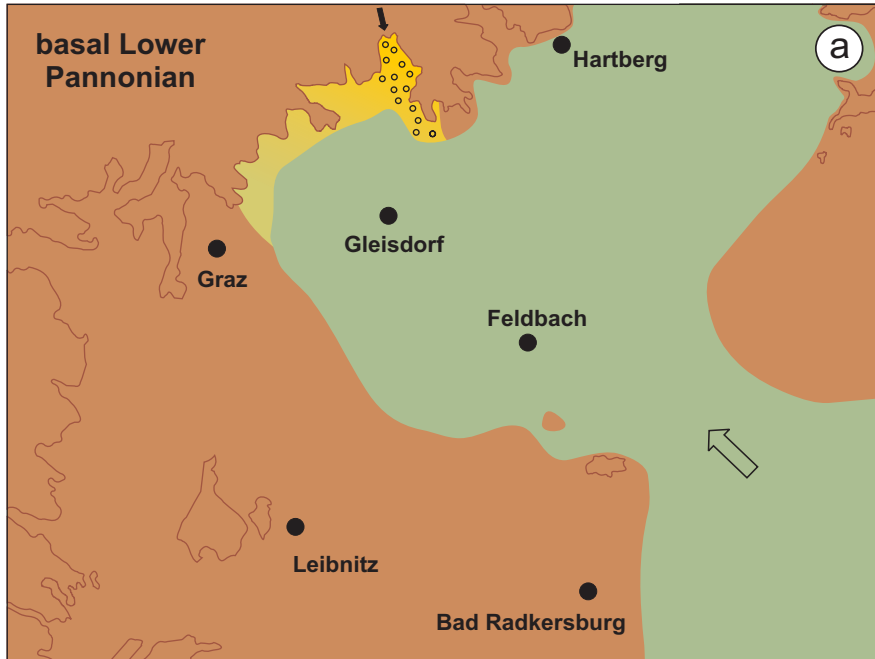
A regression in the upper Lower Pannonian was associated with pronounced erosion and led over to a predominately fluvial sedimentation regime. Alluvial fans developed close to the northern basin margin ("Puch Gravel") and passed into braided and meandering rivers (Paldau Formation) and finally into deltaic environments in the south-eastern Styrian Basin (Winkler 1927c; Krainer 1987a, b; Gross 1998a; Fig. 7b). At least, in the lower and eastern part of the Paldau Formation ostracods, molluscs and a flora, distinctly different from the azonal vegetation of the meandering rivers (Kovar-Eder & Krainer 1990, 1991), indicate a short-term ingression of the Lake Pannon (Gross 1998b, 2000). This is also supported by the interpretation of seismic profiles (Kosi et al. 2003).

In central basin areas, the Paldau Formation can be differentiated into several members resp. parasequences. For their cyclicity increasingly allogene factors (astronomically initiated climate changes) are considered (Kollmann 1965; Juhasz et al. 1997; Harzhauser et al. 2004). Of supra-regional biostratigraphical importance is the occurrence of the three-toed horse *Hippotherium* in the upper part of the Paldau Formation (Karnerberg Member; Mottl 1970).

Middle and Upper Pannonian sediments are restricted to the borderland of Styria and Burgenland in the east. Sometimes coal-bearing alternations of mud, sand and gravel are termed "Beds of Loipersdorf and Unterlamm" resp. "Beds of Stegersbach" and assigned to the Middle Pannonian (Sauerzopf 1952; Kollmann 1965).

Coarse clastics ("Tabor Gravel", "Gravels of the Millstone Quarry") and associated muds and sands ("Beds of Jennersdorf") belong questionably to the Upper Pannonian (Winkler 1927a; Kollmann 1965).

Well-dated, Late Pannonian fissure and cave fillings as well as gastropod-bearing freshwater opals are noticed from the South Burgenland Swell in the area of Eisenberg (Kümel 1957; Bachmayer & Zapfe 1969). These are the youngest Miocene deposits known in the Styrian Basin.

basal Lower Pannonian (a): Graz, Gleisdorf, Hartberg, Feldbach, Leibnitz, Bad Radkersburg

higher Lower Pannonian (b): Graz, Gleisdorf, Hartberg, Feldbach, Leibnitz, Radkersburg

Fig. 7: Facies maps for the Upper Miocene of the Styrian Basin (legend cf. Fig. 5).
a) Basal Lower Pannonian. b) Upper Lower Pannonian.
Abb. 7: Fazieskarten für das Ober-Miozän des Steirischen Beckens (Legende vgl. Abb. 5).
a) Basales Unter-Pannonium. b) Höheres Unter-Pannonium.

Subsequent basin inversion as the result of the major change in stress field – from extension to E–W directed compression (Peresson & Decker 1996) – caused considerable erosion and a hiatus ranging up to the Pliocene.

2.6. Pliocene and Quaternary

Alkali basaltic volcanism was widespread in the Carpathian-Pannonian region from the early Late Miocene up to Middle Pleistocene times (11.5–0.2 Ma), leading to the formation of distinct volcanic fields (Konecny et al. 2004).

Besides the Southern Slovakia Alkali Basalt Volcanic Field (SSABVF; Lexa & Konecny 1998), the Little Hungarian Plain Volcanic Field (LHPVF; Martin & Nemeth 2004) and the Bacony–Balaton Highland Volcanic Field (BBHVF; Martin & Nemeth 2004), there are several volcanic remnants with similar genetic development in the Styrian Basin (Fritz 1996).

The Pliocene–Pleistocene alkali basaltic volcanism seems to be related to an up-welled, then cooled asthenospheric dome (Szabo et al. 1992), formed during the post-orogenic phase. Data from "Styrian" xenoliths suggest that their source was at a depth of 50–80 km within subcrustal lithosphere (Kurat et al. 1980).

Within the Pliocene a basaltic phase of volcanism started in the Styrian Basin, which lasted until the Early Pleistocene (Balogh et al. 1994). Lava flows are partly underlain by "Pre-basaltic Gravels" (Winkler-Hermaden 1957). Beside lava extrusions (Stradner Kogel, Klöch; cf. Stop 6) and intrusions (Steinberg, Stein), phreatomagmatic explosions delivered pyroclastic rocks and formed diatrems, which became filled with fine-clastic maar lake deposits (Burgfeld/Fehring; Pöschl 1991; Fritz 1996; cf. Stops 1-2, 7).

Fluvial gravels ("Post-basaltic Gravels") and residual soils partly cover these volcanic rocks and are interpreted as preglacial deposits. In Quaternary times erosion, terraces, alluvial cones and landslides formed the manifold landscape of today (Winkler-Hermaden 1957; Flügel & Neubauer 1984; Ebner & Sachsenhofer 1991).

3. Excursion stops

Stop 1 – Geotrail Kapfenstein

Topic: Diatrem, pyroclastic rocks, lherzolite xenolithes, geotourism.
Locality: Kapfensteiner Kogel, 15°58'38''E, 46°53'24''N (Figs. 8-10).
Lithostratigraphy: Informal "basaltic tuff/tuffite" (GROSS 2003).
Chronostratigraphy: Pliocene to Lower Pleistocene (BALOGH et al. 1994).

Description: The pyroclastic Kapfensteiner Kogel reaches 461 m in elevation, is formed by inward to the centre dipping pyroclastic beds and surrounded by Pannonian sediments. Chaotic, unsorted pyroclastic rocks with a high content of Neogene sediments form the basis of the southern flank of the hill. Going up the way on the southern side (beneath the castle) the matrix supported rocks become layered and increase gradually in pyroclasts and xenocrysts, embedded in a fine-grained matrix. The pyroclastic succession in the centre of the hill shows well-layered ash tuffs and lapilli tuffs, locally enriched with lherzolite xenoliths ("Olivinbomben").

Fig. 8: Geotrail Kapfenstein.
Abb. 8: Geotrail Kapfenstein.

From an outcrop on top of the hill chaotic sedimentation with a high content of re-deposited pyroclastic rocks and gravel are described. Several outcrops around the flanks of the hill are like windows into the architecture of the volcano and are integrated in a geotrail. Eleven stations inform about volcanism in the Styrian Basin and the volcanic genesis of the Kapfensteiner Kogel (MESSNER & LOITZENBAUER 2001). Figure 9 gives an overview about volcanic remnants in the Styrian Basin.
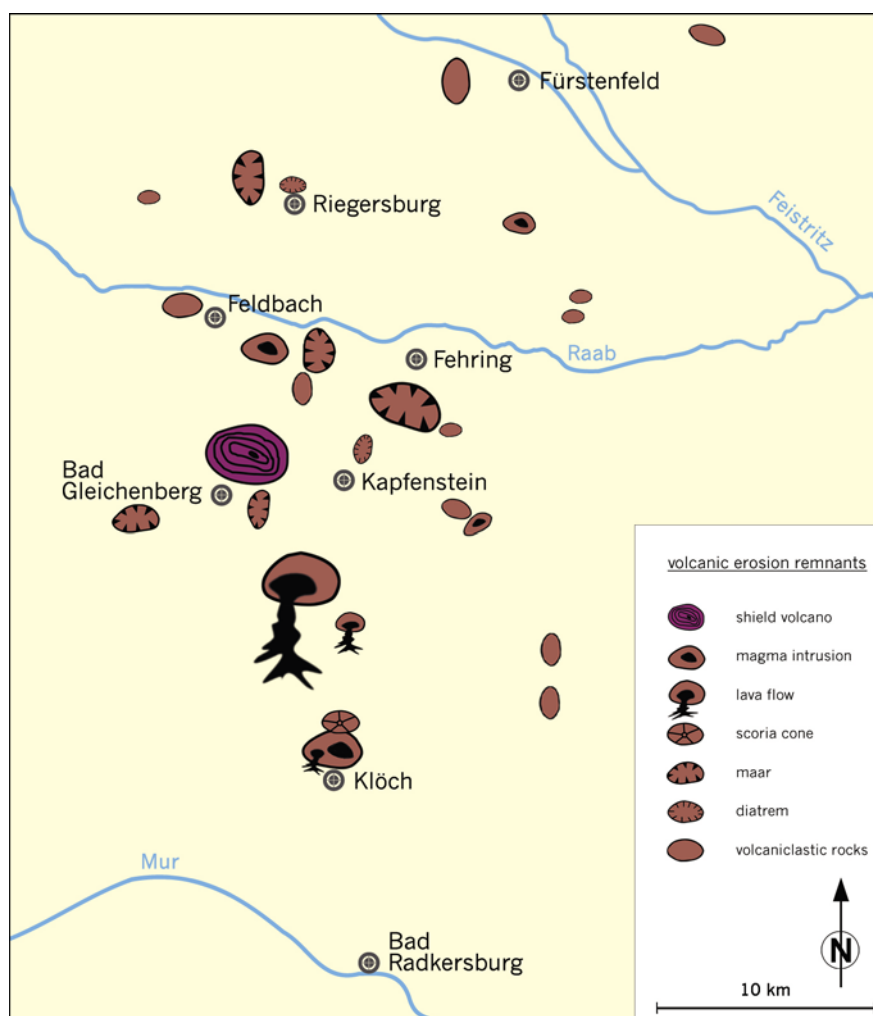

Fig. 9: Volcanic remnants in the "Steirisches Vulkanland".
Abb. 9: Vulkanische Relikte im „Steirisches Vulkanland".

Interpretation: In comparison with the volcanic succession of Riegersburg (Fritz 1996) and similar volcanic remnants in the Southern Slovakia (e.g., Hajnacka, Surice; Konecny et al. 2004) and the Bakony–Balaton Highland in Hungary (e.g., Var-hegy; Martin & Nemeth 2004), the pyroclastic succession of the Kapfensteiner Kogel seems to be an exposed diatrem. The high content of Neogene sedimentary rock fragments in a fine-grained, tuffaceous matrix, represents the initial, phreatomagmatic stage of a maar development. Well-stratified, palagonite tuffs with a changing percentage of basaltic fragments, synvolcanic deformations, alternating surge and pyroclastic fall deposits with impact structures, imply variable mechanisms of eruption in the development stage. The uppermost succession documents a predominantly sedimentary development influenced by erosive processes at the end of the volcanic activity.

The Kapfensteiner Kogel and the surrounding volcanic remnants in the area south of Fehring are famous for the occurrence of lhercolite xenolithes ("Olivinbomben") from the upper mantle (Kurat et al. 1980; Dobosi et al. 1999; Falus et al. 2000).

The community Kapfenstein, situated in the "Steirisches Vulkanland", has a great historical connection to earth sciences because of the famous geologist Winkler-Hermaden, who was the owner of Kapfenstein castle. In 2001 a geotrail was installed and visitors have the possibility to get information about volcanism in the Styrian Basin (Messner & Loitzenbauer 2001). Several projects with geo-scientific content (e.g., info-centre to the regional geology, based on the rock-collection of Winkler-Hermaden) are supported by the community Kapfenstein. The name "Steirisches Vulkanland" is used for the organisation, which is the backbone of the economic and cultural development of this region.

Important references: Heritsch (1915), Winkler-Hermaden (1957, cum lit.), Messner & Loitzenbauer (2001).

Stop 2 – Burgfeld

Topic: Maar lake sediments, pyroclastic rocks, soft-sediment deformation, geophysics.
Locality: Clay pit Burgfeld (owned by the Lias Österreich GesmbH), 2 km S Fehring, 16°00'25"E, 46°55'07"N (Figs. 10-18).
Lithostratigraphy: Informal „basaltic tuff/tuffite" (Gross 2003).
Chronostratigraphy: Pliocene to Lower Pleistocene (Balogh et al. 1994).
Description: There are erosive remnants of a complex maar/tuff ring volcano south of Fehring, which has a diameter of at least 3 km. The volcanic succession passes discordantly the Neogene sediments. Although the maar lake sediments (laminated pelites) have been mined since 1961, there is no detailed geological map available and the genesis of the volcanic area of Fehring is still under discussion.
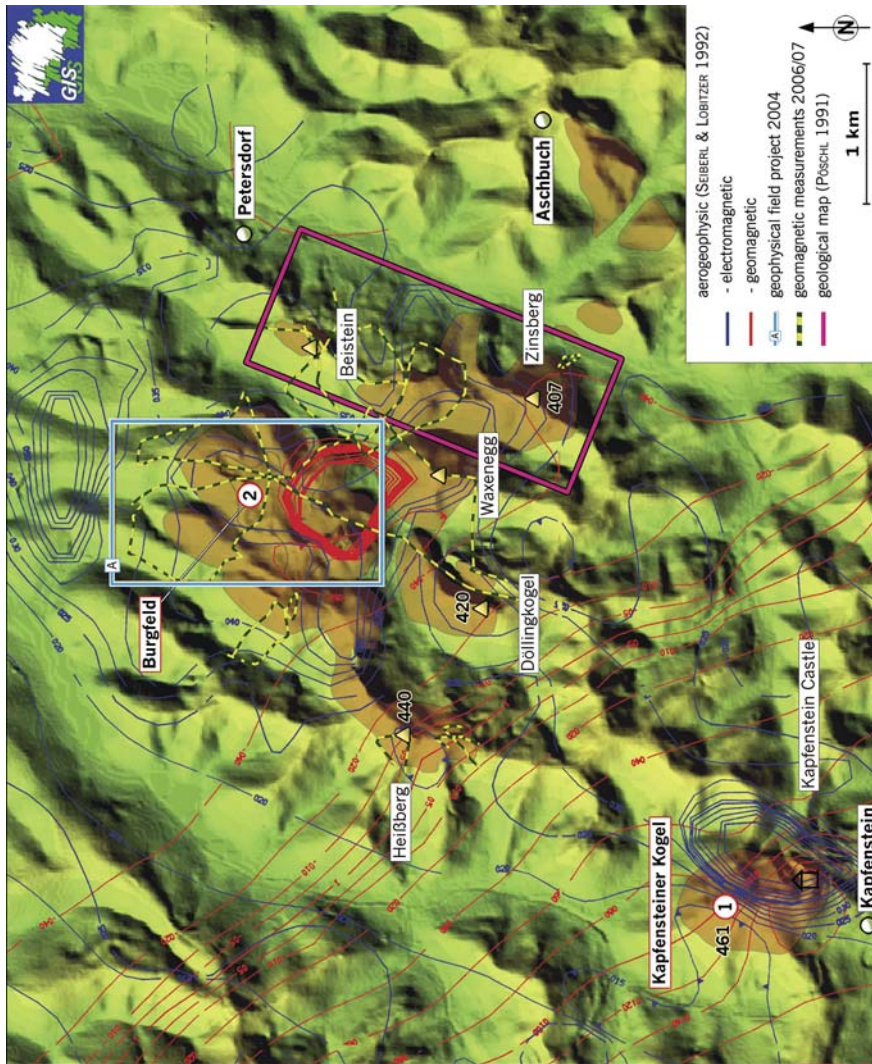
Fig. 10: Digital elevation model of the Fehring-Kapfenstein volcanic area with geophysical results and measurement fields.
Abb. 10: Digitales Höhenmodell des Vulkangebietes von Fehring-Kapfenstein mit geophysikalischen Ergebnissen und Messgebieten.

VINCENZ (1988) described a general profile for the lake sediments in the clay pit, based on exploration drillings and PÖSCHL (1991) created a model for the volcaniclastic succession at Beistein (at the eastern side of the volcanic area; Fig. 10).
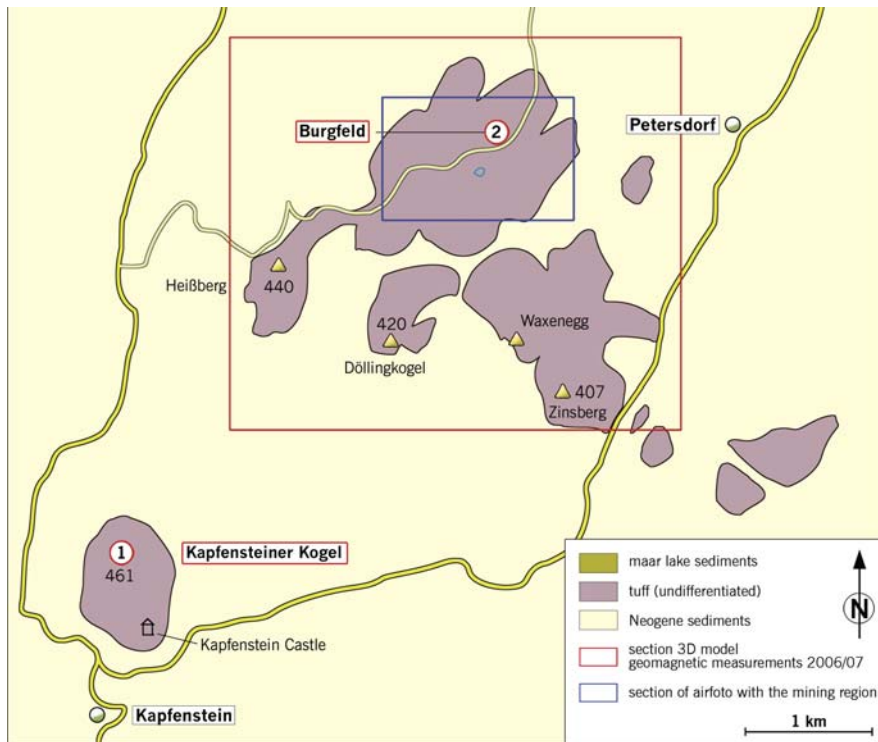
Fig. 11: Simplified geological map (GIS-Steiermark).
Abb. 11: Geologische Karte aus dem GIS-Steiermark.

Several small outcrops, where "tuff-stones" have been quarried for building houses, show ash tuff, lapilli tuff and massive pyroclastic flow deposits. A big abandoned quarry ("Quarry chapel" A1; Figs. 13, 14a) with at least 100 m extension, is located on the north side of the clay pit. Well-layered ash/ lapilli tuffs show ripple marks (Fig. 14b), cross-stratification and are locally cut by channels (Fig. 14d). Small layers with fine-grained sediments (pelites) are intercalated at the hanging of this quarry. Rounded sedimentary blocks, up to 50 cm in diameter, embedded in ash/lapilli tuff, can be seen sporadically (Fig. 14c).

Outcrop A2 and A3 (Figs. 13, 15-16) show laminated pelites with sheets of light mica and thin sand and tuff layers. Small water escape pipes were recognized at the basis of this succession. Scarcely wood remains and ostracods (Candonidae) can be found within the greyish silty clays. The interbedding of silty clay and fine sand is not rhythmic. A high content of flat embedded light mica can be recognized in the whole succession and some sheets with up to 5 mm thickness consist mainly of these minerals. A massive, unsorted bed with about 30–50 cm thickness contains quartz pebbles, angular tuff blocks (sometimes with accretionary lapilli), blocks of poorly consolidated
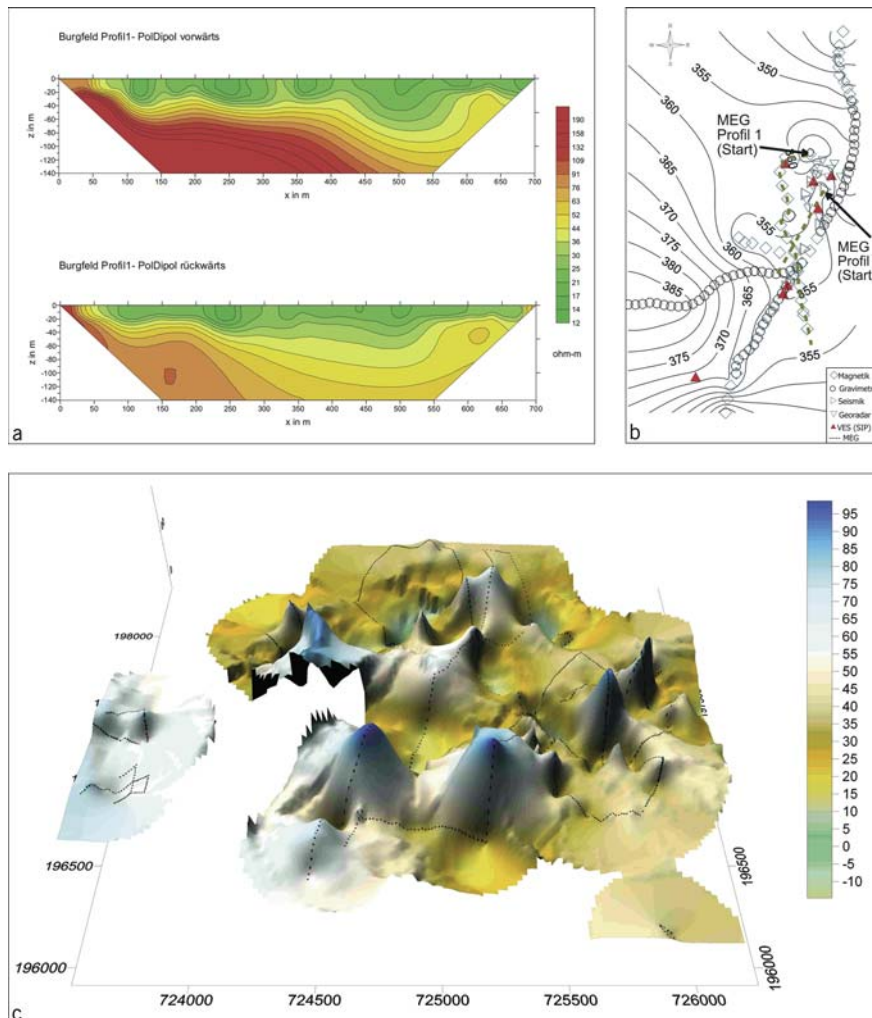
Fig. 12: Overview and results from geophysical measurements in the area of Burgfeld. a) Geo-electrical resistivity measurements. b) Measuring lines 2004 (cf. Fig. 10). c) 3D-plot (cf. Fig. 11).
Abb. 12: Übersicht und Ergebnisse der geophysikalischen Messungen im Raum Burgfeld. a) Geoelektrische Widerstandsprofile. b) Lage der Messlinien 2004 (vgl. Abb. 10). c) 3D-Plot der Geomagnetikmessungen 2006/07 (vgl. Abb. 11).

Neogene sediments and sporadically lherzolite xenoliths ("Olivinbomben") in a fine-grained ground mass. Plant impressions and isolated shell fragments can be found on the upper part of this bed (Figs. 16c-d). It marks the top of the simplified stratigraphic column in outcrop A3 and underlies the section A2. Small (syn-sedimentary?) faults and rotated blocks are thought to be associated with rill-washing erosion.
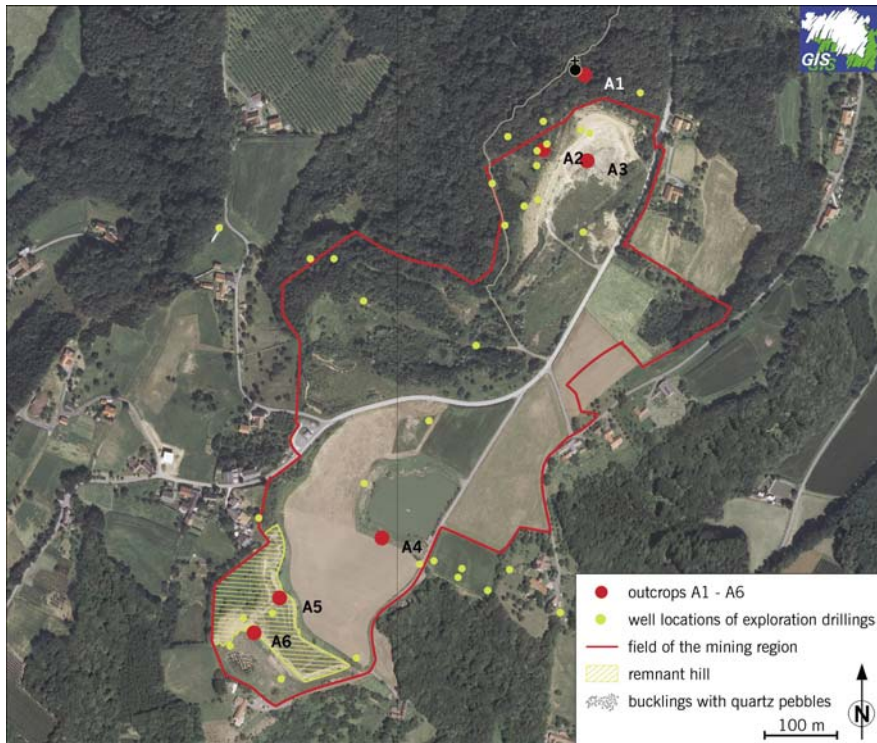
Fig. 13: Airphoto with outcrops in the clay pit Burgfeld.
Abb. 13: Luftbild mit Aufschlüssen in der Tongrube Burgfeld.

A channel with about 8 m exposed length was located in the southern area of the clay pit (Figs. 13, 17) – here is a fishpond today (A4). Rooted floors, wood remains and conifer cones in a massive, chaotic deposition with tuff blocks have been recognized (FRITZ 1996; VINCENZ 1990).

The outcrops A5 and A6 are located at the remnant hill of the southern field in the clay pit (Figs. 13, 18) and show laminated pelites, which are covered from massive layers with a different kind of soft-sediment deformation structures (e.g., load casts, slump overfolds). Sporadic water escape structures can be recognized (Fig. 18b) in plastically deformed, stratified tuff deposits within the slump body. Some sandy layers yielded numerous plant fragments and a poor aquatic mollusc fauna (Lymnaeidae, Planorbidae, Sphaeriidae). The succession is locally covered from reassorted sediments and volcaniclastics (Fig. 18e).

A new geological mapping of the volcanic area of Fehring is in progress and started with geophysical investigations. In 1992 the Geological Survey of Austria performed aerogeophysical measurements in the region of Bad Gleichenberg to verify the mineral resources and to assist regional mapping (SEIBERL & LOBITZER 1992).

Fig. 14: Outcrop A1 ("Quarry chapel"). a) Overview. b) Ripple marks. c) Sedimentary block, embedded in ash/lapilli tuff. d) Channel.
Abb. 14: Aufschluss A1 („Steinbruch Kapelle"). a) Übersicht. b) Rippelmarken. c) Sediment-block, eingebettet in Asche/Lapillituff. d) Rinnenbildung.

Electromagnetic, magnetic and radiometric methods were applied along profiles with 200 m distance. Anomalies with high resistivity values correlate with the Plio-/Pleistocene volcanic remnants and there is a significant maximum especially in Burgfeld (Fig. 10, 12). Electromagnetic measurements seem to be better suitable to discriminate between volcaniclastic rocks and the pre-volcanic sediments than magnetic measurements.

Based on the successful geomagnetic measurements in the volcanic area of Altenmarkt near Riegersburg with a similar maar volcano structure (Fritz 1996) the deployment of ground geophysics in the volcanic area south of Fehring was discussed.

The joint geophysical field project 2004 of the universities MU Leoben and TU Clausthal yielded first ground-geophysical data including gravimetric, magnetic, multielectrode geo-electrical and IP measurements, georadar and refraction seismics of the Burgfeld area (Fig. 12). The investigations aimed at getting new information about the total extension of this geological structure, the position of its centre, and the thickness of the lake sediments. Samples for petrophysical laboratory measurements were taken from the northern part of the clay pit.
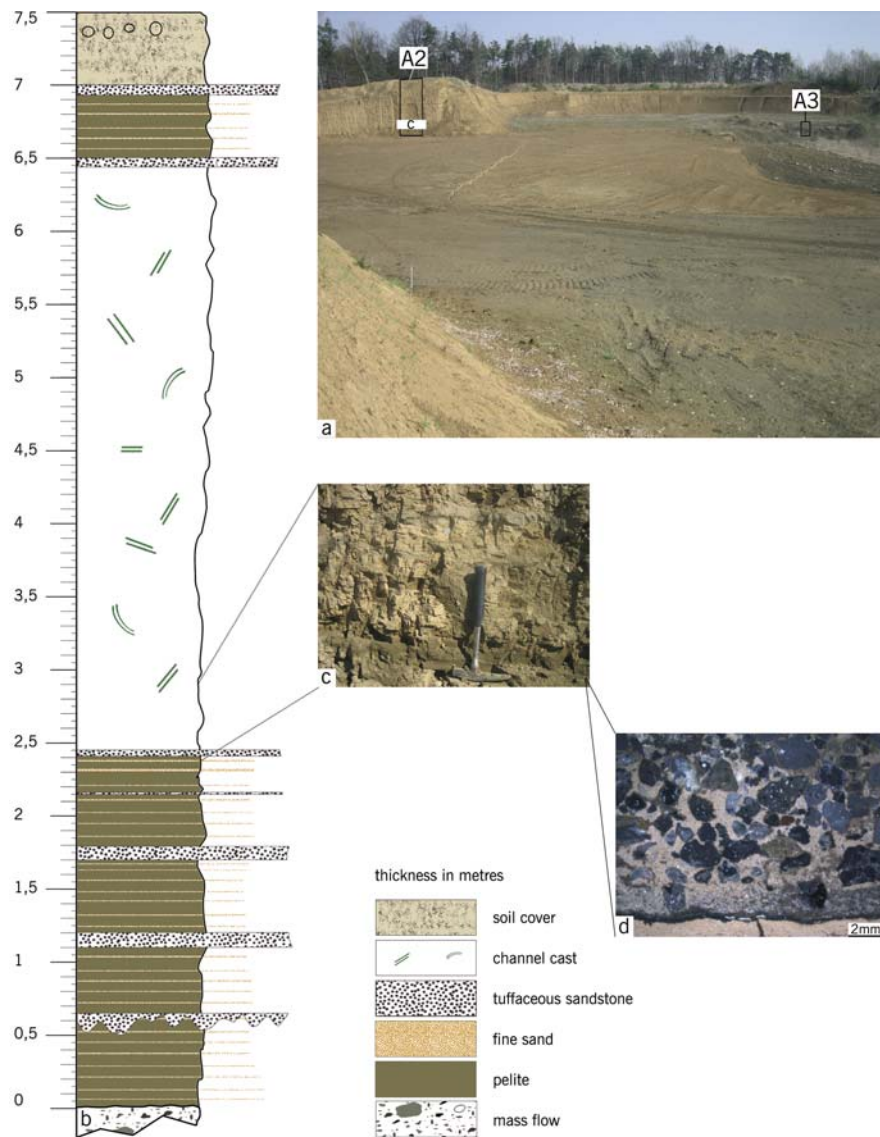
Fig. 15: Section A2 in the clay pit Burgfeld. a) Overview. b) Section. c-d) Details of the section.
Abb. 15: Profil A2 in der Tongrube Burgfeld. a) Übersicht. b) Profil. c-d) Details aus dem Profil.

The gravimetric profiles detected a zone with a positive Bouguer anomaly trend spanning more than 1500 m in N–S projection, probably indicating rocks with higher density (basalt) at depth.

A smaller, local anomaly with negative sign located north of the centre of the main structure could be attributed to a disturbed zone in the central part.

The results of the geo-electrical resistivity measurements (Fig. 12a) indicate a trough-like structure with considerable variation of the resistivity values near the surface. The highest values, which are comparable with the results from laboratory measurements of tuff samples, appeared at the northern end of profile MEG1, at a depth of 10 metres.

Supplementary to the geomagnetic measurements from the project in 2004 in the northern area (clay pit Burgfeld), several profiles with radial orientation were measured in 2006/2007 in the volcanic area of Fehring to place the basaltic feeding dikes (Fig. 10). The volcaniclastics, which are locally rich in Neogene sediments (clays, silts, sands and gravels), show minor differences in their magnetic behaviour compared to the pre-volcanic background. The high content of primarily epiclastic material in individual layers and the comparatively low forming temperature of many pyroclastic layers within the system might be the reasons therefore.

Well-hardened lapilli tuffs, rich in juvenile components with a high content of magnetic minerals (titanomagnetite), which were hot enough during their sedimentation to preserve the direction of magnetization of that time, show more significant results. Because of secondary cementation some layered ash/lapillituffs have a great resistance to weathering.

The 3D-plot (Fig. 12c) shows several positive magnetic peaks situated along a circle surrounding a smaller magnetic maximum in the centre (clay pit Burgfeld) of the whole structure. Completing measurements have to be done in the south-western area to assist the geological interpretation of the volcanic succession and the connection between maar lake sediments in the north and the pyroclastic deposits at Heißberg.

Interpretation: The clay pit Burgfeld represents the remnants of maar lake sediments (WINKLER 1927a; WIEDEN & SCHMIDT 1956). The laminated pelites are underlain by several metres thick, gravelly, coarse sands with lherzolite xenoliths. Horizontal bedding of the laminated pelites with great extension documents a continuous, quiet development. The massive bed, which can be observed in a great area, too, might be deposited by a pyroclastic surge. Rough edged quartz pebbles, some of them are brittle, angular lapilli tuff fragments as clasts, "fresh", angular lherzolite xenoliths and irregular formed blocks of Neogene sediment indicate dynamic source aspects. Small tuffaceous layers with blocky shaped, slightly vesicular glass shards, hosted in a quartz-rich matrix and impact structures prove fall deposits (Fig. 15d).

A tuff layer, with rounded lapilli from the uppermost outcrop (A2), indicate some degree of reworking and remobilisation of tephra.Indications to phreatomagmatic and sedimentary processes can be recognized in the succession of the old quarry (A1). It represents the northern marginal facies of the maar lake. PÖSCHL (1991) made a schematic model for the volcaniclastic succession and the assumed maar-environment of this volcanic area.

thickness in centimetres

pelite

fine sand

light mica

mass flow
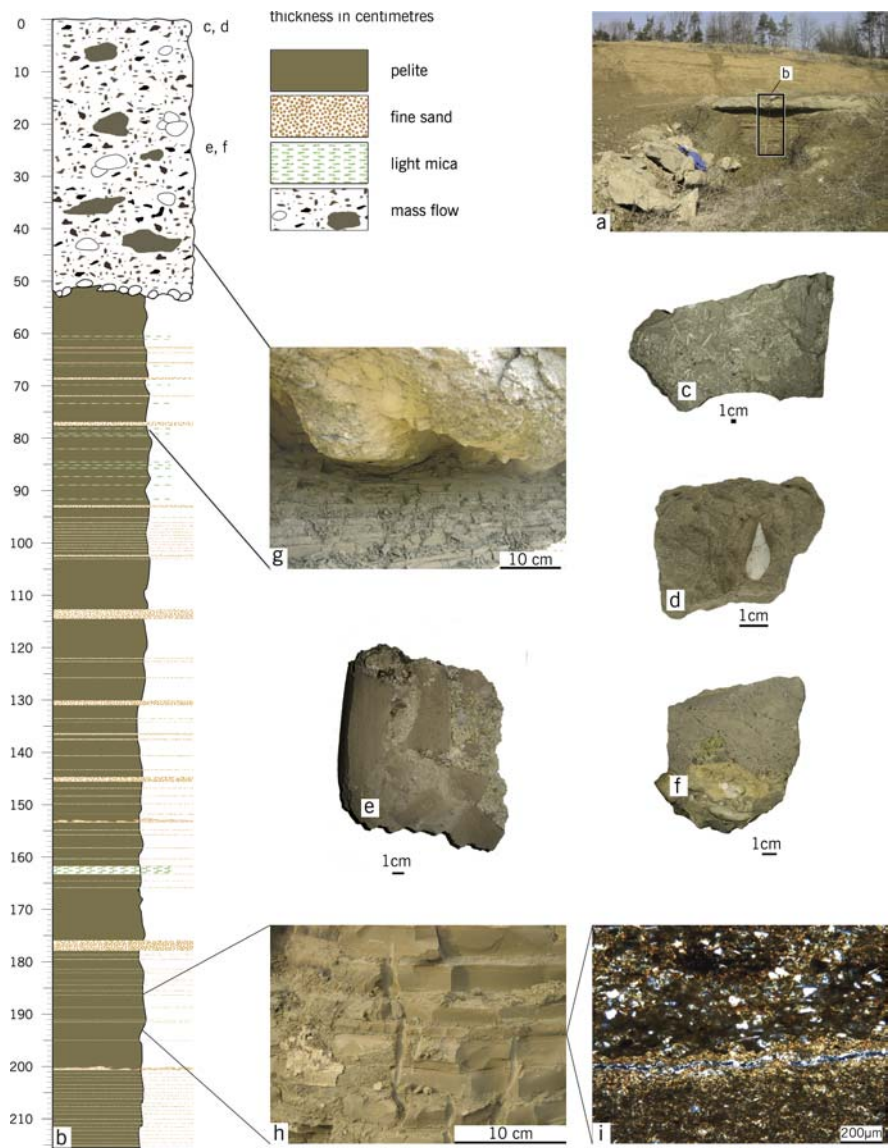
New geophysical data indicate a ring structure, including almost all volcanic remnants and a significant disturbing body located in the centre (south of clay pit Burgfeld) of the volcanic area of Fehring. A detailed geological mapping is necessary to understand the relation between phreatomagmatic deposits from the surrounding elevations.

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Fig. 16: Outcrop A3. a) Overview. b) Section. c) Zeolitic preserved plant remains. d) Freshwater gastropod. e) Angular tuff blocks in a fine-grained matrix. f) Lherzolite xenoliths and brittle quartz-pebbles. g) Load casts. h) Detail of section A3. i) Thin section of graded pelites.
Abb. 16: Aufschluss A3. a) Übersicht. b) Profil. c) Zeolitisch erhaltene Pflanzenreste. d) Süßwasser-Gastropode. e) Kantige Tuffblöcke in feinkörniger Matrix. f) „Olivinbomben" und spröde Quarzgerölle. g) Belastungsmarken. h) Detail von Profil A3. Pelit-Feinsand-Wechsellagerung. i) Dünnschliff, Übergang von zwei gradierten Pelitlagen.
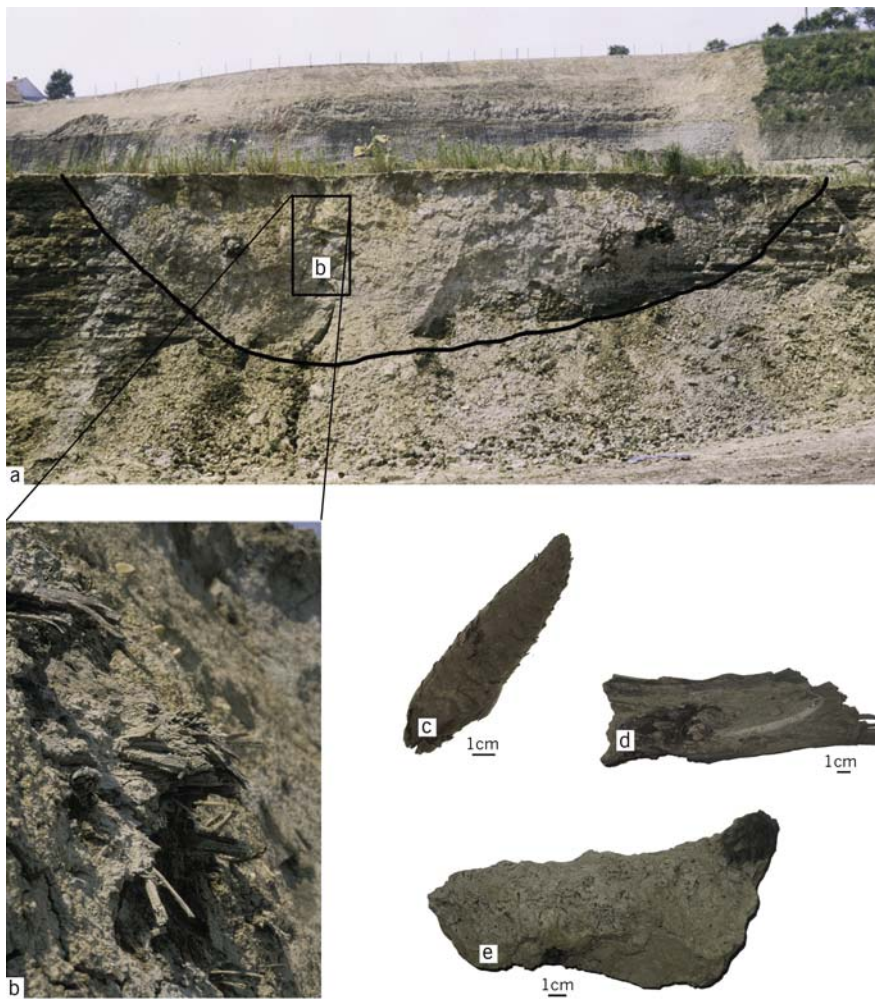
Fig. 17: a) Outcrop A4 in the clay pit Burgfeld with channel structure. b) Detail with wood remains. c) Cone. d) Splittered wood fragment. e) Conifer needles.
Abb. 17: a) Aufschluss A4 in der Tongrube Burgfeld mit Rinnenstruktur. b) Detail mit Holzresten. c) Zapfen. d) Zersplittertes Holzfragment. e) Koniferennadeln.
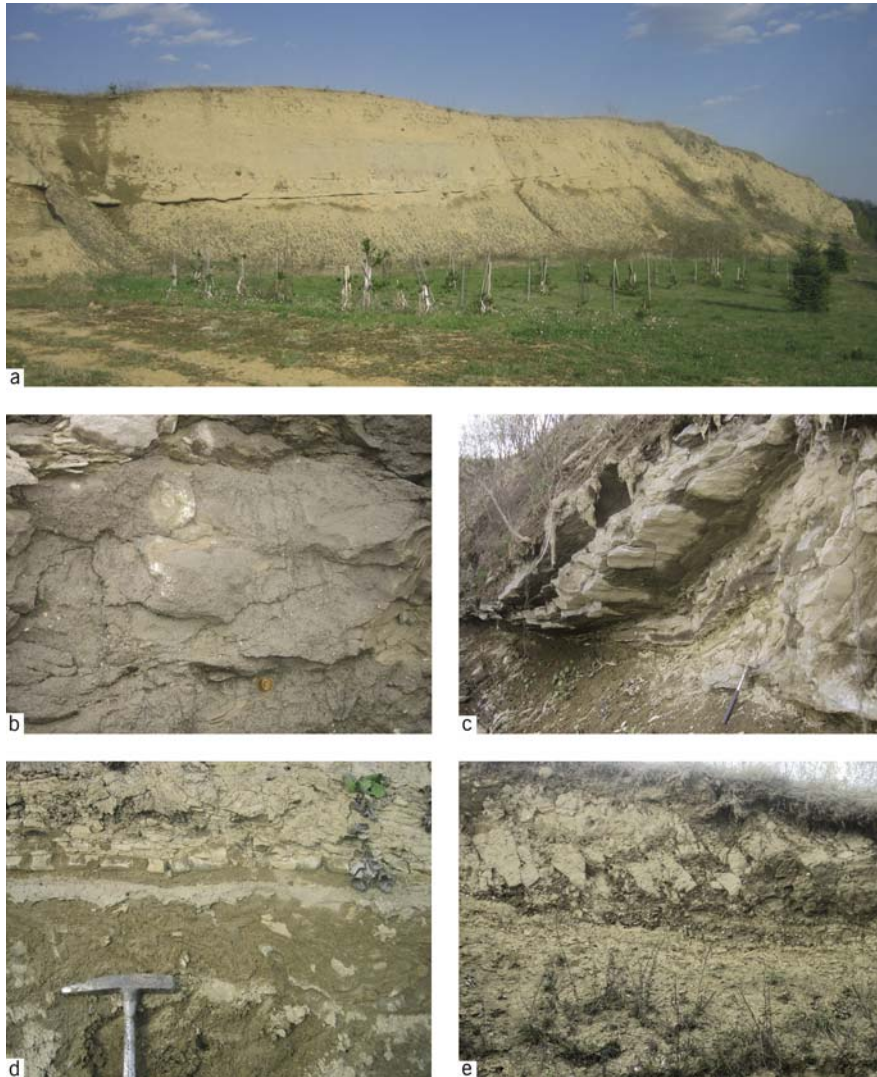
Fig. 18: Outcrops A5, A6 in the southern part of the clay pit. a) View towards NE, remnant hill. b) Water escape structures. c-d) Load casts and slump folds. e) Reassorted sediments and volcaniclastics.

Abb. 18: Aufschlüsse A5, A6 im Südteil der Tongrube. a) Blick nach NE, Restpfeiler. b) Entwässerungsstrukturen. c-d) Belastungsmarken und Rutschfalten. e) Umgelagerte Sedimente und Vulkaniklastika.

The maar lake sediments with intercalated volcaniclastic layers and the supposed post-volcanic mass movements, which seem to have happened when erosion started and creeks began to incise. The relation of the volcanoes of Riegersburg (diatrem) to Altenmarkt (maar; FRITZ 2006) looks similar to the one of Kapfenstein (diatrem) to Fehring (maar). They might have had comparable developments too.

These maar lake sediments are mixed with Lower Pannonian clays from Mataschen and loams from the overlay of the "Basalts of Klöch" and processed into foam-clay products (Leca = light expanded clay aggregate). Ceramic sintered surface and porous internal structure make Leca to a useful building material with low specific weight, high noise absorption and good heath insulation.

Despite extensive mineralogical and granulometirical investigations the applicability of the raw material is detected empirically up to now (WIEDEN & SCHMIDT 1956; BERTOLDI et al. 1983; VINCENZ 1990).

Important references: WINKLER (1927a), BERTOLDI et al. (1983), PÖSCHL (1991), FRITZ (1996).

Stop 3 – Clay Pit Mataschen near Kapfenstein

Topic: Limnic-deltaic sediments of the Lower Pannonian (Fig. 19).
Locality: Clay pit Mataschen (owned by the Lias Österreich Gmbh; "New" and "Old pit"), 5.3 km SW Fehring, 15°57'29''E, 46°54'17''N.
Lithostratigraphy: Feldbach Formation (Eisengraben and Sieglegg Member).
Chrono-/Biostratigraphy: Lower Pannonian (*Mytilopsis ornithopsis/Melanopsis impressa* Zone).

Description: The exposed strata start up with >1.5 m thick sands and silts, which are overlain by 0.2–0.3 m of coal-rich muds with plant and vertebrate remains (beavers, dwarf hamster, pond turtles). This bed forms the base of up to 4 m high, autochthonous stubs – most probably of *Glyptostrobus*. Above follows a 0.3–0.4 m thick horizon with accumulations of the dreissenid bivalve *Mytilopsis neumayri*. This coquina is overlain by 4 m of muddy sediments with concretionary layers, where the amount of *M. neumayri* and plant fragments decreases successively. Numerous shells of lymnocardiids, rare fragments of the biostratigraphically important *Mytilopsis ornithopsis*, some vertebras of the giant salamander *Andrias scheuchzeri* and remains of fishes (e.g., porgies, croakers) can be found beside rich micro- and nannofossil assemblages in the superimposed clays. Two, up to 0.2 m thick sandy layers are intercalated near the top of this muddy unit.
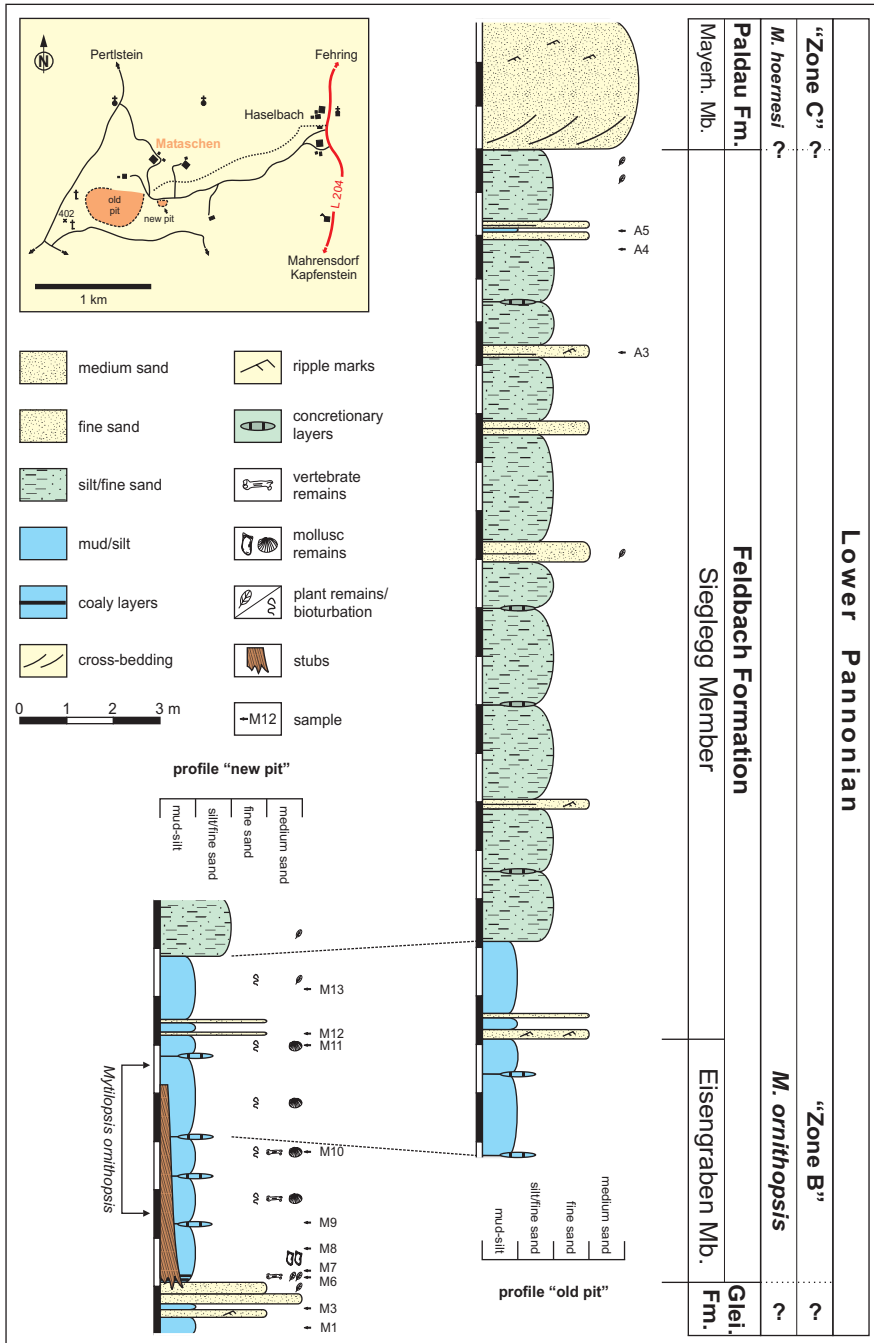
Fig. 19: Clay pit Mataschen ("Old pit").
Abb. 19: Tongrube Mataschen („Alte Grube").

The hanging sediments of the pit consist of approximately 17 m thick sandy pelite- and fine sand-alternations, which display an overall coarsening upward trend. A silty to sandy horizon in the uppermost part yielded a remarkable fossil flora and is topped by >3 m thick large-scale cross-bedded sands (Fig. 20).

Interpretation: After deposition of sandy sediments in a fluvial-limnic setting (base of the site) the water level of the Lake Pannon rose and plant-rich mud was deposited in a swampy area at the lake margin. Ostracods (*Cyprinotus* sp.; Fig. 21) and the giant salamander *Andrias* give hints at a subtropical, overall mainly frost-free climate. While at the beginning freshwater conditions prevailed (layers with *M. neumayri*), the swamp drowned rapidly afterwards and salinity increased up to brackish waters as registered by ostracods, dinoflagellates, calcareous nannoplankton and geochemical analyses (Eisengraben Member). Pronounced terrigenous and freshwater influx in the overlying, generally coarsening upward section led over to the next regressive phase and the pro-gradation of deltaic sediments towards the top (Sieglegg Member).

Fig. 20: Summarized section of the clay pit Mataschen and stratigraphy.
Abb. 20: Sammelprofil der Tongrube Mataschen und Stratigraphie.

This is a stratigraphic/geological figure containing the following labels:

Map area:
Pertlstein, Fehring, Haselbach, Mataschen, old pit, new pit, 402, 1 km, L 204, Mahrensdorf, Kapfenstein

Legend:
medium sand, fine sand, silt/fine sand, mud/silt, coaly layers, cross-bedding, ripple marks, concretionary layers, vertebrate remains, mollusc remains, plant remains/bioturbation, stubs, M12 sample

0 1 2 3 m

profile "new pit":
mud-silt, silt/fine sand, fine sand, medium sand
Mytilopsis ornithopsis
M13, M12, M11, M10, M9, M8, M7, M6, M3, M1

profile "old pit":
mud-silt, silt/fine sand, fine sand, medium sand

Right-hand stratigraphic column:
Lower Pannonian

"Zone C"? — M. hoernesi ? — Paldau Fm. / Mayerh. Mb.

Feldbach Formation / Sieglegg Member

"Zone B" — M. ornithopsis — Eisengraben Mb.
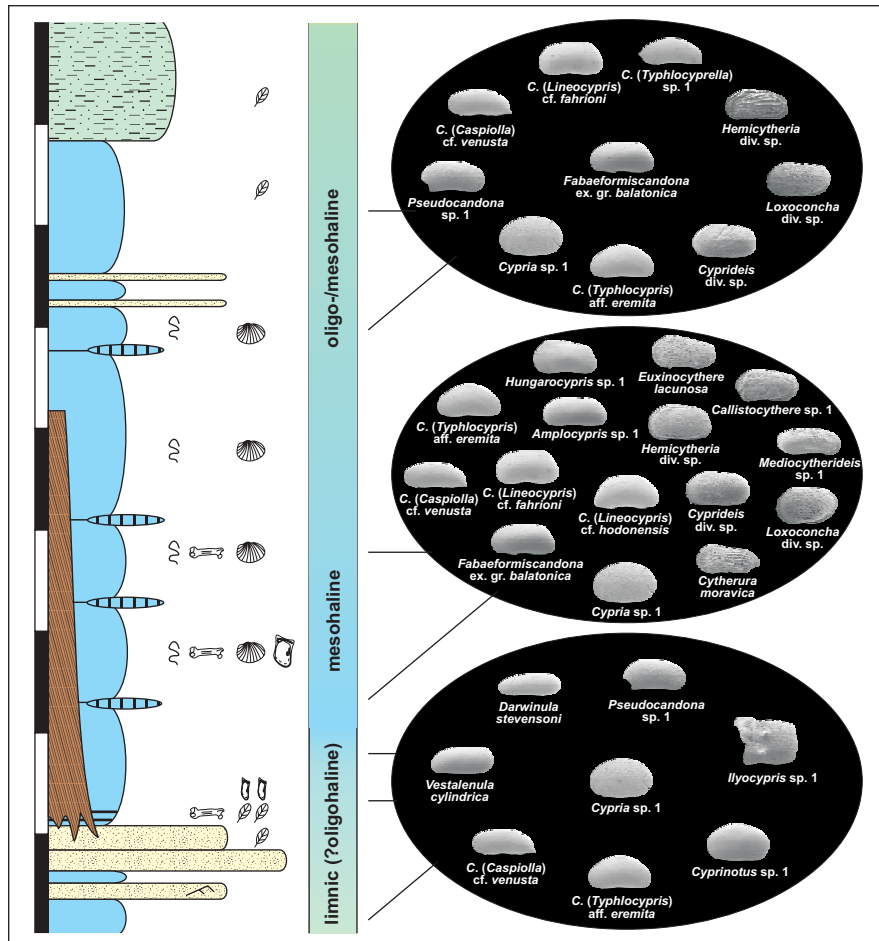
Glei. Fm. ?

A5, A4, A3

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Fig. 21: Section of the "New pit" Mataschen and schematic illustration of the ostracod fauna.
Abb. 21: Profil der "Neuen Tongrube" Mataschen und schematische Darstellung der Ostracoden-fauna.

The leaf-flora just below the deltaic sands at the top of the pit with an unusually high content of evergreen elements points to a humid warm-temperate to subtropical environment.

Important references: DRAXLER et al. (1994), GROSS (2003, 2004, 2006).

Stop 4 – Quarry Sotina and Leinergraben

Topic: Paleozoic basement, Southern Burgenland Swell and overview of the subsurface geology of the Styrian Basin (cf. Fig. 4).
Locality: "Schist Quarry Sotina", 3 km SE Kalch, 16°01'33"E, 46°49'55"N and Leinergraben (Fig. 22).
Lithostratigraphy: Blumau Formation (?).
Chronostratigraphy: Upper Silurian to Lower Devonian (FLÜGEL 1988).

Description: Green schist metamorphic pelites, basaltic volcanic rocks (metatuffs) and some banded carbonates are united to a pool of rocks (Fig. 23) that crop out at St. Anna am Aigen (southern Styria), Kalch, and Rotterberg/Stadelberg in southern Burgenland and northern Slovenia. Their assignment either to the Sausal Group (FLÜGEL 1988) or to the Blumau Formation (herein) is ambiguous (cf. 2.2).

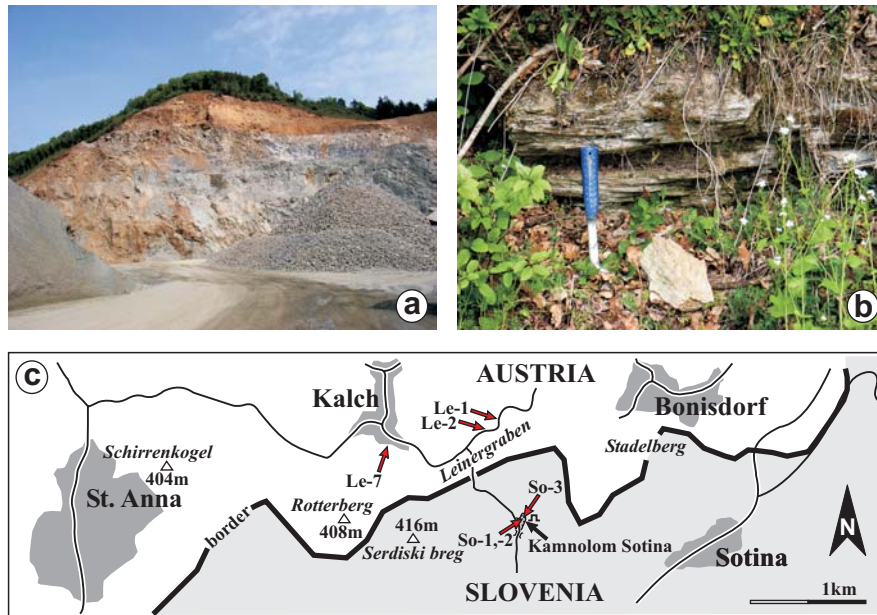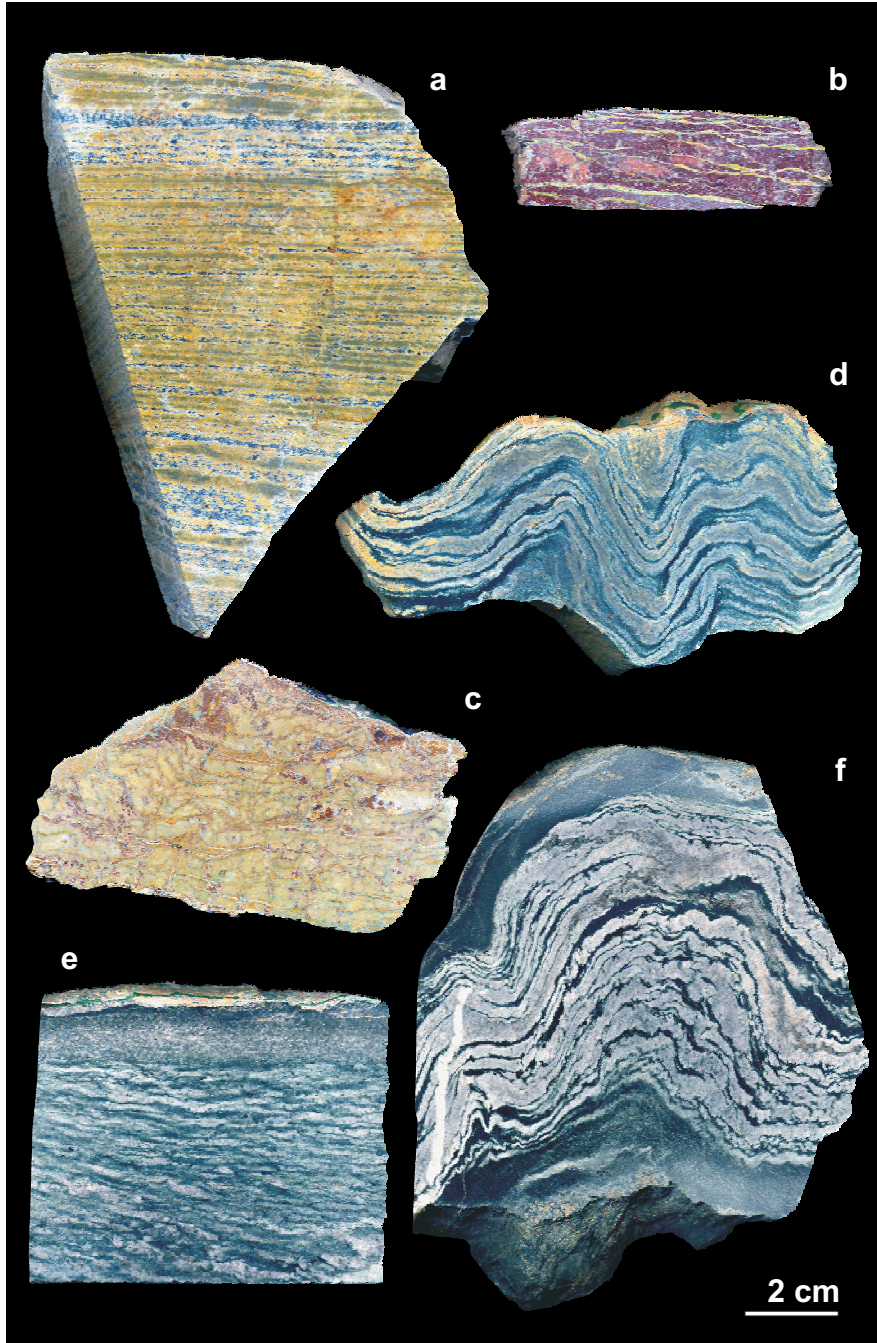Important references: WINKLER (1927a), FLÜGEL (1988).

Fig. 22: a) Quarry Sotina (= Kamnolom Sotina). b) Outcrop near the road Leinergraben (sample Le-1). c) Detailed map with sampling locations indicated.
Abb. 22: a) Steinbruch Sotina (= Kamnolom Sotina). b) Straßenaufschluß im Leinergraben (Probe Le-1). c) Detailkarte mit Probenpunkten.

a b d c f e

2 cm

Fig. 23: a) Banded carbonate with idiomorphous pyrites enriched in schist layers, Le-7, abandoned quarry at Kalch. b) Phyllitic schists, Le-2, Leinergraben. c) Quartzitic phyllites, Le-1, Leinergraben. d) Metatuff, So-1, quarry Sotina. e) Metatuff, So-2, quarry Sotina. f) Metatuff, So-3, quarry Sotina.
Abb. 23: a) Bänderkalk mit idiomorphen Pyriten in dünnen Schieferlagen, Le-7, aufgelassener Steinbruch bei Kalch. b) Phyllitischer Schiefer, Le-2, Leinergraben. c) Quarzitischer Phyllit, Le-1, Leinergraben. d) Metatuff, So-1, Steinbruch Sotina. e) Metatuff, So-2, Steinbruch Sotina. f) Metatuff, So-3, Steinbruch Sotina.

Stop 5 – Quarry Klapping near St. Anna am Aigen

Topic: Marine *Hydroides*/bryozoan bioconstructions of the Lower Sarmatian (Fig. 24).
Locality: Abandoned quarry in the forest close to Klapping south of St. Anna am Aigen in Styria, 15°58'25"E/46°48'44"N.
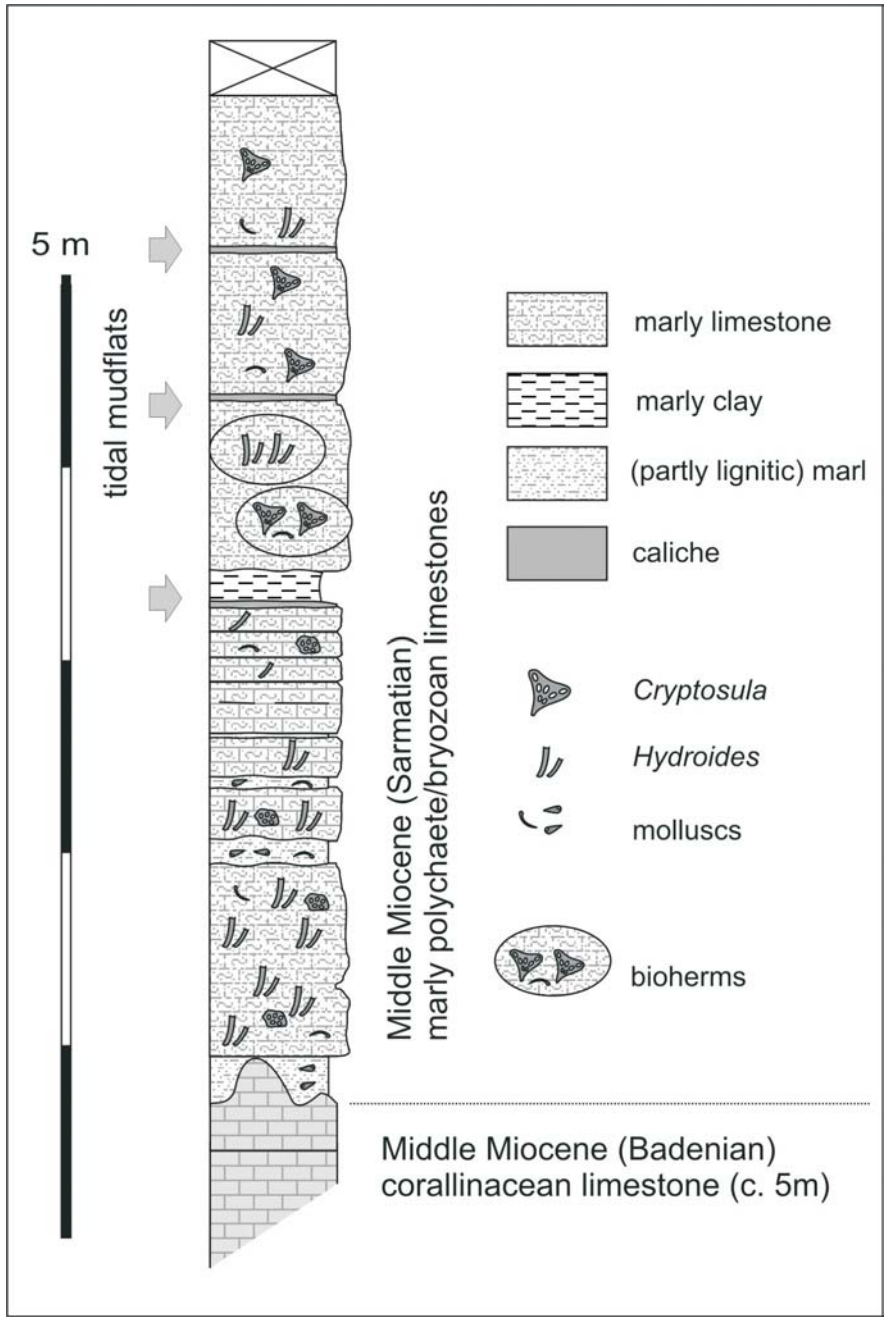Lithostratigraphy: Grafenberg Formation.
Chrono-/Biostratigraphy: Lower Sarmatian (*Elphidium reginum* Zone; *Mohrensternia* Zone).

Description: Badenian corallinacean limestones form the base of the Sarmatian sequence, which represents a part of the Grafenberg Formation. The corallinacean limestones form a humpy palaeorelief, which reaches up to 70 cm height but lacks sharp ridges. Immediately below this discontinuity, *Microcodium* is very abundant.

Above this surface large boulders of the underlying limestone are absent and instead a thin layer of clay with lignite and scattered oysters marks the base of the Sarmatian transgression. Pebbles of 3–4 cm diameter indicate some reworking of the underlying Badenian limestones.

Upsection follow about 3 m, thick-bedded, marly limestone consisting mainly of *Hydroides*, *Cryptosula*, *Schizoporella* and nodular bryozoans (celleporids). This unit is subdivided by few, thin intercalations of clay and marl, which contain pebbles of reworked Sarmatian limestone and scattered, small-sized archaeogastropods (*Gibbula* ssp.). The tops of the limestone beds display a low relief. The carbonatic top bed of the unit is strongly altered, forming a characteristic layer of unstructured white grind. This is overlain by 20 cm clay that can be traced throughout the outcrop. A second, about 2 m thick unit of indistinctly bedded *Hydroides*/bryozoan limestone represents the top of the section.

Two layers of weathered whitish layers of altered limestone divide this unit. Within all limestone beds, *Hydroides*/bryozoan bioconstructions measuring up to 40 cm in diameter and 30 cm in height appear. The irregular growth and succession of such colonies and various small cavities and caverns yield a very bumpy surface, which obscures the bedding.

5 m

tidal mudflats

marly limestone

marly clay

(partly lignitic) marl

caliche

Cryptosula

Hydroides

molluscs

bioherms

Middle Miocene (Sarmatian)
marly polychaete/bryozoan limestones

Middle Miocene (Badenian)
corallinacean limestone (c. 5m)

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Fig. 24: Klapping section close to St. Anna am Aigen, with polychaete/bryozoan bioconstructions which are typical throughout the Central Paratethys during the Early Sarmatian.
Abb. 24: Das Profil von Klapping bei St. Anna am Aigen mit den für die gesamte Zentrale Paratethys typischen Polychaeten-Bryozoen-Biokonstruktionen des frühen Sarmatium.

Interpretation: The palaeorelief on top of the corallinacean limestones most probably formed during the LST at the Badenian/Sarmatian boundary. Subaerial exposure is indicated by the abundance of *Microcodium*, which is interpreted as calcified roots. During the Early Sarmatian the sea transgraded onto this landscape. Clay, lignites and the minor reworking of the Badenian limestones document a low-energy coastal environment. A small colony of *Crassostrea gryphoides* accompanied by scarce *Terebralia bidendata* and numerous *Granulolabium bicinctum* point to the presence of a littoral mudflat. The relief, however, was sealed soon after by *Hydroides* and bryozoan bioconstructions. Bituminous exhalation of the sediment indicates a high content of organic matter contained by the highly porous framestone.

The following unit suggests a fluctuating coastline. Phases of flourishing *Hydroides*/bryozoan colonies of considerable size were interrupted at least 2–3 times by the formation of tidal mudflats. The low relief on the tops of the limestone beds and the scattered chips of weathered limestone in the base of the overlying beds document some erosion due to phases of emersion. The clay layer separating the lower unit from the top unit indicates a major interruption. The 3 strongly altered, unstructured crusts in the top bed of the lower unit and within the upper limestone unit are interpreted as caliche, which formed during phases of emersion. Thus, the Lower Sarmatian deposits at Klapping may represent at least 4–5 parasequences.

About 1.1 km W of the abandoned quarry (15°57'31''E, 46°48'42''N) bubbles of gas can be observed in the headwaters of a small brook at the village Klapping. The water in a shaft shows very impressive the permanent uprising of carbonic acid gas-bubbles. The origin of the mofette is discussed to be a post-volcanic phenomenon, situated on an E–W-orientated fault (SCHOUPPE 1952; ZETINIGG 1993). The local name "Brodlsulz" derivates from the dialectical word "brodln", which means "boiling".

Important references: KOLLMANN (1965), HARZHAUSER & PILLER (2004a, b), PILLER & HARZHAUSER (2005).

Stop 6 – Quarry Klöch

Topic: Basanite, scoria, minerals.
Locality: Quarry Klöch (owned by the Klöcher Basaltwerke GmbH & Co KG), about 300 m N Klöch, Klöcher Klause, 15°57'38''E, 46°46'07''N (Figs. 25-27).
Lithostratigraphy: Informal "basalts, scoria" (GROSS 2003).
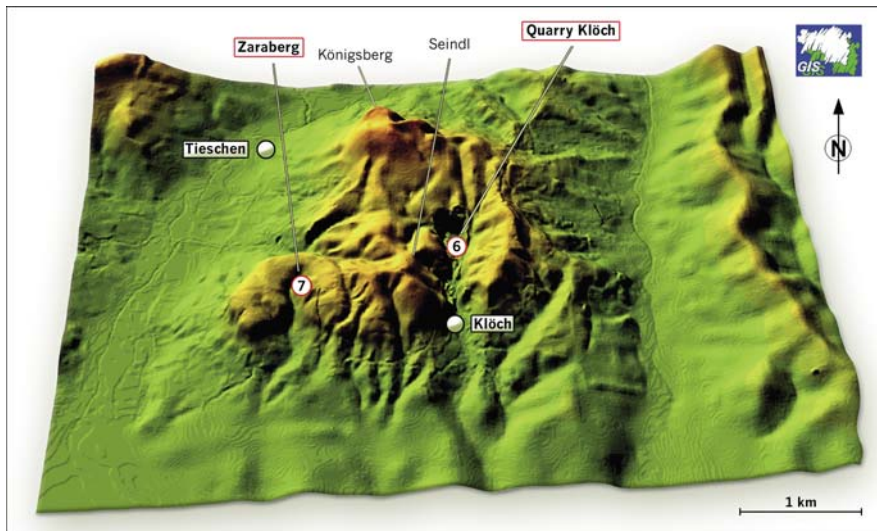Chronostratigraphy: Pliocene to Lower Pleistocene (BALOGH et al. 1994).

Fig. 25: Digital elevation model of Klöch (GIS-Steiermark).
Abb. 25: Digitales Höhenmodell von Klöch (GIS-Steiermark).

Description: One of the first authors, who mentioned the basaltic rocks of Klöch was J.M. ANKER (1809). He described black/grey basalt and 3 different types of lava. He talked about the fact that these rock types of "Klech" can be used as building stones well and especially the lava-type rocks with bubbles were good for grinding salt.

WINKLER (1913) gave a comprehensive description of the "Basaltmassiv von Klöch". He supposed a caldera, filled up with tuff, basanite and scoria. WINKLER described a fluctuating development with explosive volcanism at the beginning.

Well-bedded tuff-layers (ash-, lapilli tuffs) form the basis of the volcanic succession and are in discordant contact to Sarmatian sediments. Pyroclastic rocks and intrusive nepheline-basanites are exposed in the quarry. The intrusions are voluminous at the basis, sometimes form columnar joints, and reduce to the top. Some dikes have a sharp but irregular contact zone to the scoria. At the upper part of the quarry red, weakly bedded scoriaceous tuff breccia with small lava flows crop out and form the top of the volcanic succession.

A depression between Seindl and Königsberg (Kindsberg in some maps) shows approximately horizontal-layered fine sediments with a great variety of colours. This succession is commonly truncated by large impact sags caused by ballistically emplaced basaltic blocks (Fig. 28). The distinctive morphological elevation of Königsberg is build up by pyroclastic rocks like tuff breccias with small dikes.

The quarry Klöch is the largest still active basalt quarry in Austria. Intensive quarrying, which began in the 1930s, has removed a significant part of the eastern edge of the Seindl.

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Fig. 26: Quarry Klöch.
Abb. 26: Steinbruch Klöch.

The several 10's of metres thick gobble, a pyroclastic breccia with highly vesicular basanitic lava clasts, is relocated to the already exhausted northern part of the quarry.

Even though no geological research has been done in this area since WINKLER-HERMADEN, we know much about the minerals. ANKER (1809) described the first mineral from Klöch – hyalite. HATLE (1885) mentioned hyalite, ilmenite and olivine (partly referring to former authors). Most of the mineral-species from Klöch were described in the 20th century. TAUCHER et al. (1989) publish a monograph about this quarry, listing more than 80 mineral species. This book also contains a lot of photographs and crystal-drawings. TAUCHER & HOLLERER (2001) give a very detailed mineralogical overview including all the references known up to the publishing year.

In the meantime, far more than 100 mineral-species are known from this locality – a very high number compared to the actual number of more than 550 mineral-species for the whole of the country of Styria. New mineral species from Klöch can be added almost every second year. New and interesting samples are very often found by highly specialized private-collectors and through sampling and investigations by the Joanneum-scientists. But, why are there so many different species in only one quarry? The wide range of conditions of formation is the reason:
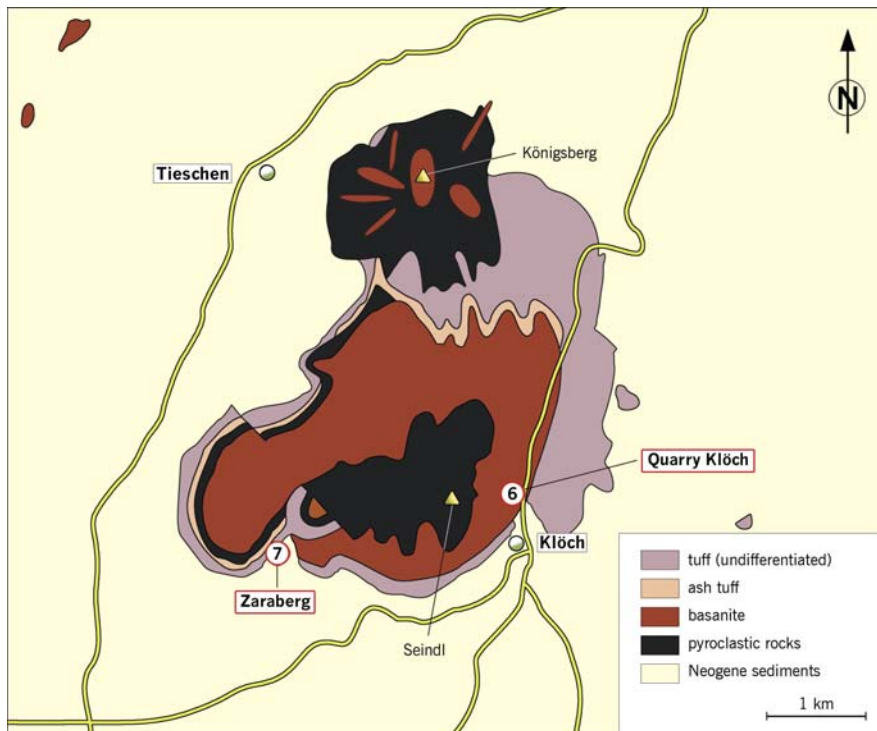
Fig. 27: Simplified geological map (GIS-Steiermark).
Abb. 27: Geologische Karte aus dem GIS-Steiermark.

1. Minerals belonging to the host-rock – a nepheline-basanite with a low content of about 44 % SiO_2, e.g., olivine, feldspars, pyroxene, nepheline, magnetite and apatite.

2. Minerals in the degassing-bubbles of the rock, which grow in the pneumatolytic and hydrothermal field, e.g., the "famous" zeolites (like natrolite, gonnardite, thomsonite, chabasite, gismondine, etc.) and carbonates like calcite and aragonite. The low content of silica causes e.g., the complete lack of nice geodes filled with rock-crystal, amethyst, chalcedony and agate, which are known from a lot of basaltic rocks around the world or even nearer from the shoshonite of Weitendorf, about 40 km WNW of Klöch.

3. Minerals, which originate from the reaction of xenolithes with the hot ascending magma and fluids. Such xenolithes belong mostly to the sedimentary series and can range from quartzitic over carbonatic and other sedimentary rocks to metamorphic rocks like garnet-micaschists.

Fig. 28: Bomb-sag structure. Ballistically transported basanite block deformed wet, fine-grained layers.
Abb. 28: Einschlagsdelle. Ballistisch transportierter Basanitblock deformierte feuchte, feinkörnige Lagen.

This means a very wide range of "additional" chemical elements and therefore a lot of possible combinations.

Especially this kind of formation leads to very exotic minerals, but often also very tiny crystals. The "latest results" are e.g., huntite and Al-bearing jarosite (Postl 1999), hydrocalumite (Postl & Bojar 2003), mottramite and a zinc-silicate – possibly a totally new mineral-species (Postl & Bojar 2006).

4. The latest formation of minerals can be found in the surface-near parts of the basaltic body through oxidation and weathering, e.g., thin layers of clay-minerals or pseudomorphs of clay-minerals after carbonates or zeolites.

During the 1950s to 1970s many good samples were found in the southern part of the quarry, due to the ideal host-rocks for fantastic zeolite-crystals like phillipsite and thomsonite. In the 1970s the northern part was opened and there could be found a lot of xenolithe-magma-reaction-products.

During the last few years the quality of the rock in the northern part decreased, the production was stopped and the company began to fill up the northern quarry with

tailings of the new places of interest, which are the central and again the southern parts of the elongated quarry.

So there are new chances to find again nice zeolites. And since the last 2–3 years such good samples have been collected again. During a short excursion stop it should be possible to find calcite, aragonite, phillipsite and maybe also thomsonite or gonnardite/natrolite (Fig. 29).

Fig. 29: Some minerals from Klöch. a) Gonnardite (fawn bowl) adjacent to phillipsite (white, shiny crystals; width of view 9 cm). b) Calcite (white bowls) on phillipsite and natrolite (substratum; width of view 2 cm). c) Aragonite (width of view 2 cm). d) Natrolite (white bowl) on phillipsite (white crust; width of view 7 cm).
Abb. 29: Einige Mineralien aus Klöch. a) Gonnardit (beige Kugel) neben Phillipsit (weiße, glänzende Kristalle; Bildbreite 9 cm). b) Calcit (weiße Kugeln) auf Phillipsit und Natrolith (Untergrund; Bildbreite 2 cm). c) Aragonit (Bildbreite 2 cm). d) Natrolith (weiße Kugeln) auf Phillipsit (weiße Kruste; Bildbreite 7 cm).

Interpretation: About 2 Ma years ago (K/Ar age 2.6 ± 1.2 Ma for the basalt of Klöch; BALOGH et al. 1994) ascending magma interacted with water in the area of Klöch. The palaeogeographic situation at that time is uncertain. Beside sediments from the Sarmatian, like gravel, sand and silt,

WINKLER (1913) described a pre-volcanic gravel cover. Phreatomagmatic explosions (FISHER & SCHMINCKE 1984) were caused by the interactions between magma and external water and/or water-saturated sediments. These initial phreatomagmatic eruptions produced pyroclastic rocks like ash tuffs and lapilli tuffs rich in siliciclastic clasts,

which are inferred to have been derived from the Neogene succession. A big crater was formed in this first stage of volcanic succession (initial stage sensu Lorenz 1986).

After the external water supply had exhausted, magma reached the surface and magmatic explosive and effusive volcanic activity started. Several feeder dikes produced small lava flows, welded and unconsolidated spatter rich deposits.

In the northern area of the quarry blocky jointing basanites are covered from a fine-grained, and well-layered succession. This reddish, brown, yellowish and grey development is locally interrupted by a lava flow, which started with an explosive phase documented by bomb sag structures and fallout lapilli.

The development of the diverse types of preserved pyroclastic and intrusive/extrusive rocks from the volcanic remnant "Basaltmassiv von Klöch" is not yet fully understood. A companying volcano geological documentation and a monitoring in the mining region, supported by the quarrying, will help us to understand the volcanic succession in this area and to get a 3D-model from the inner architecture of the intrusive/effusive basanite and agglutinated scoria capped mesa. There is a great demand on the exploit basanite. Because of the high quality of the material it is used as superficial layer on roads and aero landing runways.

Important references: Winkler (1913, 1927a), Winkler-Hermaden (1939), Taucher et al. (1989).

Stop 7 – Zaraberg

Topic: Phreatomagmatic tuff, accretionary lapilli, lava flow.
Locality: Old quarry at the southern flank of the Zaraberg, about 600 m north of the mainstreet, 15°56'46''E, 46°45'51''N (Figs. 25, 27, 30).
Lithostratigraphy: Informal "basaltic tuff/tuffite, basalts, scoria" (Gross 2003).
Chronostratigraphy: Pliocene to Lower Pleistocene (Balogh et al. 1994).

Description: The outcrop of an old small quarry on the southern flank of the Zaraberg shows well-layered tuffs, covered by a basanitic lava flow. The succession is built up by alternating ash tuff and lapilli tuff of phreatomagmatic origin with accretionary lapilli rich units and dunes. The upper part of the tuffs is reddish coloured. The tuff development is overlain by partly agglutinated scoria passing vertically into a lava flow.

Interpretation: The pyroclastic succession, with finely bedded accretionary lapilli tuffs (Fritz 1996), indicates phreatomagmatic explosions and were formed in the initial stage of the volcanic development. Palagonitization indicates wet conditions. Moderately dipping pyroclastic beds, probably surge and fall deposits, dip inward to the centre of the hill. When the lava flow covered this succession, the top was fritted.

Fig. 30: Outcrop Zaraberg. Ash/lapilli tuffs covered by a lava flow.
Abb. 30: Aufschluss Zaraberg. Asche/Lapillituffe überlagert von einem Lavastrom.

Important reference: Winkler (1913).

Stop 8 – Quarry Retznei near Ehrenhausen

Topic: Carbonate complex of terrigenous coral- and coralline algal-limestones with volcanoclastics; overlying sequence of siliciclastics.
Locality: "Old Quarry" and "Quarry Rosenberg" in the area of Retznei near Ehrenhausen (owned by Larfage-Perlmooser Concrete AG), 15°33'35''E, 46°44'41''N, 280 m above s.l. (concrete bridge between the two quarry areas).
Lithostratigraphy: Weissenegg Formation.
Chrono-/Biostratigraphy: Lower Badenian (Lagenidae Zone; NN5).

Description: The "Old quarry" is only poorly preserved and used as waste dump. The quarry area of Rosenberg measures 600 m (SW–NE-direction) by ca. 200 m, size and shape. However, it is constantly changing due to active quarrying. Several excavation levels are present along the slope oriented to the NE (Fig. 31). The carbonate complex is about 25 m thick.
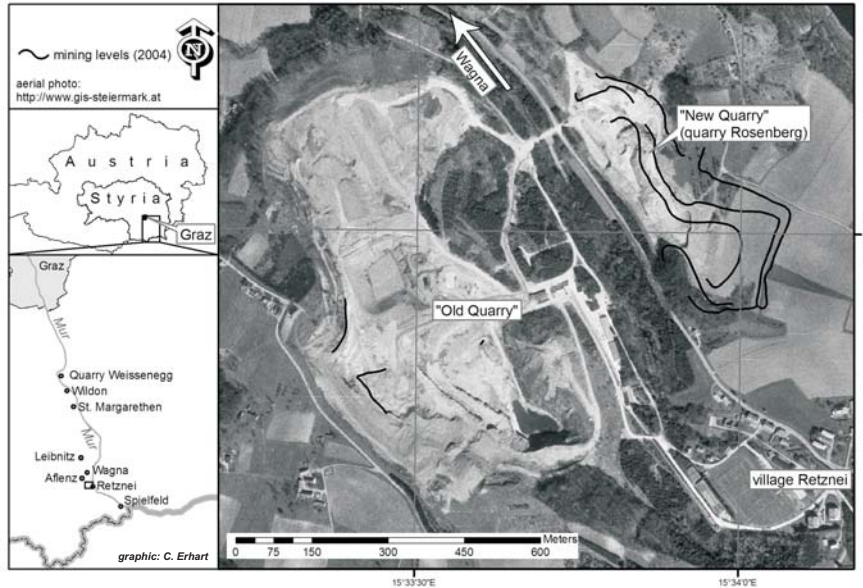
Fig. 31: Overview of the quarry area Retznei. "Old Quarry" and "New Quarry" (quarry Rosenberg; status: April 2004).
Abb. 31: Übersicht über das Steinbruchareal von Retznei. „Alter" und „Neuer" (= Rosenberg) Steinbruch (Stand: April 2004).

Carbonates of Quarry Rosenberg

The carbonate succession starts on top of a "basal conglomerate" which is exposed on a slight topographic high (Figs. 32-33). It is built by a few mm to 50 cm large, rounded components (limestone, dolomite, marl, gneiss, micaschists, phyllite, quartz) in a grey to brown, marly, sandy to silty matrix. Frequent intraclasts (up to 20 cm diameter) of marly, brownish sand- to siltstones are heavily bored by *Lithophaga* sp. and *Gastrochaena* sp. This conglomerate is called "Geröllmergel" by various authors (e. g., KOLLMANN 1965; FRIEBE 1988).

The above following carbonate complex is very heterogeneous, vertically as well as horizontally. The limestones are generally impure and are interrupted by marl layers, which are excellent correlation horizons reflecting the internal structure of the carbonate complex (Figs. 32-33). The limestones can be differentiated into 12 facies types partly grading one into each other: massive coral facies, branched coral facies, platy coral facies, algal debris-marl facies, rhodolite-*Porites* facies, rhodolite facies, algal debris facies, glauconite-*Planostegina* facies, algal debris-*Planostegina* facies, bioclastic *Planostegina* facies, bioclastic facies, molluscan debris facies.

Directly on top of the basal conglomerate the limestone is made up of corals (Figs. 32-33). The coral dominated areas form topographic elevations of up to 10 metres in height pinching out laterally.
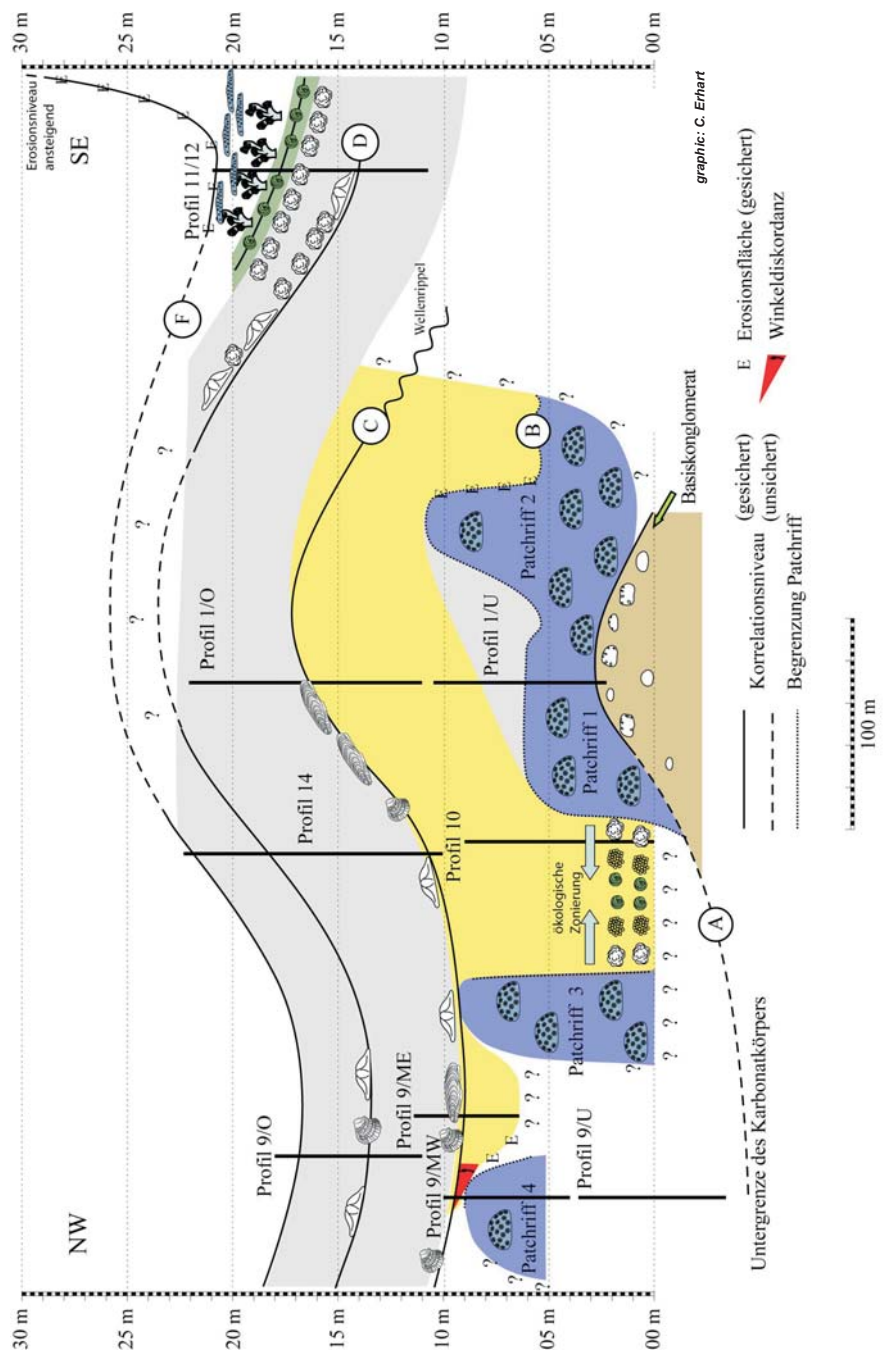
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graphic: C. Erhart

Fig. 32: Schematic section through the carbonate body of quarry Rosenberg (studied sections indicated; blue: patch reefs, yellow: calcareous sandstone ("Aflenz Stone") with cross-bedding and ripples, grey: coralline algal limestone, green: facies with platy corals; vertical exaggeration: 10 ×).
Abb. 32: Schematischer Schnitt durch den Karbonatkörper des Steinbruchs Rosenberg (untersuchte Profile eingetragen; blau: Patchriff, gelb: Kalkarenit („Aflenzer Stein") mit Schrägschichtung und Rippeln, grau: Corallinaceenkalke, grün: Fazies mit plattigen Korallen; vertikale Überhöhung: 10 ×).

graphic: C. Erhart

larger foraminifers
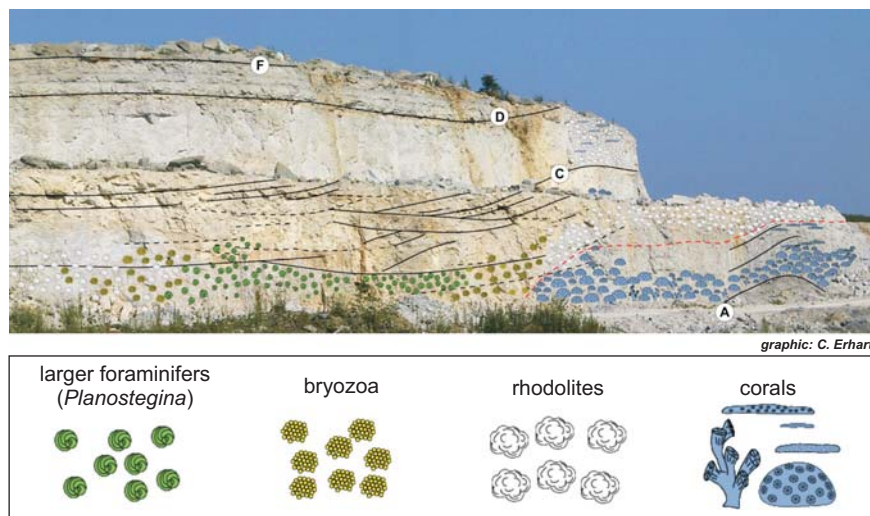(*Planostegina*)   bryozoa   rhodolites   corals

Fig. 33: Central sector of quarry Rosenberg. The base of the Leitha Limestone ("basal conglomerate") is visible as a distinct topographic elevation (A) overgrown by a coral patch reef. This is overlain by a coralline algal limestone laterally grading first into bryozoan and than into Larger foraminiferal facies. These facies are overlain by a carbonate sandstone ("Aflenz Stone") with distinct cross-bedding (foreset structures). The latter indicate currents from SE.
Upsection, two distinct marl horizons (C, D) trace the topographic high of the base. A wavy erosional surface terminates the carbonate body (F).
Abb. 33: Zentralbereich des Steinbruchs Rosenberg. Die Basis des Leithakalks („Basalkonglomerat") bildet ein deutliches Relief (A), überwachsen von einem Korallen-Patchriff. Dieses überlagern Corallinaceenkalke, die lateral in eine Bryozoen- und Großforaminiferen-Fazies übergehen. Darüber folgten Kalkarenite („Aflenzer Stein") mit deutlicher Schrägschichtung, die auf eine Strömung aus SE hinweist. Zwei markante Mergelhorizonte im Hangenden (C, D) folgen dem basalen Relief. Eine wellige Erosionsfläche begrenzt den Karbonatkörper (F).

The corals are predominantly of massive growth form and are dominated by three taxa, out of which *Tarbellastrea reussiana* is the most abundant one (ca. 60 %), followed by *Porites* sp. and *Montastrea* sp. *Tarbellastrea* is most dominant in the thickest parts and is laterally replaced by *Porites*. Also the growth forms change laterally from hemispherical *Tarbellastrea* colonies in the center and more inflated shapes laterally.

The coral colonies are frequently in lateral contact and occur in live position. The colonies are incrusted by thin coralline algae and heavily bored (*Lithophaga* sp.); their surface is frequently encrusted by balanids. The sediment between the corals is a bioclastic marl (coralline algal debris), in more marginal positions of the elevations marly layers are intercalated in the limestone. This limestone is classified as massive coral facies representing a framestone, which formed a series of patch reefs. This massive coral facies is overlain by algal debris-marl facies (ca. 2.5 m), in which 2 horizons with platy corals (*Tarbellastrea*, *Porites*) and rhodolites are intercalated.

The rocks above these patch reefs and coral sediments (above level B; Fig. 32) belong to algal debris and algal debris-*Planostegina* facies and show the least fine clastic fraction of all carbonates in the quarry area. The size of the coralline algal debris as well as amount and size of rhodolites (rhodolite facies) change rapidly laterally. This rock is also characterized by a variety of sedimentary structures as cross-bedding and ripples and is also called "Aflenz Stone". It was already quarried by the Romans north of the quarry Rosenberg (cf. chapter 2.3.1.; Stop 4). Between patch reefs 1 and 3 (Figs. 32-33) a laterally symmetrical succession of biotic associations is remarkable: patch reef 1 and 3 are overlain by coralline algal limestones (rhodolite facies), capping the relief of the patch reefs. In the depression between the reefs the coralline algal limestones are replaced by nodular bryozoan limestones, which grade into a algal debris-*Planostegina* facies. The latter is characterized by large individuals of *Planostegina giganteoformis*, which occur in rock-forming quantities. Further into the direction to patch reef 3 again a bryozoan dominated facies follows grading firstly into rhodolite facies and finally in the massive coral facies of patch reef 3. Further to the NW, the coral dominated limestones reach higher up, and patch reef 4 is not overlain by the "Aflenz Stone" but the reef is cut by erosion and the sediments of the "Aflenz Stone" exhibit a typical onlap geometry (Fig. 32). These pure carbonate sands of various facies types are terminated by level C representing a wavy but sharp bedding plane with only a few cm of dark grey to grey-greenish marls.

Immediately on and above level C, clusters of oysters and *Isognomon* are abundant as well as well preserved clypeasterid echinoids. The majority of the following rocks is algal dominated (algal debris-marl facies, rhodolite-*Porites* facies, rhodolite facies) and is interrupted by several marl levels (D, F). These marls, including level C, contain reworked volcanoclastics in variable quantities (biotite platelets; heavily weathered volcanoclastic boulders up to 15 cm in diameter). Similarly to level C, also in and on level D, oysters and clypeasterids occur frequently. The rhodolites are mainly discoidal or spherical with laminar or branching growth form. Their average diameter is around 7 cm, reaching a maximum of 20 cm. The *Porites*-colonies are mostly platy, in places their fragments act as nuclei for rhodolites.

In the highest parts of the carbonate succession the abundance of coralline algae generally decreases and the larger foraminifer *Planostegina* increases together with the amount of glauconite (glauconite-*Planostegina* facies). Above, again a coral dominated portion follows starting with massive colonies followed by branching (branched coral
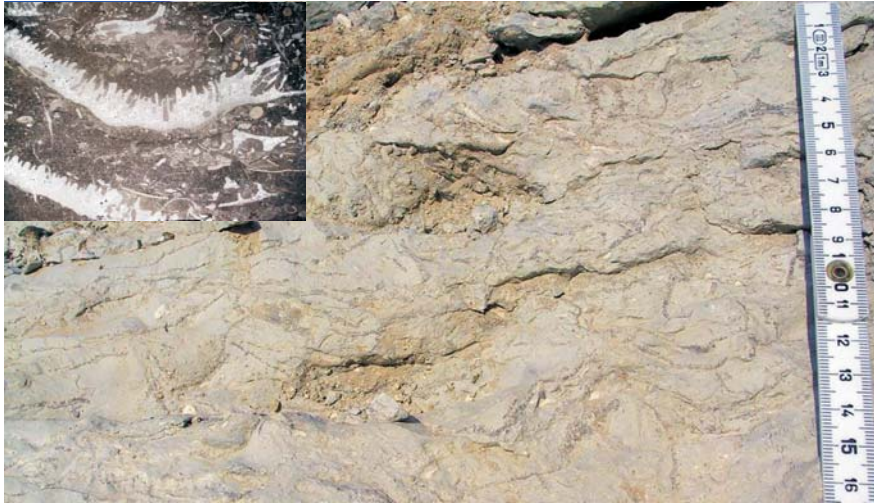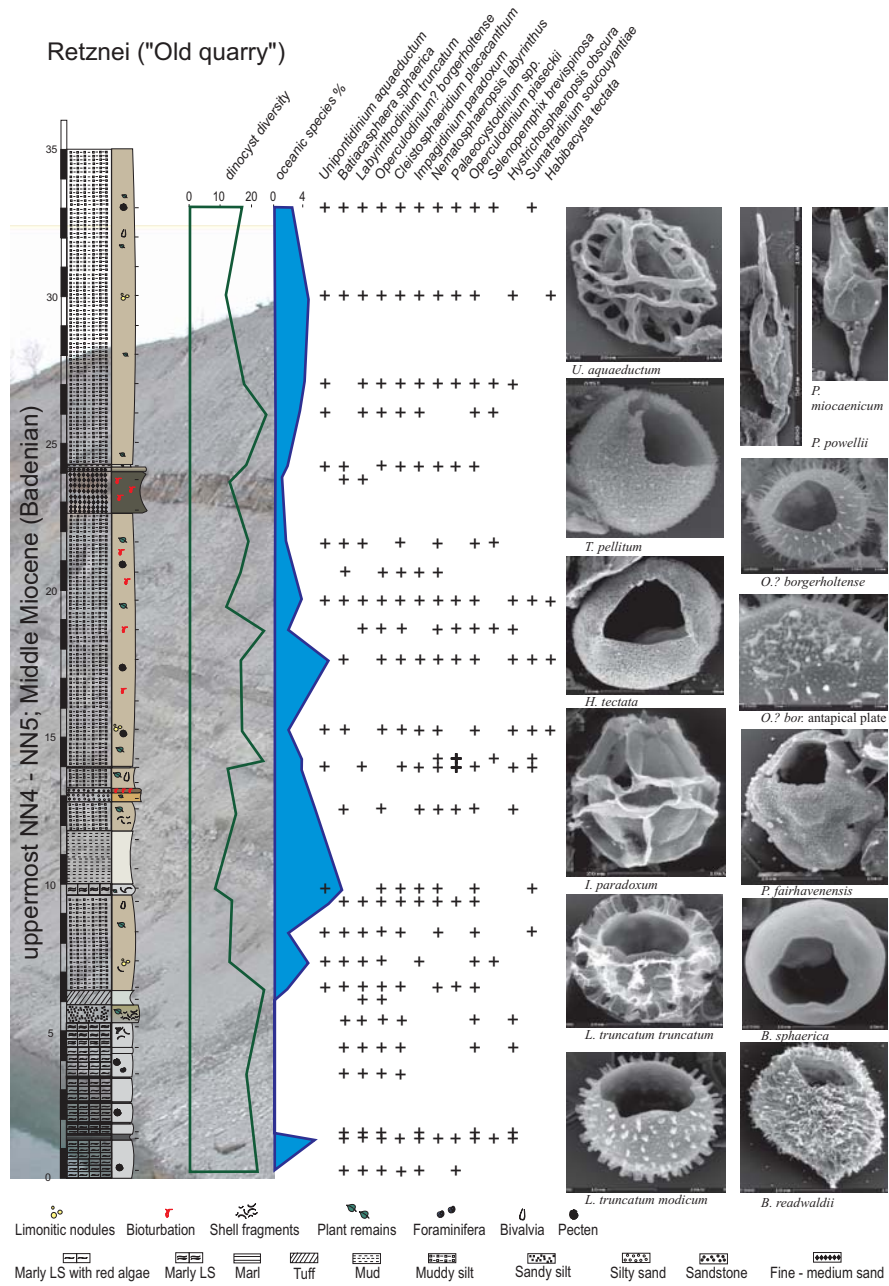
Fig. 34: Platy coral facies. Framestone, built by thin-platy colonies of *Leptoseris* sp.
Abb. 34: Plattige Korallen-Fazies. Framestone, gebildet von dünnplattigen Kolonien von *Lepto-seris* sp.

facies) and finally terminated by thin-platy colonies (platy coral facies). The latter form a frame- or floatstone with silty matrix. This platy coral facies is 50 cm thick in the south-eastern part of the quarry and composed of two coral species replacing each other laterally. One of them belongs to the genus *Leptoseris*. Their colonies are 10–20 cm wide and only 0.5–3 mm thick. Their shape is wavy and neighbouring colonies touch each other (Fig. 34). Both taxa show a dense settlement by the sessile foramini-fer *Acervulina* at their lower surfaces. This foraminifer is restricted to this facies type. Besides corals polychaete tubes are abundant and also echinoid spines; coralline algae are rare (5 %).

A wavy surface (level F), which truncates several stratigraphic levels separates the limestone from overlying silts and sands and sharply marks the end of the carbonate development. This level represents a clear erosive surface with a distinct relief (Fig. 33).

Fossils: The quarry area of Retznei is well known because of its rich and well-preserved fossils. The terrigenous content allows an easy collection of fossils out of the carbonates and even aragonitic skeletons – although dissolved – are better preserved due to mud infiltration as in pure carbonates. Beside mass occurrences of the larger foraminifer *Planostegina giganteoformis*, the abundant scleractinian corals, comprising the genera *Porites*, *Tarbellastrea*, *Montastrea*, *Mussismilia* and *Leptoseris*, are well known. To our knowledge the occurrence of *Leptoseris* is the only record from the Pa-ratethys up till know. Among molluscs oysters, *Isognomon*, *Pinna* and pectinids (e. g., *Macrochlamis*, *Flabellipecten*) are most abundant.

Retznei ("Old quarry")

uppermost NN4 - NN5; Middle Miocene (Badenian)

dinocyst diversity

oceanic species %

Uniontidinium aquaeductum
Batiacasphaera sphaerica
Labyrinthodinium truncatum
Operculodinium? borgerholtense
Cleistosphaeridium placacanthum
Impagidinium paradoxum
Nematosphaeropsis labyrinthus
Palaeocystodinium spp.
Operculodinium piasecki
Selenopemphix brevispinosa
Hystrichosphaeropsis obscura
Sumatradinium soucouyantiae
Habibacysta tectata

35
30
25
20
15
10
5
0

0 10 20   0   4

U. aquaeductum

P. miocaenicum

P. powellii

T. pellitum

O.? borgerholtense

H. tectata

O.? bor. antapical plate

I. paradoxum

P. fairhavenensis

L. truncatum truncatum

B. sphaerica

L. truncatum modicum

B. readwaldii

Limonitic nodules   Bioturbation   Shell fragments   Plant remains   Foraminifera   Bivalvia   Pecten

Marly LS with red algae   Marly LS   Marl   Tuff   Mud   Muddy silt   Sandy silt   Silty sand   Sandstone   Fine - medium sand

Fig. 35: Sedimentary succession overlying the carbonate complex in the "Old quarry" of Retznei (left: outcrop photograph and corresponding litholog, center: occurrence of selected dinocyst taxa and diversity, right: SEM photographs of selected dinocyst taxa).
Abb. 35: Sedimentäre Abfolge über dem Karbonatkomplex von Retznei im „Alten Steinbruch" (links: Aufschlussfoto und Profil, Mitte: Vorkommen ausgewählter Dinoflagellaten-Zysten und Diversität, rechts: REM-Fotos ausgewählter Dinoflagellaten).

Widely known is the rich occurrence of echinoids, which comprise the abundant taxa *Clypeaster scillae* and *Parascutella gibbercula*, but also include the recently described leather sea-urchin *Retzneiosoma jaseneki* (KROH 2005). Beside crabs also fish remains are abundant. The latter include sharks and rays but also wrasses, trigger-, surgeon- and porcupinefishes (HIDEN 1996; SCHULTZ 2006).

Siliciclastics above the carbonate complex ("Old Quarry")
Above the carbonate complex a sequence of mainly fine-siliciclastics with intercalated sandstone beds follows, including also a the tuff horizon, which was dated to 14.2 ± 0.1 Ma (BOJAR et al. 2004; HANDLER et al. 2005, 2006; Fig. 35).

These sediments are rich in plant remains, molluscs and foraminifers. Dinoflagellate cysts are diverse and mostly well preserved. Other palynomorphs such as acritarchs (*Cymatiosphaera* spp., *Nannobarbophora gedlii*, *Cyclopsiella* spp.), foraminiferal test linings and miospores were also recorded.

The presence of many biostratigraphic dinocyst markers, such as *Cerebrocysta poulsenii*, *C. placacanthum*, *H. tectata*, *L. truncatum*, *O.? borgerholtense*, *P. miocaenicum*, and *U. aquaeductum*, strongly supports the Middle Miocene (Badenian) age equivalent to the uppermost part of NN4 to NN5 (personal communication, S. CORIC).

Interpretation: Occurrence of patch reefs is restricted below level C in the carbonate compex. This distinct level clearly coincides with an erosional surface in patch reef 4, which indicates subaerial exposure due to increasing dissolution features. The above sediments show clear onlapping to the reef surface and the surface was densely settled by bivalves (oysters, *Isognomon*) during flooding. The following interruptions in sedimentation, reflected in levels D and F, are not only due to higher terrigenous input but also due to increased volcanoclastic influence. Volcanoclastics, however, have always been delivered throughout the formation of the carbonate complex.

The preserved top of the carbonate complex is characterized by reduced sedimentation rates leading to the formation of glauconite-*Planostegina* facies. The above succession of coral growth forms (from massive over branching to platy) indicates deepening of the depositional environment. The end of the carbonate complex is represented by a discontinuity surface. Its origin may be either caused by subaerial exposure or by subaquatic erosion.

In general, the carbonate complex of Retznei reflects tropical-subtropical conditions indicated by the patch reefs and co-occurring biota. Besides corals these tropical biota are larger foraminifers (*Planostegina*, *Amphistegina*, *Borelis*), specific molluscs,

sea urchins (*Clypeaster*), and a diverse fish fauna. Also stable oxygen isotope data indicate subtropical conditions (BOJAR et al. 2004).

For the succession overlying the carbonate body, a generally increasing water depth can be reconstructed based on foraminiferal and mollusc data as well dinocyst assemblages. The deepening is indicated by the increasing abundance of *Nematosphaeropsis* spp. and *Impagidinium* spp. and also by generally increasing dinocyst diversity. Isotope data of a brachiopod shell indicate cooler water temperatures for this succession (BOJAR et al. 2004).

Important references: FRIEBE (1988, 1990), ERHART & PILLER (2003), BOJAR et al. (2004).

Stop 9 – Roman Limestone Quarry at Aflenz/Sulm

Topic: Subsurface Roman Limestone quarry (Fig. 36).
Locality: Roman limestone quarry, 4.2 km S Leibnitz, 15°33'00''E, 46°44'57''N.
Lithostratigraphy: Corallinacean limestones of the Weissenegg Formation.
Chrono-/Biostratigraphy: Lower Badenian (Lagenidae Zone).

Description: The quarry is up to 250 m long, 6–8 m high and 12–30 m below the surface. The base area comprises approximately 20,000 sqm. The mined arenitic limestones are composed mainly of corallinacean detritus and rhodolites but also some fragments of echinoids, bivalves, corals and foraminifera can be observed. The rocks contain only minor insoluble terrigenous components and are highly weatherproof.

At least, since the 1st century AD corallinacean limestones ("Aflenz Bivalve Limestone", "Aflenz Stone") have been mined in this area, when the Roman emperor Titus Flavius Vespasianus founded the town Flavia Solva near today's Leibnitz. Parts of the surrounding buildings (e.g., Seggau Castle) were built with these limestones in the Middle Ages too. Especially in the 19th century, the Aflenz stones were dug intensively and also used at the "Ringstrassen"-buildings of Vienna. During the Second World War the subsurface quarry was substantially enlarged and weapons were produced by up to 450 prisoners of war within the caves. After a short active time in the postwar period the quarry was closed until 1987. Since this year the stonecutter company of E. GREIN GesmbH. has been using the quarry again for mining building rocks but also for cultural events, like concerts and exhibitions.

Important references: ZIRKL (1994), HIDEN (2001).

Fig. 36: The subsurface "Roman Quarry" at Aflenz/Sulm (Photo: E. Grein GesmbH.).
Abb. 36: Der unterirdische „Römersteinbruch" bei Aflenz/Sulm (Foto: E. Grein GesmbH.).

Stop 10 – Abandoned Brickyard Wagna

Topic: Deeper water sediments (grey shales and siltstones) of the Karpatian "Steirischer Schlier", "Styrian unconformity", Karpatian/Badenian boundary, Badenian shallow water sliciclastics and carbonates.

Locality: Abandoned brickyard at Aflenz an der Sulm near Wagna (Fig. 37), the brickyard is immediately south of the bridge over the river Sulm, 15°32'50''E, 46°45'12''N.

Lithostratigraphy: "Steirischer Schlier" (Kreuzkrumpel Formation), Weissenegg Formation.

Chrono-/Biostratigraphy: Middle Karpatian to Lower Badenian (NN4–NN5).

Description: Total thickness of the outcropping section is around 80 m. In the lower part of the outcrop dipping of the beds is around 20–25° to the SE whereas in the upper part only 5° dipping is observed. This dipping necessitated measuring of a composite section (Figs. 38-39). The sediments in the lower part of the section are generally grey shales with cm-thick intercalations of turbiditic siltstones every 2–5 m. In section 1 (Fig. 37), at around 57 m crystalline pebbles occur which probably represent a channel deposit. Two metres above, a distinct angular disconformity separates the shales ("Steirischer Schlier") from overlying sandy sediments.

Section 1

metres

Section 2

metres

Badenian

Karpatian

M5a
M4b
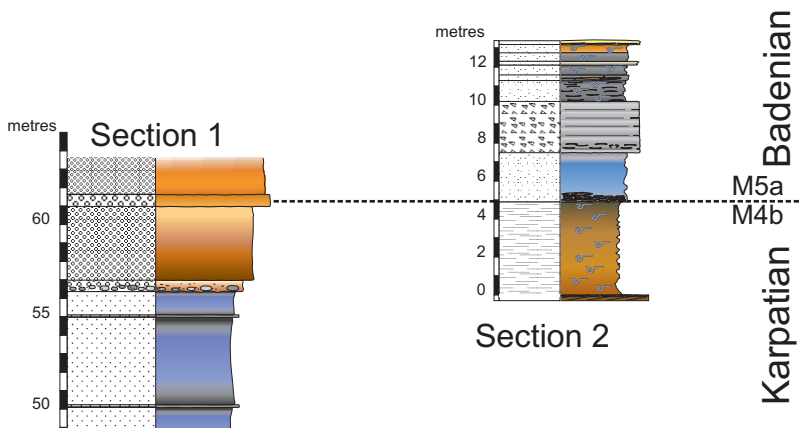
Brickyard Wagna

Fig. 37: Two sections of brickyard Wagna and photograph with inclined Karpatian fine-silici-clastic sediments at the base and overlying Badenian carbonate/coarse siliciclastics on top.
Abb. 37: Zwei Profile in der Ziegelei Wagna und Foto mit den schrägeinfallenden, karpatischen Feinklastika an der Basis und den überlagernden, badenischen Karbonaten/Grobklastika am Top.

In section 2, 5 m below this unconformity another unconformity occurs, where the above-mentioned change in dip from 20° to 5° occurs.

Above the disconformity marls and silt with pebbles ("Geröllmergel") occur indicating an erosional surface. They are followed by an approx. 2 m thick succession of marls, silts and fine sands. Above, limestones with corals (*Porites*) occur which are laterally discontinuous. On top of the coral limestone again sand, silt and marl follow, overlain by a ca. 4 m thick corallinacean grainstone. The section ends with a nearly 7 m thick marly-silty, red algal limestone (Leitha Limestone of the Weissenegg Fm.).

Fossils: The "Steirischer Schlier" is very poor in megafossils. However, microfossils are very abundant. Calcareous nannofossils, foraminifers and dinoflagellate cysts were recently studied in detail (RÖGL et al. 2002; SPEZZAFERRI et al. 2002, 2004; SOLIMAN & PILLER 2007).

The foraminiferal fauna is characterized by a dominance of large agglutinated taxa, e. g., *Gaudryinopsis beregoviensis*, *Textularia laevigata* and *Cribrostomoides* ssp., which are associated with large-sized calcareous benthics, e. g., *Praeglobobulimina pyrula-pupoides* gr., *Pullenia bulloides*, *Valvulineria complanata*, and *Chilostomella ovoidea*. Among smaller calcareous benthics *Nonion commune*, *Bulimina elongata*, *Uvigerina graciliformis*, *Pappina primiformis*, *Amphimorphina haueriana*, and bolivinids are important constituents. Planktonic taxa are generally rare and dominated by *Globigerina ottnangiensis*. Above the disconformity the foraminiferal assemblage changes drastically and is characterized by the genera *Ammonia*, *Nonion*, *Elphidiella*, and *Elphidium*. In marly layers between the corallinacean limestones diversity of benthics increases and planktonic forms appear (*Globigerinoides trilobus*, *Praeorbulina glomerosa circularis*) which are completely absent in the "Steirischer Schlier".

The nannofossil assemblages are dominated by *Coccolithus pelagicus*, *Reticulofenestra minuta* and *Sphenolithus heteromorphus*. Above the unconformity *Helicosphaera ampliaperta* becomes more abundant. Approximately 8 m above the unconformity, also in the marly corallinacean limestones, *Helicosphaera waltrans* occurs.

Concerning dinoflagellate cysts most samples from the studied sections were productive, in a fair preservation state but low in diversity (Fig. 38). The dinoflagellate cyst assemblages contain common *Spiniferites/Achomosphaera* spp., *Cleistosphaeridium* spp., *Operculodinium* spp., *Hystrichokolpoma* spp., *Cribroperidinium* spp., *Dapsilidinium* spp., *Lingulodinium machaerophorum*, *Polysphaeridium zoharyi* and *Reticulatosphaera actinocoronata.* In addition, some Early Miocene marker taxa are recorded, as *Hystrichosphaeropsis obscura*, *Sumatradinium soucouyantiae*, *Distatodinium paradoxum*, and *Cousteaudinium aubryae.* With regard to the dinocyst assemblages, the Karpatian/Badenian-boundary is marked by the lowest occurrences (LO) of *Operculodinium*? *borgerholtense* and *Batiacasphaera sphaerica*.
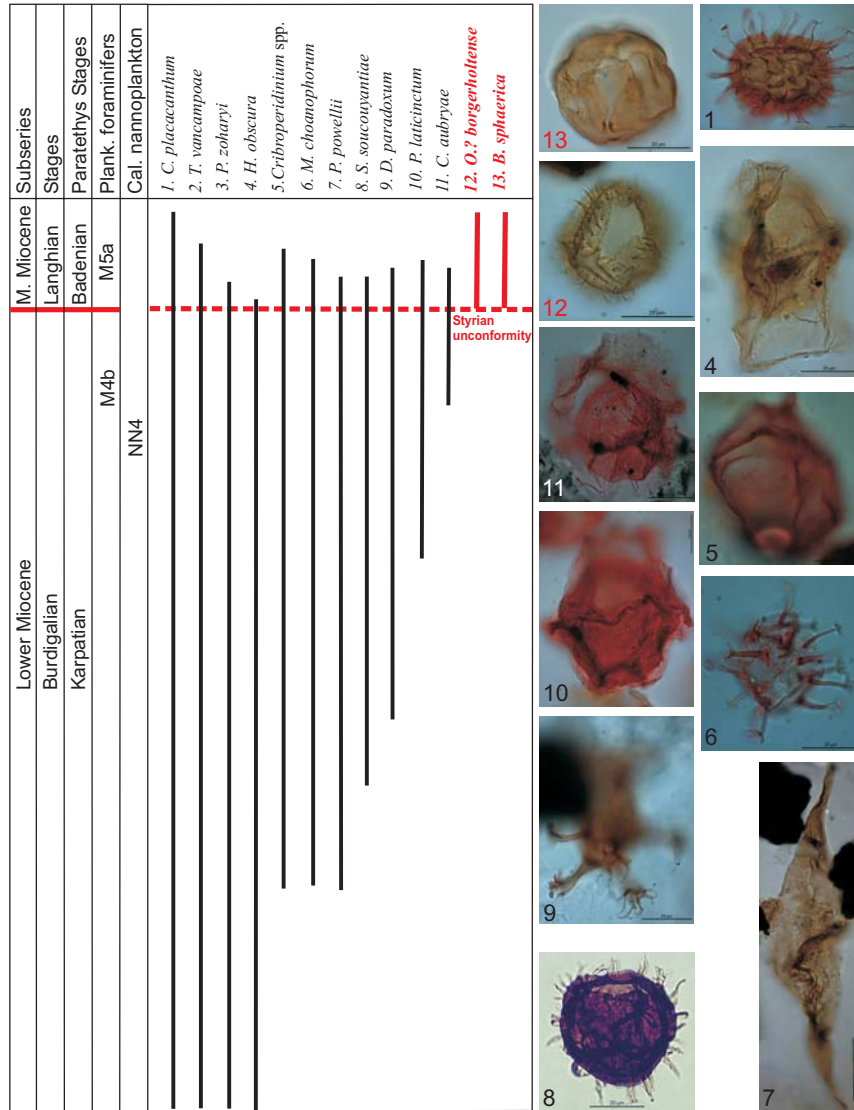
Fig. 38: Composite section of brickyard Wagna and distribution of selected dinoflagellate taxa.
Abb. 38: Sammelprofil Wagna und Verteilung ausgewählter Dinoflagellaten.

Both species are not recorded below the unconformity but occur persistently above, especially *O.? borgerholtense* (Fig. 39). Although the dinocyst diversity is relatively low in all the studied samples, a sharp decline is noted just below the Karpatian/Badenian boundary (Fig. 38).
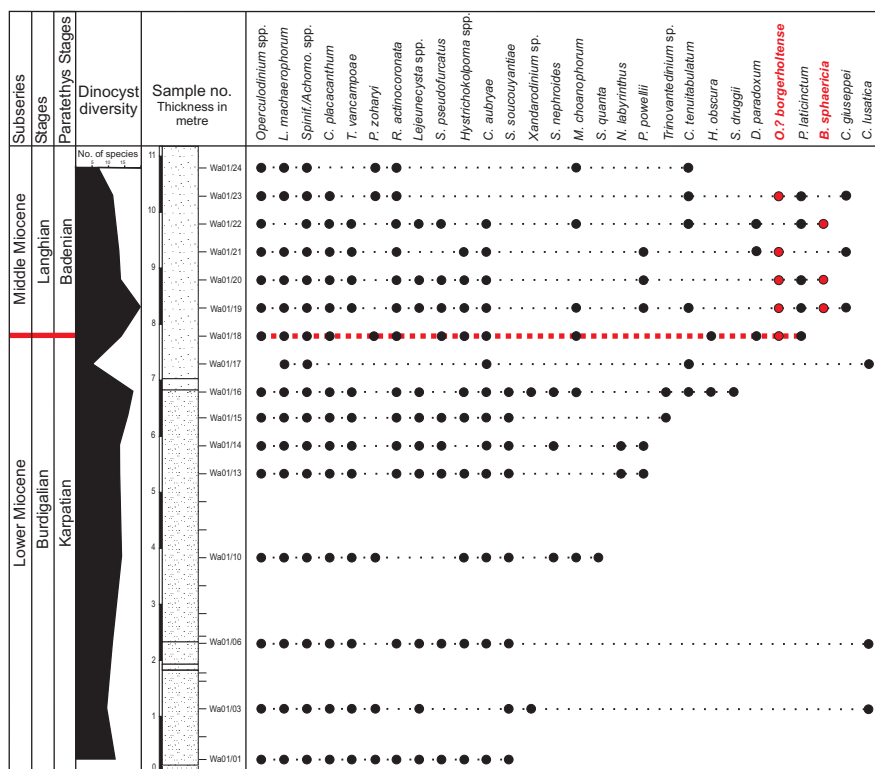
174

Fig. 39: Composite section of brickyard Wagna showing general lithology, dinoflagellate diversity and ranges of selected dinoflagellate taxa.
Abb. 39: Sammelprofil Wagna (generalisierte Lithologie, Dinoflagellaten-Diversität und Reichweiten ausgewählter Taxa).

Generally, the recorded dinoflagellate cyst assemblages (Figs. 38-39) reflect a neritic environment for the studied area. The sporadic occurrences of *Nematosphaeropsis labyrinthus* in the "Steirischer Schlier" (Karpatian) indicate that these beds were deposited in a deep water environment (SOLIMAN & PILLER 2007). In the Badenian parts of the sections *N. labyrinthus* is completely missing (Fig. 38).

A significant number of thermophile species, as *Tuberculodinium vancampoae*, *L. machaerophorum*, *Selenopemphix nephroides*, *P. zoharyi*, and *Melitasphaeridium choanophorum*, indicates subtropical conditions for all studied samples (e.g., EDWARDS & ANDRLE 1992; HEAD & WESTPHAL 1999). No distinct change between the Karpatian and Badenian parts of the sections was detected. A hint to a nutrient enrichment in the Karpatian part of the sections is the higher abundance and diversification of heterotrophic protoperidinioid dinoflagellate cysts, as *Lejeunecysta* spp., *Selenopemphix* spp., and *Trinovantedinium* spp. (e.g., WALL et al. 1977; SOLIMAN 2006).

Interpretation: Based on the occurrence of *U. graciliformis* and *P. primiformis* as well as rare occurrences of *Globigerinoides bisphericus*, the "Steirischer Schlier" is assigned to the Middle Karpatian. The succession above the unconformity can be clearly attributed to the Early Badenian (*Globigerinoides trilobus*, *Praeorbulina glomerosa circularis*), however, sedimentologic features as well as an incomplete evolutionary lineage from *Globigerinoides bisphericus* to *Praeorbulina* species clearly indicate a gap in sedimentation (Rögl et al. 2002; Spezzaferri et al. 2002, 2004).

Due to the co-occurrence of *S. heteromorphus* and *H. ampliaperta* the major part of the section can be attributed to zone NN4. Only in the uppermost part of the section NN5 is indicated by, e.g., *Helicosphaera waltrans* (Rögl et al. 2002; Spezzaferri et al. 2002, 2004).

The benthos/plankton ratio indicates inner shelf environments for the "Steirischer Schlier" (50 m maximum) what is in discordance with specific taxa indicating depths between 200 and 350 m (e.g., *Spirorutilis carinatus*, *Budashevaella* spp., *Gaudryinopsis beregoviensis*, *Karrerulina* spp., *Bathysiphion* spp.). One explanation for this discrepancy may be a depletion of planktonic taxa due to certain oceanographic parameters (e.g., carbonate undersaturation, corrosive bottom waters). The fauna also indicates cool climate for the Karpatian and high productivity of the surface waters. The latter may be related to a high nutrient concentration due to volcanic activity.

The presence of *N. labyrinthus* indicates neritic to oceanic environments (Edwards & Andrle 1992). The dominating heterotrophic taxa of dinoflagellates as *Lejeunecysta*, *Selenopemphix* and *Sumatradinium* indicate nutrient rich waters. In contrast to calcareous planktonic foraminifers, organic-walled dinocysts seem not to be affected by higher nutrient levels, which may have been induced by increased volcanic activities during the Karpatian.

Important references: Rögl et al. (2002), Spezzaferri et al. (2002, 2004), Latal & Piller 2003), Soliman & Piller (2007).

Stop 11 – Kreuzkogel Look-out

Topic: Paleozoic basement, Middle Styrian Swell and overview of the Styrian Basin (Fig. 40).
Locality: Kreuzkogel look-out, 2 km W of Leibnitz, 15°30'49''E, 46°47'21''N.
Lithostratigraphy: Sausal Group (Flügel 1988; Piller et al. 2004).
Chronostratigraphy: Ordovician to Lower Devonian (Schlamberger 1987).

Description: The Kreuzkogel look-out (496 m above s.l.) was built on Paleozoic metapelites of the Middle Styrian Swell. Low-grade metamorphic pelites, sandstones, acidic and basaltic volcanic rocks and some carbonates are united to the Sausal Group,

Fig. 40: View from the Kreuzkogel look-out near Leibnitz towards the east.
Abb. 40: Blick von der Kreuzkogel Warte bei Leibnitz gegen Osten.

which belongs to the Upper Austroalpine Nappe systems (Gurktal Nappe; FLÜGEL 1988). The Middle Styrian Swell extends from the Sausal to the north below Neogene surface rocks to the Plabutsch-Buchkogel hills W of Graz. This basement high was a more or less active barrier in Neogene times and separates the Western from the Eastern Styrian Basin.

Important references: SCHLAMBERGER (1987), FLÜGEL (1988).

Stop 12 – Clay Pit St. Stefan at Gratkorn

Topic: Limnic sedimentation at the north-western margin of the Styrian Basin; vertebrate-bearing paleosol (Fig. 41).
Locality: Clay pit St. Stefan (owned by the Wietersdorfer & Peggauer Zementwerke AG, 10 km NW Graz, 15°20'55"E/47°08'15"N.
Lithostratigraphy: Informally "Gravels of Gratkorn", Gleisdorf Formation ("Peterstal Member"; GROSS et al. 2007).
Chrono-/Biostratigraphy: Upper Sarmatian (Upper *Ervilia* Zone; *Porosononion granosum* Zone).

Description: The clay pit St. Stefan is situated in the Gratkorn Basin, which is a small, approximately 7 km long and 3 km wide satellite basin beyond the north-western margin of the Styrian Basin (Fig. 42). Paleozoic rocks (mainly carbonates and phyllites) roughly encircle the Gratkorn Basin.

Fig. 41: Clay pit St. Stefan at Gratkorn.
Abb. 41: Tongrube St. Stefan bei Gratkorn.

The knowledge of the basin filling is restricted to rare outcrops and shallow drillings in the area to the northeast of Gratkorn. In general, the lowermost part of the exposed, approximately 190 m thick rock column of the Gratkorn Basin consists of polymict gravels/conglomerates with some rounded outsized gneiss-boulders ($>1\,m^3$). These coarse clastics reach out from the Gratkorn Basin to the southeast into the transition to the Styrian Basin, where they are underlain by marine Lower Sarmatian marls (CLAR 1938; WINKLER-HERMADEN 1957; FLÜGEL 1958; 1959; GROSS et al. 2007; Fig. 42).

In the Gratkorn Basin, the basal clastics are overlain by up to 20 m thick, occasionally plant-bearing pelites. Alternations of gravels/conglomerates, sands and pelites follow above. In the adjacent transition to the Styrian Basin, cm-thick-intercalations of oolites are documented from that level (GROSS et al. 2007). The topmost strata are formed by medium- to fine-grained, mainly quartz-rich gravels/conglomerates with minor sandy and pelitic intercalations of Pannonian age. Matrix supported breccias and red earths occur attached to the Paleozoic basement and are interpreted as heterochronous Miocene talus deposits (CLAR 1933; FLÜGEL 1975).

Even though plant remains are described from the area of St. Stefan in the middle of 19th century (UNGER 1852), there were no biostratigraphical data available for the overall limnic-fluvial sediments in the Gratkorn Basin up to now.
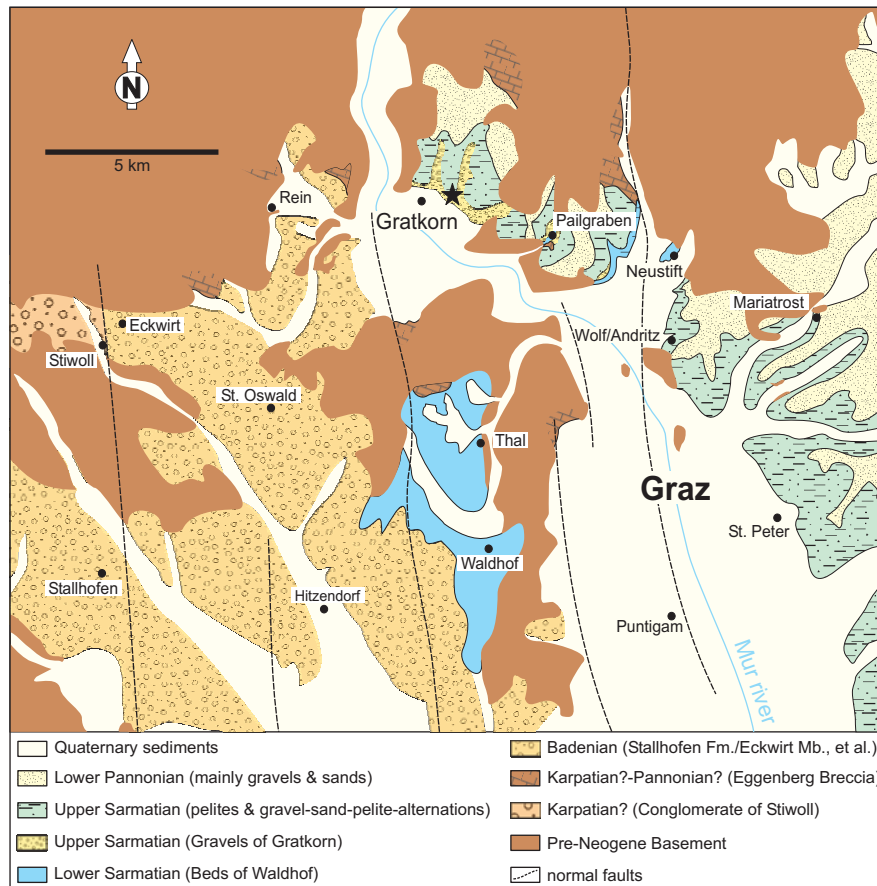
Fig. 42: Simplified geological map of the north-western margin of the Styrian Basin (based on KOLLMANN 1965; EBNER 1983; FLÜGEL & NEUBAUER 1984; KRÖLL et al. 1988; RIEPLER 1988 and own data).
Abb. 42: Schematische geologische Karte des nordwestlichen Beckenrandes basierend auf KOLLMANN (1965), EBNER (1983), RIEPLER (1988) und eigenen Daten.

Biota typical for the marine Paratethys or the brackish Lake Pannon – e.g., molluscs, foraminifers and ostracods – are completely missing as well as geochronologically dateable tuffitic layers (EBNER et al. 1998, 2000). Not only due to the lack of index fossils, but also because of tectonic movements and strong erosional events, stratigraphy in this badly exposed area is rather complex. Preceding conclusions based on lithologic correlations were often contradictory and assigned these strata to the Early, Middle or Late Miocene (HILBER 1893; CLAR 1938; WINKLER-HERMADEN 1957; EBNER 1983; FLÜGEL 1997; MOSER 1997).

However, the clay pit St. Stefan turned out to be a key section for an integrated stratigraphical approach due to its rather rich fossil content.

Badly sorted silts with isolated bones and teeth of amphibians, reptiles and mammals, calcareous endocarps of *Celtis* (hackberry) as well as a moderate diverse gastropod fauna are exposed at the base of the pit. This mottled layer is intensively bioturbated. Ferruginous concretions and root traces are common, indicating the development of a paleosol. In the northern part of the pit it is overlain by more than 1.5 m thick matrix supported, polymict debris flow gravels, which taper off to the south. Gravels and paleosol are superimposed by more than 15 m thick pelites with several intercalated lignitic layers, especially in the lower part of the section. Stumps of trees several metres in height occur sporadically. While the leaf-flora of the pelites is rather poor, more than 30 fruit and seed taxa beside 11 freshwater ostracod species (MELLER & GROSS 2006; GROSS, submitted) are recorded.

Gastropod-operculi (*Bithynia*) and fish fragments (Cyprinids) occur frequently in these fine clastics. Some layers contain mass occurrences of the fossil legume *Podocarpium podocarpum*. Especially two beds yielded good preserved specimens of freshwater crabs (*Potamon proavitum*; GROSS & KLAUS 2005; KLAUS & GROSS 2007). Unpublished palaeomagnetical analyses recorded normal polarity for the pelites of St. Stefan (MOSER 1997 and personal communication, R. SCHOLGER).

Very coarse gravels are developed below the base of this outcrop, indicated by geologic mapping of the surroundings, shallow borings at the close-by motorway and within the pit (unpublished logs and PEER 1998). Coarse gravels have been previously reported from the top of the clay pit but are no longer visible (FLÜGEL 1995).

Interpretation: The ostracod assemblages of the fine clastics – as well as the potamonid crabs – signify the formation of a shallow, sometimes richly vegetated, freshwater lake within warm, maybe subtropical climate. But, based solely on the recorded ostracod fauna, only a Miocene age can be suggested. Preliminary investigations of the mammal fauna from the basal beds of St. Stefan most probably point to a Late Sarmatian age (personal communication, G. DAXNER-HÖCK). Reference for an age not younger than late Middle Miocene is given by the occurrence of *Podocarpium*, which seems to vanish in the Pannonian Basin at the end of the Sarmatian (MELLER & GROSS 2006).

However, the terrestrial gastropod fauna from the basal paleosol proved a Sarmatian age of the sediments (HARZHAUSER et al., submitted). Palaeoecologically, these basal strata are interpreted to be deposits of a vegetated alluvial plain with a moist soil cover, some sun-exposed open areas and nearby limestone-screes.

Fig. 43: Section of the clay pit St. Stefan and schematic illustration of the ostracod and gastropod fauna.
Abb. 43: Profil der Tongrube St. Stefan und schematische Darstellung der Ostracoden- und Gastropodenfauna.
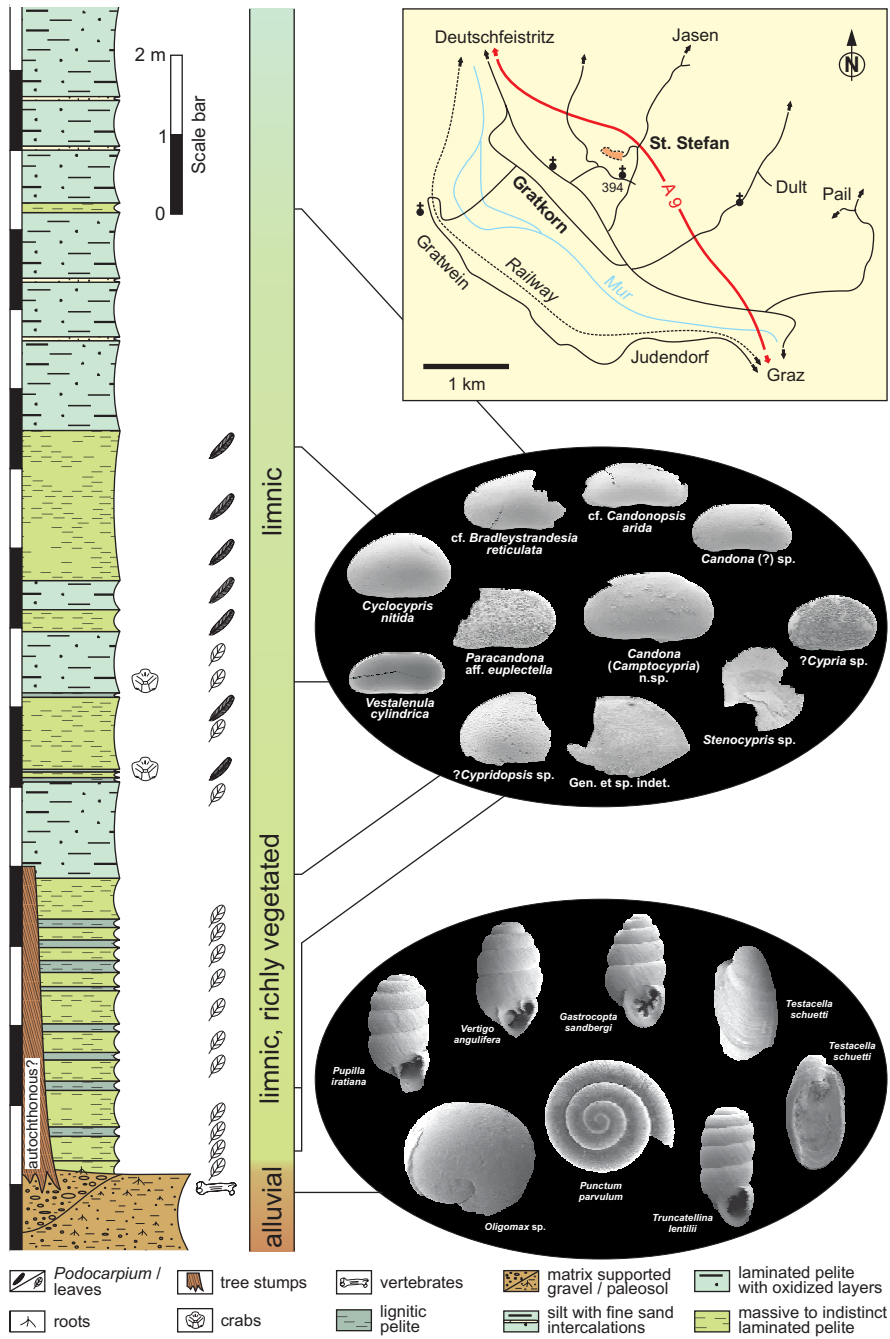
Considering the regional geologic situation (underlying Lower Sarmatian sediments, normal polarity of the pelites), the deposits at St. Stefan can be assigned to the basal Late Sarmatian (Chron C5An.1n; Upper *Ervilia* Zone).

At the end of the Early Sarmatian a period of intense regression is widely recognized in the Eastern Alpine realm. Erosion and basinward progradation of alluvial-fluvial/deltaic systems occurred ("Carinthian phase"; Winkler 1927a, c; Harzhauser & Piller 2004b; Strauss et al. 2006; Gross et al. 2007). Up to 100 m of coarse clastics were deposited in the Styrian and Vienna basins. Several authors correlate this drop in relative sea level with a pronounced uplift of the basement (e. g., Winkler-Hermaden 1951, 1957; Harzhauser & Piller 2004b). While the paleosol at the base of the clay pit St. Stefan documents a short period of landscape stability on an alluvial plain, the overlying pelites of the clay pit are supposed to be related to the transgression at the beginning of the Late Sarmatian. A limnic environment developed in the Gratkorn Basin, whereas in the open Styrian Basin marine depositional sediments predominated.

Important references: Clar (1938), Flügel (1997), Gross et al. (2007), Gross (submitted), Harzhauser et al. (submitted).

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Authors address:
Martin Gross, Ingomar Fritz, Bernd Moser & Hans-Peter Bojar
Landesmuseum Joanneum
Geologie & Paläontologie, Mineralogie
Raubergasse 10
A-8010 Graz
martin.gross@museum-joanneum.at

Mathias Harzhauser
Natural History Museum Vienna
Geological-Palaeontological Department
Burgring 7
A-1010 Vienna

Bernhard Hubmann, Werner E. Piller, Ali Soliman & Thomas J. Suttner
University of Graz
Institute for Earth Sciences
Geology and Palaeontology
Heinrichstraße 26
A-8010 Graz

Robert Scholger
University of Leoben
Department of Geosciences and Geophysics
Peter-Tunner-Strasse 25-27
A-8700 Leoben

Pailgraben near Gratkorn (Neogene tectonics).