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Preconference Excursion

Quaternary Periglacial Mammal Fauna and Miocene Lignites of East Styria.

by

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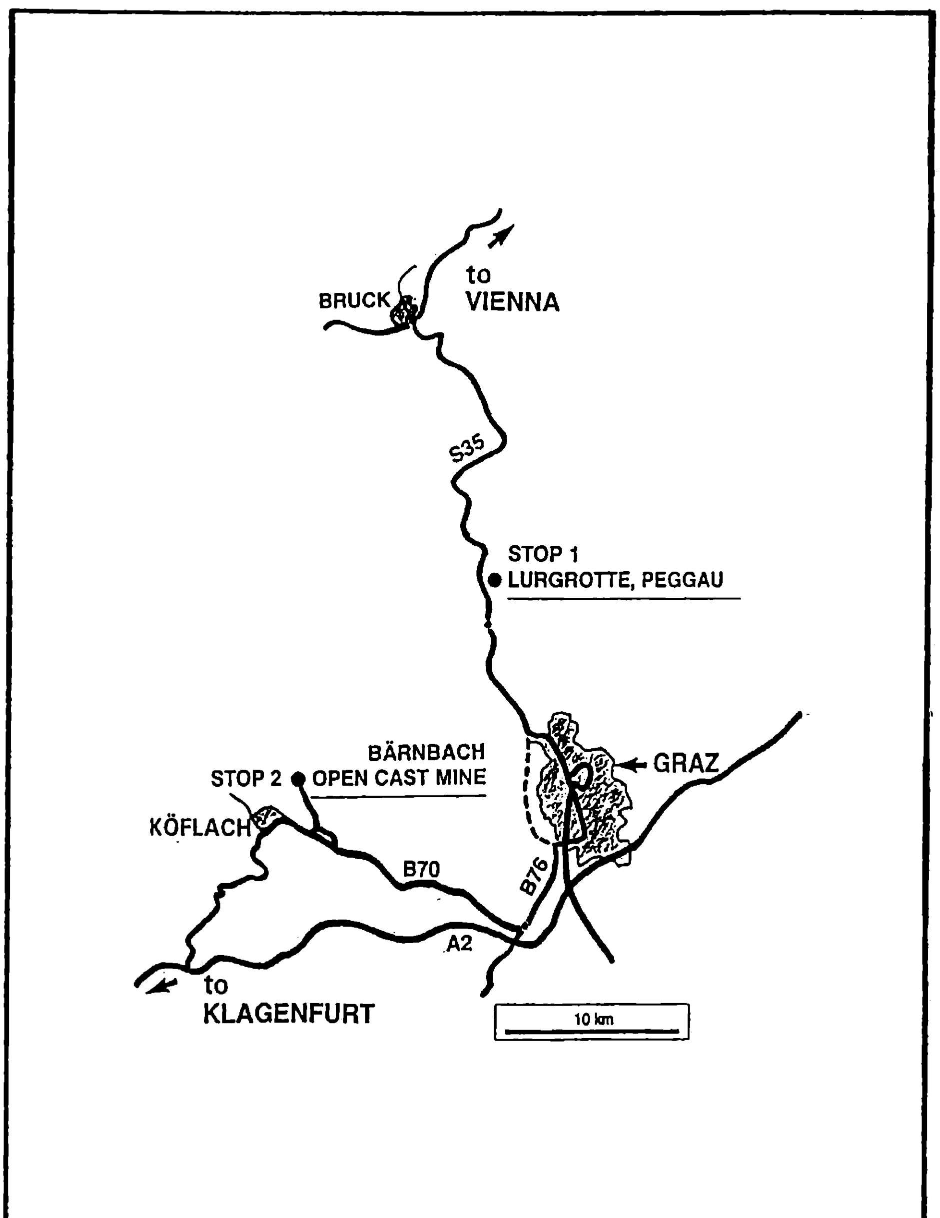

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1. The Lurgrotte in Peggau. Vertebrate taphanocoenoses from middle to latest Pleistocene cave deposits (F. A. FLADERER)

1.1.History of research

The Grazer Bergland is situated north and west of Graz, the capital of the Austrian Province Styria . The first scientific excavations in caves with more or less strtigraphic control and documentation of profiles were carried out in the early 1920s (ABEL & KYRLE 1931). Investigations under the leadership of biologists (F. Unger, 1838), prehistorians (G. Wurmbrand, 1871) or geologists (F. Hilber, 1890s, 1922) reach back more than 150 years. Though these excavations have never been documented by publications, finds of that early era cannot be ignored. The first evidence for Pleistocene man in the southeastern margin of the Eastern Alps is a pointed antler fragment which was excavated as early as 1837 in the Große Badlhöhle. However, it was not recognized as a Late Palaeolithic artefact prior to 1870.
At the Styrian provincial Museum Joanneum, M. MOTTL (1949, 1951, 1953, 1955, 1975), a former student of the Hungarian palaeontologist D. Kormos, carried out a basic survey from 1946 to the 1960s. This survey involved more than 20 caves in the Central Styrian karst and in Upper Styria.

In 1984, a small excavation at the entrance of the Große Badlhöhle marked the beginning of the most recent era. In 1986-1992, small-scale excavations in 5 caves with special reference to the Late Pleistocene palaeoclimatic development of the Styrian foothills (FUCHS 1989, FLADERER 1993, REINER 1995) were carried out. They were supported by the Styrian Nature Conservation authorities and by the Austrian Science Foundation (FWF P8246: Cave Sediments in the Grazer Bergland). Detailed results of the current investigations - revisions from earlier excavations as well as from later sampling - will be presented in the catalogue 'Pliocene and Pleistocene Faunas from Austria' (DÖPPES & RABEDER, in prep.).
In June 1997 an excavation in the fore-cave of the Lurgrotte near Peggau was conducted by the author together with G. Fuchs, Graz, for an assessement and for display purposes.

1.2. The regional framework

1.2.1. Geological and morphological setting

The maximum extension of the 'Grazer Bergland' is 50km from southwest to northeast (Fig. 1). It consists mainly of carbonates and clastic sediments of Silurian to Carboniferous age. Geologically, it is therefore known as 'Palaeozoic of Graz' (FLÜGEL 1975). Devonian rocks, mostly carbonates, are most widely spread. Parametamorphic basement-rocks form the fringe and also outcrop in the southeast. In the south the Pre-Tertiary formations dip under Neogene marine and terrestrial sediments. In the west, Palaeozoic rocks are covered by Cretaceous molasse-sediments, termed Kainacher Gosau (GRÄF 1975). In the east, the small Basin of Semriach and the larger Basin of Passail contain Late Tertiary sediments.

The Grazer Bergland is a hilly and mountainous countryside that is extensively covered by deciduous forests and coniferous plantations. The mountains reach an altitude of 1720m. The valleys are generally narrow and steep sided. The southwards orientated breakthrough valley of the Mur is a Late Tertiary feature. The tops of the hills as well as the cave-systems in the carbonate rocks occur at around 500-1000m. They correspond to Late Tertiary/Early Pleistocene river terraces and karstification levels. The most important cave-bearing formation is the Devonian Schöckelkalk. The karstification process started in the Upper Miocene and is still active.

The area was never connected to the Pleistocene Alpine glacier systems (Fig. 2). Periglacial features as aeolian, fluvial and slope deposits are common._During the last glacial cycle a fluvial accumulation of up to more than 30m of gravels and sands covered the Interglacial/Early Würmian Mur valley floor (MAURIN 1994).

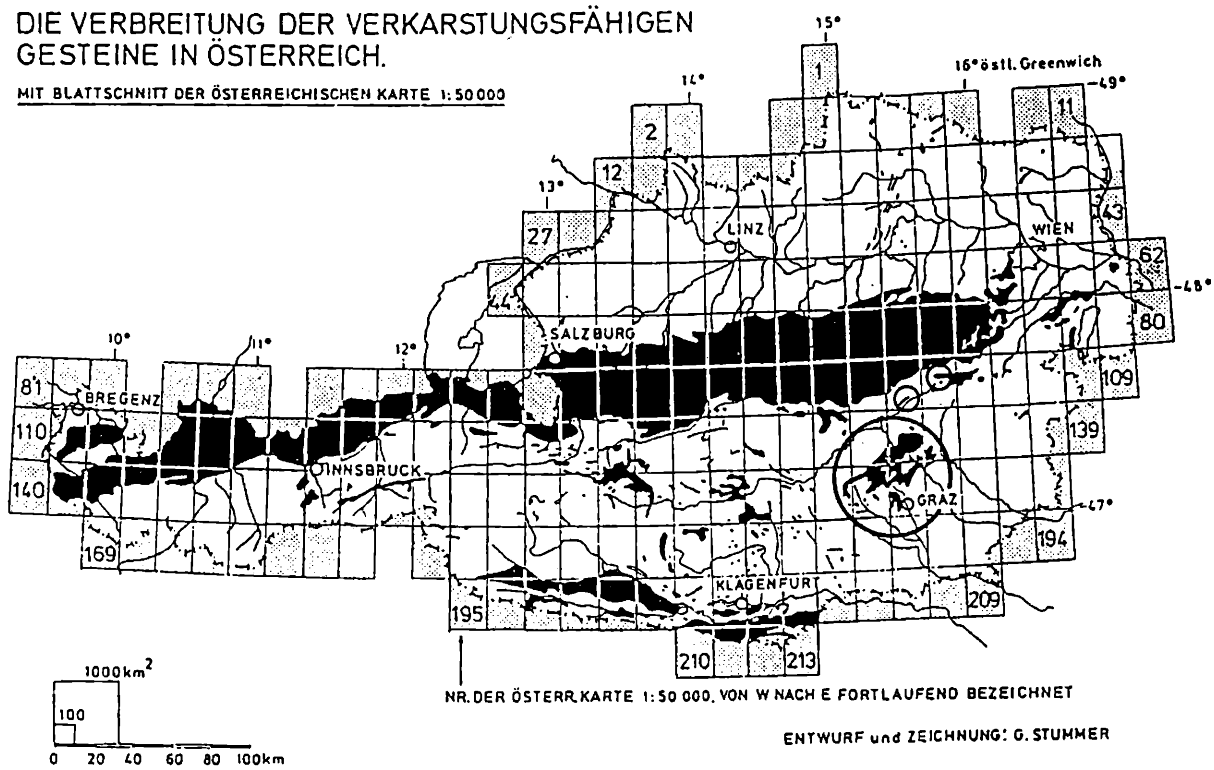

Fig. 1. Karstified (carbonate) rocks in Austria (after TRIMMEL 1978, modified). Large circle: Central Styrian karst, small circles: caves in the Mürzalpen. In the northeast (Lower Austria) evidence of Pleistocene vertebrate taxa is restricted to loess deposits, in the shaded areas to cave sediments, and to isolated sites in river sands and gravels.

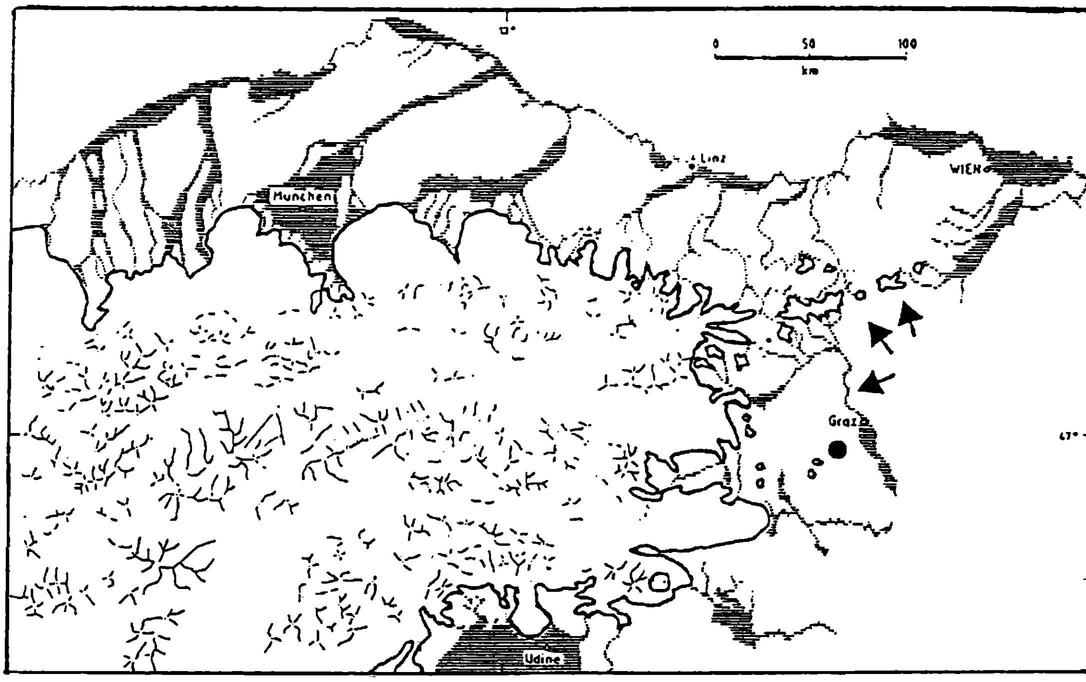

Fig. 2. The Eastern Alps during the Würm Full Glacial. Maximum extension of glaciers, nunataks, and river terraces ('Niederterrasse'); major local glaciers in the east (after van HUSEN 1997, simplified). Arrows point to the palaeontological cave sites. The large dot
indicates the Full Glacial pollen-site Neurath near Stainz (compare Fig. 1).

1.2.2 The current climatic setting

In the Central European context, the Grazer Bergland is climatically protected against Atlantic marine influences from southwest to northwest. It is more open to the continental influence from northeast to the south. Thus, wind activity in lower and mid-altitudes is less significant than under Atlantic regime. Temperature inversions in which a layer of warm air traps cooler air near the surface and prevent the normal gradient are frequent. The annual mean precipitation is around 800-1000mm. Lowest values in January and a maximum in early summer express more continentality than western Austria or its central regions (WAKONIGG 1978). Mean temperature in January is ca. -2/-3°C, in July +16/18°C. Daily temperature ranges in low altitudes may exceed 20°C. About 55% of summer days and 35% of winter days have sunshine. In winter, the valley floors are generally cold and foggy. The small basins in the Highland and the valley floors of the central Mur valley, e. g. the Basin of Peggau-Deutschfeistritz, correspond climatically with the Basin of Graz. The climate is generally described as temperate continental (PASCHINGER 1974).

2.3 Vertebrate sites

All caves studied are located in the submontane vegetational zone dominated by deciduous forests (500-1100m). Due to the tectonic, geomorphologic and
50km and 30km NNW, close to the Mürz valley (Fig. 1). Taphanocoenoses from the Luegloch near Köflach (550m), 25km to southwest on the western margin of the Central Styrian karst give evidence of the vertebrate faunas of the last Glacial. (Tab. 1).

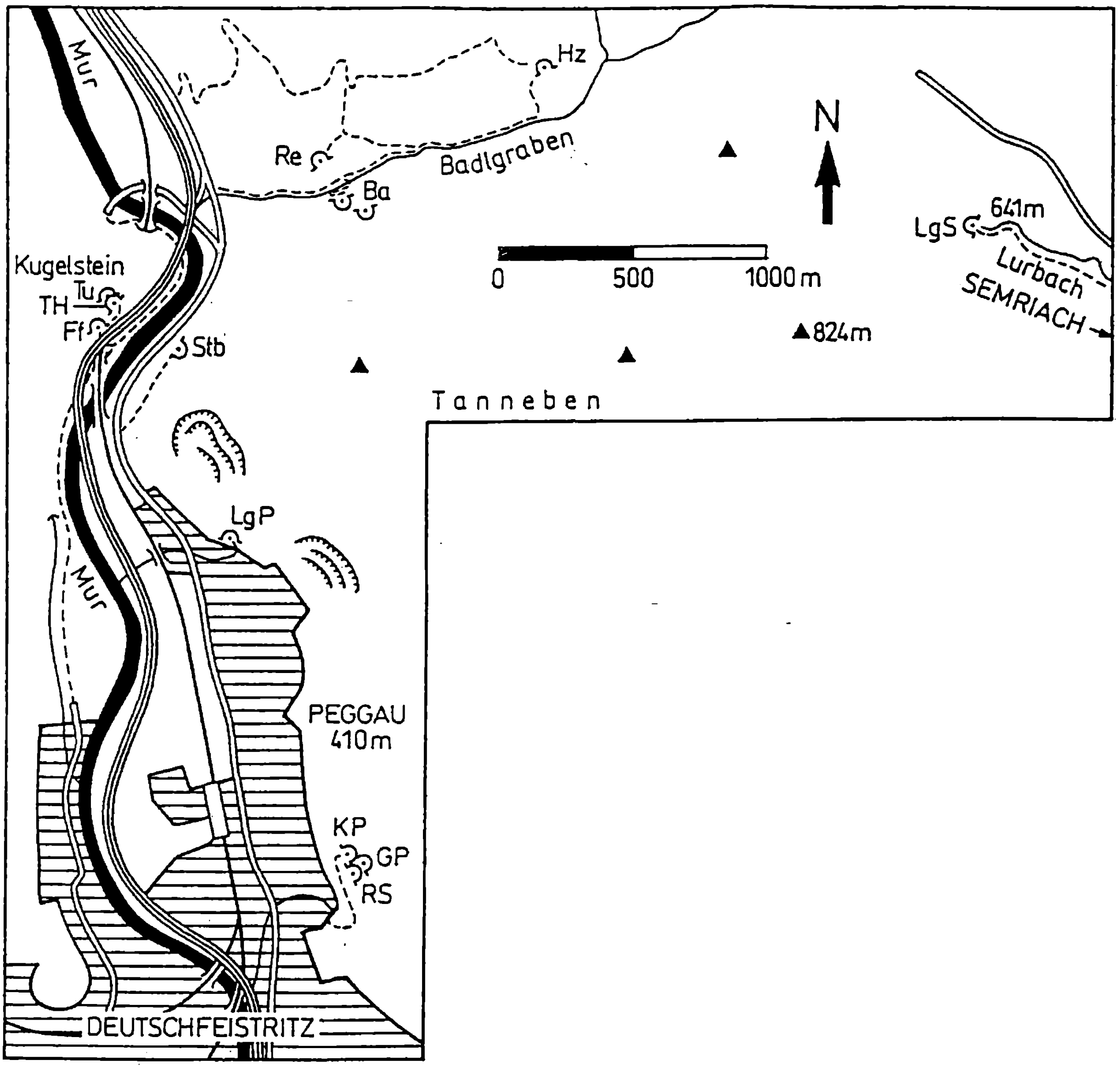

Fig. 3. Palaeontological cave sites in the region Peggau-Deutschfeistritz-Frohnleiten. Ba - Große Badlhöhle, Ff - Fünffenstergrotte, GP - Große Peggauerwandhöhle, Hz - Holzingerhöhle, KP - Kleine Peggauerwandhöhle, LgS - Lurgrotte-Semriach, LgP - Lurgrotte-Peggau, Re - Repolusthöhle, RS - Rittersaal, Stb - Steinbockhöhle, TH - Tropfsteinhöhle am Kugelstein, Tu - Tunnelhöhle.

1.3. Faunas, diversity and palaeoclimatic significance

1.3.1 The evidence

The list of vertebrate taxa from Middle to Late Pleistocene cave sediments in the Central Styrian karst and the Mürzalpen (Knochenhöhle, Große Ofenbergerhöhle) comprises at least 43 species of birds and 74 species of mammals (Tab. 1). The quality of the information is strongly influenced by the actual status of the investigations. There is only one Middle Pleistocene faunal complex

(Repolusthöhle, excavated by M. Mottl in 1950-54; unstratified later finds are listed without documentation by RABEDER & TEMMEL, in prep.). Seven complexes are considered to be Interglacial to older Middle Würmian (Drachenhöhle, Frauenhöhle bei Semriach, Repolusthöhle, Kleine Peggauerwandhöhle, Rittersaal, Tropfsteinhöhle am Kugelstein, Tunnelhöhle), eight as upper Middle Würmian, six as Full Glacial, four as Late Glacial.

	M Pleist	IG - loM W	Up MW	Full Gla c	Kn	GOf	Ba	Late Gla c
number of sites (complexes)	1 -	7	8	6	1	1	1	4
time span (absolute age) in 1,000 years before present (BP)	250-130 appr.	130-40	-40-25	25-13	14.1 OD	13.7 OD	12.4 All/YD	13-10
Salmo trutta f. *fario* (River Trout)				•			•	•
Thymallus thymallus (Grayling)							•	•
Leuciscus leuciscus (Dace)							•	•
Cyprinidae indet.					•			
Perca fluviatilis (River Perch)							•	
Pisces indet.				•				•
Anura	?			•				•
Squamata				•				
Natrix sp. (adder)							•	•
Ophidia	?							
Anas erythropus (Lesser White-fronted Goose)						•		
Anas platyrhynchos (Mallard)						•		
Anas crecca/qerquedulina (Teal/Garganey)							•	•
Aegypius monachus (Black Vulture)			?	?				
# *Gyps melitensis aegypioides* (fossil Griffon Vulture)	•:							
Aquila sp.(eagle)	•							•
Accipiter nisus (Sparrow Hawk)				?				?
Falco subbuteo (Hobby)			•					
Falco peregrinus (Peregrine Falcon)				cf.				
Falco tinnunculus (Kestrel)						•		•
Lagopus mutus (Ptarmigan)					•	•	•	•
Lagopus lagopus (Willow Grouse)		-	•	•	•	•	•	•
Tetrao tetrix (Black Grouse)	•						cf.	•
Tetrao urogallus (Capercaillie)		-	•					
Tetrastes bonasia (Hazelhen)						•		•

Coturnix coturnix (Partidge)			?	?			•	•
Gallinula chloropus (Moorhen)			?	?		•	•	•
Crex crex (Corncrake)					•			•
Scolopax rusticola (Woodcock)						•		•
Gallinago media (Great Snipe)						•		•
Lymnocryptus minimus (Jack Snipe)						•		•
Tringa sp. (Shank)						•		•
Nyctea scandiaca (Snowy Owl)					•	•		•
Asio flammeus (Short-eared Owl)						•	•	•
Strix uralensis (Ural Owl)								•
Aegolius funereus (Tengmalm's Owl)								•
Dendrocopus leucotos (White-backed Woodpecker)								•
Eremophila alpestris (Shore Lark)						•		•
Hirundo rustica (Swallow)						•		•
Delichon urbica (House Martin)						•		•
Lanius sp.(Shrike)								•
Cinclus cinclus (Dipper)						•		•
Prunella collaris (Alpine Accentor)							•	•
Acrocephalus arundinaceus (Great Reed Warbler)						•		•
Phoenicurus ochruros (Black Redstart)						•		•
Oenanthe oenanthe (Wheatear)						•		•
Monticola saxatilis (Rock Thrush)								•
Parus caerulaeus (Blue Dit)								•
Emberiza sp. (Bunting)						•		•
Montifringilla nivalis (Snow Finch)			•			•		•
Garrulus glandarius (Jay)								•
Nucifraga caryocatactes (Nutcracker)								•
Pica pica (Magpie)								•
Pyrrhocorax graculus (Alpine Chough)				•	•	•		•
Pyrrhocorax pyrrhocorax (Chough)			•	•		•		•
Coloedus monedula (Jackdaw)								•
Corvus corax (Raven)			•					
Talpa europaea (incl. f. *magna*) (European Mole)		•	•	•			•	•
# *Talpa minor* (Lesser Mole)	?							
Sorex araneus (Common Shrew)	?		•	•		•	•	•
Sorex alpinus (Alpine Shrew)						•		•
Sorex minutus (Pigmy Shrew)	?						•	•
Sorex minutissimus (Least Shrew)							•	•
# *Sorex hundsheimensis* (Hundsheim Shrew)	?							

Neomys fodiens (Watershrew)							•	•
Erinaceus europaeus (incl. *Erinaceus* sp.) (Hedgehog)			•					•
Myotis myotis (Large Mouse-eared Bat)						•		•
Myotis bechsteini (Bechstein's Bat)	?		?			•		•
Myotis nattereri (incl. aff. *nattereri*) (Natterer's Bat)			?			•		•
Vespertilio sp. (incl. cf. *V. murinus*, Parti-coloured Bat)				•		•		•
Eptesicus serotinus (Serotine)						•		•
Eptesicus nilssoni (Northern Bat)			?					
Barbastella barbastellus (Barbastelle)	?					•		•
# *Barbastella schadleri* (Schadler's Bat)			?					?
Plecotus auritus (incl. *Plecotus* sp.) (Longeared Bat)				•		•		•
# *Plecotus abeli* (Abel's Bat)			?					?
Marmota marmota (Alpine Marmot)	•	•	•	•	•	•		•
Citellus citellus (European Suslik)	cf.			•				•
Castor fiber (Beaver)	•							
Glis glis (Fat Dormouse)	?					•		•
Microspalax leucodon (Lesser Mole Rat)	?		?	•				
# *Cricetulus bursae* (Schaub's Dwarf Hamster)	?							
Cricetus cricetus (Common Hamster)	•						•	•
# *Cricetus cricetus major* (Giant Mamster)	•	•	•	•				
Apodemus sylvaticus (incl. *Apodemus sp.*) (Woodmouse)	?						•	•
Apodemus flavicollis (Yellownecked Fieldmouse)	?							
Clethrionomys glareolus (Bank Vole)		•	•	•			•	•
Arvicola terrestris (Ground Vole)	•	•	•	•	•	•	•	•
Microtus arvalis/agrestis (Common Vole/Field Vole)		•	•	•	•	•	•	•
Microtus gregalis (Gregarious Vole, Narrow-skulled Vole))		•	•	•		•	cf.	•
Microtus nivalis (Snow vole)		•	•	•	•	•	•	•
Microtus oeconomus (Northern Vole, Root Vole)		cf.				cf.	cf.	cf.
Microtus (Terricola) sp./*Pitymys* sp. (Pine Vole)			•					cf.
Microtus (Terricola) cf. *multiplex* (Alpine Pine Vole)							•	•
Dicrostonyx torquatus f. *gulielmi* (Arctic Lemming)					•			•
Sicista betulina (Northern Birch Mouse)				•		•	•	•
Hystrix cf. *vinogradovi* (Small Porcupine)	•	•						
Ochotona pusilla (Steppe Pika)	?		•	•	•	•	•	•

Lepus timidus / sp. indet. (Blue Hare)	•	•	•	•	•	•	•	•
Lepus europaeus (Brown Hare)					•			•
# *Canis mosbachensis* (Mosbach Wolf)	•							
Canis lupus (Wolf)		•	•	•		•	•	•
Cuon alpinus (incl. *Cuon* aff. *alpinus)* (Reddog)	•		?	?				?
Vulpes vulpes (Red Fox)	•	•	•	•	•	•		•
Alopex lagopus (Arctic Fox)				•	•	•		•
Mustela erminea (Stoat)					•	•	•	•
Mustela nivalis (Weasel)	•		•	•	•	•	•	•
Putorius sp. (Polecat)	•							
Martes martes (incl. *Martes* sp.) (Pine Marten)	•		•	•				•
Meles meles (Badger)	•							•
# *Gulo* cf. *schlosseri* (Schlosser's Wolverine)	•							
Gulo gulo (Wolverine)			•	•				?
Ursus arctos (incl. # f. *priscus*) (Brown Bear)	•		•	•	•			•
# *Ursus deningeri* (Deninger's Bear)	•							
# *Ursus spelaeus* (Cave Bear)		•	•	•				
# *Panthera leo spelaea* (Cave Lion)	•	•	•	•				
# *Crocuta crocuta spelaea* (Cave Hyena)	•		•					
Panthera pardus (Leopard)		•						
Lynx lynx (Northern Lynx)	•							cf.
Felis silvestris (Wild Cat)	•							
Cervus elaphus (Red Deer)	•	•	•	•				•
Rangifer tarandus (Reindeer)	cf.		•	•	•			
# *Megaloceros giganteus* (Giant Deer)	•	•	?					
Alces sp. (incl. *A. alces*) (Moose)								cf.
Capreolus capreolus (Roe Deer)	•		?	?				
Sus scrofa (Wild Boar)	•	•						•
Capra ibex (Ibex)	•	•	•	•	•			•
Rupicapra rupicapra (Chamois)	•		?	cf.				•
# *Bison schoetensacki* (Schoetensack's Bison)	cf.							
# *Bison priscus* (incl. *priscus* seu *bonasus*) (Steppe Bison)	•	•	?	•				•
Bos primigenius / Bison sp. (Aurochs/Bison)								•
# *Equus mosbachensis* (Mosbach Horse)	cf.							
# *Equus* sp. (Horse)		•	•	•				
# *Coelodonta antiquitatis* (Wholly Rhino)			•	•				
# Elephantide	•	•						
# *Mammuthus primigenius* (Mammoth)				•				
Macaca sylvanus (European Macaque)		•						

Tab. 1. Middle to Late Pleistocene taxa recorded from the Central Styrian karst and the Mürzalpen (Knochenhöhle, Große Ofenbergerhöhle) (after MOTTL 1975, FLADERER 1993-in prep., BOCHENSKI & TOMEK 1994, MLÍKOVSKY 1994, REINER 1995, RABEDER & TEMMEL, in prep.; critically compiled by the author). Note bias by taphonomic differences caused by sedimentation and by age (only one Middle Pleistocene faunal complex from the Repolusthöhle, excavated in 1950-54 *versus* modern small-scale excavations that yielded mainly Middle Würmian and Full to Late Glacial remains). Abbreviations: All/YD - Alleröd/Younger Dryas, Ba - Große Badlhöhle (lower entrance), Full Glac - Full Glacial, Gof - Große Ofenbergerhöhle, IG - Riss-Würm-Interglacial, Kn - Knochenhöhle near Kapellen, Mpleist - Middle Pleistocene, Late Glac - Late Glacial in general, loMW - lower Middle Würm, OD - Oldest Dryas, UpMW - Upper Middle Würm, # - fossil species/form, • - evidence, ? - uncertain stratigraphical position. Species absent in the regional Holocene communities are underlined.

1.3.2. The biological and archaeological bias

1. Taphocoenoses from cave sediments are the sum of 'selected' specimens of the local fauna. Some species needed or used caves occasionally as habitats. This increased the chance that their remains become fossilized (e. g. cave bears, wolves, foxes, bats, owls). Others usually did not use caves themselves, but their predators did (e. g. hares, deer). Others may or may not be imported into the cave because their habitats were several kilometers away. Taphonomic patterns on the Late Glacial micromammals from the Große Badlhöhle, as the frequency and the intensity of the molar-corrosion, suggest Canidae and owls, too, as predators (REINER & BICHLER 1996).

2. The site formation is highly complex. In this process, the setting of cave sediments and their mechanical, chemical and biological aspects are involved. Sediment profiles consist largely of gaps (FUCHS 1989; FLADERER 1994b, Fig. 4). Consequently, the palaeoclimatic record is fragmentary.

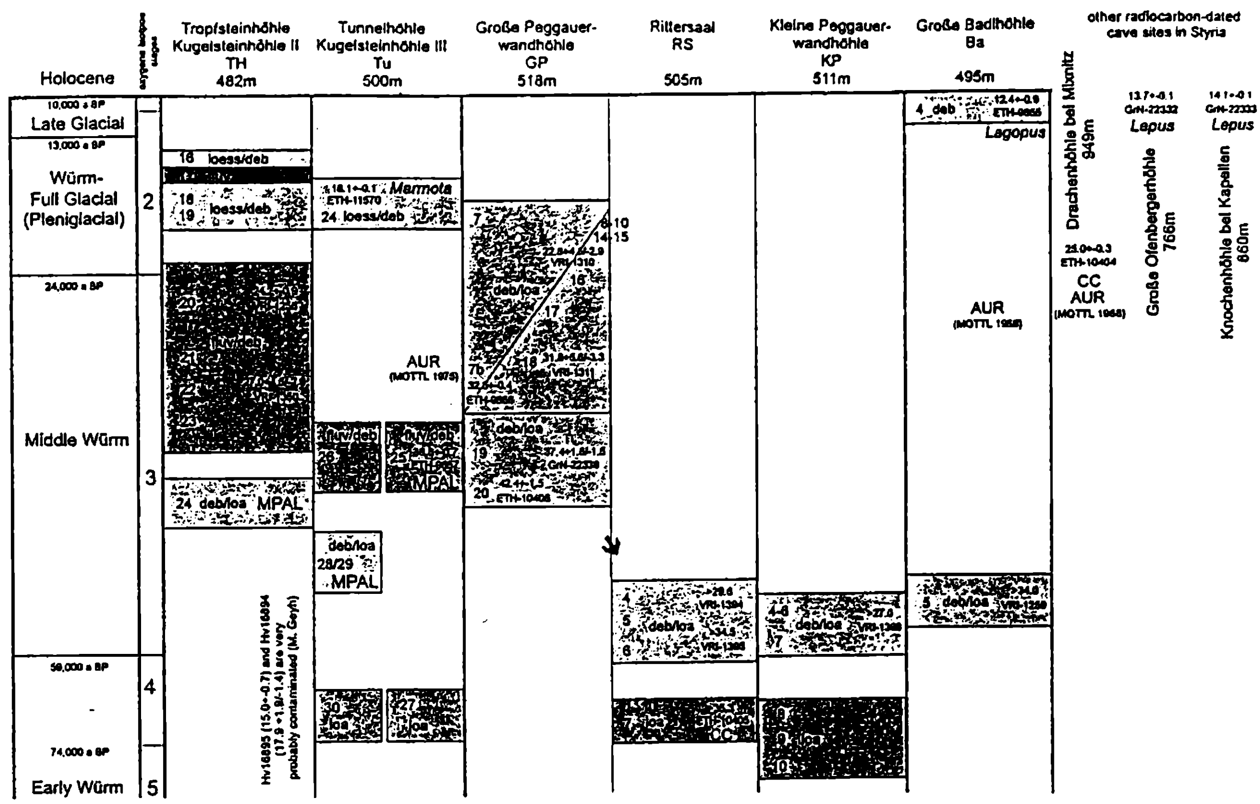

Fig. 4. Chronology of cave sediments in the Central Styrian karst; excavations 1984-1993. Numbers indicate sedimentary units. They are treated like site-entities that are taphonomically influenced by the surrounding ones. Radiocarbon dates in 1,000 years, with sample numbers of laboratory. Unless indicated otherwise (CC, genus name) data from cave bear remains. The fillings indicate the type of sediment: deb - debris, mainly autochthonous limestone dominates, fluv - fluvial sands and silts, loa - loam or hardened clay, loess - silty deposits with a distinctly aeolian influence. Further abbreviations: AUR - Aurignacian, CC - charcoal, MPAL - Middle Palaeolithic.

3. AMS and conventional collagen radiocarbon dates pertain to only one bone from one individual from one species or a sample of different bones. All 17 radiocarbon dates from the observed karst areas derived from isolated finds. With two exceptions bone material was used: charcoal samples from the Early upper Palaeolithic fire place in the Drachenhöhle and from a deep layer in the Rittersaal (Fig. 4). Sampling for radiocarbon dating began less than 10 years ago.

4. Excavations in caves that meet modern criteria are much more expensive than common open air collecting and excavating.

1.4. Discussion

A. Middle to Late Pleistocene faunal evidence in Central Styria is derived in nearly 100% of the cases from cave sediments. Large mammal finds from Pleistocene river terraces are not yet dated. Generally, their significance is limited.

B. Accuracy of age differences and resolving power rapidly decrease with the absolute age (Tab. 1).

C. A few species or forms are first rank climate indicators. *Lagopus lagopus*, *Dicrostonyx* sp., *Sorex minutissimus*, *Gulo gulo*, *Alopex lagopus*, *Rangifer tarandus* and the large form of *Lepus timidus* are boreal species that now range from the northern temperate to the arctic climate in tundra, forest tundra and taiga. They are absent in the Holocene Central European communities. The avian species *Anser erythropus*, *Nyctea scandiaca* and *Eremophila alpestris* are rare to very rare winter visitors that breed in northern biotopes. Other species inhabit at present alpine habitats at altitudes above the timber line: *Lagopus mutus*, both *Pyrrhocorax* species, *Marmota marmota*. A third group of species belongs to the East European to Central Asian steppe-communities and are adapted to strong seasonality: *Microspalax*, *Ochotona* and *Microtus gregalis* (Not yet recorded from Styrian sites are the Jerboa *Allactaga* and the *Saiga*-antilope; they have scarcely been recorded from Lower Austrian lowland sites and from low-lying areas near cave sites. *Microtus oeconomus* is a reed and marsh dweller within a core area between Northern and Eastern Europe and Central Asia. Isolated relict populations are still found in Central Europe (Lake Neusiedl). *Citellus citellus* inhabits some open regions in northern and eastern Austria, but typically lives in Eastern European open country.
To a certain percentage, fossil taphocoenoses contain temperate woodland species (*Tetrao urogallus, Scolopax rusticola, Garrulus glandarius, Sorex araneus, Glis glis, Clethrionomys glareolus, Meles meles, Martes martes, Lynx lynx, Sus scrofa*) but a few of the abundant species of the extant fauna, like the squirrel, are lacking in the local fossil record of the Late Pleistocene up to now. Thus, humid periods with a stronger Atlantic influence are either nor recorded or they are masked by the „continental“ record.

D. Middle to Late Pleistocene taxa partly reflect speciation (*Ursus deningeri* into *U. spelaeus*, *Canis mosbachensis* into *C. lupus*). Within the Late Pleistocene (<100ka), shifting of skeletal morphology features can be observed. In *U. spelaeus* the complexity of the premolars and molars cusp pattern increases within a time span of around 10,000 years. The evaluation of such phylogenetic shifts provides useful chronological information (RABEDER 1989).

E. Taphocoenosis spectra from Middle Würmian strata reveal differences to the preceeding time span. The 'mediterranean' temperate Macaques and porcupines are absent; boreal and montane species (cave bear, polar fox, reindeer, ptarmigan etc.) became more frequent. Full Glacial communities were dominated by boreal-alpine species. The cave bears' habitat shifted from its Middle Würmian alpine range to the foothills. Younger Full Glacial (18,000-13,000 BP) to Late Glacial communities lack cave bears (FLADERER 1995); up to now, no finds of lion, hyena, giant deer and rhino exist. It is concluded that these species become extinct in the region at the height of the Full Glacial.

F. The percentage of distinct tooth-morphotypes within the Microtinae of one taphocoenosis, shows pecularities that strongly correlate with the frequency of other climate indicators. It is caused by different ecological demands of the arvicolid species, which reflect plant cover and humidity (Tab. 2).

Tab. 2. Ratios of *Microtus*-morphotypes from 3 Styrian caves. arv/agr - *arvalis/agrestis*, greg - *gregalis*, niv - *nivalis*, oec - *oeconomus*.

site	AMS C14	arv/agr	greg	niv	oec
Große Badlhöhle	12.4+-0.1	60.9	1.0	37.1	1.0
Große Ofenbergerhöhle	13.7+-0.1	29,6	0.2	70.0	0.2
Knochenhöhle	14.1+-0.1	35	-	65	-

H. 54% of the taxa mainly identified to the species level of the (?Oldest Dryas-) taphocoenosis of the Knochenhöhle near Kapellen (GrN-22333: 14,070 +- 100 BP) do not occur in the Holocene fauna. In the Große Ofenbergerhöhle (GrN-22332: 13,690 +- 100 BP) the 'non-Holocene' part in the (?Oldest Dryas-) association even exceeds 32%. It decreases to 28% in the youngest taphocoenosis from the Große Badlhöhle, whose AMS-date corresponds to the Bölling-Alleröd-interstadial complex (ETH-9655: 12,430 +- 95 BP) (FLADERER & REINER 1996).

H. The changes are mainly due to the absence of individual 'Pleistocene' species and much less due to the occurrence of 'Holocene' species. The faunal diversity in the Late Glacial periglacial foothills was greater than in the Holocene. It is expected that the vegetation was more diversified due to the relief of the landscape and to the stronger climatic seasonality. It cannot be excluded that the differences in the species spectra between the northern Knochenhöhle and Ofenbergerhöhle and the Große Badlhöhle is also due to the distance of 30-50km. This would mean a much lower faunal similiarity across the regions and, again, a higher degree of heterogeneity within a region than is the case in the Holocene.

I. Palaeobotanical data lag behind the zoological analyses: Because of the destruction of the pollen exines, palynological prospection in the sandy sediments yielded no evidence. Analyses from the loamy Middle Würmian sediments from the caves (ca. 510m a. s. l.) in the cliff of Peggau (Peggauer Wand) are in progress. The input via the fur and the dung of the cave bears is partly preserved in the sediments. It mainly reflects part of the forage plant spectrum of the animals. The herb and perennial flora is diverse. It mainly comprises a large amount of Compositae and Dipsacacaeae but only a few species of trees, like *Pinus, Betula, Alnus* and rarely *Tilia* (I. Draxler, Vienna). The communities strongly resemble parts of the extant subalpine meadows (1.500-2.000m). Terrace-sediments 16km SSW of Peggau-Deutschfeistritz, in the West Styrian hills, at a height of ca. 380m, contained an association from 19ka BP. It consists of a diversified herb pollen flora, dominated by grasses and sedges, without any thermophilous trees. It indicates forest-free tundra-like conditions at the height of the Full Glacial (DRAXLER & van HUSEN 1989). A preliminary study of the younger pollen assemblage from the Knochenhöhle near Kapellen (860m) (?Oldest Dryas) shows for that time close analogies to the extant alpine vegetational zone at 2000-2400m.

J. In recent excavations special attention was given to malacology that deals with the immediate surroundings of the caves. Analyses of the mollusc taphocoenoses suggest climatically similar habitats for the Central Styrian uplands in the Full Glacial and the loess areas of Lower Austria (FRANK, in prep.). Due to the rocky and sometimes steep environments a variety of petricole species is present. In the (?Oldest Dryas) associations from the Knochenhöhle near Kapellen the terrestruak snails indicate open as well as half-open to shady habitats. The most striking feature of the Last Glacial interstadial fauna of the Große Badlhöhle, which contains a high percentage of taxa reflecting open, but cool habitats, are aquatic molluscs including a *Congeria*-species (FRANK 1993).

K. Shifts within the Late Würmian communities correlate with sedimentological and glaciological evidence of climatic fluctuations in the Eastern Alps (van HUSEN 1997). The last Glacial Alpine ice-shield, which stretched from Western Europe over the Eastern Alps, ended abruptly near 15° east, as shown by the end-moraines of the Enns-, Mur- and Drau-glaciers (Fig. 2). Single mountain-glaciers in the east intercede with the loess area of the Middle Danube lowland in the north and the Styrian foothills and lowlands in the east and south. Apparently, the ice decayed rapidly after the cold phase at ca. 21ka BP and the more prolonged 'Hochstand' until ca. 17ka BP.. A distinct glacier readvance and standstill ('Gschnitz') very probably reflects the Oldest Dryas of NW Europe (16ka - ca.14ka BP). In the periphery of the Alps, the deglaciation is accompanied by an *Artemisia*-pioneer phase. This is followed by a rapid increase of *Pinus*. There is no evidence for permafrost conditions on the floors of the main valleys with the Bölling, which defines the beginning of the Late Glacial,. Of the following two glacier readvances ('Daun' and 'Egesen'), the second is glaciologically known for its rock glacier activity (Blockgletscher). This occurred during drier, more continental conditions; the precipitation was ca. 30 percent less than today and the mean annual temperature was 2.5-4°C lower (van HUSEN 1997).

L. Prehistorically, the Repolusthöhle near Frohnleiten to the north of Peggau (Fig. 3) is the site with the oldest proved lithic industry in the Eastern Alps. Artefacts from the basal sediments are described typologically as belonging to a Middle Palaeolithic tradition that follows a pebble tool technique. Due to the sampling method of the excavations in the early 1950s, no exact information is available about the game animals and other contextural data concerning the climate (see Table 1). A somewhat more advanced technology that closely resembles the Taubachien from the sites Ganovce and Horka in Slovakia and Diósgyör-Tapolca in Hungary is reported from the Repolusthöhle, from deeper layers in the Große Badlhöhle and from the Tunnelhöhle (FUCHS & RINGER 1996). The Taubachian is often correlated with the Late Riss to the Riss-Würm-Interglacial. To date, there is no clear local evidence of a later Moustérian occupation. Single lithic artefacts from the Tropfsteinhöhle am Kugelstein were interpreted as Moustérian (JÉQUIER 1975). The more temperate Middle Würmian climate may have stimulated early Upper Palaeolithic immigrations into the eastern part of the Eastern Alps. Aurignacian finds have been made in the Drachenhöhle and from the Große Badlhöhle. Unstratified isolated atypical objects from the Fünfenstergrotte, the Frauenhöhle near Semriach, the Steinbockhöhle, the Lurgotte-Peggau and from two caves in the westernmost part of the Central Styrian karst ('West Styrian karst') provide only a very incomplete picture of Upper Palaeolithic hunter-gatherers' land use strategies. This fact is regarded to reflect both former excavation methods and the very poor data density in modern excavations and prospection. Old excavations in the open Zigeunerhöhle near Gratkorn, to the north of Graz, yielded bone and lithic artefacts of Late Palaeolithic fishers and red-deer hunters. The site is correlated with the youngest Late Glacial, Preboreal to Boreal.

1.5. The Lurgrotte near Peggau

The part of the cave, which is situated close to Peggau is the largest stalactitic cave (Tropfsteinhöhle) of Styria. It is accessible to the public since 1836 (BENISCHKE et al. 1994). Beneath the karst-plateau Tanneben, its galleries have a total length of approximately five kilometers. The eastern entrance is situated in the upland basin of Semriach (641m a.s.l.), the western intrance in the Mur valley (419m). In 1934, the entire length of the Lurgrotte was made accessible to the public through spelaeological investigations and tunnelling. In 1894, seven speleologists were trapped by a spring 100m inside the eastern entrance, close to Semriach for eight days. This entrance of the cave is the ponor, the pipe, that drains 16 square kilometers of the Basin of Semriach. The rescue activities - damming, blasting and emergency diving - were seriously impaired by continuously gushing water, but finally succeeded).
To facilitate the access for the public, the floor at the Peggau entrance was changed considerably. The Schmelzbach which formerly flowed through the entrance hall and passed the fore-cave was tunnelled at a lower level.

1.5.1. Palaeontology

In the Semriach part of the cave, fossil collecting activities were undertaken between 1871 and 1906. They were partly supervised by geological authorities. About 98% of the recovered bones and teeth are from cave bears. For the construction of the exhibition hall in the fore-cave of Peggau ('Höhlenmuseum'), sediments were dug out during three periods between the 1940s and 1963 without any documentation.

Morphodynamic analysis of cave bear teeth (*Ursus spelaeus*) from the Semriach part in the east proved an advanced phylogenetic level (FLADERER 1994). The patterns correspond to Central European Würmian Full Glacial taphocoenoses. The broad variability in size is due to sexual dimorphism. Although the samples at the Landesmuseum Joanneum, Graz, have been selected according to their completeness („collectors specimens"), the high percentage of juvenile to subadult elements is striking: 10 out of 25 specimens of the third lower molar show no traces of attritional. The cave bear den is characterized by a high degree of infant mortality during the first and second winter. By analogy with extant brown bear populations in subarctic climates, an increased susceptibility to infection due to low fat reserves is assumed. Some bones from Semriach show distinct chew marks produced by hyenas (*Crocuta spelaea*). Red fox (*Vulpes vulpes*) and lion (*Panthera [leo] spelaea*) are also reported from the site.
The old collection from the Peggau fore-cave comprises *Pyrrhocorax graculus, Marmota marmota, Canis lupus, Vulpes vulpes, Martes martes, Ursus spelaeus, Cervus elaphus, Rangifer tarandus, Bison priscus, Capra ibex*. The boreal-alpine

chough, marmot, reindeer and ibex reflect a continental palaeoclimate. The complexity of the profiles rules our the homogeneity of the ensemble.
The current excavation for display purposes exposes stadial debris-flow deposits in the upper part and fluvial gravels, sands and clay in the lower part of the 7m high profile. The coarse fraction in this part consists of a high percentage of schists which were washed into the Semriach Basin. The upper sediments generally consist of weakly rounded and corroded autochthonous limestone debris with a clayey matrix formed by water leakage. Because the overlying unit which contains cave bear remains, has two coarse atypical quartz-artefacts and a distal humerus from a reindeer, this is preliminarily interpreted as being Middle Palaeolithic in age.

1.5.2. Late Quaternary features outside the cave

The Würmian terrace (Niederterrasse) is exposed 80m away from the entrance of the Lurgrotte. Its surface lies 15-20m above the recent valley floor, at a level of 410-420m (Riss terrace: 450m). The accumulation of terraces ended in the Late Glacial (MAURIN 1994). In the Holocene, the Mur, cut more than 25m into its Würmian bed. Late Würmian loess and aeolian sands were blown into the entrances of the caves (Tunnelhöhle and Tropfsteinhöhle am Kugelstein) mainly by northerly winds or they were washed in by water. The loess cover in Central Styria was never thick. It probably was rapidly changed in the course of the development (Lösslehme, Staublehme).

Along the concrete pathway from the ticket office of the Lurgrotte to the entrance, sill-like remnants of travertine-cascades (Kalktuff) are visible. They were deposited in the Early Holocene climatic optimum (Atlantic; ca. 7.000-4.500BP). The travertine was cut until the 1880s and was used locally as a building stone.

The excavation in June 1997 was conducted with support by the Styrian Provincial Government, the Marktgemeinde Peggau & Lurgrottengesellschaft, the Wietersdorfer & Peggauer Zementwerke GmbH and the Landesmuseum Joanneum, Referat Geologie und Paläontologie. The author thanks the authorities and Dr. G. Fuchs, Fa. ARGIS, Archäologie und Geodaten Service, Graz, for their help.

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2. The Styrian Basin

2.1. Geodynamics, Palaeogeography, Volcanism (Karl STINGL)

The Styrian Basin (SB) is a marginal basin of the Pannonian Basin (Fig.5a). The origin of these basins is explained today largely through Miocene kinematics (late collision stage) in the East Alps. In the last decade, the combination between the new tectonic models "tectonic escape" and "extensional collapse" (PLATT 1987, DEWEY 1988) provided the basis for interpreting the development of the Carpathian Arc and the Pannonian Basin.

In the final phases of the generally northerly directed collision of the Adriatic Plate with the European Plate, crust sections were extruded laterally to the east ("tectonic escape"). These eastward movements of the crust sections must be compensated by orogenetically parallel lateral shifts ("strike-slips") running east-west. Smaller intramontane basins (Mur-Mürztal, Fig.5a) developed along these strike-slips mostly in the form of "pull-apart" basins (RATSCHBACHER et al. 1991ab). The second part of the combined model is based on strong crustal thickening in the region of the colliding orogenes. The lower density of the continental crust as opposed to the Earth's mantle leads to morphological upliftings of unstable, thickened continental crusts. This instability is compensated by the isostatic rise of the continental crust. This in turn leads to a gravitational slippage of higher crustal elements (nappes) from the isostatically rising lower crust sections (RATSCHBERGER et al. 1991a,b). The slippage of such layers occurs along flat thrust planes and is repeated numerous times until the deepest crust sections are exposed in the central orogenetic zone (Penninic Tauern Window of the East Alps).

NEUBAUER & GENSER (1990) explain the origin of the SB by such flat thrust planes, whereby the shifts are also interpreted as a connection between the strike-slips. Due to the opposite movement of the strike-slips, the crust between them is thinned out. This thinning of the uppermost levels of the crust is evident through north-south oriented block rotations between the east-west running strike-slips. The block rotations form asymmetrical north-south directed trenches. One of these trenches is the West Styrian Basin (WSB). It is separated from the East Styrian Basin (OSB) by the Middle Styrian Sill, which is a rotated block (Fig.5b). The separation between the individual basins is incomplete. Deep zones are always present between the sills (KRÖLL et al. 1988), which enable a partial link between the subbasins.

The brief description of this model cannot go into other facts such as the rotation of the crust elements during the collision (MAURITSCH & BECKE 1987). A more detailed summary of the model is presented in NEUBAUER et al. (1995).

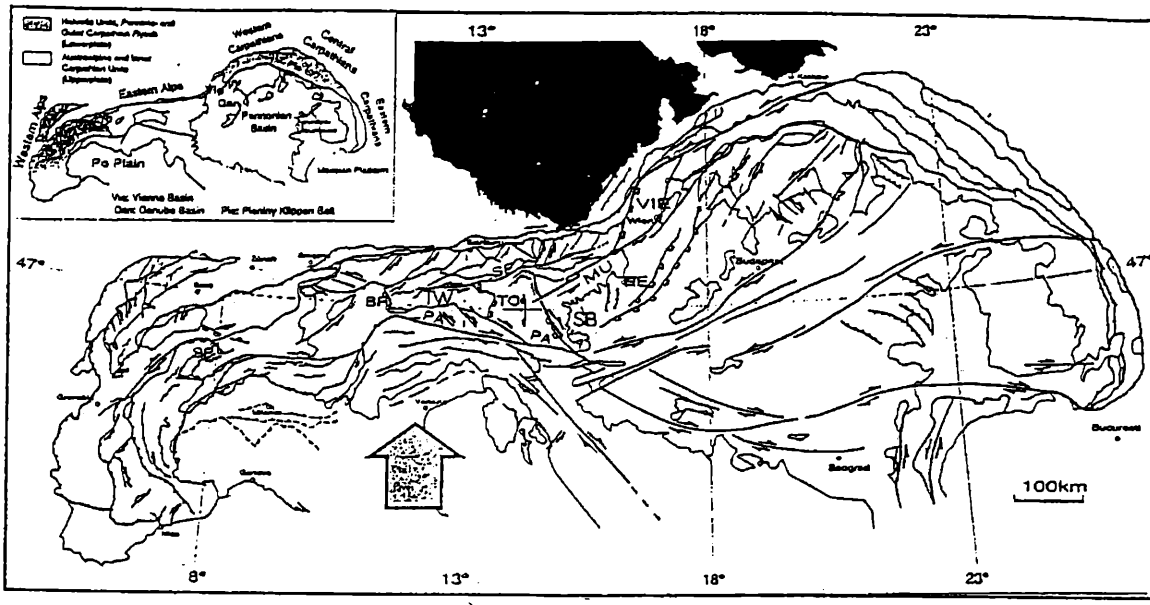


Fig.5a. Tectonic overview of the Pannonian Basin (from DECKER, 1996)

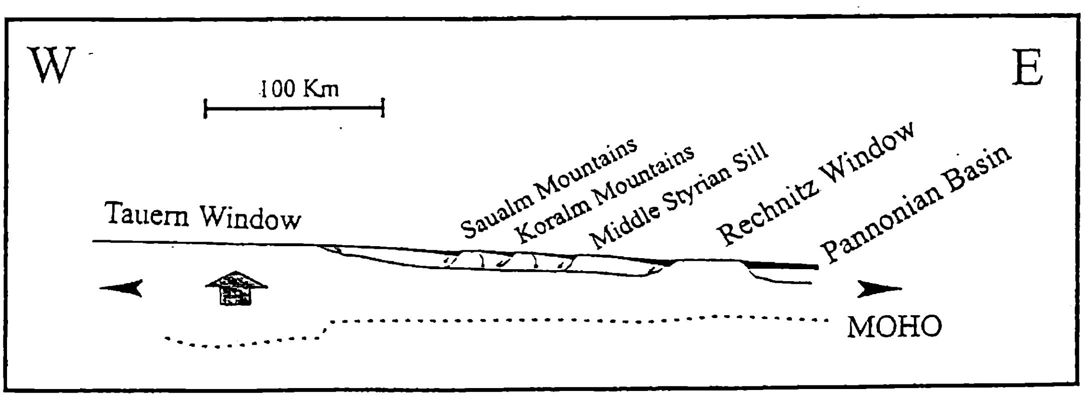


Fig.5b. Model of the development of the Styrian Basin (from NEUBAUER & GENSER, 1990)

Palaeogeographically, the SB was part of the Central Paratethys. The stratigraphy of the sedimentary basin filling encompasses the Miocene (the deepest confirmed stage is Ottnangian) and the Pliocene/Pleistocene. The earliest sediments need not necessarily represent the Ottnangian stage since most of the sediments of the basin floor are coarse clastics which are not known to contain any stratigraphically exploitable information. For the excursion, sediments of Ottnangian, Karpatian and Badenian age are of interest (the Ottnangian/Karpatian boundary cannot be drawn with certainty). The Sarmatian and Pannonian are not treated in this excursion guide.

In the Oligocene, the marine depositional area of the Tethys was already divided into the Paratethys region and the Mediterranean region (Mediterranean Tethys). In the course of the Miocene, the Paratethys was periodically connected with the Mediterranean Tethys. At times, the Central Paratethys was separated from the Eastern Paratethys. The connection to the Mediterranean Tethys also involved the Croatian-Slovenian region bordering the SB. Faunistic affinities to the Mediterranean region are often stronger than to the Paratethys. The palaeogeographic development in the Neogene of the Tethys and Paratethys are described and discussed in detail in RÖGL & STEININGER (1984).

Three phases of volcanism are known in the SB (Karpatian/Lower Badenian, at the Sarmatian/Pannonian boundary, and in the Pliocene; EBNER & SACHSENHOFER 1991). In the WSB, volcanoclastics (various tuffs and tuffites) of the first volcanic phase (Karpatian/Lower Badenian) occur. The volcanoes themselves (trachyandesite, andesite and rhyolite) are most abundant in the OSB. They are shield volcanoes, which cover approximately 1/4 of the subsurface of the OSB. On surface, they are only visible in the region of Gleichenberg and in Weitendorf. Several intrusions occur in Slovenia and in the Lavant Valley. Only one large intrusion, the shoshonite of Weitendorf, partially extends into the WSB and the Middle Styrian Sill. The volcanism is interpreted as being part of the intracarpathian volcanic arc, which arose through a subduction within the Carpathians (ROYDEN & HORVATH 1988). BALOGH et al. (1991) provide a summary of volcanism in the SB.

In this description we will not discuss earlier attempts to draw biostratigraphic boundaries at lithostratigraphic boundaries. It is also not attempted to present the large number of regional geologic observations in a larger scale synthesis.

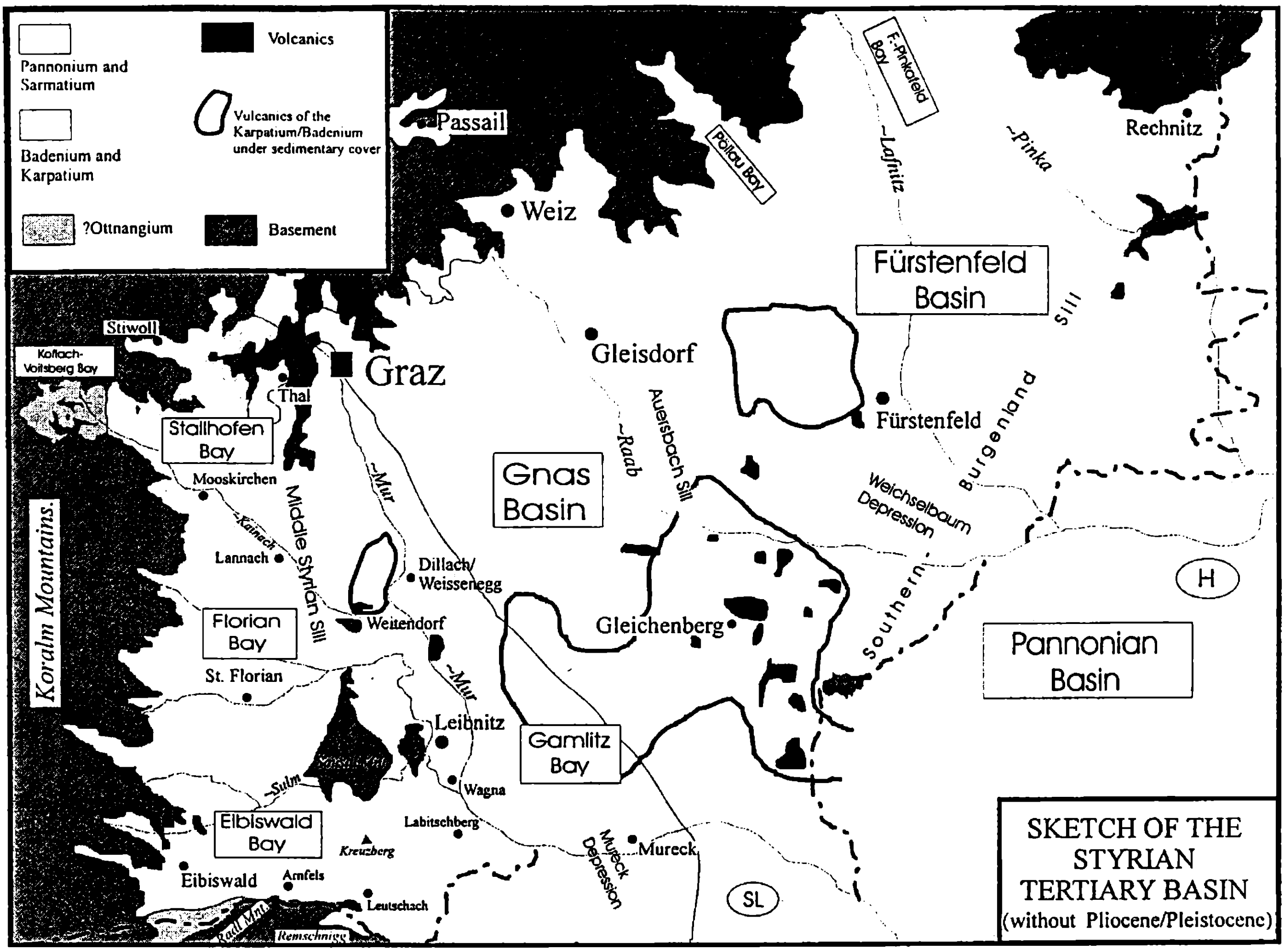


Fig.6. Geological sketch of the Styrian Basin

2.1 The East Styrian Tertiary Basin (Karl STINGL)

The Middle Styrian Sill divides the SB into a West Styrian Basin (WSB) and an East Styrian Basin (OSB). The OSB is subdivided into the Gnas Basin, Fürstenfeld Basin, numerous deep marginal embayments as well as sills in between. In the Gnas Basin the thickness of sediments is up to 2000m. It is separated from the Fürstenfeld Basin (maximum sediment thickness 4000m, SACHSENHOFER et al. 1996)) by the Auersbach Sill, which merges with the volcanic massif of Gleichenberg to the south. The Gamlitz Embayment is part of the Gnas Basin near the Middle Styrian Sill. With the exception of the Friedberg-Pinkafeld Embayment and the Gamlitz Embayment, only sediments from the Sarmatian and Pannonian are exposed on the surface. The stratigraphy of the older deposits (Badenian, Karpatian, Ottnagian) is based on deep boreholes drilled during oil exploration, on thermal boreholes, as well as on comparisons with the WSB and its correlation through tuff horizons.

The Southern Burgenland Sill separates the OSB from the Pannonian Basin, whereby the two basins are connected by the Mureck Depression adjoining the Gamlitz Embayment and the Weichselbaum Depression. It is beyond the scope of this guide to discuss the periods in which the individual basin sections were separated or connected by sills and depressions, or to more closely go into the partially reduced sedimentation in the high areas. For a more detailed discussion see EBNER & SACHSENHOFER (1991) and FRITZ (1996).

2.1.1. Basin Deposits. Ottnangian to Badenian (Fig.7)

Information is based on the boreholes Mitterabill 1, Mureck 1, Paldau 1, Perbersdorf 1, Übersbach 1, Walkersdorf 1, after KOLLMANN (1965) as well as on thermal boreholes Fürstenfeld 1 after FRIEBE & POLTNIG (1991).

Ottnangian

With the exception of the "Naas Beds" and the Zöben Breccia, no potential Ottnangian sediments are exposed in the OSB. In the boreholes drilled in the Gnas and the Fürstenfeld Basins, phyllite breccias and red clays with intercalated lignitic layers are attributed to the Ottnangian (no stratigraphic data is available; this division is based solely on the lithostratigraphic position).

Karpatian

The Sinnersdorf Conglomerates (with tuffaceous layers on top) of the Friedberg-Pinkafeld Embayment are dated as Karpatian. Above basal red sediments (Ottnangian ?), boreholes yielded alternating sequences of sand-, silt- and clay-stones. They are largely marly, partially bituminous, and bear isolated lignite deposits and lignite seams. In top layers, coarse clastic sediments are more common. These sequences are generally interpreted as lacustrine-fluvial basal series and dated as Karpatian. The fact that the the Ottnangian/Karpatian boundary could be proved neither by biostratigraphic nor by chronostratigraphic data prohibits any clarification of its stratigraphic position.

Upwards, the first definitive Karpatian sediments containing a marine fauna are following without a distinct lithological break. Generally, the diversity of the fauna is low. At the surface, these sediments are exposed in the Gamlitz Embayment as Styrian "Schlier" (Styrian Marls). They indicate a connection towards the Pannonian Basin via the Mureck Depression. Sand-, silt- and clay-stones with marly character and lenticular intercalations of coarse clastics and lignitic plant debris may also be developed. Shortly before the first appearance of marine fossils in the sections and thereafter, tuffaceous intercalations were recorded in the boreholes.

Within the Styrian "Schlier" the Karpatian/Badenian boundary is exposed in the type profile Wagna which is situated in the Gamlitz Embayment (AUER 1996). The deposition of "Schlier" is followed by the Styrian Discordance (see paragraph on the Styrian Discordance).

Badenian

In the Friedberg-Pinkafeld Embayment, the lignite seams of Tauchen and Schreibersdorf overlie the Sinnersdorf Conglomerates. They are followed in turn by the "Tauchen Beds" (sands and gravels with a few intercalations of detrital corallinacean limestones ("Nullipora Limestones" of the Badenian). In the boreholes, there are no major lithological changes at the base of the Badenian. Marly sands, silt- and clay-stones with lenticular accumulations of lignitic plant debris predominate. Conglomeratic intercalations decrease. On the other hand, the content of corallinacean debris of the sandstones increases ("Nullipora Limestones"). In the Lower Badenian (Lagenid Zone), tuffaceous and tuffitic intercalations are still present.

This situation is partially controversal to the borehole Fürstenfeld Thermal 1, which is the only one examined according to new biostratigraphic concepts (PAPP & CICHA 1978). There are no lacustrine-fluvial series developed at the base. Fine to coarse marine clastics of the Karpatian directly overlie the basement (-2747m). At the Karpatian/Badenian boundary which was hit at -2620m fine to coarse clastics are developed.

In the Badenian, the sedimentation along the Middle Styrian Sill differs distinctly from the basin facies penetrated by the boreholes (FRIEBE, 1990, Fig.2-4)). Along elevated zones of the Middle Styrian Sill, "carbonate buildups" intercalate into the basin facies at various stratigraphic levels. They were formerly termed "Leithakalk "(Leitha Limestone"). Together with the surrounding basin deposits, these are combined as the

Weissenegg Formation. FRIEBE (1990) describes the coarse clastic sediments of the Badenian as the Kreuzberg Formation; he interprets them as the subaquatic part of a delta (whose alluvial plain has been obliterated by erosion). Interfingerings between the Weissenegg Formation and the Kreuzberg Formations are termed Ottenberg Member of the Kreuzberg Formation. "Leitha Limestone" is also present along highs, which are not exposed on the surface (PAPP 1975, EBNER & SACHSENHOFER 1991).

2.1.2. Styrian Discordance

Along the Middle Styrian Sill, the Styrian "Schlier" is overlain unconformably by the Weissenegg Formation. This discordance is named Styrian Discordance. Currently, three outcrops showing the discordance are known (Katzengraben at Spielfeld, Retznei Quarry, and Wagna Clay Pit). In the Wagna Clay Pit (type locality), the Styrian Marl is overlain unconformly by reworked material. It is followed by the limestones, marls and sands of the Weissenegg Formation. The Karpatian/Badenian boundary is drawn below the reworking horizon, which encompasses a time period of 1.1 Ma. In Retznei the reworking horizon contains consolidated rounded "Schlier" clasts which in partly are bored by lamellibranchs (FENNINGER & HUBMANN, 1997). At Labitschberg, a lignite seam is correlated with the Styrian Discordance. It overlies the Leutschach Sands, which are equivalent to the Styrian "Schlier" and are followed by Badenian marine sediments of the Lagenid Zone. This supports the lowermost Badenian age of the Styrian Discordance. For a detailed description of the outcrops see FRIEBE (1991).

2.1.3. Overview

Except for a simple distinction into marine versus lacustrine-fluvial deposits based on the fossil content, the facies and depositional conditions of sediments recovered in boreholes have only been superficially examined. It has long been known that the marine deposits and those interpreted as being lacustrine-fluvial are often differentiated only by their fossil content, but not by their facies. The simple differentiation mentioned above is therefore not definitive, especially since large core sections interpreted as being purely marine bear absolutely no fossils (KOLLMANN 1965, FRIEBE & POLTNIG 1991). Equally, no conclusions can be drawn about the stratigraphic range of the sediments (Ottnangian/Karpatian boundary unknown, no confirmed Ottnangian). Finally, the stratigraphic determination of the Karpatian/Badenian carried out in the 1950s based on foraminifera is now considered to be insufficient to prove this boundary in the OSB.

It seems most promising to apply the new sequence stratigraphical models from the adjoining Vienna and Pannonian Basins (POGACSAS & SEIFERT 1991) to the OSB: from the Ottnangian onward, they show alternating transgressions and regressions combined with local erosional discordances, prograding deltas and marine incursions over terrestrial deposits. Coarse and fine clastic series described from boreholes (Mitterabill 1, Perbersdorf 1, Übersbach 1, Walkersdorf 1) have been considered as being lacustrine-fluvial. Today, we interpret these deposists in a different way: Together with the overlying marine sediments they mostly represent subaquatic mass movements ("debris-flows and turbidity currents"). This new view is mainly based on recent investigations of the WSB and the Middle Styrian Sill where equivalent sediments outcrop on the surface. Styrian "Schlier", Lower Eibiswald Beds, Arnsfelder Conglomerates, Leutschach Sands, Heil.Geist Beds, Radl Formation; KRAINER 1989 & 1988, STINGL 1994, SCHELL 1994 are interpreted to be subaquatic debris-flows or delta formations.

Based on nannoplankton and magnetostratigraphy the Styrian Discordance in the Styrian "Schlier" of the SB was dated as Lower Badenian by AUER (1996) . There is a correlation with the only conspicuous discordance in the Vienna Basin which is of Lower Badenian age. Note that the Karpatian/Badenian boundary in the SB is drawn within marly sediments and does not correspond to a lithological change.

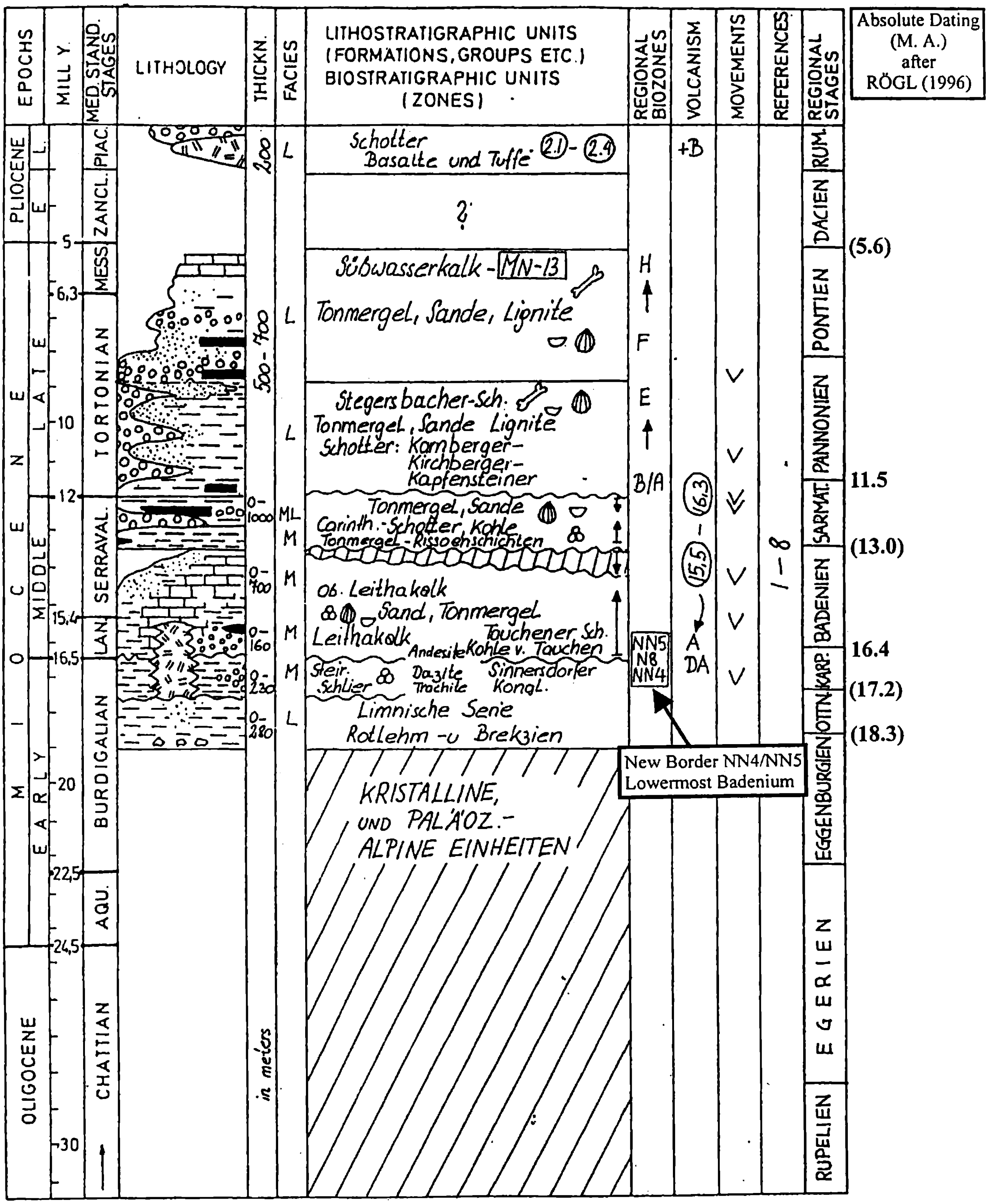


Fig.7. Simplified stratigraphy of the sediments in the East Styrian Basin (from PAPP in STEININGER et al. 1985)

2.2. The West Styrian Tertiary Basin (Karl STINGL)

The WSB is divided into subbasins, although they are not as accentuated as in the OSB. The southernmost basin is the Eibiswald Embayment, which is followed to the north by the Florian Embayment and, at the northern end, by the Stallhofen Embayment. The Köflach-Voitsberg Embayment is a marginal embayment of the Stallhofen Embayment. The basin filling extends from the Ottnangian into the Badenian. Sediments of Sarmatian age were deposited only in marginal areas and embayments (the present excursion guide cannot go into the details of the Slovenian parts of the WSB).

2.2.1. Basin deposits of the WSB. Ottnangian to Badenian (Abb.9)

Ottnangian

Basal sediments of the Eibiswald Embayment are currently dated as Ottnangian. They comprise the Radl Formation and the Lower Eibiswald Beds which form a fan delta along the Radl Mountains and the Remschnigg. The Radl Formation consists of alluvial fan sediments (subaeric debris-flows and turbidity sediments) and proximal delta sediments (coarse clastic, subaquatic debris-flows). The Lower Eibiswald Beds form the distal delta (turbidites with intercalations of coarse clastic debris-flows). Because of the Karpatian age of the Middle Eibiswald Beds the age of the Radl Formation is considered as Ottnangian. The Lower Eibiswald Beds are dated as terminal Ottnangian/early Karpatian. In the uppermost part of the lignite-bearing sediments of Köflach-Voitsberg the neogene mammal unit has been recorded (DAXNER-HÖCK 1990; see chapter 2.2.2). It is correlated with the Upper Ottnangian/Lower Karpatian.

Karpatian

Styrian "Schlier" was deposited in the Gamlitz Embayment (and the Mureck Depression). Further marine sediments have been deposited between the Sausal Mountains (Middle Styrian Sill) and the Remschnigg in the transition to the WSB. They comprise the Arnfels Conglomerates and the Leutschach Sands, whose marine nature is revealed by sparse fossil remains. These sediments are subaquatic debris-flows, whereby the Arnfels Conglomerates bear a greater proportion of coarse clastics (proximal depositional area). The influence of wave action (oscillation ripple marks, shallower depositional area) is evident in the Leutschach Sands. The boundaries between the sediments are transitional or interfingering. WINKLER-HERMADEN (1957) did not distinguish between the Styrian "Schlier" and the Leutschach Sands. The lithology of the sediments (sands, silts, clays, partially marly, with conglomerate intercalations as well as lignitic seams) is equivalent to the deposits in the OSB. The boundary between Karpatian sediments and the overlying Kreuzberg Formation of Badenian age is gradual as well.

The Middle and Upper Eibiswald Beds were deposited in the central sections of the Eibiswald Embayment. The Middle Eibiswald Beds are interpreted as lacustrine-fluvial deposits. They include the lignite seams which were dated as Karpatian with vertebrate fossils (MOTTL 1970.) The Schönegg flora (ETTINGSHAUSEN 1893) has also been collected in this lignite-bearing sequence.

Because the transition is gradual, the Upper Eibiswald Beds of the Florian Embayment cannot be separated from deposits of Badenian age (KOPETZKY 1957). Basal sediments of the Florian Embayment can also be dated as Karpatian. In the Stallhofen Embayment, both the uppermost parts of the Köflach-Voitsberg lignite basin and the conglomerates of Stiwoll (delta formation, EBNER 1986) have been dated as Karpatian.

Badenian

In addition to the Weissenegg and Kreuzberg Formations described from the Middle Styrian Sill and the Gamlitz Embayment, as well the lignitic seam of Labitschberg, the WSB is characterized by extensive Florian Layers. They are composed of alternating sequences of fossil-rich sands, silts and clays, which are partly marly (interpreted as brackish and shallow marine formations), partly coarse clastic sands to coarse gravels (interpreted as terrestrial influences and shore formations). At Lannach, a small shed is intercalated into the basal series.
Additional Badenian deposits include the Eckwirt Gravels in the Stallhofen Embayment. They are of fluvial origin and continue into the Dillach Member of the uppermost Weissenegg Formation, which is of deltaic origin. The boundary between the Eckwirt Gravels and the Florian Beds is not exposed. A transition similar to that between Upper Eibiswald Beds and Florian Beds can be expected. In conclusion, the WSB sediments consist largely of lacustrine-fluvial deposits with intercalating lignite seams; these merge into delta formations in the region of the Middle Styrian Sill. Closely related to the morphology, "carbonate buildups" developed on the Middle Styrian Sill. In the Florian Embayment, marine deposits have occasionally transgressed further toward the basin margins. The lignitic seam of Labitschberg gives evidence of the farthest prograding of lacustrine-fluvial (and paralic) deposits into the basin (see paragraph on Styrian Discordance). A sequence stratigraphic model with transgressions and regressions in connection with delta formations might well serve as an interpretational approach.

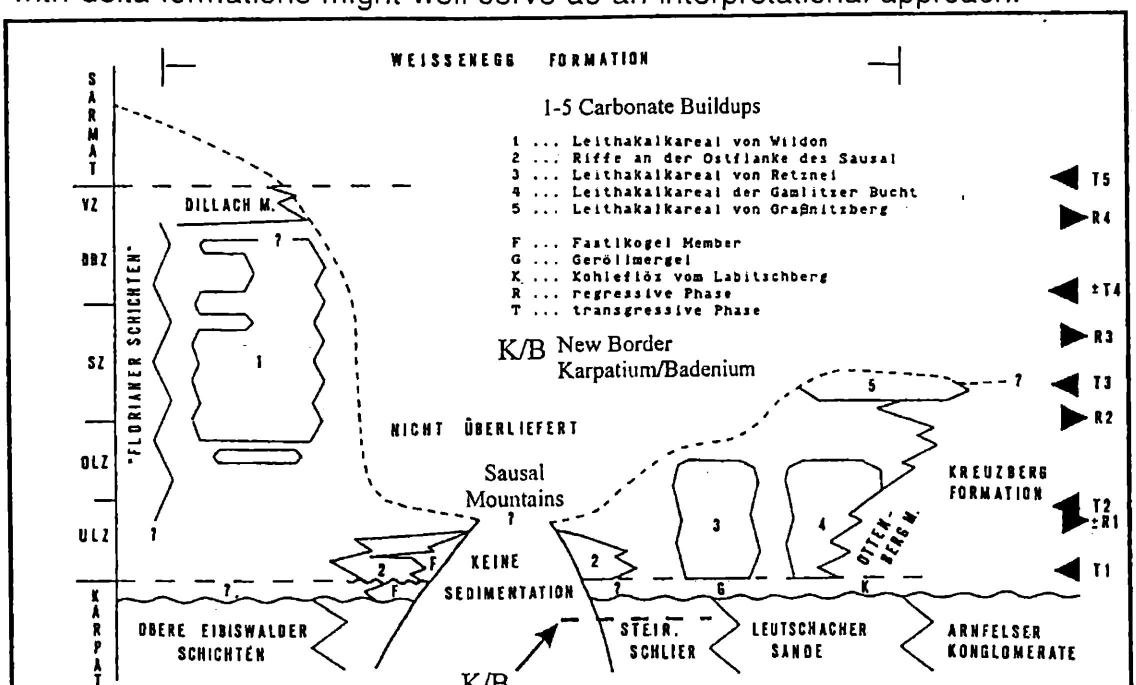


Fig.8. Lithostratigraphic column of sediments along the Middle Styrian Sill (from FRIEBE 1990)

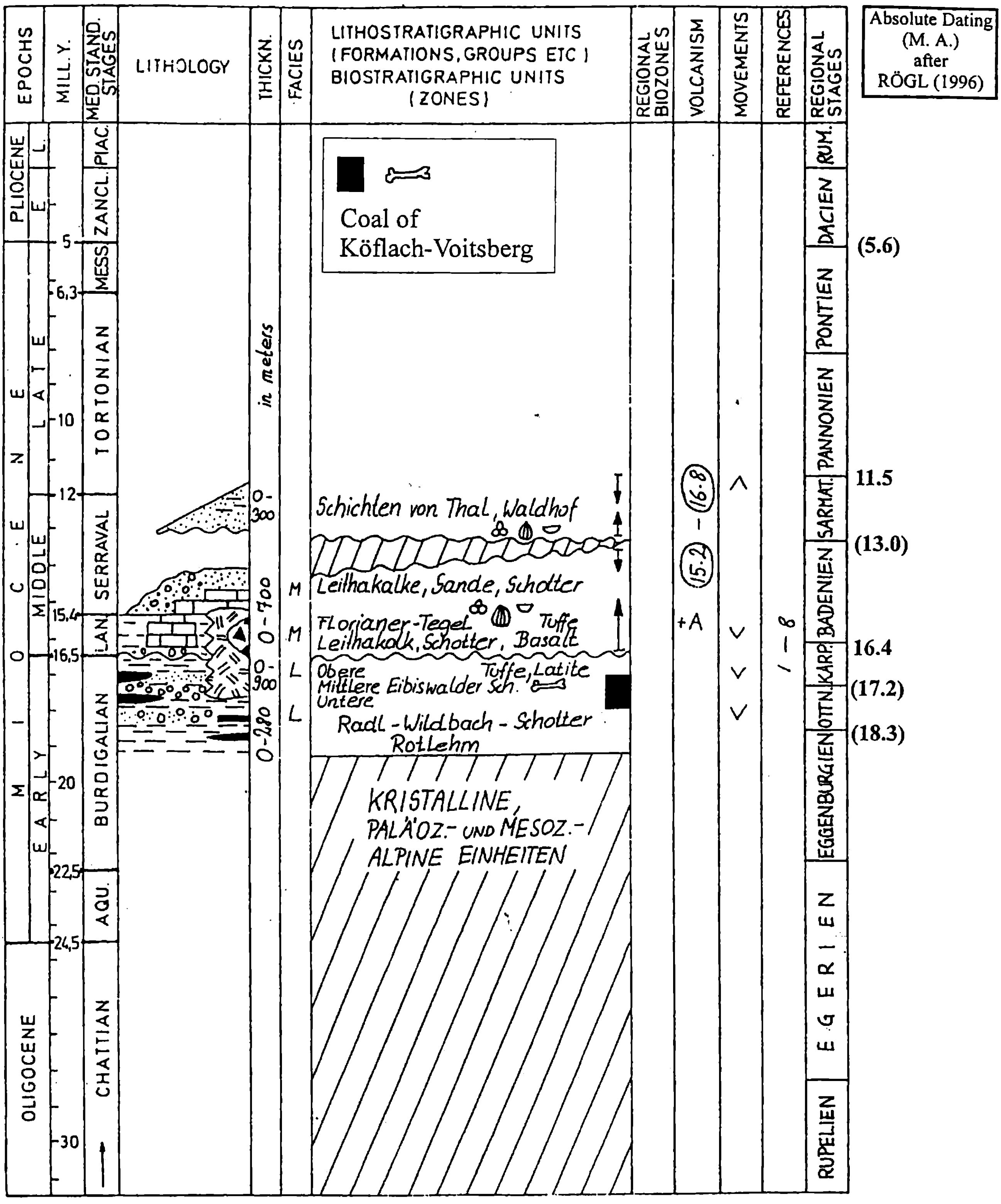


Fig.9. Simplified stratigraphy of the sediments of the West Styrian Basin (from PAPP in STEININGER et al. 1985)

2.2.2. Lignite-bearing sediments of Köflach-Voitsberg

The lignite deposits of Köflach-Voitsberg are located in a marginal embayment of the Stallhofen Embayment. The basement consists of Koralm crystalline, the "Raasberg sequence" (dolomites, limestones, sandstones), sediments of the Gosau Group (Kainach Gosau), as well as Palaeozoic limestones. To the west, the basement of the Piberstein-Lankowitz Depression is formed by crystalline rocks. In this depression, the maximum sediment thickness is approximately 350m. The sedimentation began with coarse clastic, red-brown alluvial fan sediments (conglomerates and breccias). They are followed by lacustrine formations that are intercalated by several up to 5m-thick lignite horizons with associated fluvial sediments (sandy and silty "overbank" sediments and sandy to fine gravel fluvial channel fillings).

In the other depressions sedimentation begins with the Raasberg Sequence. It consists of turbiditic, subaquatic deposits that are gradually replaced by lignite-bearing lacustrine layers. In the Piber-Bärnbach Depression, several lignite horizons (up to 3m thick) are intercalated in lacustrine silts and clays. Sediments of the Graden Depressions (among others Karlschacht) have a similar composition. In Karlschacht, only an 80m-thick lignite seam is present. Towards the middle of the depression, the seam splits and becomes considerably thinner. Interspersed lacustrine sediments show silt-clay rhythmites which are interpreted as the repeated formation of a deep lake. Fluviatile sediments only play a subordinate role in this depression.

Analogous to the other depressions, the basal sediments of the Oberdorf Depression are turbiditic. In the western sub-basin a single main seam is developed (see contribution of M.HAAS). In the region of Tregist, the Oberdorf Depression adjoins the Stallhofen Embayment. In this area the basement is formed by the Kainach Gosau and by Palaeozoic limestones. The basin filling is predominantly turbiditic. Lignitic formations are absent in the lacustrine sequences; two sheds are intercalated in the uppermost section.
The basement of the Zangtal Depression is formed by the "Raasberg Series". There are two seams. In the center of the depression, the Zangtal lower seam directly overlies the basement. The coarse clastic sediments following above the lower seam still remain to be investigated in detail. The overlying Zangtal upper seam, which thins out below the town of Voitsberg, partly overlies the crystalline basement. The Zangtal upper seam, which partly progrades onto the adjoining Oberdorf Depression, caps the lignite-bearing layers.

The correlation of 4 partially amalgamated lignite horizons- as it was considered previously-can no longer be maintained. In general, the lignites have been deposited synsedimentarily. The stated thicknesses of the seams refer to pure lignite with virtually no smits (in the range of decimeters). Extensive parts of the sequences are eroded at various levels; this further complicates a correlation.
The lignite-bearing sediments of the Oberdorf and Zangtal Depression are overlain - with an erosional discordance - by fine to coarse clastics with intercalated marls. They are correlated with the Eckwirt Gravels of the Badenian (FLÜGEL 1975).
An introduction into the geology of Austrian lignite deposits is provided in WEBER & WEISS (1983).

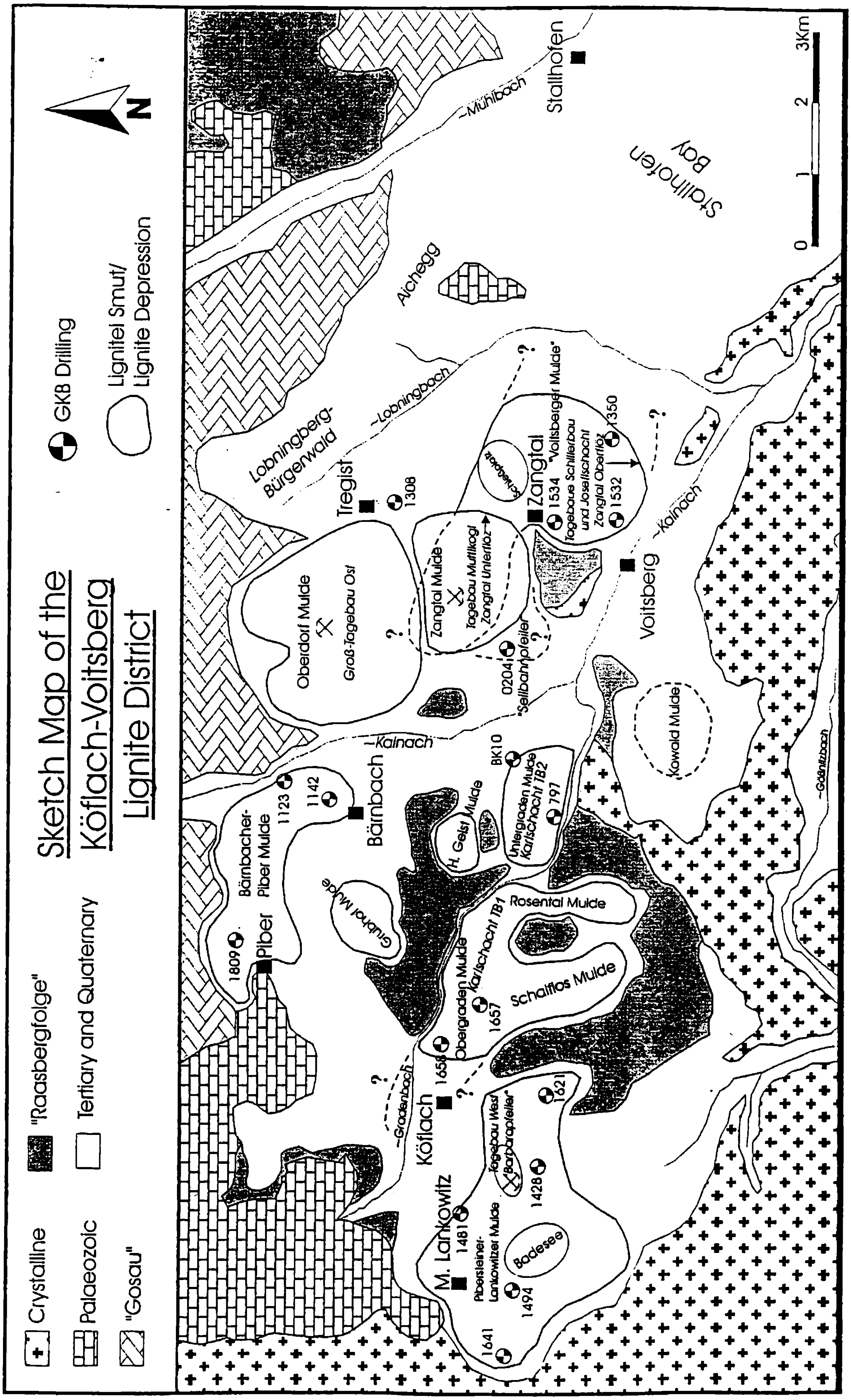


Fig.10. Schematic overview of the Köflach-Voitsberg lignite basin

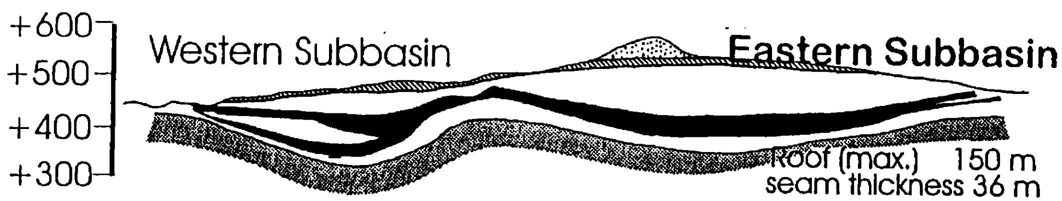
2.2.3. Sedimentary Sequences in the Opencast Mines Oberdorf and Zangtal (Margit HAAS)

2.2.3.1. Introduction

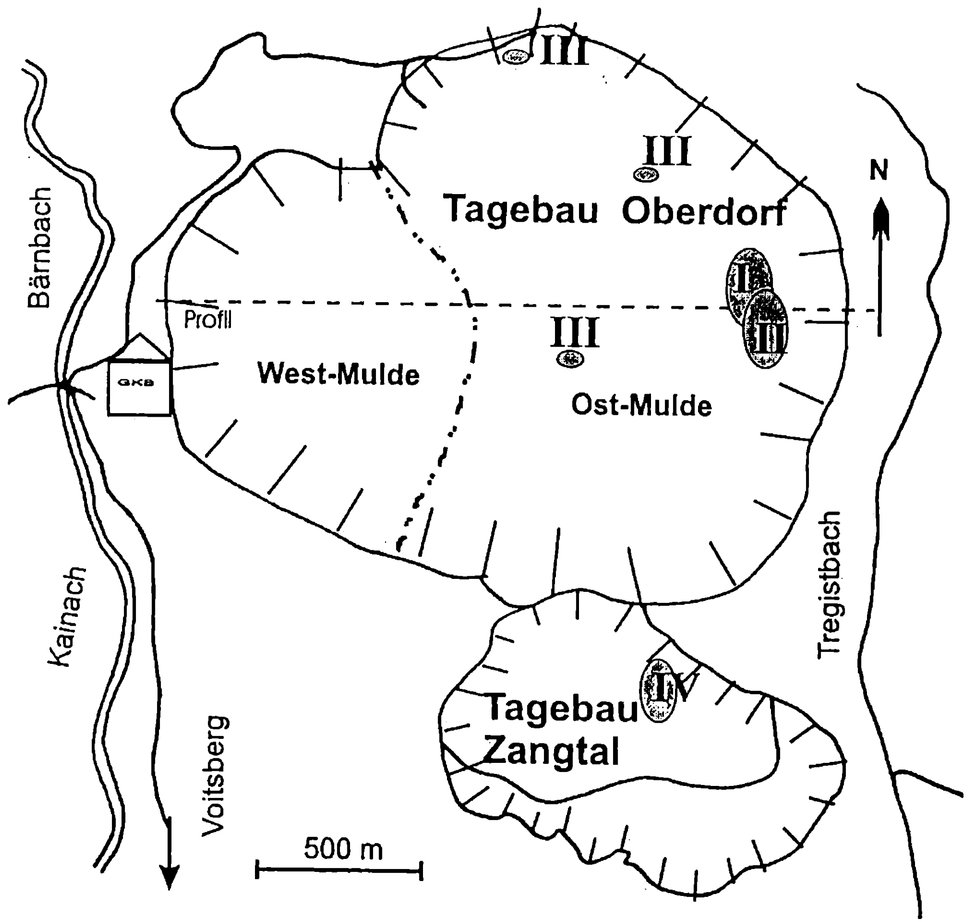
The Neogene basin filling reaches a thickness of more than 300 m in the region of the Köflach-Voitsberg lignite deposits.
The environmental analysis currently being conducted in the framework of an FWF project (P 10339-GEO) on siliciclastic sediments in the opencast mines Oberdorf and Zangtal is designed to provide the first concrete answers to the question whether a marine influence existed at any time. The lacustrine-fluvial character of the sediments in the West Styrian Basin, as opposed to the definitive marine deposits of the East Styrian Basin, has often been postulated but never proven (KOLLMANN, 1964, EBNER & SACHSENHOFER, 1991). The contour map of the Pre-Tertiary basement (KRÖLL et al., 1988) reveals an approximately 800-900m-deep corridor north of the Palaeozoic units of the Sausal; this may have enabled a marine connection to the West Styrian Basin.

The investigations in the opencast mine Oberdorf dealt, among others, with the Tertiary sediments underlying the main seam and the thick main parting dividing the seam along the eastern subbasin (Ostmulde). Additional investigations in the directly adjoining opencast mine Zangtal examined the sediments of the Muttlkogel (Fig.11).

The environmental interpretation of the available data is based on a combination of the observed cyclicities in the field outcrops, the granulometric evaluation using facies-sensitive methods, and evaluation of diagenesis from thin-section analyses. Due to the regionally high content of organic material in the clastic sediments of the lignitic layers, the investigation of TOC (total organic carbon) is of particular interest (TYSON, 1995). Ultimately, the palaeobotanical and lignite-petrographic investigations allowed reconstruction of the interrelationships between the sedimentological deposition conditions, the plant associations, and the onset of the lignitic phase (see contribution: KOVAR-EDER, KOLCON & SACHSENHOFER).



Profile (WEBER & WEISS, 1983)



Opencast mine Oberdorf

I: Sediments underlying the main seam
II: Main parting
III: Boreholes

Opencast mine Zangtal

IV: Muttlkogel

Fig.11: Map of the Oberdorf and Zangtal opencast mines including the investigated outcrops and boreholes

2.2.3.2. Opencast Mine Oberdorf

Sediments underlying the main seam

The Pre-Tertiary basement is exposed at the east margin of the eastern subbasin. It consists of low-grade metamorphic Upper East Alpine Units of the Graz Palaeozoic ("Raasberg Series"?). Due to the uplift of Palaeozoic rocks the basal Tertiary sediments form a dome-like structure. About 15 metres of these sediments are exposed. The compression of the sediments resulted in frequent small-scale folding ("slumping-like" structures). The period of tectonic influence is therefore considered to be syn- to postsedimentary.
The sediments underlying the main seam can mostly be assigned to a marginal facies of a fluvial environment (Fig.12, Fig.13). A short-term lacustrine influence cannot be excluded.
The sedimentation cycle is initiated by sandy-gravelly sediments. Even to wavy laminated bedding are typical structural features. Manganese and iron incrustations are abundant. In the uppermost section, the direct fluviatile influence decreases and overbank sediments are deposited. The characteristic log-probability curve of grain size distribution (Fig.14) (VISHER, 1969) clearly points to a marginal facies depositional milieu of a low-gradient fluvial environment. The low-energy current area is characterized by the sedimentation of floodplain and crevasse deposits. The general fining upward within the sequence is accompanied by an increase of organic material. The cyclic appearence of horizons with diagenetically altered, oxidized organic material indicates that former root horizons are involved. The siliciclastic sedimentation is increasingly replaced by organic sedimentation and merges into the main seam (lower seam). The frequent occurrence of Fusain layers indicates forest fires. Such phenomena are known from recent subtropical to tropical swamps and play a system-regulating role (STACH et al., 1982).

In the absence of subsidence, the peat in the uppermost units is repeatedly reduced by forest fires. Peat thickness therefore remains constant. Basin subsidence and fluctuating water levels are a prerequisite for peat accumulation and subsequent lignite formation. The palaeobotanical results from the investigation of two horizons in the upper part of the profile are comparable with the sedimentological results. Species-rich plant communities of various sites from mesophytic forests to river bank vegetation and aquatic elements have been recorded (KOVAR-EDER et al., MELLER et al.; in print).

The total carbon (TC) content in the sediment (Fig.15) ranges from 0 to 1.5%, whereby the fine-grained sediments contain the most organic material. The occasionally elevated "inorganic carbon" content can largely be attributed to the occurrence of siderite. XRD- and thin-section analyses revealed no noteworthy amounts of additional carbonates. Siderite occurs in the Tertiary sediments of the series underlying the main seam as radially organized, spherical structures with a series of concentric shells. As an early diagenetic structure, siderite occurs with a concurrent absence of iron sulfide minerals such as pyrite. A prerequisite for the formation of siderite is a high concentration of carbonate ions and an only weakly effective sulfide ion concentration. Such conditions are rare in the sediment pore waters of marine-influenced environments due to the high sulfate content. In this form, siderite typically occurs in non-marine sediments, whose Ca/Fe ratio promotes the formation of iron carbonates (TUCKER 1985).

Opencast mine Oberdorf

Sediments underlying the main seam

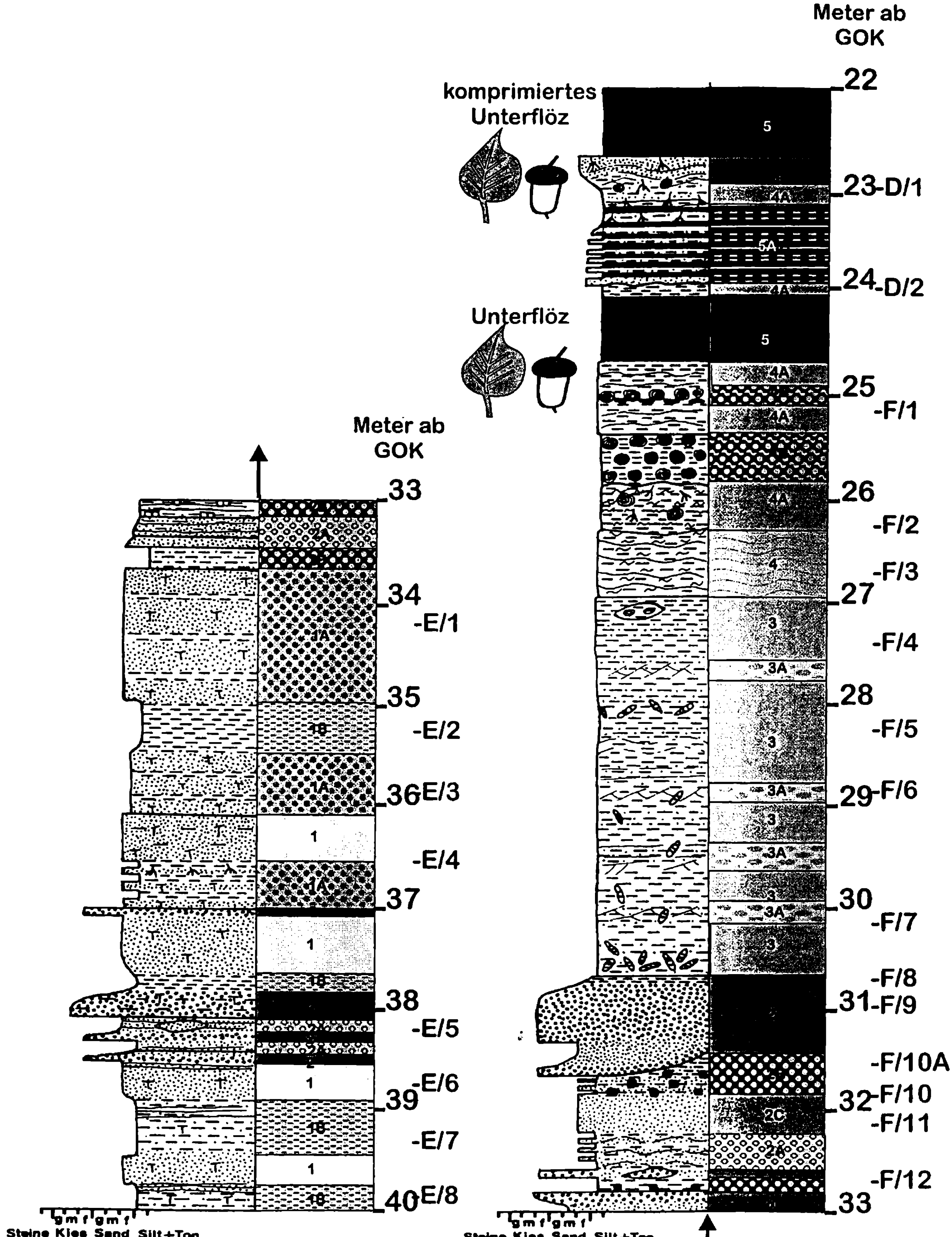
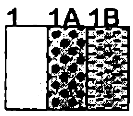
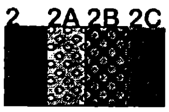


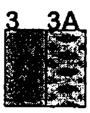
Fig.12: Lithology of the sediments underlying the main seam at the opencast mine Oberdorf



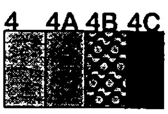
Basement: uplifted units of the "Raasberg Series" (?Graz Palaeozoic), partially block-faulted-low-grade metamorphic 1. fine grained sand quartzarenite,1A. interlayered fine grained sand to silt, 1B. lithic graywacke: diagenetic siderite as fracture filling.



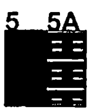
Sands to pebbles, heavily compacted; isolated, small-scale channels; manganese-iron incrustations; even to wavy laminated bedding; accumulation of organic material in thin mudstone layers.



Silty/clayey sediments, wavy laminated bedding, in certain areas small-scale cross- to ripple lamination; abundant diagenetically altered wood remains in horizons with increased fine sand fraction; siderite cements and siderite-ooids.



Silty/clayey sediments; organic material content increases rapidly - dark brown to black mudstone; plant debris and wood remains; fruit and pollen along with heavily fragmented leaf remains ; elements of a Younger Mastixioid flora (predominantly evergreen forest vegetation); herbaceus elements of river banks and aquatic origin (results: "Co-op Palaeobotany": KOVAR-EDER, MELLER).



5 Lignite: 5A. thin parting - interlayered carboshales/lignite; occurrence of Fusain; elements of a Younger Mastixioid flora (leaves, fruit and pollen).

Fig. 13: Differentiation of ithofacies in the sediments underlying the main lignite seam (legend to Fig. 12)

Opencast mine Oberdorf

Sediments underlying the main seam

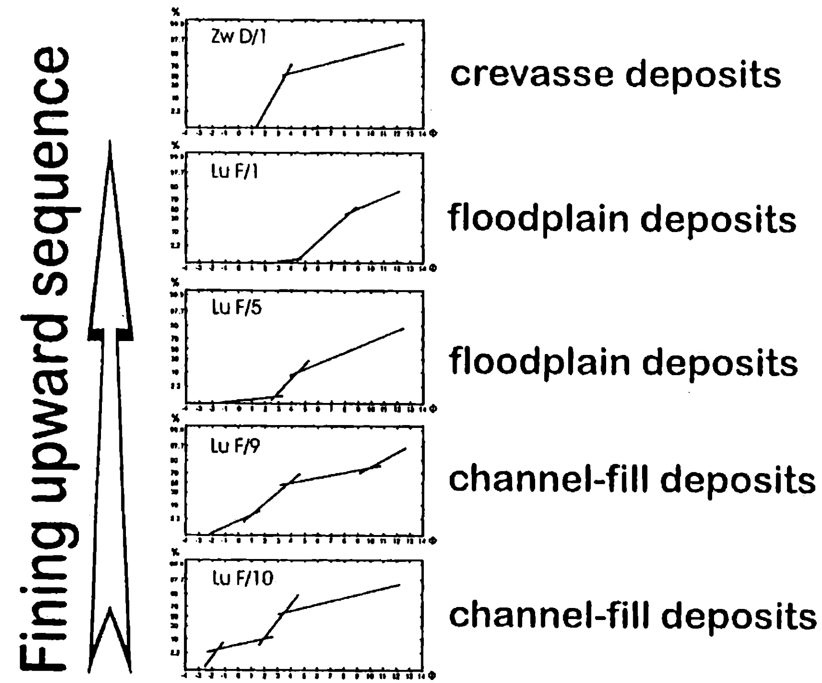


Fig.14 : Characteristic log-probability curve of grain size distribution (after VISHER, 1969)

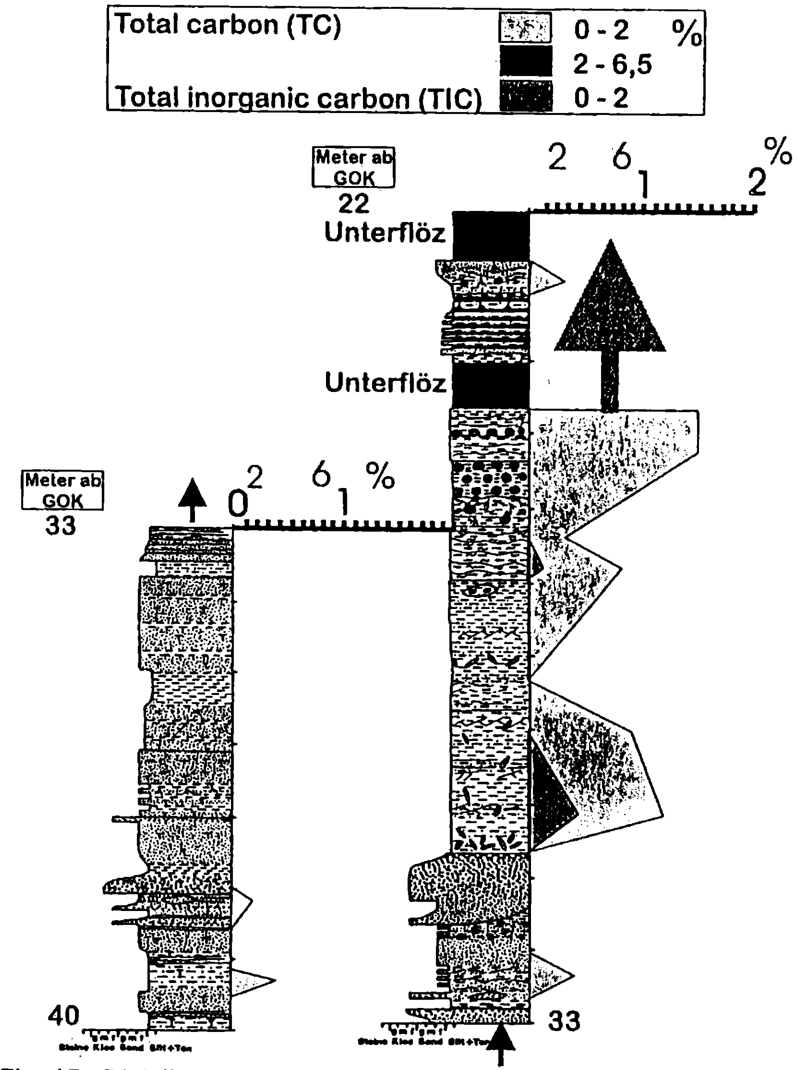


Fig. 15 : Distribution of Total Carbon (TC) and Total Inorganic Carbon (TIC) in the sediments underlying the main seam

Main parting

Along the eastern subbasin, an approximately 22m-thick main parting (Fig.16 and Fig.17) separates the main seam into an upper and a lower seam, which thins out considerably toward the center of the basin. The sedimentological conditions in the main partings reflect a distinct sandy/silty development and differ considerably from the silty/clayey development of the horizons underlying the lower seam.

The rapid transition from sandy/fine-gravelly to silty/clayey sediments as well as the occurrence of small-scale ripple marks, decimeter-sized fine-grained sand lenses, and normal graded sediment layers point to a depositional milieu of a fuviatile marginal facies with subordinate characteristics of a "river-delta-environment". Based on a facies analysis after VISHER (1969), the sediments can be compared with recent "distributary channel deposits", "natural levee-" and "crevasse deposits". The increased organic sedimentation in the uppermost "fining upward cycles" (Fig.18) and Fig.19) is documented by very high TOC contents (up to 3%) in the siliciclastic sediment. This is due to plant detritus as well as often excellently preserved, drifted wood remains, but also to secondary, diagenetically altered root horizons. The definitive proof of river bank plant communities in two horizons in the upper part of the outcrop (palaeobotanical study: KOVAR-EDER, MELLER), as well as the isolated occurrence of tree stumps successively lead to a transition from the siliciclastic-dominated sedimentation to the organic-dominated sedimentation and to the formation of the upper seam. Siderite and Fusain are again present as environmental indicators.

Opencast mine Oberdorf
Main Parting

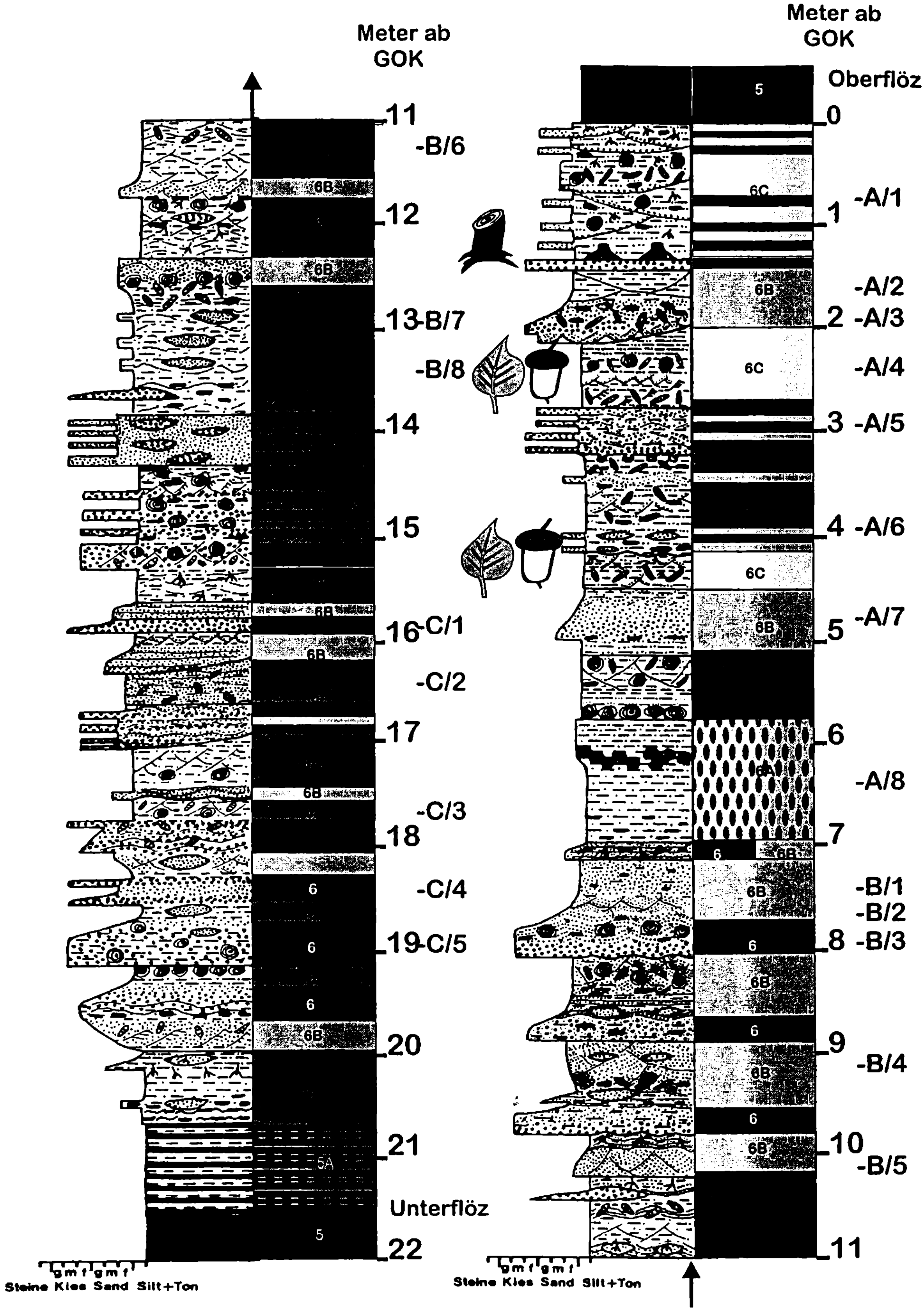
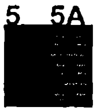


Fig.16: Lithology of the main parting in the Zangtal opencast minel

5 5A



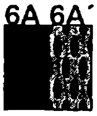
5. Bipartite main seam (upper and lower seam)

5A. Interlayered carbonshale and ignite; occurrence of Fusain.

6

Medium-coarse gravel, mostly well-sorted; abundant drifted? wood (<50cm); normal grading and occasinal interlayering of fine and medium sands as well as silts..

6A 6A´



Silty/clayey sediments; fine sand lenses and small ripple marks; occasional wood remains; high organic content (plant detritus).

6B

Fine-grained to medium-grain sand with high silt content, low-angle cross-stratification or occasional small-scale ripple marks alternating with even to wavy laminated bedding; occasionally alternating layers of fine gravel/fine sand; no sedimentary structures are recognizable in areas with a layered accumulation of secondarily modified wood remains (root horizons?)

6C

Silty/clayey sediments, brownish black; extremely high content of organic material; leaves and fruit reflect riverine plant associations (Results: "Co-op Palaebotany": KOVAR-EDER, MELLER);
Occasional tree stumps - probably in life position 

Fig. 17: Differentiation of lithofacies in the main parting (figure legend to Fig. 16)

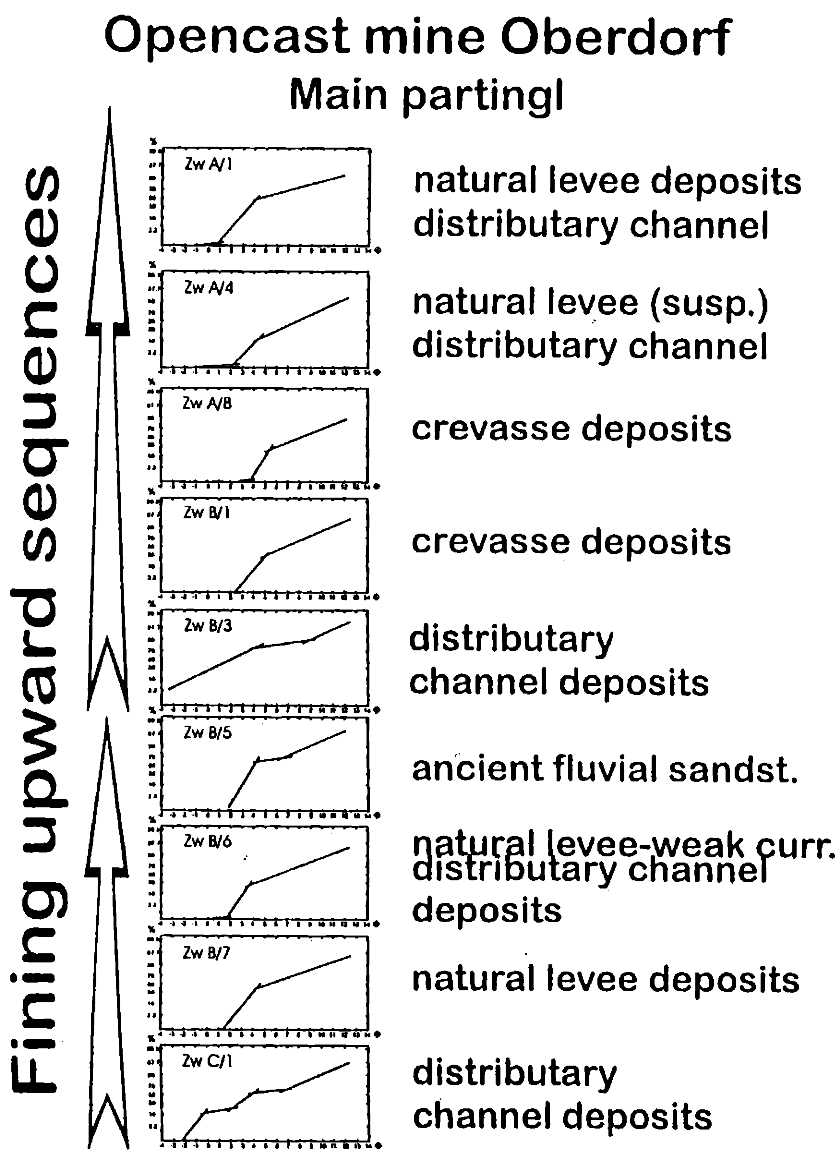


Fig. 18: Characteristic log-probability curve of grain size distribution (after VISHER, 1969))

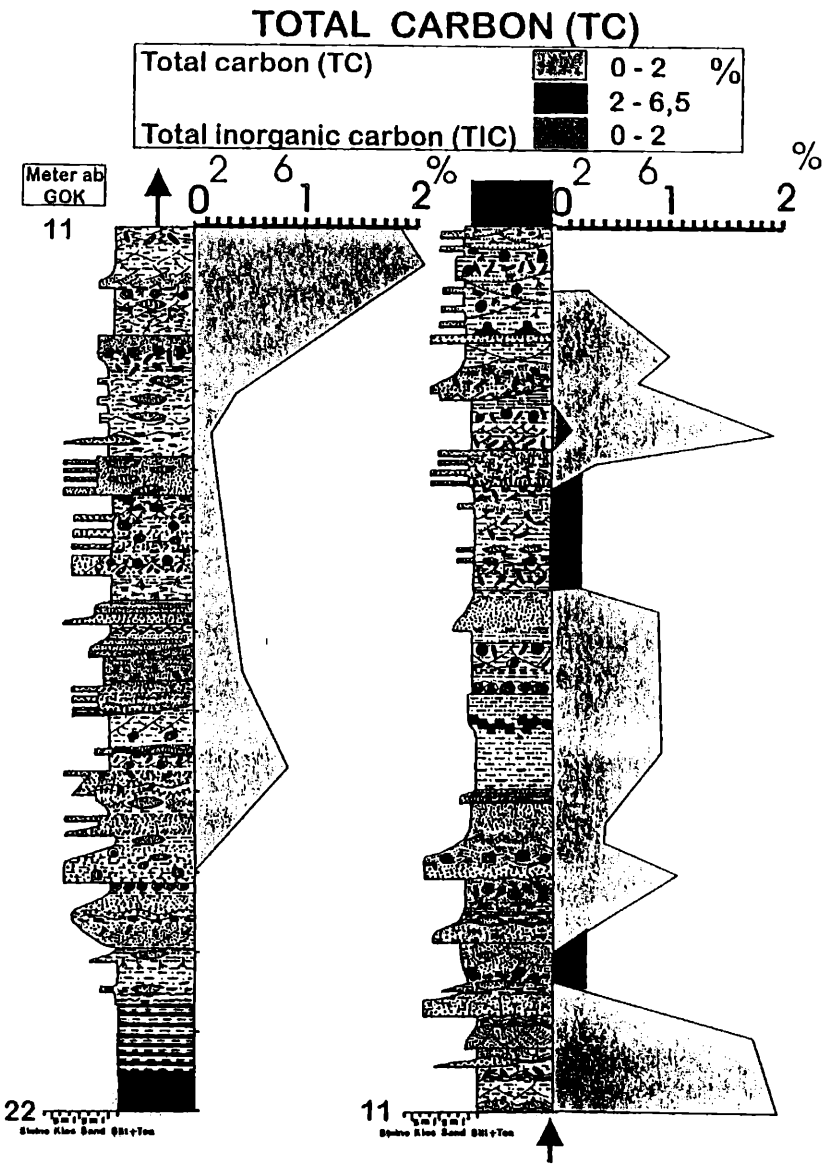


Fig. 19: Content of Total Carbon (TC) and Total Inorganic Carbon (TIC) in the main parting (opencast mine Oberdorf)

2.2.3.3. Opencast Mine Zangtal - Muttlkogel

The 69m-thick Muttlkogel profile in the opencast mine Zangtal represents an independent sedimentary development as opposed to the directly adjoining opencast mine Oberdorf. A high in the transitional zone between the two mines separates these different depositional areas.

The persistent deposition of coarse clastics shows a trend toward decreasing median grain size from the base to the top (Fig.20 and Fig.21). The basal coarsening upward sequence (Fig.22) leads to the deposition of channel fill deposits. It terminates the organic sedimentation cycle in the Zangtal lower seam. The transition from a high-gradient fluvial system to an uppermost low-gradient fluvial system, with the sedimentation of characteristic fluviatile marginal facies (current laminated sediments, natural levee deposits, floodplain deposits) accompanied by the deposition of delta sediments, ultimately leads - via continuous fining upward sequences - to the deposition of lacustrine sediments. The probable scenario is a typical succession for lignite-forming environments; it involves the development of a lake, including its progressive sedimentation, the formation of marshland, to the accumulation of peat-forming floras and, finally, the formation of seams (Zangtal upper seam).

The generally low TC content varies greatly, increasing to values of 6.5% only in the uppermost lacustrine sediments and especially in the transition to the Zangtal upper seam. The presence of Fusain in the lowermost sections of the Zangtal upper seam is an indicator of forest fires.

Siderite often occurs in great quantities. Thin-section analysis clearly shows its diagenetic formation by secondary displacement reactions along crystallographic surfaces of biotite. This leads to a splitting of the biotite lamellae (brittle structures) and ultimately to the complete displacement of biotite by siderite (BJORLYKKE & BRENSDAL, 1986).

Fig.25 shows a simplified representation (modified after McCABE, 1984) of the characteristic depositional areas of the sediments in the opencast mines Oberdorf and Zangtal.

Opencast mine Zangtal Muttlkogel

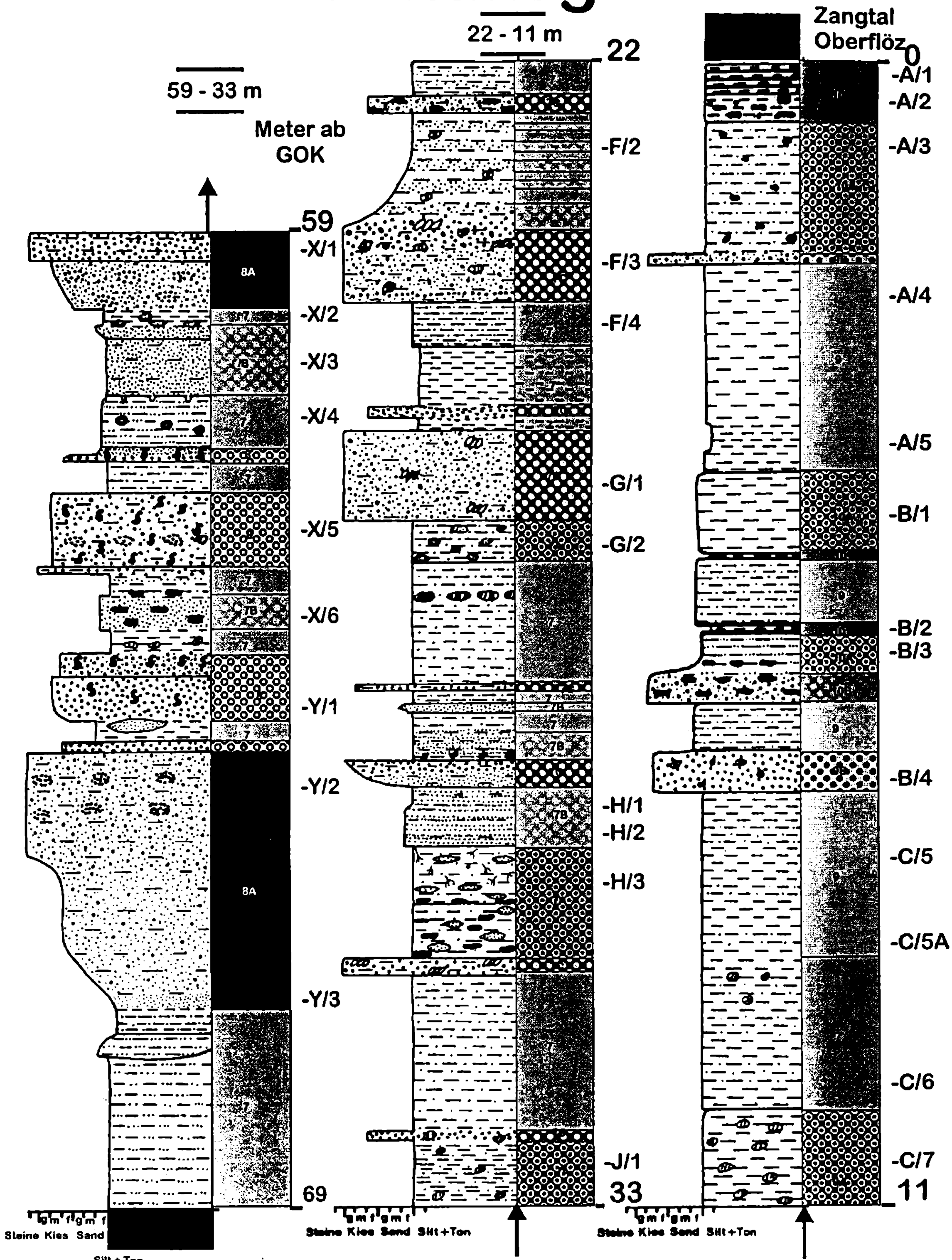
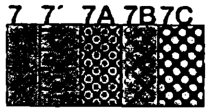
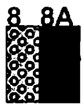


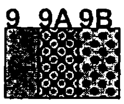
Fig. 20: Lithology of Muttlkogel in the opencast mine Zangtal (excerpts)



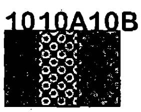
7., 7´. Silty clays - clayey silts, massive bedding, partly bioturbated 0.5 to 2m thick; 7A. clayey silts with lenses of fine to medium sand manganese precipitations, rip-up clasts, plant detritus, isolated wood remains. 7B. Laminated fine-grained sands, silts, and clays; 7C. Coarse gravel, channel fillings, imbrication, normal grading.



8., 8A. Sediment with gravel and boulder vompnents, rich in sulfureous residuals and iron oxide products; secondary diagenetic siderite formation; thick channel fillings (up to 3m) interrupted by thin sandy silts of a levee.



Silty clay - clayey silt, predominantly massive, partly medium-scale bedding, occasional lamination; clay layers with lignite seams, islated plant remains.



10B. The uniform sedimentation is interrupted by short-term, thin, sandy to medium-coarse gravel intercalations with manganese precipitations; silts and clay layers with increasing organic material content in the uppermost transition into the Zangtal upperseam; isolated Magnolia seeds; distinct Fusain layers in the basal Zangtal upper seam.

Fig. 21: Differentiation of lithofacies in the Muttlkogel profile (legend to Fig. 20)

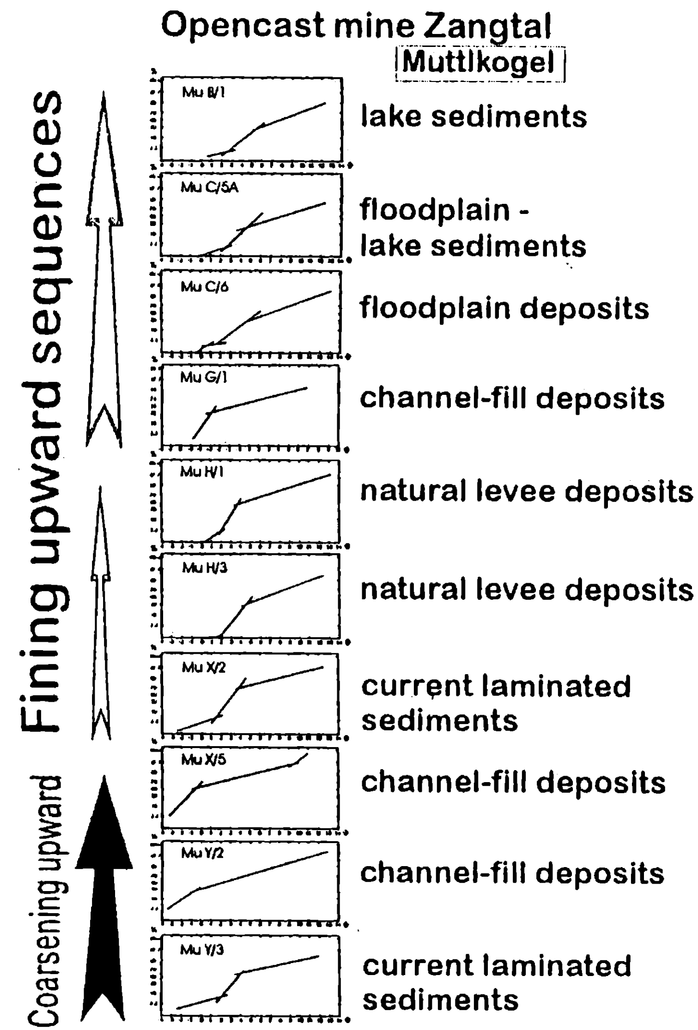


Fig. 22: Characteristic log-probability curve of grain size distribution (after VISHER, 1969)

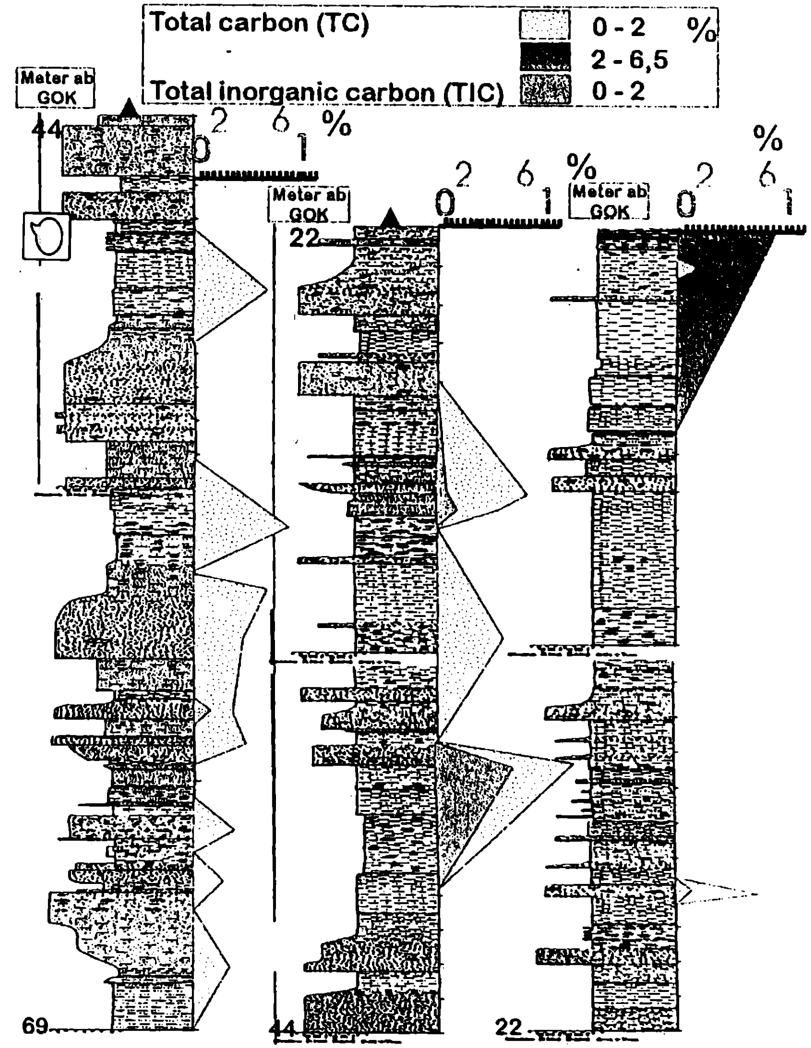


Fig. 23: Content of Total Carbon (TC) and Total inorganic Carbon (TIC) in the Muttlkogel profile (opencast mine Zangtal)

2.2.3.4. Heavy Mineral Distribution

The current status of sedimentological research in the region of the Oberdorf and Zangtal opencast mines allows two distinct erosional areas to be differentiated. In the main parting of the opencast mine Oberdorf, a significant garnet-chloritoid-dominated heavy mineral spectrum is evident within the siliciclastic lignite-bearing layers (source area: upper green schist facies, low-grade-metamorphism, absence of staurolite, green hornblende and zoisite; the introduction of reworked Gosau sediments cannot be excluded). The siliciclastics of the Muttlkogel outcrop in the opencast mine Zangtal show a garnet green hornblende-staurolite-zoisite (+ epidote and clinozoisite) (source area: amphibolite facies, medium grade metamorphism, absence of chloritoid; see Fig.17). The sediments underlying the lower seam are extremely poor in heavy minerals and therefore unsuitable for statistical analysis.

Acknowledgements: Thanks go to Prof. F. Steininger for directing and coordinationg the overall project. The investigations were made possible by an FWF grant (Project P10339 GEO).

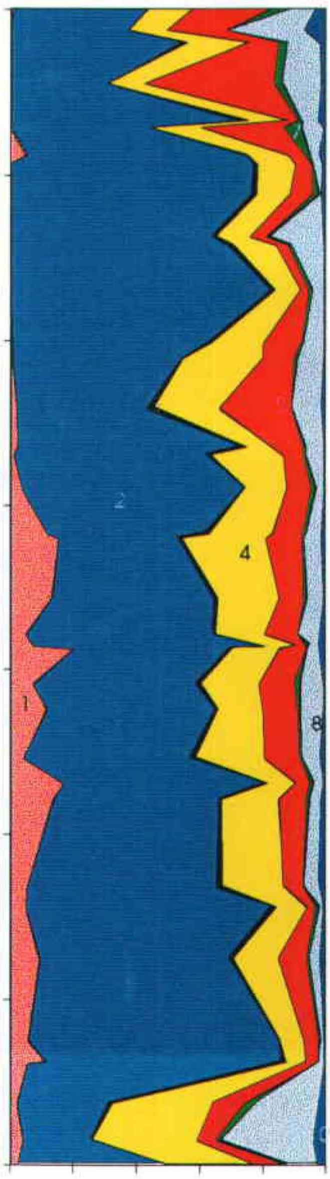
Heavy mineral distribution in the opencast mine Oberdorf and Zangtal

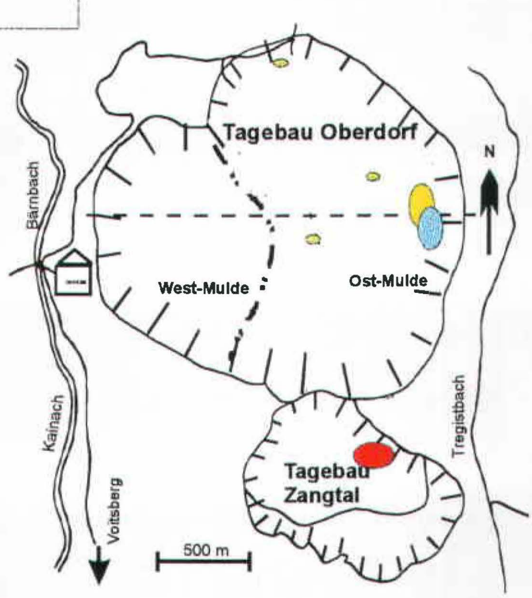
Source area:
Upper green schist fazies,
Low-grade metamorphism, Absence of staurolite, green hornblende und zoisit

→ **Opencast mine Oberdorf Main parting**

Source area:
Amphibolite facies,
Medium-grade metamorphism,
Absence of chloritoid

↓ **Opencast mine Zangtal Muttlkogel**



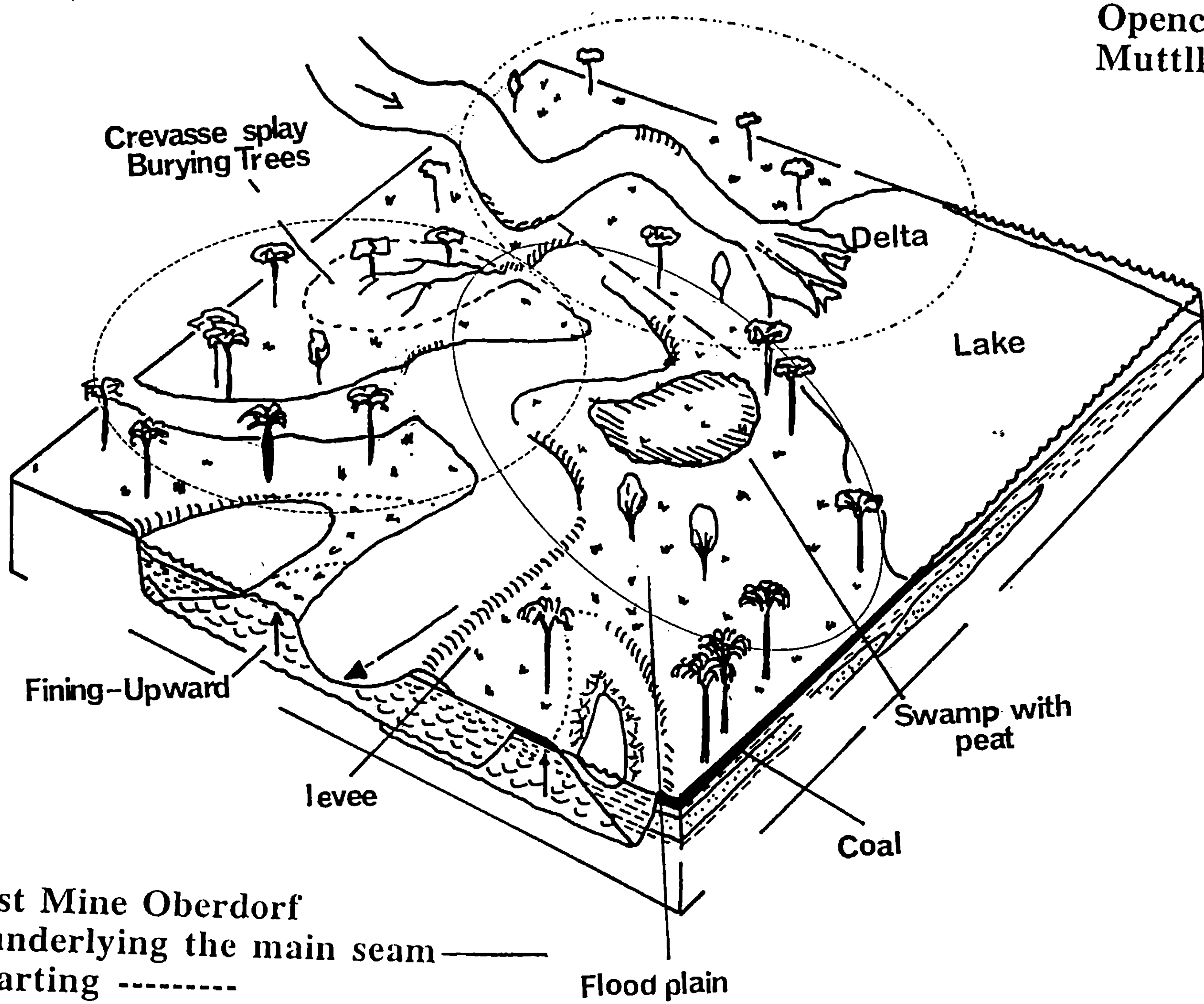


- 2 Rest
- 9 Zirkon
- 8 Turmalin
- 7 Ru+Br/An
- 6 Chloritoid
- 5 Zoisit
- 4 Epidot+Klzoi
- 3 Staurolith
- Granat
- 1 Hornblende, grün

Fig. 24: Differentiation of various source areas based on the heavy mineral analysis

Fig. 25: Model of lacustrine-fluvial depositional area (modified after P.J.Mc Cabe, 1984)

Opencast Mine Zangtal
Muttlkogel



Opencast Mine Oberdorf
Series underlying the main seam———
Main parting ---------

2.2.4. Petrology and Palynology of the Lignite at the Opencast Mine Oberdorf (I. KOLCON, R.F. SACHSENHOFER)

2.2.4.1. Introduction

The lignite petrography and palynology of several seam profiles was carried out in order to characterize the depositional milieux of the lignite. The results of borehole 304, which was drilled near the center of the basin, have been selected here as a case example. In this area, the main parting is thin (Fig.26). Based on its water content of approx. 40% (Pohl, 1970) the lignite can be characterized as soft lignite .

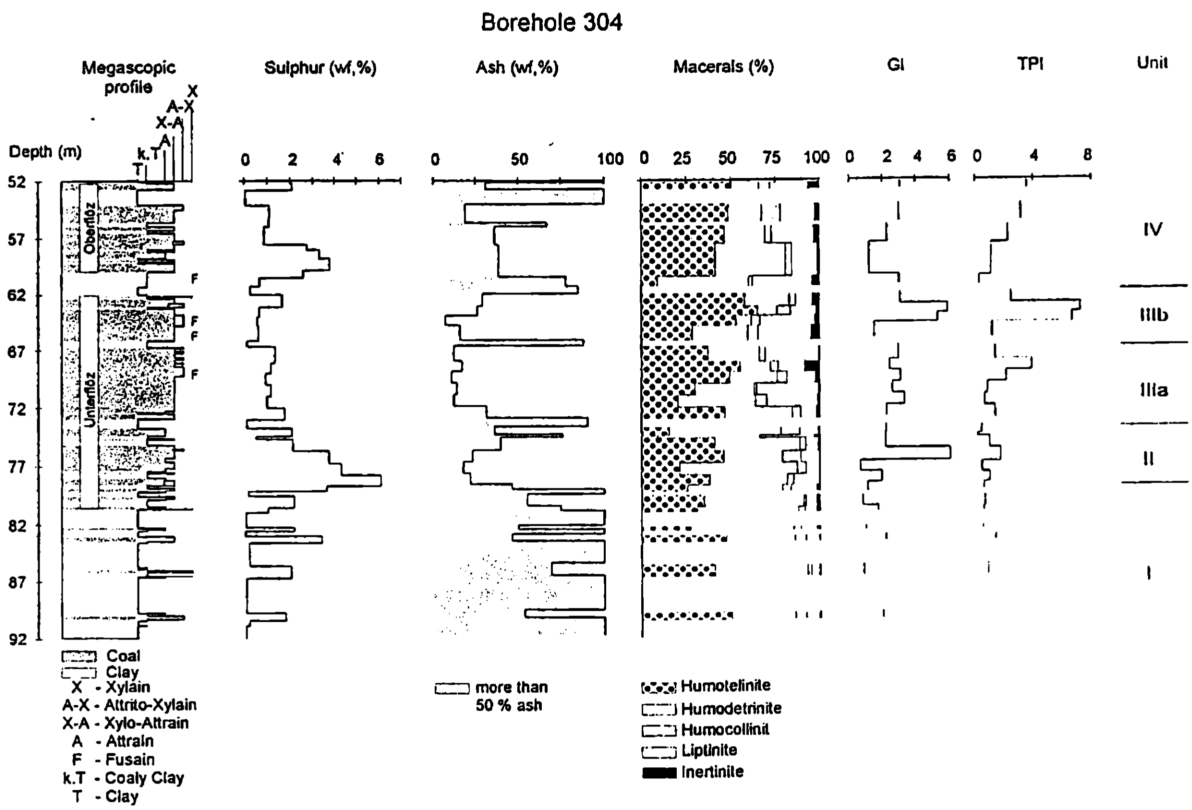


Fig.26. Megascopic profile, sulphur, ash, maceral group content, Gelification Index (GI), Tissue Preservation Index (TPI) of borehole 304

2.2.4.2. Megascopy and ash content (Fig.26)

The workable part of the seam lies between 54.15 and 79.24 m depth. The base of the seam bears several unworkable lignite layers. Seam correlation shows that the boundary between the upper and lower seam is represented at approx. 61 m depth in the main parting. The most abundant macrolithotype is xylo-attrain (fine detritic plant material, less frequently fossil wood). Attro-xylain (fossil wood, less frequently detritic matter) is followed by attrain and xylain. Fusain (fossil wood charcoal) is present in thin layers. Nearly half of the seam profile consists of clay or carboshale. The lignite is generally rich in ash and confirms its origin in a lowland moor.

2.2.4.3. Sulphur content and pH conditions

The sulphur content of lignites depends on the pH value (S-reducing bacteria prefer pH values around 7) and on the supply of sulphate (e.g., CASAGRANDE, 1987). Marine lignites are therefore always rich in sulphur, while non-marine lignites are mostly poor in sulphur. The exception is non-marine moors with a relatively high pH value. Changes in the sulphur content can therefore be discussed in connection with pH conditions.
The sulphur content (wf) reaches a maximum near the base of the lower and upper seam (Fig.26). This is attributable to a concentration of acidic, sulphate-rich moor water close to the less permeable base. The observed moderate increase in the sulphur content towards the top layers is typical for lignite in a transgressive cycle (flooding of the moor). The sulphur content of the lignite is positively correlated with the ash content and indicates that water flowing into the moor not only sedimented mineral substances but also raised the pH value by diluting the humic acid formed in the moor. The carbonate-rich surface waters from the north (Graz Palaeozoic) most likely further raised the pH value and are therefore responsible for the high sulphur content which often is unusually high for non-marine lignites.

In lignitic sediments with an ash content exceeding 50%, the sulphur content decreases with increasing ash content. The low amount of organic material limits the sulphur content of these sediments. On the other hand, a sulphur content of $<$ 1% (wf) is a clear indicator for non-marine sedimentation.

2.2.4.4. Micropetrography, Facies indicators

The petrographic composition of lignite depends on the ecology of the place of origin, the climate, the plant community and the degree of coalification. The petrographic composition therefore provides information about the moor facies. As moor plants react sensitively to changes in local conditions, lignite-petrographic investigations provide a precise tool for facies analysis (TEICHMÜLLER & TEICHMÜLLER 1982).

During the last decade, a number of authors have developed facies indicators based on maceral analysis. The most commonly used are those of DIESSEL (1986):

* Gelification Index (GI; proportion of gelified to non-gelified macerals), which represents a measure for the wetness of the moor

* Tissue Preservation Index (TPI; proportion of preserved to degraded plant tissues), which is a measure of tree density or for suitable conditions for tissue preservation (DEHMER 1989, 1995).
The change in the maceral group contents with depth is evident in Fig.26. Huminite (62-95 Vol. % mmf) is by far the most abundant maceral group. Liptinite (above all resinite, suberinite, sporinite, liptodetrinite) contributes 4-35 Vol. % to the composition of the lignite, while inertinite (fusinite, sclerotinite, inertodetrinite) contributes 0.4-8 Vol. %.
Tissue preservation (TPI) decreases slightly within the unworkable layers at the base of the seam (unit I) and generally increases within the lower seam. Partings at 66.5 and 73.5 m depth enable a subdivision of the lower seam into units (units II, IIIa, IIIb), whereby the tissues are best preserved in the middle of this seam. In the upper seam (unit IV), TPI increases towards the uppermost layer. With the exception of unit IIIa (68-76 m depth), which is characterized by constant GIs, the GI and TPI values are in agreement. This confirms that tissue preservation is controlled not only by tree density, but also by the wetness of the moor.

2.2.4.5. Palynology

Thirty point samples (from lignites and partings) were investigated palynologically. Eighty-seven different taxa were determined and assigned to different plant communities:
* plants from open water and the shore zone (Fig.27),
* the forest swamp (Fig.28),
* the shrub moor (Fig.28) and
* a mixed mesophytic forest (Fig.29).
* spores of Bryopsida and Pteridophyta are represented separately (Fig.30).

The statistical evaluation of the counts (cluster analysis) enabled the samples to be arranged into 5 groups (A1, A2, B1, B2, B3). Fig.31 shows their average composition with regard to plants of the different facies zones; Fig.32 shows their succession in the seam profile. Accordingly, lignite formation began in forest swamps and shrub moors. The large number of barren partings points to interruptions in moor growth due to flooding. The average palynological spectrum of this phase (B2) is presented in Fig.31. The subsequent phases of moor development are characterized by numerous fluctuations in the water level and corresponding changes in the flora. Very moist periods are correlated with a greater abundance of aquatic plants as well as of forms inhabiting shore zones and forest swamps (A1, A2, B1, B2). Drier periods are characterized by a greater contribution of shrub moor plants and representatives from mixed mesophytic forests (B3, B4).

In comparing the results of the lignite-petrographic and palynological investigations, note that the trees and bushes of the forest swamp contribute significantly to lignite formation, while small aquatic plants form only little peat mass. The latter, however, are good ecological indicators.

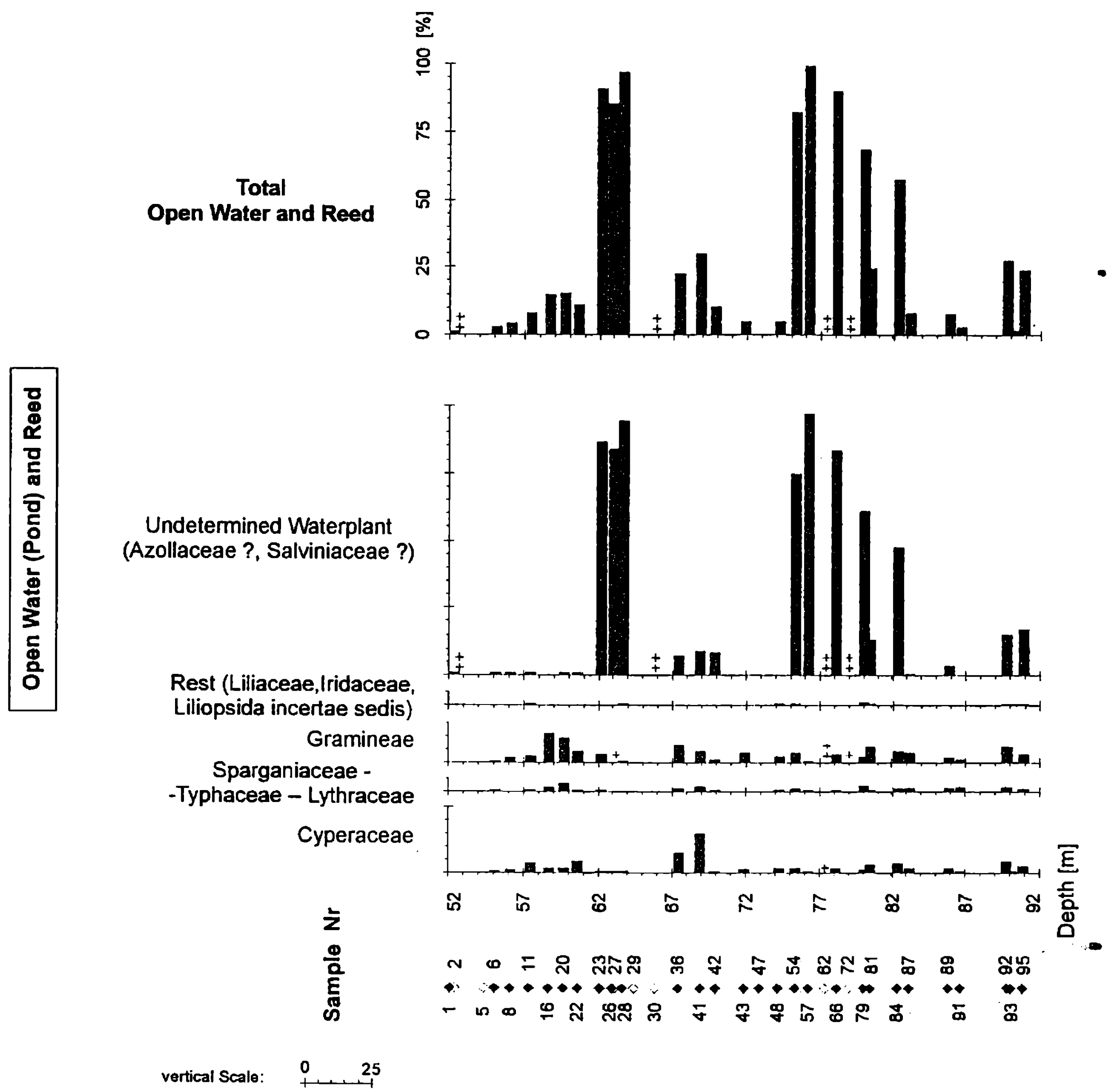


Fig. 27. Content of open-water (pond) and reed zone plant sporomorphs in the seam of borehole 304.

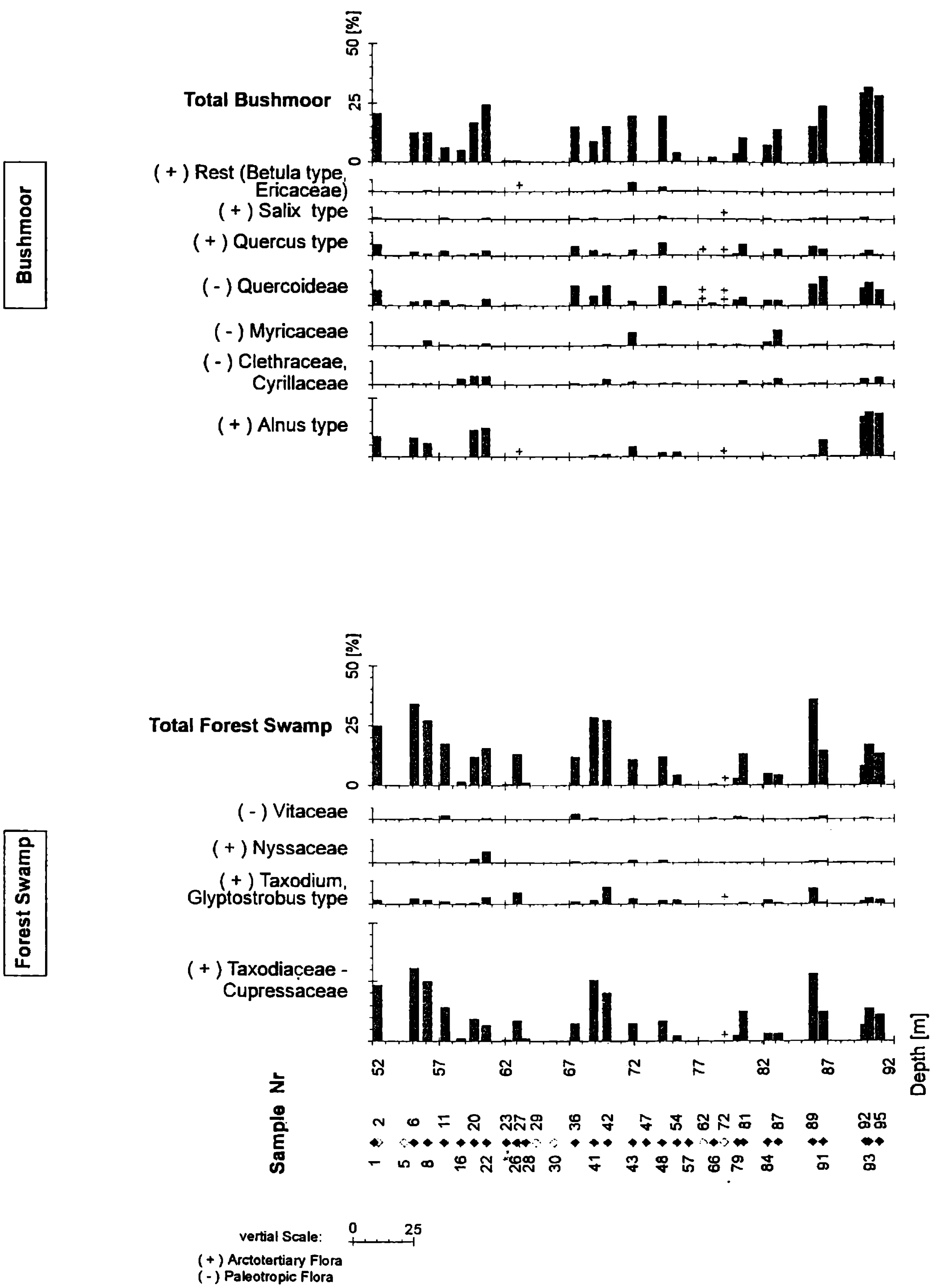


Fig.28. Content of forest swamp and shrub moor pollen of borehole 304

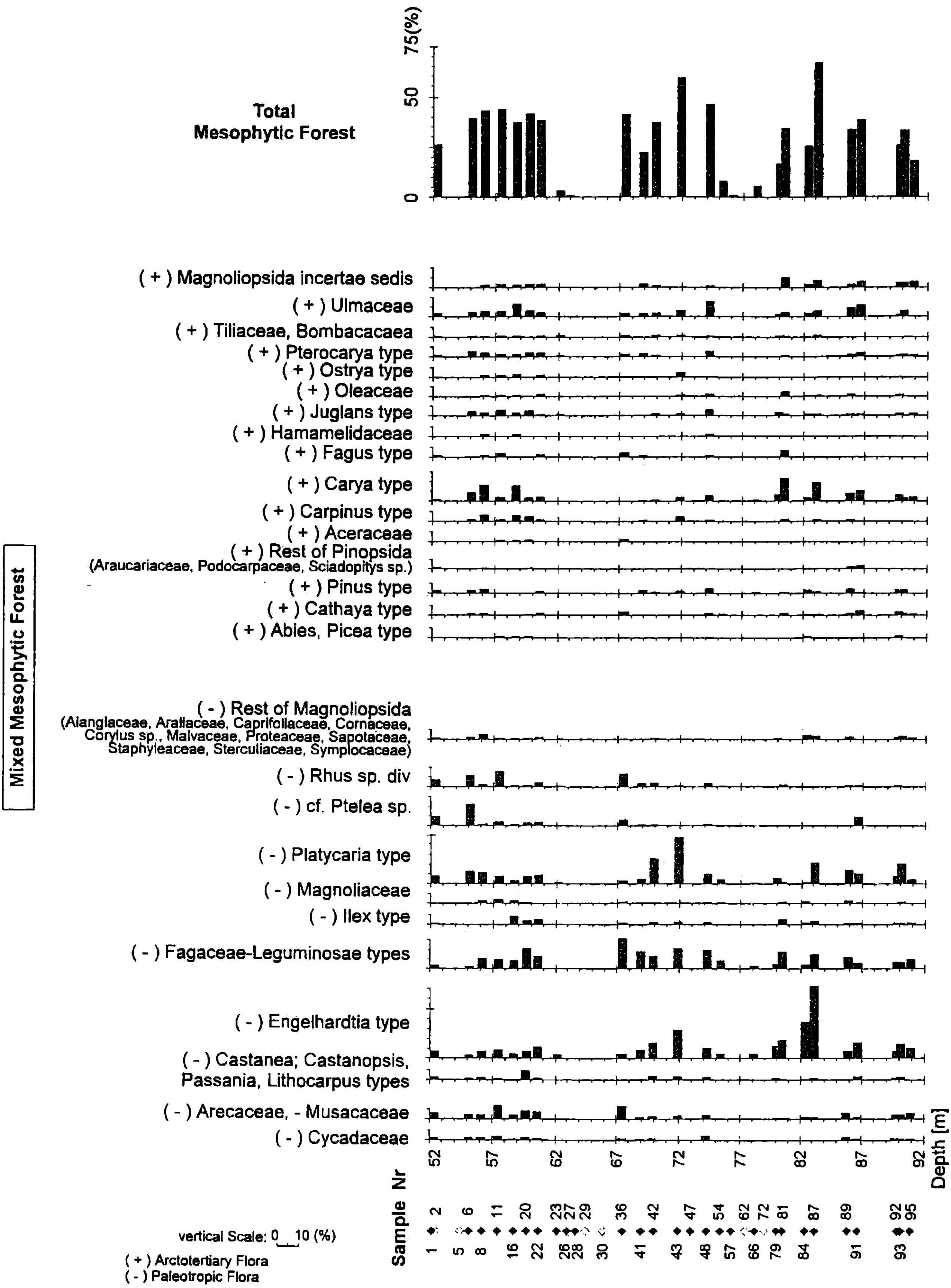


Fig.29. Content of mesophytic forest pollen in the seam of borehole 304

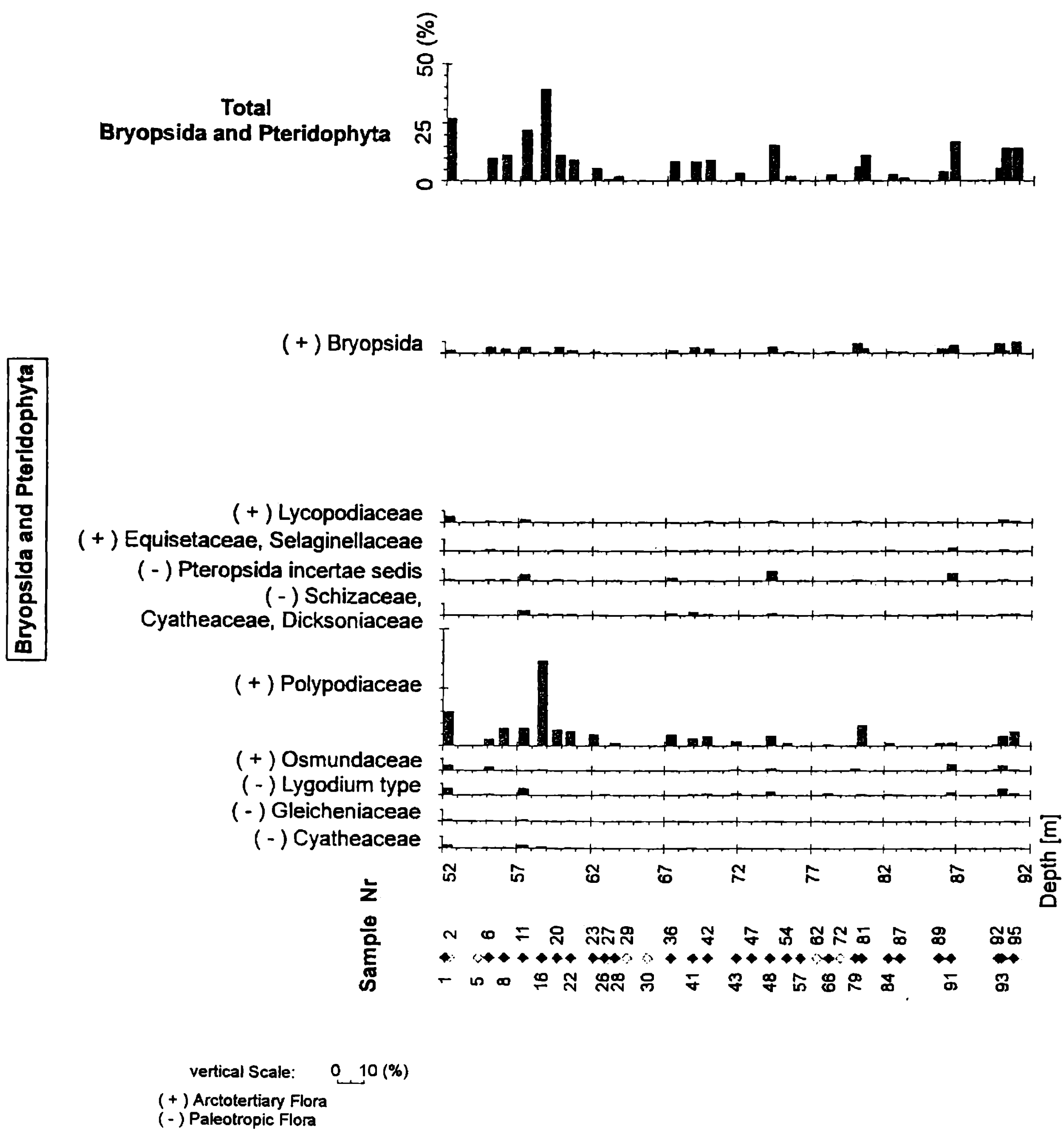


Fig.30. Spore content (without Azollaceae - Salviniaceae) in the seam of borehole 304

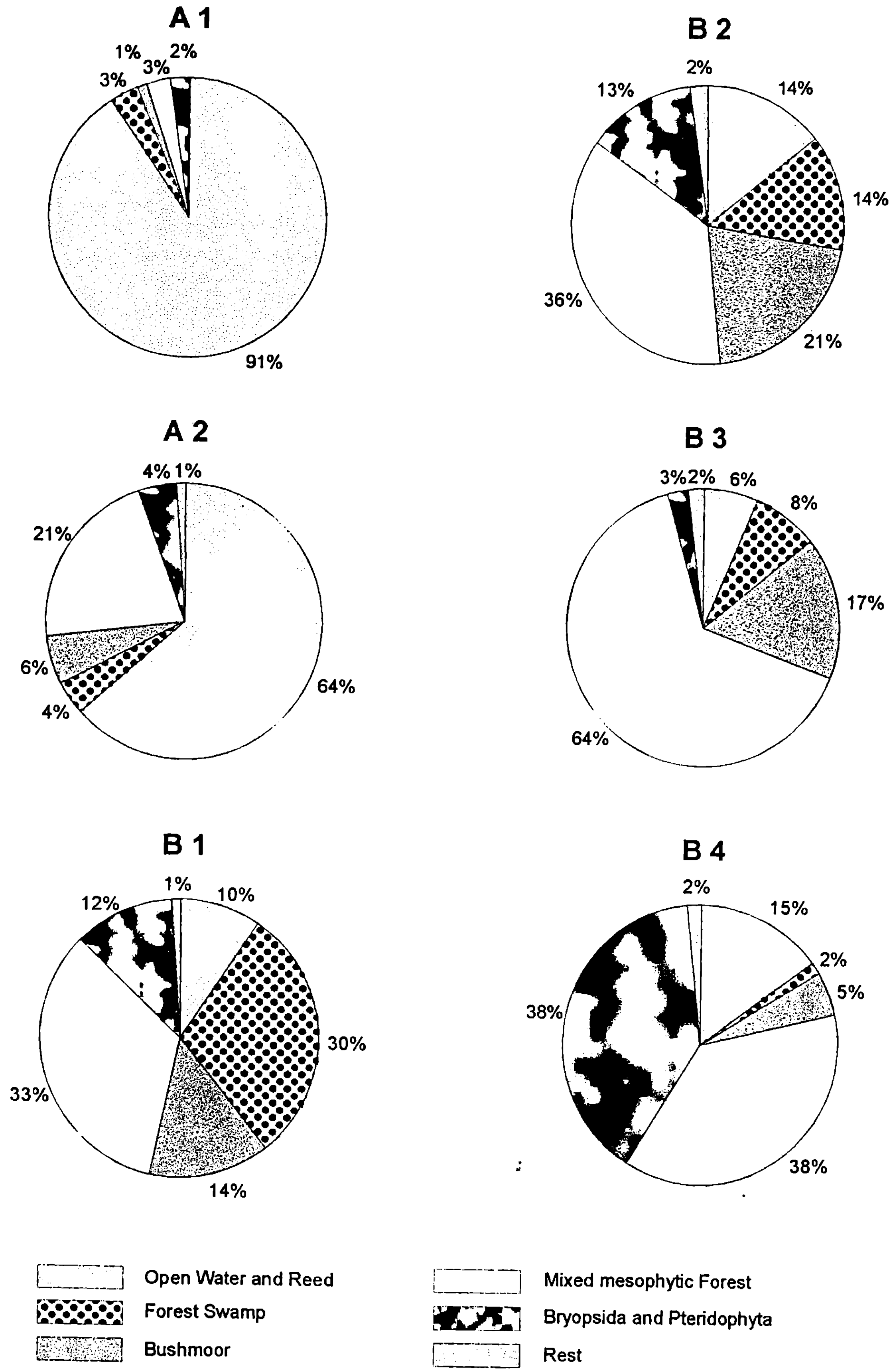


Fig.31. Average composition of the plant communities in the various phases of moor development in borehole profile 304 (in per cents)

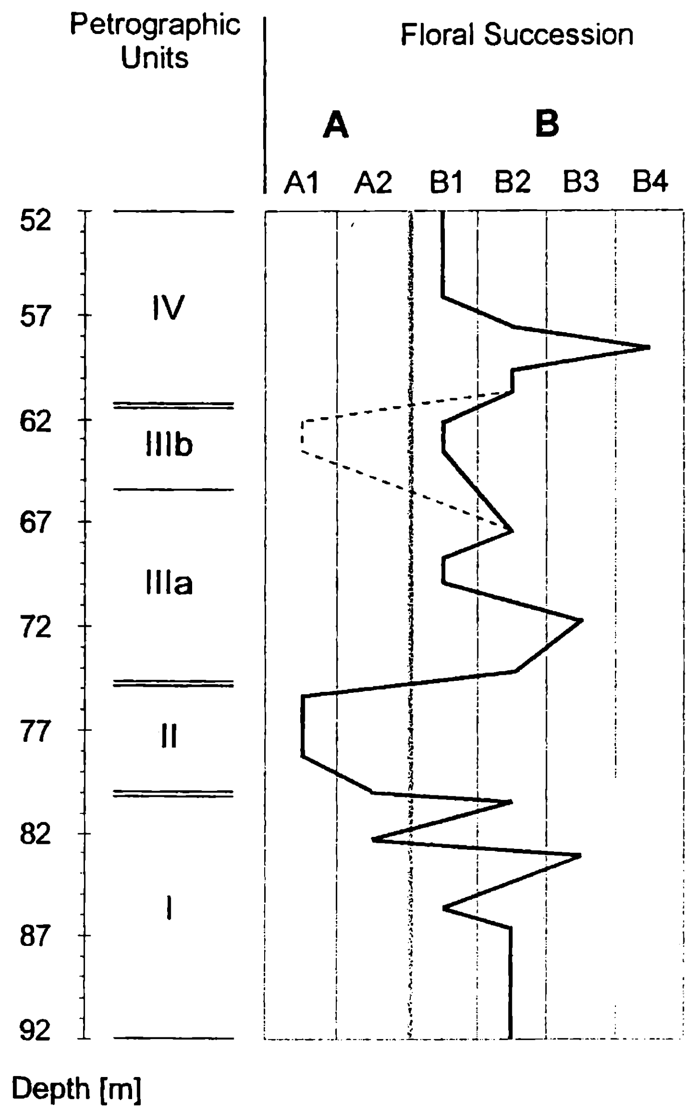


Fig.32. Lignite-petrographic units and flora sequences in the seam of borehole 304

2.2.5. Palaeobotanical Investigations in the Opencast Mine Oberdorf (Johanna KOVAR-EDER)

Numerous scientific collections contain extensive fossil plant remains from the rich Styrian Miocene localities (such as Schönegg, Parschlug, Leoben-Münzenberg and Leoben-Moskenberg); much of this material dates back to the 19th century. Many of these floras were treated in monographs by Constantin von ETTINGSHAUSEN and Franz UNGER. Although many pits in the Köflach-Voitsberg region produced coal at that time, none of the scientific institutions has a significant collection from this very rich locality. Up until a few years ago, the only publication available was that of C. v. ETTINGSHAUSEN (1858), which contained a few species descriptions. One explanation for this situation is the very difficult long-term conservation of fossil leaf remains as well as the modern techniques of obtaining and preserving fossil diapsores and palynomorphs.

Sampling for palaeobotanical investigations began in 1982, shortly after opencast mining began in Oberdorf. Over the course of the years, sampling accompanied the mining progress, i.e., initially in the subbasin to the west, later the subbasin to the east. While the base of the Western subbasin was reached in the 1980s, that in the Eastern subbasin was first mined in 1995. Currently, the Western subbasin has already been refilled and the Eastern subbasin is being mined.

The samples were not only collected vertically in all parts of the sequence, but also laterally displaced at various levels in order to determine potential local differences in species composition.

In the framework of a project funded by the Austrian Science Fund (FWF), fossil plant remains, leaves, diaspores, palynomorphs, and wood have been investigated since 1995. The state of preservation of the various organs is variable: excellently preserved palynomorphs derive from the basal layers of the seam. Diaspores are quite abundant at all levels, but are often highly compressed, similar to the woody material. Carbonized leaf remains also occur in numerous horizons, occasionally massively. Nonetheless, cuticular analysis was not always successful in all levels.

The preservation of the various plant organs and the species composition in various horizons is correlated to grain size, degree of sorting and source area of the sediment. Particularly well-preserved (entire) leaf remains are more frequent in sediments with a higher clay fraction than in sandy/silty deposits. On the other hand, species diversity (based on diaspores and leaves) is lower in the fine-grained horizons, although the number of individuals is often higher than in the coarser clastics.

The diaspore study has made the greatest progress (MELLER 1995, MELLER 1997) and has revealed a distinct differentiation between the diaspore communities from lignitic/clayey to silty sediments and those from sandy/silty deposits. In lignitic clays and clayey/silty samples, representatives of swamp forest communities and shrub bogs predominate: *Glyptostrobus europaeus*, *Nyssa ornithobroma*, *Magnolia burseracea*, *Cercidiphyllum helveticum*, *Myrica ceriferiformoides*, *Sparganium haentzschelii*, *Meliosma wetteraviensis*, *Rubus* and Vitaceae. Elements from aquatic facies are missing largely.
In coarse silty to sandy sediments, representatives of mesophytic forests predominate. This includes *Cephalotaxus miocenica*, *Fagus* sp., *Mastixia amygdalaeformis*, *Sequoia abietina*, *Carya ventricosa*, *Pterocarya*, *Actinidia*, *Eurya*, and more rarely *Toddalia latisiliquata*, *Symplocos lignitarum*, and *Meliosma pliocaenica*. Nonetheless, these samples also occasionally contain elements characteristic of moist habitats. Based on the common occurrence of seeds, MELLER termed this facies the *Cephalotaxus* facies. In general, these associations show a distinctly lower species diversity than comparable associations from Wackersdorf or Wiesa. Only those from the base of the seam in the opencast mine Oberdorf are species-rich and contain a high percentage of elements from zonal forest communities.

The numerous associations of fossil leaf remains from the opencast mine Oberdorf are also generally poor in species. They permit not only a differentiation corresponding to that of the diaspores, but also various vertical sections of the sequence:
- clayey/silty/sandy, poorly sorted layers directly at the base of the seam in the Eastern and Western subbasins,
- fine silty/clayey sediments and lignitic/clayey seam partings in the Eastern and Western subbasins,
- silty/sandy main seam parting in the Western subbasin,
- fine silty, clayey, finely layered section in the upper part of the lignite-bearing sequence of the Eastern subbasin.

The poorly sorted clayey/silty/sandy layers with coarse, breccial components directly at the base of the seam contain the most species-rich associations found to date (leaves, diaspores and palynomorphs) (KOVAR-EDER & al. in press, MELLER & al. in press). Most of the leaf remains are highly fragmented and can only be identified by cuticular analysis. A number of taxa has exclusively been documented from this level based on leaves, diaspores or pollen: *Daphnogene*, *Laurophyllum pseudoprinceps*, *L. markvarticense*, *L. pseudovillense*, *Trigonobalanopsis rhamnoides*, "*Castanopsis*" *bavarica*, *Poliothyrsis eurorimosa*, *Distylium* cf. *uralense*, *Eomastixia* cf. *holzapfelii*, ? *Fagaropsis koeflachensis*, *Gironniera verrucata*, *G. neglecta*, *Ternstroemia reniformis*, *Pentapanax tertiarius*. This is the first record in Austria for many of these taxa. The samples of the individual organ

associations supplement one another. *Trigonobalanopsis*, *Myrica*, and Taxodiaceae are represented by all three organs. Many others are documented by at least two organs, e.g. *Symplocos* (fruit, pollen), *Tetraclinis* (cones, twigs), others only by a single organ, e.g. most representatives of the Lauraceae only by leaf fragments.
These associations from the base of the seam in Oberdorf represent the first evidence of a rich Younger Mastixioid flora sensu MAI in Austria. Beyond this, the lignite-bearing sequence in the opencast mine Oberdorf contains no additional associations of this type that are equally rich in species.

Fine silty/clayey sediments and lignitic/clayey seam partings in the Eastern and Western subbasins often bear densely packed leaf remains with a monotonous species composition: *Quercus rhenana* is the absolute monodominant form here, accompanied by *Glyptostrobus europaeus*, *Myrica joannis*, and *Fraxinus ungeri* (KOVAR-EDER 1996). A corresponding association was also sampled in the opencast mine West ("Barbarapfeiler"). Similar associations are known from the lignite sequences of the Czech Republic and Poland, where they are interpreted as successional stages in the development of lignite swamps. This interpretation may also be valid for the Köflach-Voitsberg region (KOVAR-EDER 1996).

Numerous drift horizons with plant detritus were found in the silty/sandy seam parting of the Western subbasin. *Sequoia abietina* (twigs, cones) (and ? *Glyptostrobus europaeus*) associated with only a few other taxa such as *Cercidiphyllum crenatum - helveticum* (leaves, fruit), *Cephalotaxus* needles, and *Salix* sp. leaves deserve mention. The latter two species are mostly absent in other parts of the opencast mine.

The fine silty/clayey, well-layered section in the upper part of the lignite-bearing sequence in the Eastern subbasin is particularly rich in horizons bearing macro-remains. The leaves are often fully preserved and lie densely packed next to and on top of one another. In this region, the main components of these communities are *Alnus* sp., *Acer tricuspidatum*, *Fraxinus* sp., *Cercidiphyllum crenatum*, *Sequoia abietina* (and *Glyptostrubus europaeus*). Taxa that are abundant in other sections, such as *Quercus rhenana* in the lignitic/clayey seam partings or the Lauraceae and evergreen Fagaceae in the layers at the base of the seam, are absent here.

The explanation for the much more highly differentiated leaf (versus diaspore) associations may lie in the different energetic levels of the transporting water bodies: in one case they led to the accumulation of leaves, in another to accumulation of fructifications. As opposed to the situation in leaves, where autochthonous origins predominate, both the diaspore and pollen associations more often encompass elements from several different sites that can be some distance away (high allochthonous influence). Leaf associations may therefore be better suited to differentiate between various, perhaps tightly delimited sites in moist habitats.

The differences in the associations of the entire lignite-bearing sequence are interpreted to indicate facial changes in the swampy area, where fluviatile influences predominate. Mesophytic forests, characterized by the predominance of evergreen taxa and comparable to the Evergreen Broad-Leaved Forests of South and Southeast Asia, are most clearly preserved in the horizons at the base of the seam; they are also present in the sandy sediments of the subsequent sequence, although they are considerably less species-rich there. Leaves, diaspores and pollen contain a broad, complementary spectrum of this woody flora. Herbaceous elements are rare and for the most part documented in the form of pollen, spores and diaspores.
Lignitic/clayey seam partings and clayey/silty sediments reflect mostly species-poor swampland forests, alluvial forests and shruby bogs. Elements from sedge and reed banks and from aquatic plant communities are generally not very abundant and restricted to carpological and palynologicaql finds.

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Postconference Excursion

Meso- to Cenozoic tropical/subtropical climates - Selected examples from the Northern Calcareous Alps and the Vienna Basin

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Meso- to Cenozoic tropical/subtropical climates - Selected examples from the Northern Calcareous Alps and the Vienna Basin

by

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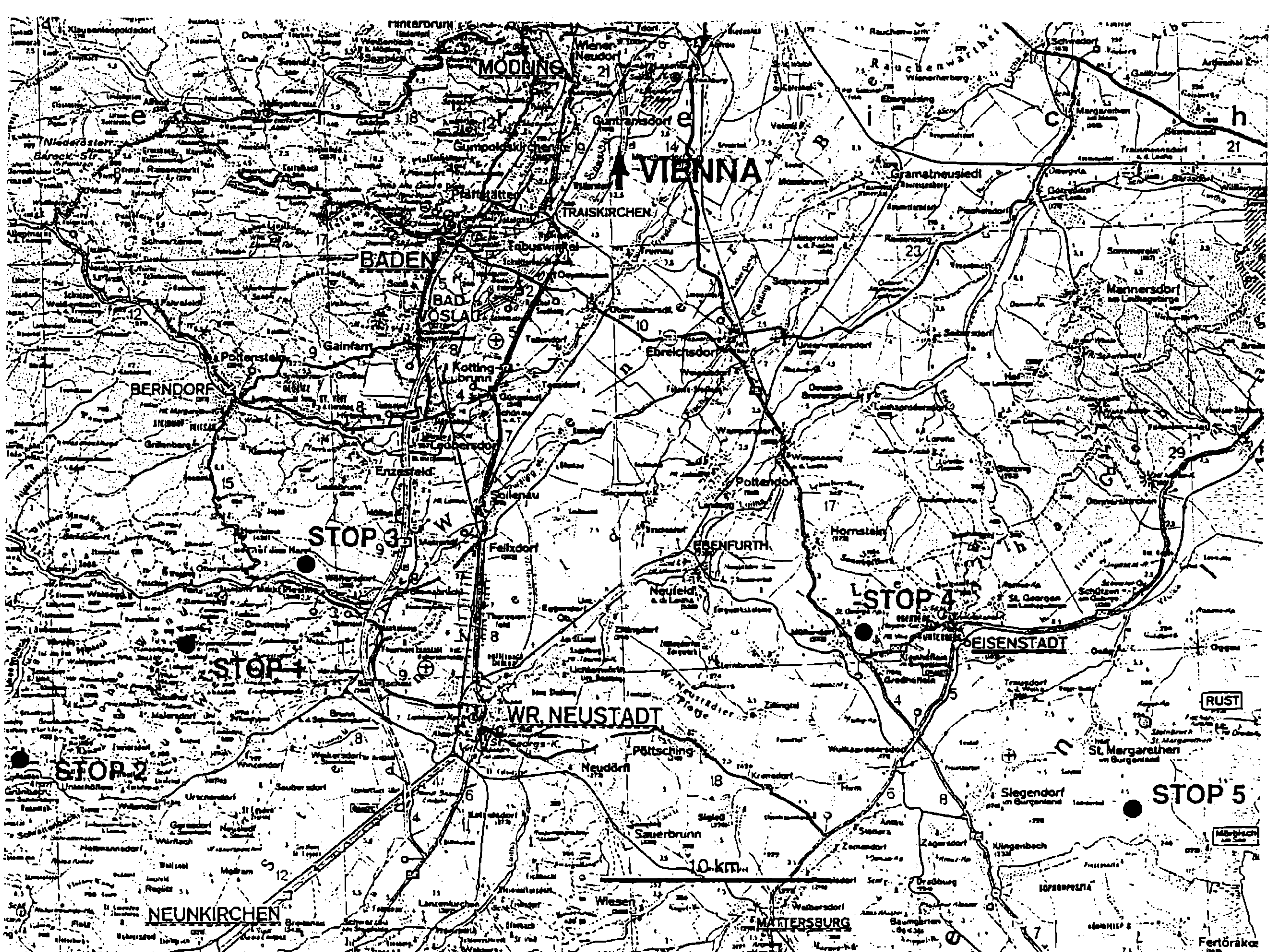
Introduction

Following the general subject of the 2nd European Palaeontological Congress "Climates: Past, Present and Future" the post-conference excursion is intended to show examples for tropical-subtropical climate indications during the Mesozoic and Cenozoic. Since this excursion is limited to one day only outcrops in the vicinity of Vienna can be visited. Due to this restriction 2 Mesozoic examples of the easternmost margin of the Northern Calcareous Alps - Late Triassic and Late Cretaceaous in age - and one example of the Neogene of the Vienna Basin can be presented. In addition, the reaction of the biotas to salinity reduction in the Sarmatian - Pannonian (Middle - Late Miocene) of the Vienna Basin will be visited.



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1. The Late Triassic Reef of the Hohe Wand (Northern Calcareous Alps)
(WERNER E. PILLER)

1.1. General overview

The Triassic sediments of the Northern Calcareous Alps were deposited on a passive continental margin adjacent to the Tethys Ocean (comp. KRYSTYN & LEIN, 1996). Due to this position on a relatively mobile crust the Triassic sequences and particularly that of the Late Triassic (Norian - Rhaetian) are characterized by thick sediment piles of shallow water carbonates which show distinct lateral facies variations (Fig. 1). The post-Triassic tectonic activities, however, produced intensive overthrusting and differentiation of tectonic units and nappes. In the middle and eastern part of the Northern Calcareous Alps three major tectonic units can be differentiated: Bajuvarikum, Tirolikum, and Juvavikum (from base to top).

The thick Late Triassic carbonates (Dachstein limestone, Hauptdolomite) were deposited on large carbonate platforms which interfinger with basinal sediments (Hallstatt limestone, Zlambach beds). The shallow/deeper water transitions were developed as slopes or ramps. The margins of the platforms or the upper part of the ramps were frequently inhabited by reefs of different categories. On the extensive platforms bedded Dachstein limestone of Lofer facies (FISCHER, 1964) with lateral facies variations were deposited (e. g., PILLER, 1976, 1981; PILLER & LOBITZER, 1979; DULLO, 1980). These mostly reflect shallow subtidal conditions with minor inter- and supratidal intervals. Further to the north these bedded Dachstein limestones grade into Hauptdolomite which is predominantly formed in intertidal environments. Tectonically, the Dachstein Limestone reefs are found in the Tirolikum and Juvavikum, whereas Hauptdolomite belongs predominantly to the Bajuvarikum but occurs also in the Tirolikum. Hallstatt limestone and Zlambach beds are restricted to the Juvavikum.

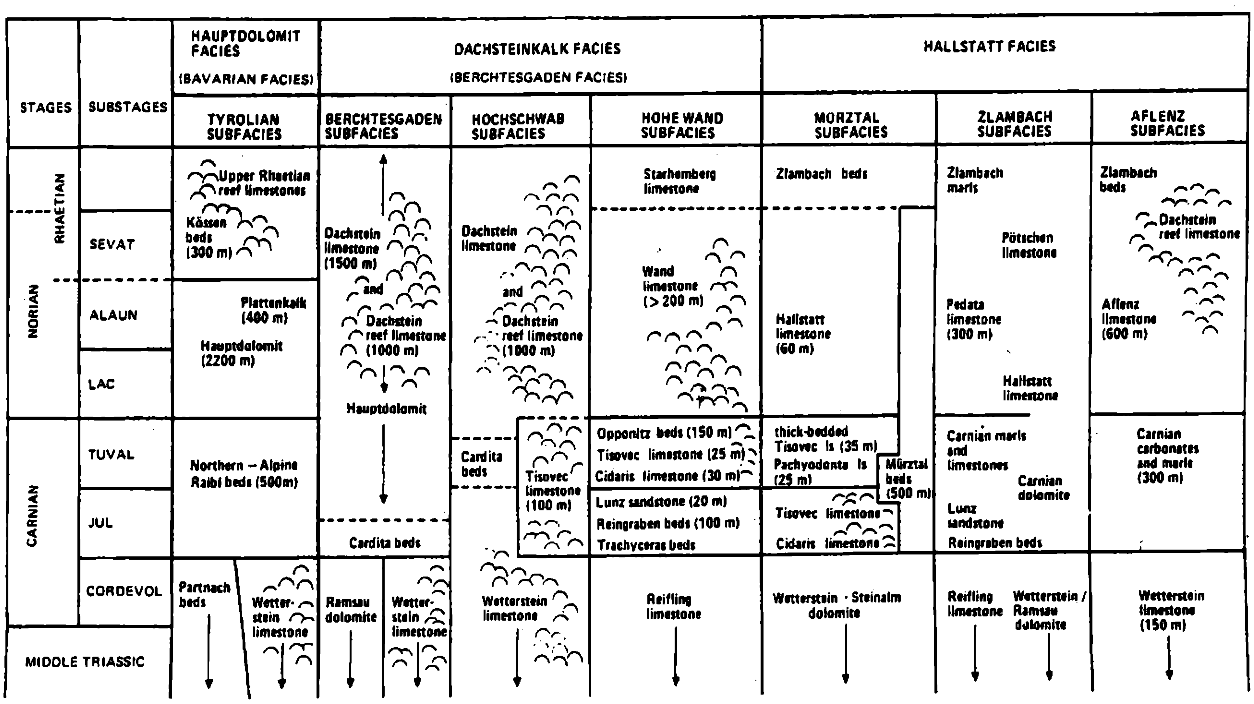

Fig. 1: Late Triassic stratigraphy, facial differentiation and reef occurrences in the Northern Calcareous Alps (after FLÜGEL, 1981).

Generally, the Norian - Rhaetian reefs are dominated by calcareous sponges and scleractinian corals (FLÜGEL, 1981). Compared to the Middle Triassic and Carnian reefs, however, the importance of sponges decreased and that of corals increased; the latter even dominated in the Rhaetian reefs (SENOWBARI-DARYAN & FLÜGEL, 1993). The zooxanthellate/non-zooxanthellate nature of Triassic scleractinian corals has been controversial (comp. FLÜGEL, 1981), the presence of zooxanthellae, however, was indicated through stable isotope studies by STANLEY & SWART (1995). In addition to these two groups sessile foraminifera, "hydrozoans", "chaetetids", bryozoans/tabulozoans, cyanobacteria, red algae and a variety of microproblematica are important reefs builders. In most Norian Dachstein limestone reefs an extensive organic framework is lacking and most rocks are coarse bioclastic sediments (e. g., Hoher Göll: ZANKL, 1969; Gosaukamm: WURM, 1982; Hochkönig: SATTERLEY, 1994). Nevertheless, a zonation was observed in the distribution of major constructor groups. Although reef dwelling organisms have only been studied to a limited extent, brachiopods, gastropods, bivalves, serpulids, crustaceans, and various echinoderm groups (crinoids, echinoids) are abundant. Destructive organisms are also frequently observed, detailed studies, however, are rare. The very abundant microborers and lithophagous bivalves are particularly noteworthy; preservation, however, is very poor in the limestones. Well preserved examples were described by KLEEMANN (1994) from corals of the Zlambach Beds.

1. 2. STOP 1: Hohe Wand

Subject: Late Triassic Reef carbonates.

Lithostratigraphic unit: Dachstein reef limestone ("Wandkalk": STUR, 1871, p. 377)).

Age: Norian (Sevat)

Tectonic unit: Hohe Wand-nappe (Juvavikum)

Locality: Road cut near the inn "Herrgottschnitzer Haus" on the plateau of the Hohe Wand (Lower Austria), ÖK 1:50.000, Sheet 76 Wiener Neustadt.

Historical outline: Although the Hohe Wand - area was mapped several times during the last century (e. g., BITTNER, 1882; KRISTAN, 1958; PLÖCHINGER, 1967) many subjects remained controversial due to complex tectonics, low stratigraphic resolution and bad outcrop situation. Particularly the differentiation of pelagic sediments (Hallstatt limestone) and reefoidal limestones was difficult and lead to the establishment of a separate lithologic unit, the "Wandkalk", summarizing both characters. The mixing of different tectonic units in the Hohe Wand - area caused additional problems since the Hohe Wand was placed in the Mürzalpen nappe by KRISTAN (1958) and KRISTAN-TOLLMANN & TOLLMANN (1963).

Based on this knowledge a microfacial study was performed by SADATI (1981) who differentiated 3 major facies units (biolithite facies, grapestone facies, mud facies). He interpreted the "Wandkalk" as "being formed within an extended shallow-water lagoon with numerous, irregularely distributed small patch reefs." New data were recently acquired in the course of a Ph. D. - thesis by M. Schauer (Institute of Palaeontology, Univ. Vienna) which are to date only documented in an internal report (SCHAUER, 1995) and briefly published in a field guide (KRYSTYN et al., 1996). The mapping results of SCHAUER are reproduced below (Fig. 2) as well as the lithologic log and facial interpretation (Fig. 3); his new stratigraphic results are based on conodonts.

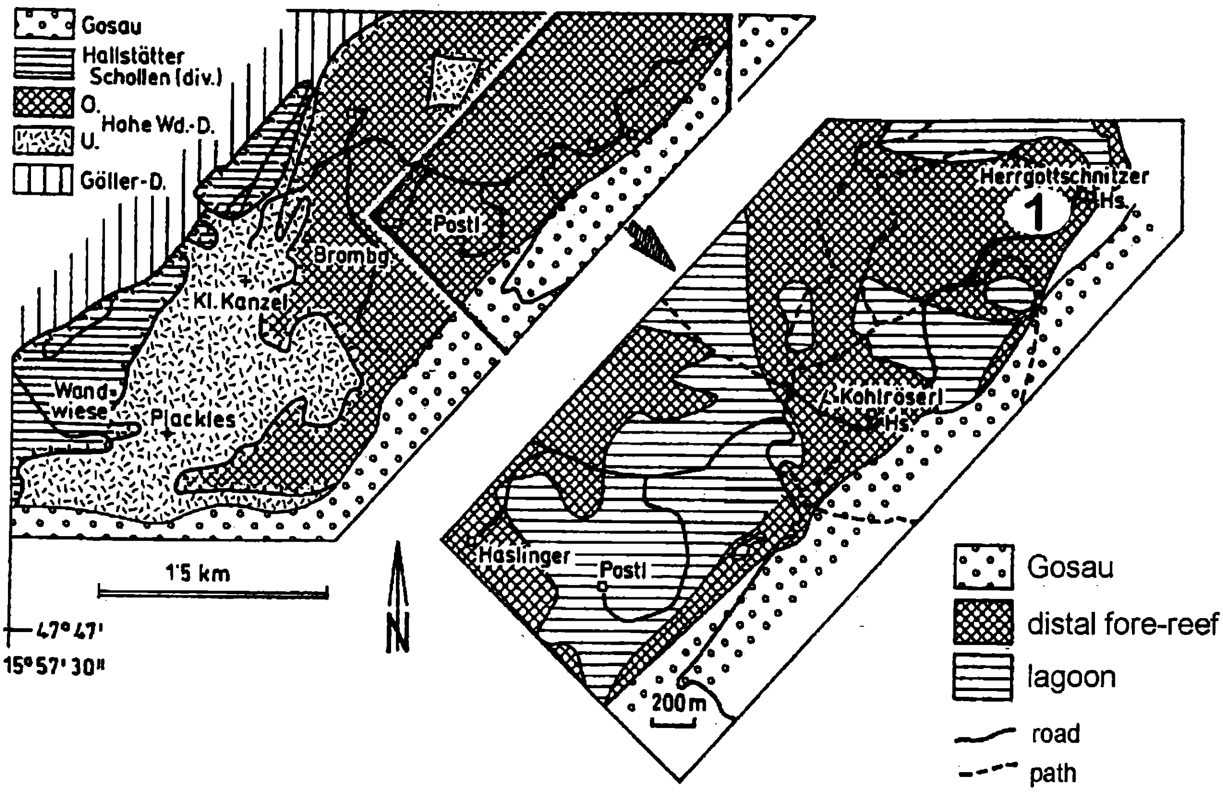

Fig. 2: Location, as well tectonical and geological situation of the Hohe Wand (after SCHAUER, 1995, in KRYSTYN et al. 1996).

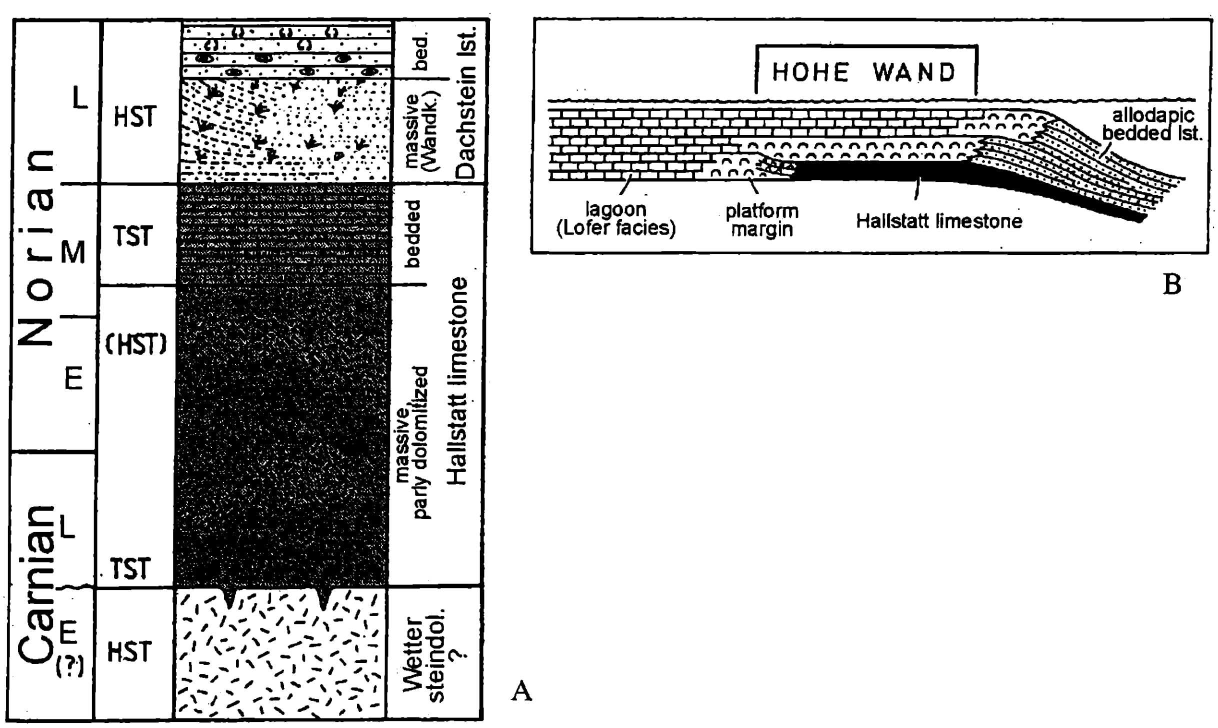

Fig. 3: Late Triassic sequence of the Hohe Wand (A) and facial reconstruction for the Norian (B) (after KRYSTYN et al., 1996).

Description: The base of the sequence is built by a dolomite member which is thought to be related to the Middle Triassic - Early Carnian Wetterstein Formation. Above, a massive, reddish-greyish partly dolomitized limestone is developed (50 - 150 m; Late Carnian - Early Norian). This package is overlain by thin-bedded, red Hallstatt limestone (20 m) which grades rapidly into a massive, grey limestone (massive Dachstein limestone; 150 - 200 m) unit which can be differentiated into two types: at the base it is built by a lithoclastic wacke- to packstone with a variegated matrix (type A). The latter was the reason for differentiating the "Wandkalk". Upsection the matrix content decreases and pack- to rudstones become dominant with abundant bioclasts of reefoidal biotas (type B). Major in situ accumulations of frame-builders, however, are missing. On top, with a sharp boundary, bedded Dachstein limestones with megalodontid bivalves and dasycladalean algae follow (Fig. 3A). Lofer facies is not developed.
In the course of the field trip type B of the massive Dachstein limestone with various reefoidal biota (e. g., calcareous sponges) will be visited approximately 300 m SW of the "Herrgottschnitzer Haus".

Interpretation: The basal Hallstatt limestones generally represent basinal deposits internally reflecting a transgressive sequence (Fig. 3 A). Above the bedded Hallstatt limestone unit the grey limestone progrades, at the base still exhibiting open marine influences (type A, "Wandkalk"). Based on Late Norian platform conodonts this unit is interpretated as deposited on a slope in water depths >50 m (KRYSTYN et al., 1996, p. 16) (Fig. 3 B). Upsection the pelagic influence decreases with decreasing water depth and the reefoidal limestone (type B) is deposited. It represents mainly bioclastic sediments with nearly no in situ frame building organisms. The bedded top unit matches a shallow subtidal Dachstein limestone, lacking Lofer facies (Fig. 3 B).
Comparing the new interpretation with the results of SADATI (1981), his "mud facies" is considered to represent the bedded Hallstatt limestones, his "biolithite facies" comprises the types A and B of the massive Dachstein limestone and his "grapestone facies" belongs to the bedded Dachstein limestone at the top of the sequence. This correlation makes lateral facies transitions sensu SADATI (1981) impossible and contradicts also his "lagoonal reef" interpretation. On the contrary, it suggests that the "Hohe Wand reef" had a similar construction as other Dachstein limestone reefs (e. g., Gosaukamm, Hochkönig, Hoher Göll).

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2. The Cretaceous of the Grünbach - Neue Welt Basin (HERBERT SUMMESBERGER)

2. 1. Introduction

The isolated Upper Cretaceous Gosau-Basins of the Eastern Alps (Fig. 4) are named after the village Gosau in Upper Austria. Most of them are pull-apart structures with transgressions in the Turonian (Fig. 5), low subsidence rates until the Santonian and acceleration of the subsidence in the Campanian. The predominantly clastic basin fillings of the synorogenic Gosau-Group represent a distinct sedimentary cycle. The palaeogeographic situation was that of an island arc subsequently partially drowned, in terms of structural geology an orogenic belt. The rich shallow marine faunas of the Gosau-Group belong to the Tethyan bioprovince.

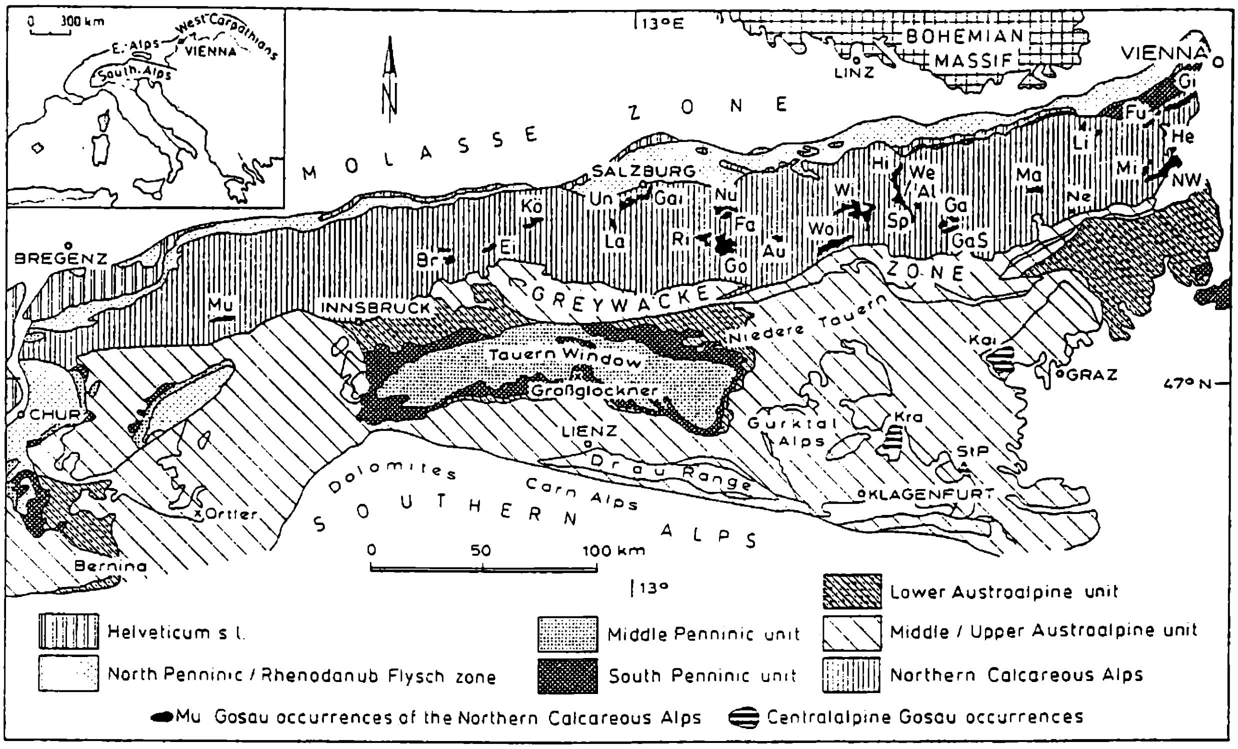


Fig. 4. Major occurrences of the **Gosau-Group** in the Eastern Alps. Al-Altenmarkt; Au-Bad Aussee, Br-Brandenberg, Ei-Eiberg, Fa-Fahrenberg, Fu-Furth, Ga-Gams, Gai-Gaisberg, GaS-Gams South, Gi-Gießhübl, Go-**Gosau**, He-Hernstein, Hi-Hieselberg, Kai-Kainach, Kö-Kössen, Kra-Krappfeld, La-Lattengebirge, Li-Lilienfeld, Ma-Mariazell, Mi-Miesenbach, Mu-Muttekopf, Ne-Neuberg, Nu-Nussensee, NW-**Neue Welt**, Ri-Rigaus, Sp-Spitzenbach, StP-St.Paul, Un-Untersberg, We-Weißwasser, Wi-Windischgarsten, Wö-Wörschach (after WAGREICH & FAUPL, 1994).

2.2. The Basin of Grünbach (= Neue Welt Basin)

The Basin of Grünbach is one of the largest Upper Cretaceous basins in the Eastern Alps. It was interpreted by ZITTEL (1864-66) and by PLOECHINGER (1961, pl.27) as a syncline with an overturned NW limb (Fig. 7). Its extension from the road saddle of Grünbach towards the Neogene Vienna Basin in the NE is about 19 kilometres. The NE striking alpine structures are cut off by the NNE striking faults of the Vienna Basin. Drillings of the OMV oil company through the Neogene basin filling made the subsurface continuation of the Grünbach syncline accessible for research. The Brezova Series in the Little Carpathians (Slovakia; Fig. 6) could be an emerged NE-end of the Grünbach Basin. The SW-NE extension would then be more than 100 kilometres. The Cretaceous sediment series are covered by Neogene conglomerates at the Eastern end of the Alps.

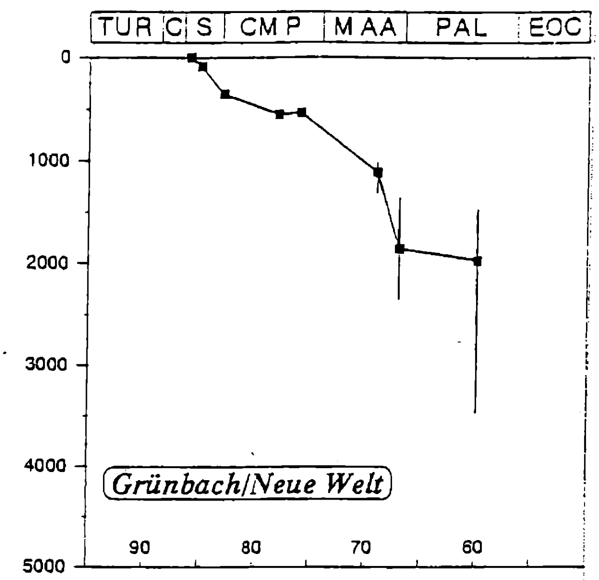


Fig. 5. Acceleration of the subsidence rates in the Late Cretaceous (after WAGREICH & MARSCHALKO, 1995, Fig. 7).

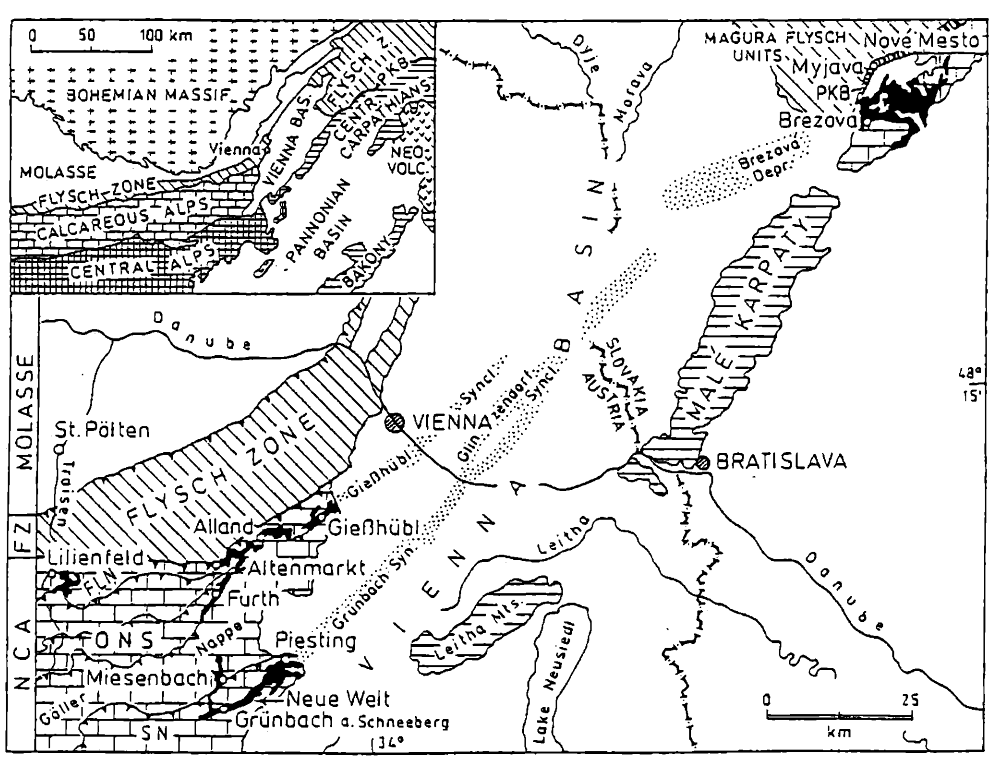


Fig. 6. Extension of the Grünbach - Neue Welt Basin across the Neogene Vienna Basin and connection with the Carpathian Brezova Series (after WAGREICH & MARSCHALKO, 1995, Fig. 1).

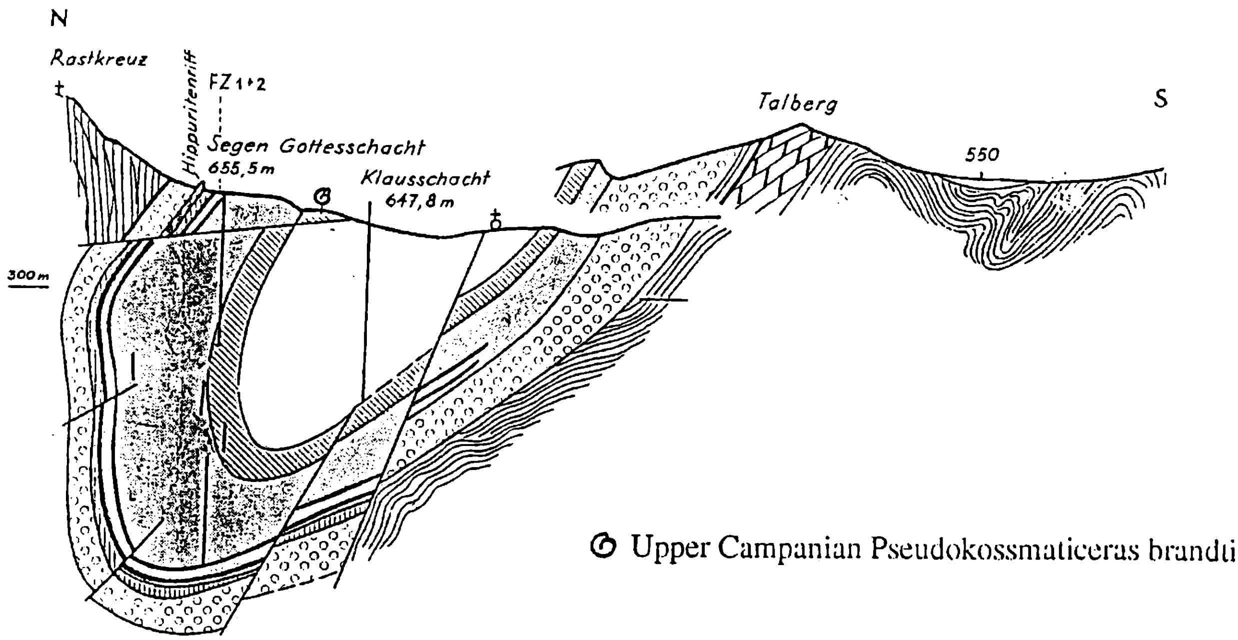


Fig. 7. Cross section through the syncline of the Grünbach - Neue Welt Basin (after PLOECHINGER, 1961).

The sedimentary basin filling comprises five distinct units; the Cretaceous ones are discussed below:

1. Transgression Series (? Late Santonian)
2. Coal-bearing Series (? Early Campanian)
3. Inoceramus Beds/Orbitoides Sandstone (Late Campanian/ Maastrichtian)
4. Zweiersdorf Fm.(Danian/Paleocene)
5. Willendorf Fm. (Eocene)

2.2.1. Transgression Series (? Late Santonian)

The Transgression Series consists of breccias, conglomerates, gastropod horizons, rudist biostromes and brachiopod limestones. Boreholes of boring bivalves in the Triassic substratum, local accretions of brachiopods and isolated rudist individuals indicate a primarily marine transgression followed by terrestrial, fluviatile and nearshore marine conglomerates. The gastropods (*Nerinea, Trochactaeon*) appear to have had high salinity tolerance. The age of the transgression is still in discussion. Recently collected inoceramid bivalves are under study. The Upper Santonian age of the Grünbach rudist biostrome (stop 2; KÜHN, 1947, PLOECHINGER, 1961) of the Transgressive Series might be confirmed by modern dating methods.

2.2.2. Coal-bearing Series (? Early Campanian)

The Coal Bearing Series of the Neue Welt Basin has been exploited since the second half of the 19^{th} century until the 1960s. A series of shafts and tunnels was dug in the northwestern limb of the overturned sequence. The repeated change of coalseams and freshwater/nearshore marine sediments is interpreted as an interactivity of subsidence and sedimentation. Mining was extremely difficult in the highly tectonised basin and was shut down due to inefficiency.

The age of the Coal Bearing Series is still a matter of discussion. Early Campanian age of the Coal Bearing Series (PLOECHINGER, 1961) was concluded from the Late Campanian and Maastrichtian age of the overlying marine *Inoceramus* Beds and *Orbitoides* Sandstone. This might be confirmed now by age indications of palynomorphs and inoceramids (TRÖGER & WALASCZYK, pers. comm. 1996).

Terrestrial freshwater swamps (Fig. 8) and shallow water sediments indicate a relatively large deltaic palaeoenvironment under warm and humid climate conditions. An excellent flora from beds accompanying the coalseams is preserved in the collections of the Museum of Natural History in Vienna. Unfortunately it was never described monographically. Identifications of KRASSER (1906) and KERNER-MARILAUN (1937) need revision. The terrestrial environment of large islands with an unknown relief was inhabited by carnosaurs, iguanodons, pterosaurs, scelidosaurs and crocodiles. The subsidence rate, sedimentary conditions and climatic parameters resulted in an extensive concentration of biomass. The situation was followed by open marine deeper water conditions in a subsiding area.

2.2.2.1 Palynological contribution on the Coal-bearing Series of Grünbach (ILSE DRAXLER)

Fifteen samples were collected by Dr. Benno PLÖCHINGER from a measured section of the Coal-bearing Series in the coal-mine of Grünbach. The samples are under study now and are the best accessible palynological material. Samples from the surface contain badly preserved pollen and spores only.

Preliminary list of form genera and species of pollen and spores :

Sphagnaceae
Stereisporites sp.

Lycopodiaceae
Retitriletes sp. (*Lycopodium* sp)
Camarozonosporites sp.

Filicatae
Cyathidites sp.
Leiotriletes sp. (*Lygodium* sp.)
Gleicheniidites senonicus ROSS
Cicatricosisporites sp.
Appendicisporites tricuspidatus WEYLAND & GREIF
Polypodiaceoisporites sp.
Echinatisporites sp.

Angiospermae
Dicotyledoneae
"Normapolles":
Oculipollis sp.
Oculipollis parvoculus GOCZAN 1964
Oculipollis zaklinskaiaiae GOCZAN 1964
Semioculipollis sp.
Longanulipollis sp.
Hungaropollis sp.
Krutzschipollites sp.
Suemegipollis sp
Extremipollis sp.
Pseudoplicapollis sp.
Laudaypollis sp.

Momipetes sp. (similar to *Engelhardtia*)
Tricolpopollenites sp (at least 5 taxa)
Tricolpopollenites sp (at least 3 taxa)

Monocotyledoneae:
Arecipites sp. (Palmae)

Gymnospermae
Pityosporites sp (at least 2 taxa, *Pinus, Cathaya?*)
Taxiodiaceaepollenites sp.

Reworked:
Circulina sp. (Upper Triassic)
Ovalipollis sp. (Upper Triassic)

Lueckisporites sp. (Upper Permian)
Illinites sp. (Upper Permian)

Discussion: The most characteristic elements are pollen from the *"Normapolles"* group of ancient angiosperms. They are of small to medium size (25-50 µm) and have complex protruding apertures. The distribution in the sequence varies. The pollen from the *"Normapolles"* group are reported from the Upper Santonian and Campanian of Hungary (GOCZAN, 1964; GOCZAN, GROOT, KRUTZSCH & PACLTOVA, 1967; SIEGL-FARKAS, 1988; KEDVES, 1989, GOCZAN & SIEGL-FARKAS, 1990). *Complexiopollis complicatus*, characteristic in the Upper Santonian of the Ajka Coal Formation, and other formspecies of *Complexiopollis* recorded from different localities of the Gosau-Group (Turonian-Santonian; SIEGL-FARKAS 1994) are absent in the Grünbach samples.
Arecipites sp. can be related to Palmae, also recorded as leaves. The large spores of Pteridophyta (*Leiotriletes* sp., *Appendicisporites tricuspidatus, Cicatricosisporites* sp.) are similar to the Schizaeaceae. This family is distributed today in tropical and subtropical climates. For most of the specimens of Angiospermae, for the *"Normapolles"* group, and for different others not mentioned in detail here no direct correlation can be made to modern plants based on the present stage of knowledge.

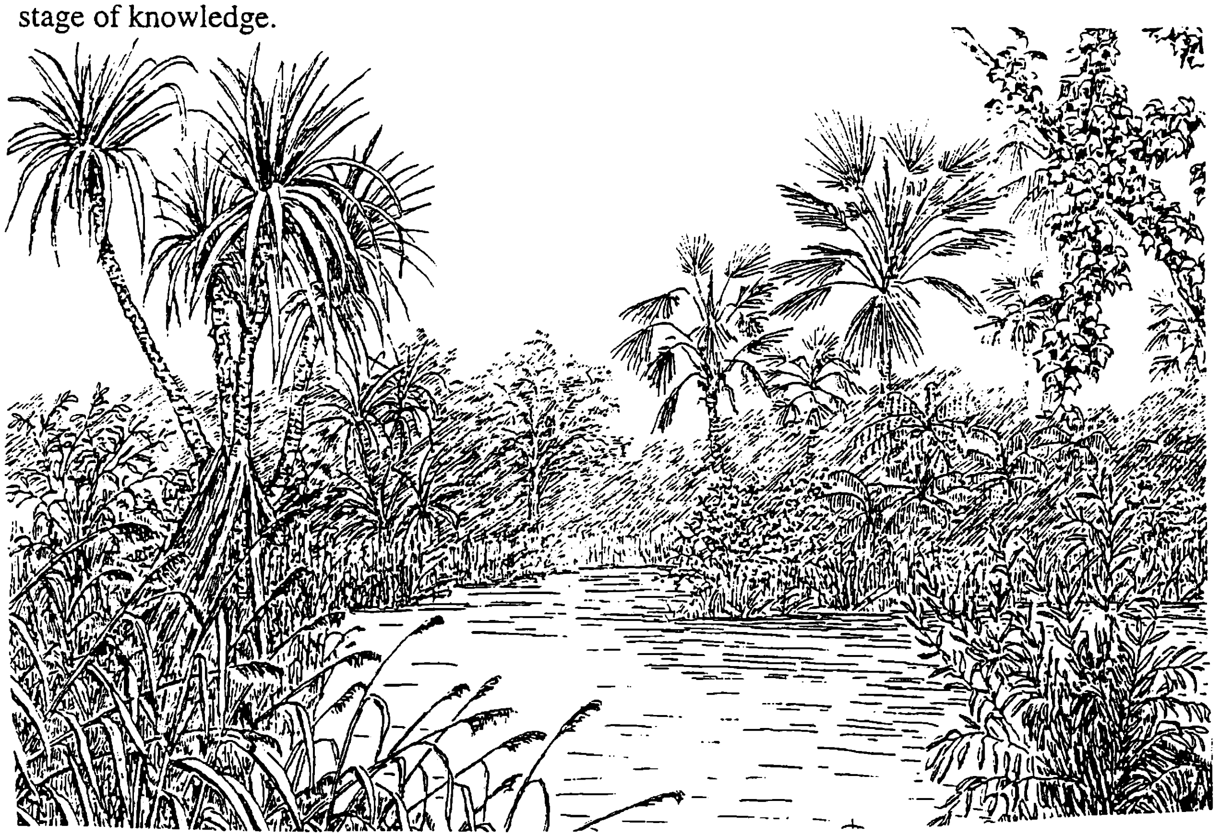


Fig. 8. Reconstruction of the paralic swamps in Late Cretaceous times reflecting the palaeoenvironmental situation of the Coal-bearing Series of Grünbach. (after: PAPP in: THENIUS, 1983).

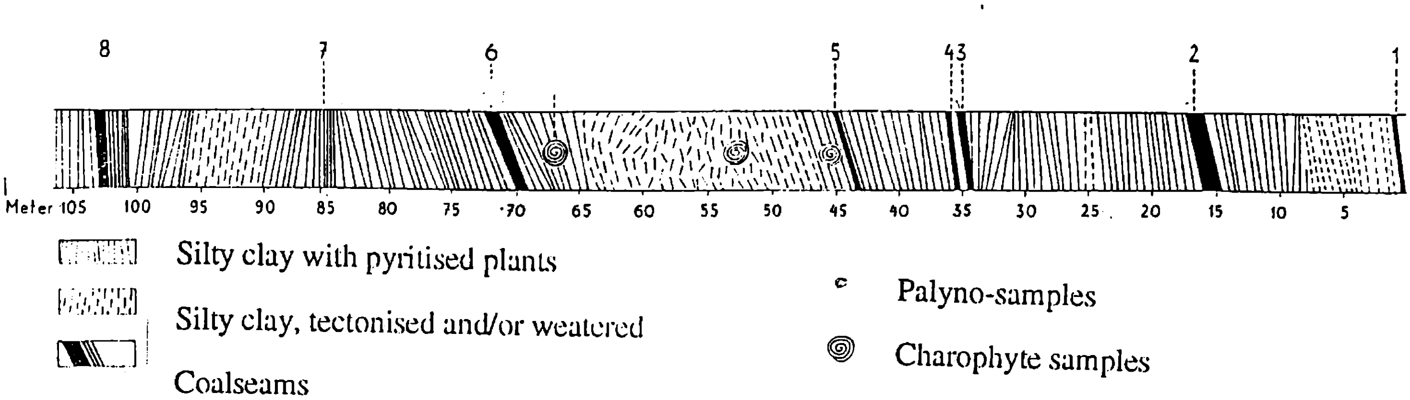


Fig. 9. Section through the Coal-bearing Series of Grünbach showing coalseams and samples with charophytes;(after PLOECHINGER, 1961, fig.6); numbers indicate palyno-samples taken by PLOECHINGER).

The coal is a subbituminous B/A coal (Glanzbraunkohle after German classification). The degree of coalification is identical in all 8 coalseams. The vitrinite reflectance is between 0.56 and 0.61 %. The estimated temperature has been 80 - 90 ° Celsius. (SACHSENHOFER, 1987 and pers. comm. 1997).

2.2.3. *Inoceramus* Beds/*Orbitoides* Sandstone (Campanian/Maastrichtian)

The fully marine sequence of the *Inoceramus* Beds and interbedded *Orbitoides* Sandstone was sedimented under faster subsidence and deeper water conditions. The Upper Campanian to Maastrichtian age is concluded from ammonites and planktic foraminifera. The Upper Campanian ammonite *Pseudokossmaticeras brandti* (REDTENBACHER) occurs at Grünbach, the Lower Maastrichtian *Pachydiscus epiplectus* (REDTENBACHER) at Muthmannsdorf. Large foraminifera (*Orbitoides*) indicate relatively warm climate. The Upper Campanian belemnite *Belemnitella hoeferi* (SCHLOENBACH) (CHRISTENSEN submitted) from Grünbach may indicate either a cooler episode or the Late Cretaceous global cooling, cold water currents or deeper water temperatures at the end of the Campanian. Relatively common "oysters" and inoceramids are not temperature indicators.

2.3. Fossils of the Neue Welt Basin

The Neue Welt Basin is best known for its fossil content:

a) the overturned *Hippurites* bioherm from the Transgression Series of Grünbach (stop 2)
b) the gastropod fauna from the Transgression Series (Grünbach, Dreistetten)
c) the coral locality Scharrergraben close to Piesting (stop 3)
d) the reptile fauna from the Coal-bearing Series of Muthmannsdorf (photostop)
e) the rich flora from the Coal-bearing Series of Grünbach

2.4. Palaeoclimatic and palaeogeographic interpretation of the Late Cretaceous Grünbach - Neue Welt Basin:

a) Separated from the sequences of the Transgression Series is the bauxite occurrence of the Malleiten close to Dreistetten (optional stop). On the base of abundant chromite MINDSZENTY et al. (1991:319) conclude that this bauxite belongs to the same bauxite horizon as the other three Austrian deposits (Brandenberg, Untersberg, Unterlaussa). Turonian age is therefore highly likely. But contemporaneous genesis with the closely neighboured Lower Campanian coal cannot be excluded. The bauxite rests unconformably upon the karstified erosion surface of Triassic platform carbonates. Karst bauxites are indicators for warm and humid climates (D'ARGENIO & MINDSZENTY, 1995). They were interpreted as occurring on the windward side of continents influenced by monsoon-type winds (BARDOSSY, 1973, 1982, 1986). This could well be seen in combination with the repeated occurrence of freshwater swamps as a presupposition for the genesis of coalseams. Upper Cretaceous coalseams occur together with bauxites at Brandenberg (Tyrol), at Unterlaussa/ Weißwasser (Styria), in the Transdanubian Central Range (Hungary) and in the Grünbach - Neue Welt Basin.

b) The repeated occurrence of freshwater swamps with (after KRASSSER, 1906) palms ("*Flabellaria*") and palmlike trees (e.g."*Pandanus*") and large-leaved ferns indicates a warm and humid climate without a distinct winter period. Leaves of "*Ginkgo*", "*Platanus*", "oaks", "elm trees" and other possibly deciduous trees indicate dry land conditions in nearby regions. A large deltaic environment was assumed by SACHSENHOFER (1987) for the genesis of the coalseams.

c) In the Grünbach - Neue Welt Basin the conditions for the growth of rudists are limited. Clusters and bioherms occur in narrow layers (stop 2). As rudists occurred to both sides of the Cretaceous equator, rudist bioherms indicate subtropical or tropical conditions in shallow marine environments. The Cretaceous tropical belt may be represented by the circum-Mediterranean occurrence of platform carbonates with rudist bioherms and bioclastic limestones. Tropical conditions may have extended towards the more northerly situated Gosau realm. Growth conditions for rudist generated platform carbonates as in the circum-Mediterranean realm may have been suppressed by high sedimentation rates of siliciclastics.

d) Solitary corals and stock corals occur at the locality Scharrergraben (Santonian; stop 3) as well as in many other Gosau fossil sites in highly diverse communities. Coral reefs are absent throughout the Gosau basins. Comparable to the above-mentioned rudists, the growth conditions for coral reefs may have been limited by high sedimentation rates. Diversity would be an argument for tropical conditions.

e) *Belemnitella hoeferi* (SCHLOENBACH) from the Inoceramus Beds is a rare species of the Late Campanian. *Belemnitella* is an indicator of boreal or northern temperate influence. In the Gosau group it is extremely rare. The exceptional occurrence is Grünbach (CHRISTENSEN, submitted). Together with the relatively common ammonite genus *Scaphites*, in the *Inoceramus* Beds it indicates cooler water temperatures or deeper water conditions. This is in accordance with the subsidence rate and the global cooling in the Campanian. A connection between the Tethyan bioprovince and the Northern Temperate bioprovince is thought to have existed throughout Late Cretaceous times.

f) A small but well known reptile fauna from the Coal-bearing Series of Muthmannsdorf (optional photostop) with crocodilians, dinosaurs (iguanodons, *Megalosaurus*, heavily armoured *Struthiosaurus austriacus* (BUNZEL), the pterosaur *Ornithocheirus bunzeli* indicates, in accordance with the above-mentioned invertebrates and plant fossils a warm and humid but not necessarily tropical climate.

2.5. Palaeoclimatic Conclusion

The Late Cretaceous sequences of the "Grünbach - Neue Welt" Basin yields a range of information on palaeoclimatic conditions. There are no indications for temperatures below the freezing point. Subtropical to tropical conditions may have prevailed through Late Cretaceous times, with passate or monsoon-type circulation. The regime of a regular circulation system may have played an important role. Seasonal oscillations - no winters sensu temperate climate belts - are intimated by deciduous trees. A tropical climate in terrestrial environments cannot be concluded with certainty based on the occurring floral and faunal indicators. A tropical climate in marine environments may be concluded from diverse shallow marine faunas; some caution is necessary as the influence of the sedimentation rate on the growth of reef organisms may have played a certain role. Water temperatures allowed the local growth of rudistid biostromes and stock corals with a diverse fauna in a shallow marine environment characterised by a high sedimentation rate.
Temperate influences in the Late Campanian may have occurred occasionally. In terrestrial areas the climate was generally warm and humid.

2.6. EXCURSION STOPS

Stop 2. Grünbach; abandoned coal mine "Segen Gottes".

Coal-bearing Series, Lower Campanian; rudist biostrome, Transgression Series.

Stop at the abandoned shaft of the "Segen Gottes" mine. Walk the footpath behind the shaft upwards, visiting the section through the overturned Coal-bearing Series with several coal seams exposed. On "top" of the sequence an overturned rudist biostrome with *Hippurites* clusters in life position gives evidence of the overturned northern limb of the Grünbach syncline. The current (1996) palaeomagnetic investigation yielded a palaeolatitude about 1000 km south of the actual position (SCHOLGER, pers. comm.). KRASSER (1906:1-3) and KERNER-MARILAUN (1934:267) recorded about 40 species in the unique flora of Grünbach.

Palaeoclimatic and palaeogeographic interpretation: Subtropical to (?) tropical climatic conditions with high precipitation prevailed while nearshore coal swamps were deposited. It cannot be substantiated if the apparent cyclicity of up to 8 coalseams (Fig. 9) is caused by astronomical parameters or by rhythmic subsidence.

Photostop at Muthmannsdorf

Local roadside exhibition and information table at Dreistetten concerning the dinosaur locality.

Optional Stop. Malleiten near Dreistetten; abandoned bauxite mine.

The bauxite of Dreistetten occurs in pockets and fissures of a karstified carbonate platform (Figs. 11, 12). It is overlain by conglomerates of Upper Campanian age (PLOECHINGER, 1961, p.372). MINDSZENTY et al. (1991, p.319) assume on the basis of chromite intraclasts that the Dreistetten bauxite belongs to the same bauxite horizon as the other NCA occurrences. They are generally interpreted as Turonian. On the basis of equal climatic conditions being assumed for bauxite and coal genesis, it should be discussed whether it might have been deposited contemporaneously with the Coal Bearing Series.

Chemical analysis (average) of the Dreistetten bauxite (after BARDOSSY, 1961):

Al_2O_3	SiO_2	Fe_2O_3	FeO	TiO_2	H_2O
41.2 %	19.0 %	23.1 %	0.44 %	2,26 %	11.05 %

Mineralogical composition

The samples 1/2 from Dreistetten yielded after BARDOSSY (l.c.):

Boehmite	30.6/ 4.6 %
Hematite	24.0/17.6 %
Goethite	3.1/ 0.0 %
Kaolinite	34.9/70.0 %
Rutile	2.1/ 1.9 %
Prochlorite	2.1/ 3.6 %
Chamosite	1.0/ 0.6 %

After BARDOSSY (in: PLOECHINGER 1961, p.406) the bauxitic matrix contains only rare ooids.

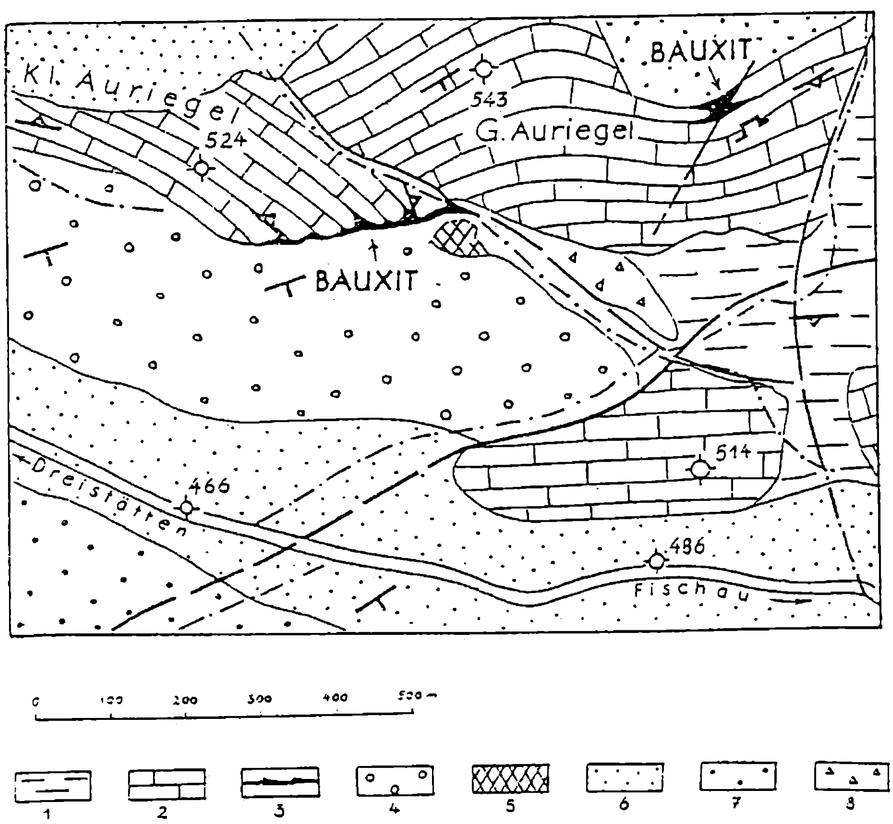


Fig. 10. Local sketch map of the bauxite occurrence of Dreistetten. (after PLOECHINGER, 1961, fig.2).
1. Wetterstein dolomite (M-Triassic), Wetterstein limestone (M-Triassic), 3. Bauxite, 4. Conglomerate (Gosau-Group, Late Cretaceous), 5. Limestone with brachiopods (Gosau-Group, Late Cretaceous), 6. Coal Bearing Series, 7 Sandstone with pebbles (Gosau-Group, Late Cretaceous), 8. Talus.

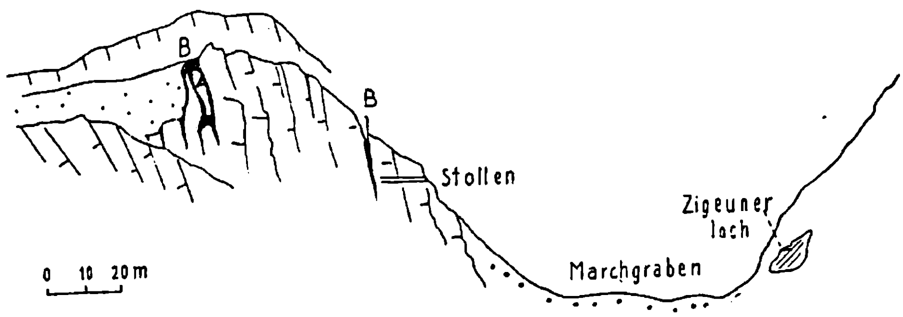
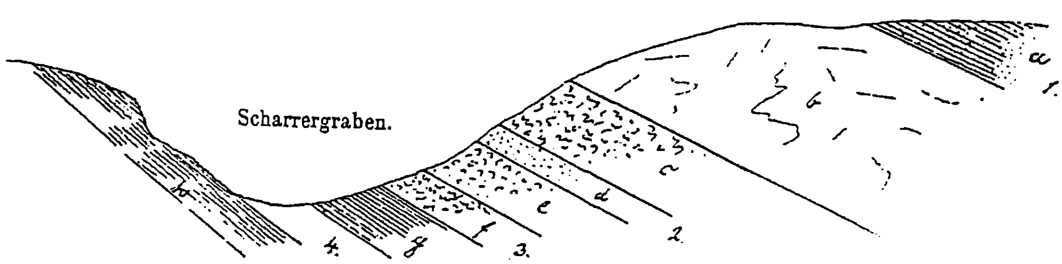


Fig. 11. (after PLOECHINGER, 1961, fig. 3). Cross section of the bauxite occurrence from Dreistetten.

Stop 3. Piesting Scharrergraben: Coral site, Santonian

Stratigraphic position: (? Late) Santonian *Placenticeras polyopsis* (DUJARDIN) was collected from beds below the outcrop visited. *"Hemitissotia" randoi* GERTH from a neighbouring abandoned building pit indicates based on its occurrence in the Basin of Gosau (SUMMESBERGER in: KOLLMANN & SUMMESBERGER, 1982, p. 59), Lower Santonian.



a. Sandstein. *b.* Kalk ohne Petrefacten. *c.* Korallen, Hippuriten, Cycloliten, Bivalven. *d.* Bivalven, Gasteropoden. *e.* Korallen, Cycloliten. *f.* Caprinen, Radiolit., Bivalven, Actäonellen. *g.* Mergel. *h.* Lima, Pecten, Actäonellen.

Fig. 12. Sketchy cross section of the Scharrergraben near Piesting (after KARRER, 1877, Fig. 20).

Fossil content: The outcrop itself was for many years the target of scientific research and of private collecting. With 60 taxa of fossil corals (BEAUVAIS, 1982) the Scharrergraben is one of the richest sites in the Eastern Alps. The corals are embedded in a marly matrix. The outcrop exposes a layer of stockcorals and rudists indicating a fully marine environment. Rudists and corals in life position (SCHÜTZ, pers. comm 1997) confirm that the layer is not the result of submarine mass transport. Moreover, delicate coral epizoans on rudists with preserved lids make a more or less quiet habitat likely. The coral fauna (not quoted here) was identified first by REDTENBACHER (STUR, 1877, p. 173). About 20 taxa of mollusks are listed by STUR (1877).

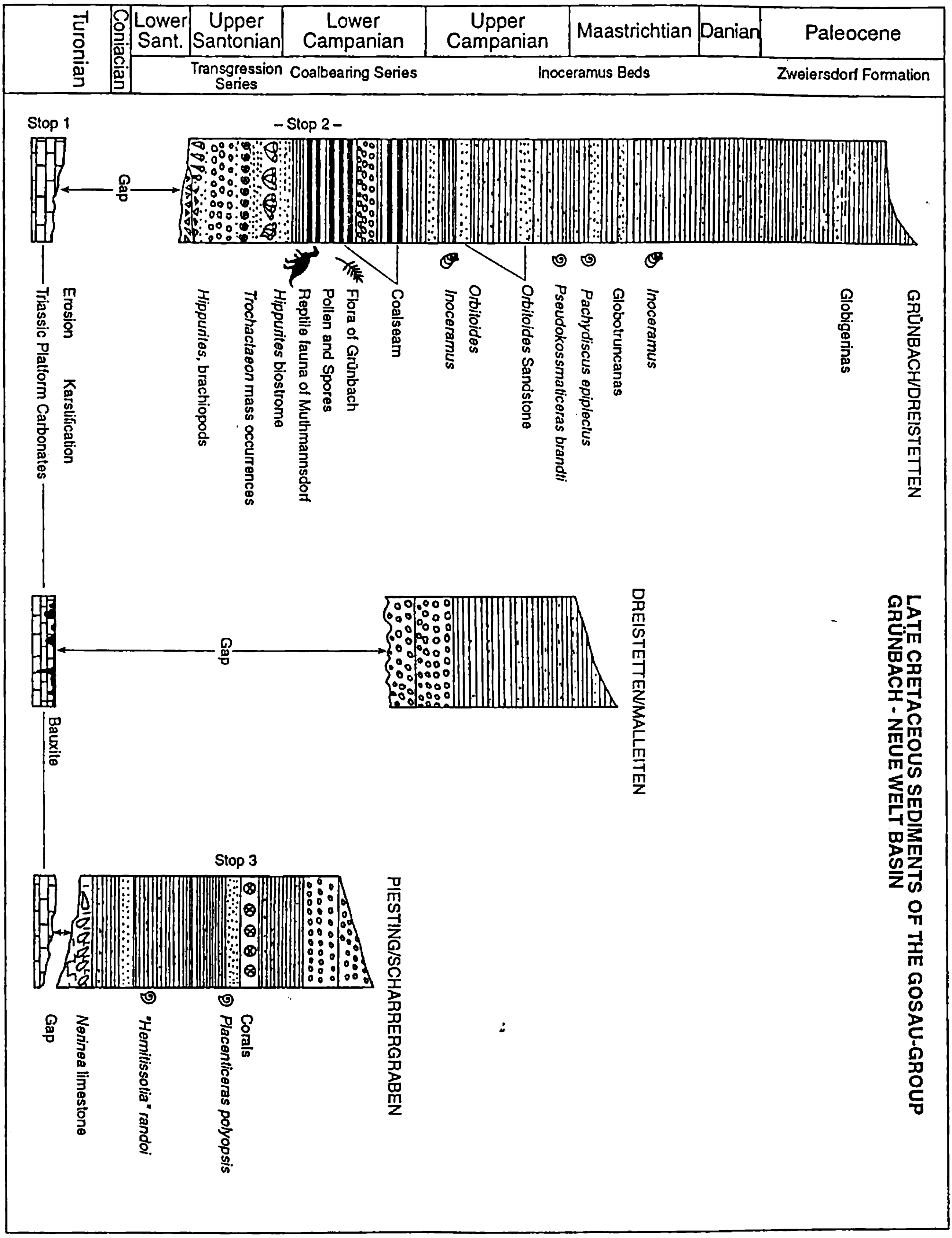


Fig. 13. Tentative sections of the Late Cretaceous sediment series in the Grünbach - Neue Welt Basin.

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3. The Neogene of the Vienna Basin (WERNER E. PILLER)

3.1. Introduction

The Vienna Basin, located between the Eastern Alps, the West Carpathians and the western part of the Pannonian Basin represents one of the best studied large pull-apart basins of the world (ROYDEN, 1985; WESSELY, 1988). Similar to other European Tertiary Basins (e.g., Paris Basin, London Basin, Mainz Basin) the Vienna Basin was the goal of very early geological studies (e.g., STÜTZ, 1807; PREVOST, 1820; SUESS, 1885; SCHAFFER, 1907). The importance for hydrocarbon exploration, however, distinctly enhanced our stratigaphic, sedimentologic and tectonic knowledge of the basin during the last 60 years. The different field of interests studied cover all topics from palaeontology, sedimentology, stratigraphy, tectonics, to natural resources like thermal water and hydrocarbon.
Due to this overall importance the Vienna Basin was the target for several field trips in the course of earth science conferences during the last years. As a result of these activities a variety of field guides were produced (e.g., PILLER & KLEEMANN, 1991; PILLER & VAVRA, 1991; SAUER et al., 1992; PILLER, 1993; PILLER et al., 1996) and the following presentation widely duplicates earlier papers.

3.2. Geographical setting

The Vienna Basin is of rhombohedral shape, strikes roughly southwest - northeast, is 200 km long and nearly 60 km wide, and extends from Gloggnitz (Lower Austria) in the SSW to Napajedl in Czekia in the NNE. The western border is bound to the south by the morphological eastern margin of the Northern Alps (represented by several Alpine tectonic units: Greywacke Zone, Northern Calcareous Alps, Flysch Zone) and to the north by the Waschberg Zone. In the east it is bordered in the south by the hills of the Rosaliengebirge, Leithagebirge and the Hainburger Berge, and in the north by the Little Carpathian Mountains; all four hill ranges are part of the Alpine-Carpathian Central Zone. The Vienna Basin is connected with the Little Hungarian Basin via the Hainburger Pforte and with the Eisenstadt Basin via the Wiener Neustädter Pforte. The Eisenstadt Basin has a triangular shape and is bordered in the east by the Ruster Höhenzug, in the north by the Leithagebirge, in the west by the Rosaliengebirge, and in the south by the Brennberg. Its maximum dimensions are approx. 20 by 20 kilometers. The subsurface separation from the Vienna Basin is represented by the continuation between the Rosalien- and Leithagebirge, its tectonic and sedimentary history, however, are very similar and the Eisenstadt Basin is therefore considered as a subbasin of the Vienna Basin.

3.3. Stratigraphy, facial and tectonic development

The Vienna Basin is part of the Paratethys which formed together with the Mediterranean Sea after vanishing of the Tethys Ocean. Due to its isolated position for most of the time a regional stratigraphic stage system different from that of the Mediterranean had to be established (e. g., RÖGL & STEININGER, 1983; SENES & STEININGER, 1985; STEININGER et al., 1988; STEININGER et al., 1990; RÖGL, 1996; Fig. 14).
Due to the rhomohedral shape and the left-stepping pattern of en-enchelon faults firstly ROYDEN (1985) interpreted the basin as pull-apart structure. This idea was strengthened lateron (ROYDEN 1988; Wessely, 1988), however, based on more profound data a much more complex tectonic evolution was shown by several authors (DECKER et al., 1994; DECKER, 1996; DECKER & LANKREIJER, 1996; DECKER & PERESSON, 1996). The pull-apart mechanism

started to act during the Karpatian (STEININGER et al., 1986; SEIFERT, 1992; DECKER, 1996) older sediments (Eggenburgian-Ottnangian) at the base of the northern part of the Vienna Basin belong to an earlier piggy-back basin of the Molasse cycle (STEININGER et al., 1986, p. 295, PILLER et al., 1996; DECKER, 1996). Between the Karpatian and Pannonian the subsidence in the central Vienna Basin reached up to 5.5 km (WESSELY et al., 1993). Since the basin is subdivided by a morphological high structure, the Spannberg ridge, into a northern and a southern part, during the Karpatian sedimentation was restricted to the north (north of the Danube) and extended into the south only during the Badenian (Fig. x). Due to the complex fault system the basin was internally highly structured into horst and graben systems. Especially at the western border of the basin, relatively uplifted blocks occur; these are separated from the deep depressions located in the east along major faults (e.g., Mistelbach block along the Steinberg fault in the northern, Mödling block along the Leopoldsdorf fault in the southern basin). The interplay of highly active synsedimentary tectonics with rapid changing trans- and regression cycles (RÖGL & STEININGER, 1983) produced a complex facial pattern inside the basin depending on distance from land and on position of the particular blocks.

The basement of the basin is built by those Alpine-Carpathian nappes bordering the basin also on the surface. The Neogene sediment fill of the basin reaches a thickness of up to 6000 m. At the base mainly clastic sediments are developed representing fluvial facies; occasionally lignite deposits occur (STEININGER et al., 1989). A fully marine development over the entire basin was established only in the Early Badenian (Lower Lagenid Zone). These sediments consist not only of clastics but also carbonates were deposited. This facial development with local coral reefs and widespread coralline algal limestones (STOP 4) is restricted to the Badenian. During the Sarmatian, a reduction in salinity already started leading to non-marine and subsequently continental conditions in the Pannonian - Pontian (STOP 5). Although tectonic subsidence was high the basin was rapidly filled due to the short distance to the source of clastic sediments and the basin cycle is therefore limited to the Middle Miocene.

3.3.1. Badenian (16.4. - 13 ma bp)

Due to the major marine transgression at the beginning of the Middle Miocene (RÖGL & STEININGER, 1983, 1984) subtropical biotas entered the Paratethys. In the Vienna Basin conditions for carbonate sedimentation and growth of coral buildups were favourable only during the Badenian stage. Within the context of the meeting the development and facial distribution for this period should be discussed in more detail.

The general biostratigraphic subdivision (PAPP et al., 1978; Fig. 15) into Lower Badenian (Lower and Upper Lagenid Zone), Middle Badenian (*Spiroplectammina* Zone) and Upper Badenian (*Bulimina-Bolivina* Zone, *Rotalia* Zone) is based on typical foraminiferal assemblages, reflecting in fact an ecostratigraphical sequence. This sequence documents the salinity reduction in the uppermost Badenian. The zonal scheme works well in central basinal sections, in marginal position, however, reliability is limited. Besides these assemblages, planktic foraminifers and certain benthic groups are also of special importance, e.g., uvigerinids, bolivinids, and to some extent also calcareous nannoplankton (e.g., STEININGER, 1977; PAPP, CICHA & CTYROKA, 1978; PAPP et al., 1978; PAPP & SCHMID, 1978; PAPP, 1978; FUCHS & STRADNER, 1977). Some species of the larger foraminferal genus *Planostegina* (=*Heterostegina* in older literature) were considered as stratigraphically usefull (e. g., PAPP & KÜPPER, 1954; PAPP, 1978). Recent investigations, however, brought fourth opposite results (PILLER et al., 1995; ABDELGHANY et al., 1996).

The sediments of the lowermost Badenian (Lower Lagenid Zone) are confined to the northern Vienna Basin. During the Upper Lagenid Zone, sedimentation is fully developed in the entire basin. At the same time marine sedimentation starts in the Eisenstadt Subbasin and facial differentiation reached its climax.

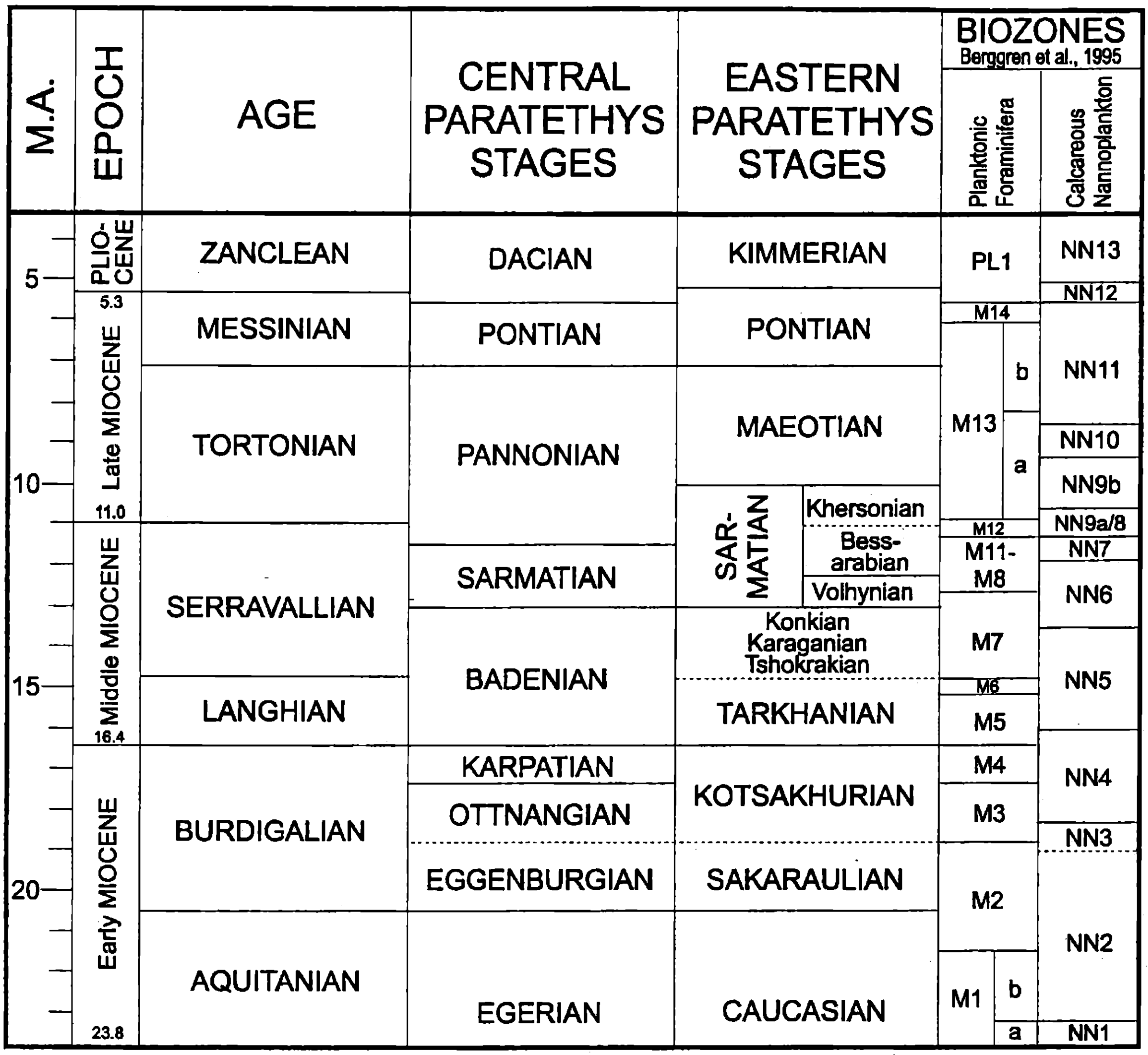


Fig. 14: Chronostratigraphy and marine biochronoloy of the Miocene (after RÖGL, 1996)

The facial development roughly reflects a distinction between marginal and central basin facies:

♦ Along the basin margins in dependence on the hinterland and coastal morphology the most complex facies pattern is developed. In general siliciclastics and carbonates can be differentiated, both exhibting a rich facial diversity.

In general, the western border of the southern Vienna Basin is highly influenced by the clastic sediment influx from the Northern Alps. Around the Leithagebirge, which represented an island, a chain of islands or a shoal during the Badenian, and along the Ruster Höhenzug, autochthonous carbonate sediments dominate (irrespective of sometimes thick basal transgressive sediments).

The coastal development along the western margin shows strong fluvial influx at some locations, expressed by thick conglomerates dominated by material derived from the Northern Calcareous Alps as well as the Flysch Zone [Baden (Vöslau) Conglomerate; comp. BRIX & PLÖCHINGER, 1988]. In some places, steep rocky shores with large boulders are also preserved (e.g., W' Sooß), while wide coastal or marginal areas are covered by sands (Gainfarn Sands) with a rich and excellently preserved fauna. These sands interfinger with the basinal Baden Tegel.

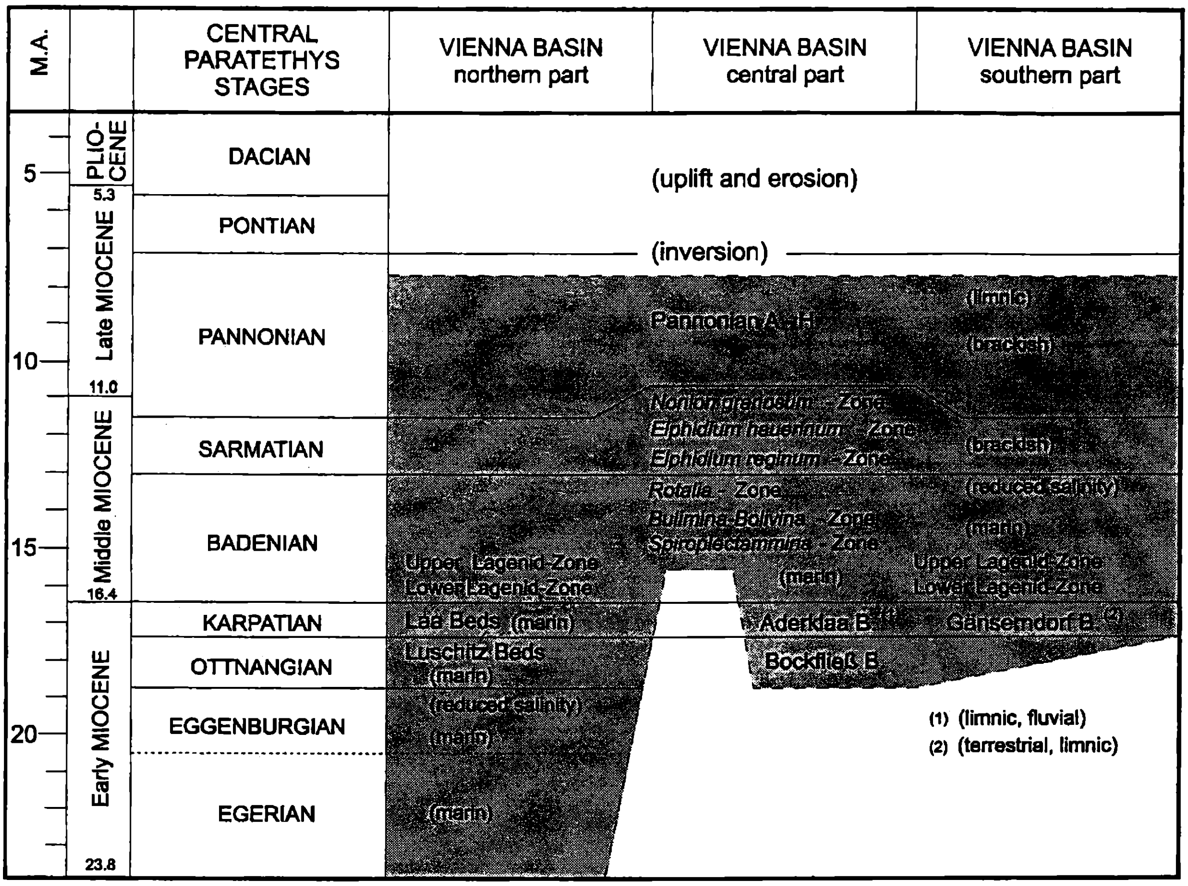


Fig. 15: Facial development and stratigraphy of the vienna Basin with schematic representation of the spannberg ridge in the central part of the basin (after WESSELY, 1988, changed).

The most widespread facies unit along the Leithagebirge and the Ruster Höhenzug as well as at certain sites along the western margins of the Vienna Basin with reduced terrigenous input (e.g., around Wöllersdorf) is the Leitha Limestone. The name of this unit was already established by KEFERSTEIN (1828) and is well known also outside the Vienna Basin. The unit was redefined by PAPP & STEININGER (in:) PAPP et al. (1978) considering the broad facial range and selecting a faciostratotype (comp. STOP 4). The microfacial diversity was worked out by DULLO (1983) into detail describing 10 microfacies types.

Due to its high abundance of coralline red algae this Leithakalk is also well known as Nullipora or Lithothamnium Limestone. Historically important is the first description of a fossil coralline red algae out of this limestone: *Nullipora ramosissima* REUSS 1847. The original material of this taxon was recently rediscovered and the species was assigned to the genus *Lithothamnion* (PILLER, 1994).

In general, the limestone is characterized by the occurrence of coralline algae in various growth forms, ranging from rhodolith dominated types of various growth forms to maërl facies. Coral buildups of limited size are developed only locally. Such buildups are rare along the western margin of the Vienna Basin due to the high terrigenous input and represented only by small patch reefs. Also along the Ruster Höhenzug no significant coral settlement is developed (or preserved); organic buildups are predominantly made up of bivalve beds accompanied, in some places, by corals (comp. DULLO, 1983, p. 37). The best developed coral buildups are present at the southern tip of the Leithagebirge (STOP 4), where the limestones reach the greatest spatial extent and the thickest sequences (about 50 m). Here, due to the island position, no major terrigenous influx restricted coral growth. On the contrary, it can be assumed that water currents or relatively strong waves favoured their growth at the southern tip of the Leithagebirge. The corals are represented mainly by various taxa of *Porites*, accompanied by *Tarbellastraea*, *Caulastrea*, *Acanthastrea*, and *Stylocora* (PILLER & KLEEMANN, 1991).

♦ The basinal facies is characterized by the Baden Tegel, a marl with variable sand and clay content. Intercalated into the marls are sandy layers. This latter material is transported from marginal sources. The marls and sandy interbeddings are highly fossiliferous, containing an extremely rich micro- (foraminifers, ostracods) and macrofauna as well as calcareous nannoplankton (comp. PAPP et al., 1978). The macrofauna is well documented since the 19th century (e.g., D'ORBIGNY, 1846; REUSS, 1849; KARRER, 1861; HÖRNES, 1856, 1870; HÖRNES & AUINGER, 1879) and is represented by solitary scleractinians, brachiopods, decapod crustaceans, molluscs, and fish remains (teeth and otoliths). In the sediments of the Lower Badenian the foraminiferal fauna is extremely rich, containing not only planktic and smaller benthic representatives but in the sandy interbeddings also larger forms as *Amphistegina*, *Planostegina* and *Borelis melo*. Remarkable is the high diversity and good preservation of molluscs (gastropods, bivalves, scaphopods).

The depositional depth of this fine-clastic material can be interpreted as being not deeper than 50 - 100 m (PAPP & STEININGER [in:] PAPP et al., 1978, p. 140) or 100 - 200 m (TOLLMANN, 1985, p. 500). The sandy layers are transported by gravitational transport from marginal areas. Although subsidence of the basin during the Badenian was very rapid, the relatively shallow water depth of the autochthonous sediments can be explained by a high sedimentation rate leading to a sediment accumulation of approx. 1500 m in the central basin during the Badenian (e.g., WESSELY, 1988, p. 342). In the Eisenstadt Basin thickness of the Baden Tegel is distinctly less.

3.3.2. Sarmatian (13 - 11.5 ma bp)

The salinity reduction which already started in the uppermost Badenian continues during the Sarmatian. Salinity decreased generally from 30 - 17 ‰ and reflects the isolation of the Paratethys from the world oceans. The westernmost extension of the Paratethys during the Sarmatian ended in Lower Austria (near Langenlois). The sedimentological inventory ranges from coastal gravel and sands, to calcareous sandstones ("Atzgersdorfer Stein") and marls (Tegel) exhibiting similarities to Badenian sediments. Additionally, "detrital Leitha Limestone" occurs which mainly represents reworked Badenian Leitha Limestone. The total thicknes of Sarmatian sediments surpasses 1000 m in central basin positions.

The reduced salinity of the Sarmatian sea caused a low diversity fauna rich in individuals. Stenohaline organisms are nearly absent, some groups (e. g., foraminifers, bryozoa, molluscs) are represented by a few genera only but occur in high densities (for molluscs comp. STOP 5). In contrast to the diverse Badenian algal flora only 2 species of coralline algae were described (KAMPTNER, 1942). These coralline algae produce small buildups in coastal areas together with the sessile foraminifer *Sinzowella caespitosa* (STEINMANN). In some locations also thin serpulid biostromes and ooliths are developed.

Based on macro- and microfaunal associations an ecostratigraphic subdivision of the Sarmatian is possible into 5 zones:

Late Sarmatian:	"Verarmungszone"
Middle Sarmatian:	*Mactra* Beds (= middle *Nonion granosum* zone)
	Upper *Ervilia* Beds (= lower *Nonion granosum* zone)
	Lower *Ervilia* Beds (= *Elphidium hauerinum* zone)
Early Sarmatian:	*Mohrensternia* Beds (= *Rissoa* Beds) (= *Elphidium reginum* zone)

3.3.3. Pannonian (11.5 - 7.1 ma bp)

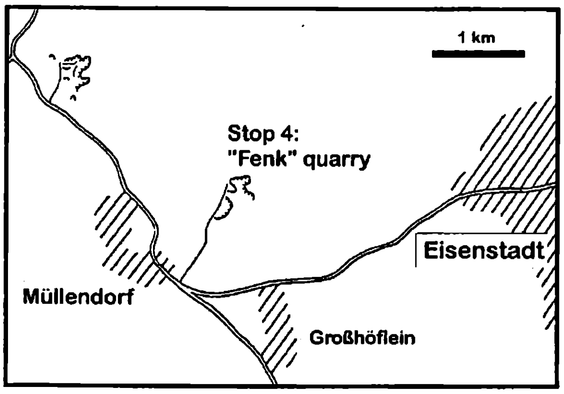
After a short regressive phase at the Sarmatian/Pannonian boundary which corresponds to a worldwide regressive tendency and local/regional tectonics the Pannonian Basin became finally isolated from the Eastern Paratethys (STEININGER & RÖGL, 1983, 1984). A following transgression was linked with a further salinity reduction to 5 ‰. In the uppermost part of the Pannonian (Zones F-H) limnic-fluvial conditions already prevailed. In central basin positions sedimentation of marls (Tegel) continued reaching a thickness > 1.500 m; in marginal positions sands and gravelly sediments were deposited.
According to the salinity reduction biotic diversity decreased further compared to the Sarmatian and particularly mollusc faunas are characterized by mass occurrences of a few taxa only which exhibit, however, a fast evolutionary development. Most important taxa are *Melanopsis*, *Congeria*, and *Limnocardium* (Stop 5), whose evolutionary lineages provide the base for the subdivision of the Pannonian into 5 zones (Zone A - E) (PAPP, 1949, 1951, 1953).

3.4. EXCURSION STOPS

STOP 4: "Fenk" Quarry

Subject: Climate optimum during the Miocene in the Vienna Basin reflected by Leitha Limestone with coral carpets and coralline algal sediments as well as well bedded slope facies.

Lithostratigraphic unit: Leitha Limestone; Faziostratotype (STEININGER & PAPP [in:] PAPP et al., 1978, p. 194 ff.).



Age: *Bulimina-Bolivina* Zone (Late Badenian).

Locality: Quarry area „Fenk" at Kalkofenwald c. 1400 m NNW of Großhöflein (SW Eisenstadt, Burgenland); ÖK 1:50.000, Sheet 77 Eisenstadt.

Fig. 16: Location map of Stop 4: "Fenk" quarry.

Description:

The former quarry area is currently used as a waste dump and therefore the outcrop accessibility is limited. The lower levels are already filled and covered by vegetation the character of the Leitha Limestone in this lower positions, however, is still observable.

A) Close to the entrance into the quarry area E of the road a c. 9 m section was cropping out (section Ff in DULLO, 1983; Fig. 8) of which only the uppermost part (c. 4 m) is still existing (Fig. 17).

At the currently preserved base bioclastic limestones occur rich in coralline algae, bryozoan, bivalves, gastropods, and echinoids. These are overlain by a thinner bedded (few cm up to 70 cm) sequence of limestones and slightly terrigenous (?), less cemented, silty layers. The limestones are mainly bioclastic and classified as foraminiferan-rhodolith facies or foraminiferan-algal debris facies by DULLO (1983). In some beds large, spherical, columnar or columnar/laminar coralline algal rhodoliths are present. The silty layers are poor in macrofossils. The foraminiferal fauna is characterized by uvigerinids and planktic forms. The silts are sometimes laminated and show signs of synsedimentary gravitational transport. The base of the calcarenites is partly erosiv.

In the upper part of the section the thin bedded sequence is obliquely cut by a limestone bed which exhibits lateral thickness variations from 40 - 145 cm. Its basal part is a coralline algal limestone (algal floatstone) with large imprints of aragonitic bivalves, pectinids, branching bryozoans, and

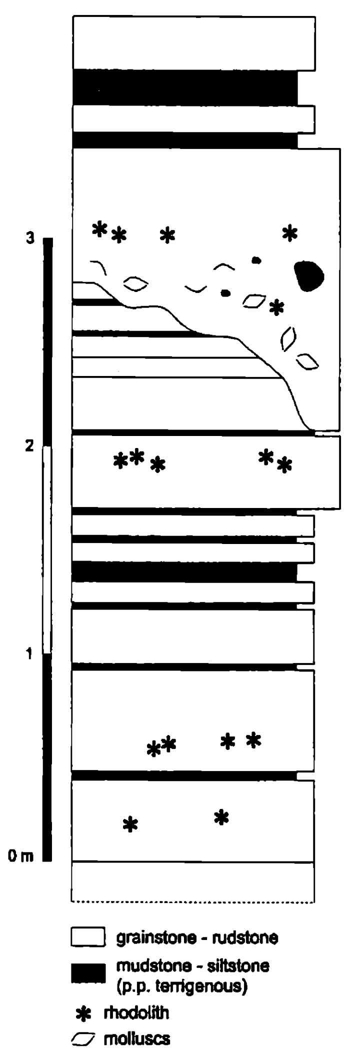


Fig. 17: Section through the slope facies of the Leitha Limestone in the lower quarry of "Fenk" area.

echinoid fragments. It is overlain by a bioclastic grainstone, fining upward and characterized by large rhodoliths (- 7 cm) and rare coral fragments. In this bed also fragments of crystalline rocks (- 10 cm Ø) of the basement and coral rocks are present. Above this bed a series of thin bedded limestones, marly limestones and terrigenous sands follow which are in part strongly weathered.

B) The uppermost part of the quarry area is represented by a nearly vertical wall exhibiting a section of approximately 20 m (Fig. 18). The section is composed of thick limestone beds, dipping with an angle between 5 - 10° in the western part in WNW direction and in the eastern part of the wall to the southwest.

Just below the base of the currently exposed quarry bottom a location with a rich and excellently preserved fauna of decapod crustaceans was described (BACHMAYER & TOLLMANN, 1953). The current outcrop can roughly be subdivided into three main units:

1) a) The lowermost part can be subdivided in several units. At the base occurs a coral limestone (90 cm) which is characterized in its uppermost 30 cm by densely packed debris of *Porites* branches. It is overlain by the "1. *Isognomum* horizon" defined by abundant occurrences of double valved oysters and *Isognomum*. Above an echinoid-rich, bioclastic limestone with large venerid bivalves (*Pitar*) follows the "2. *Isognomum* horizon" (60 - 80 cm). Double-valved individuals are abundant at the base being in a predomiantly horizontal position, whereas in the upper part more vertically orientated valves prevail. This bivalve horizon is overlain by a coral limestone in which mainly branching *Porites*-

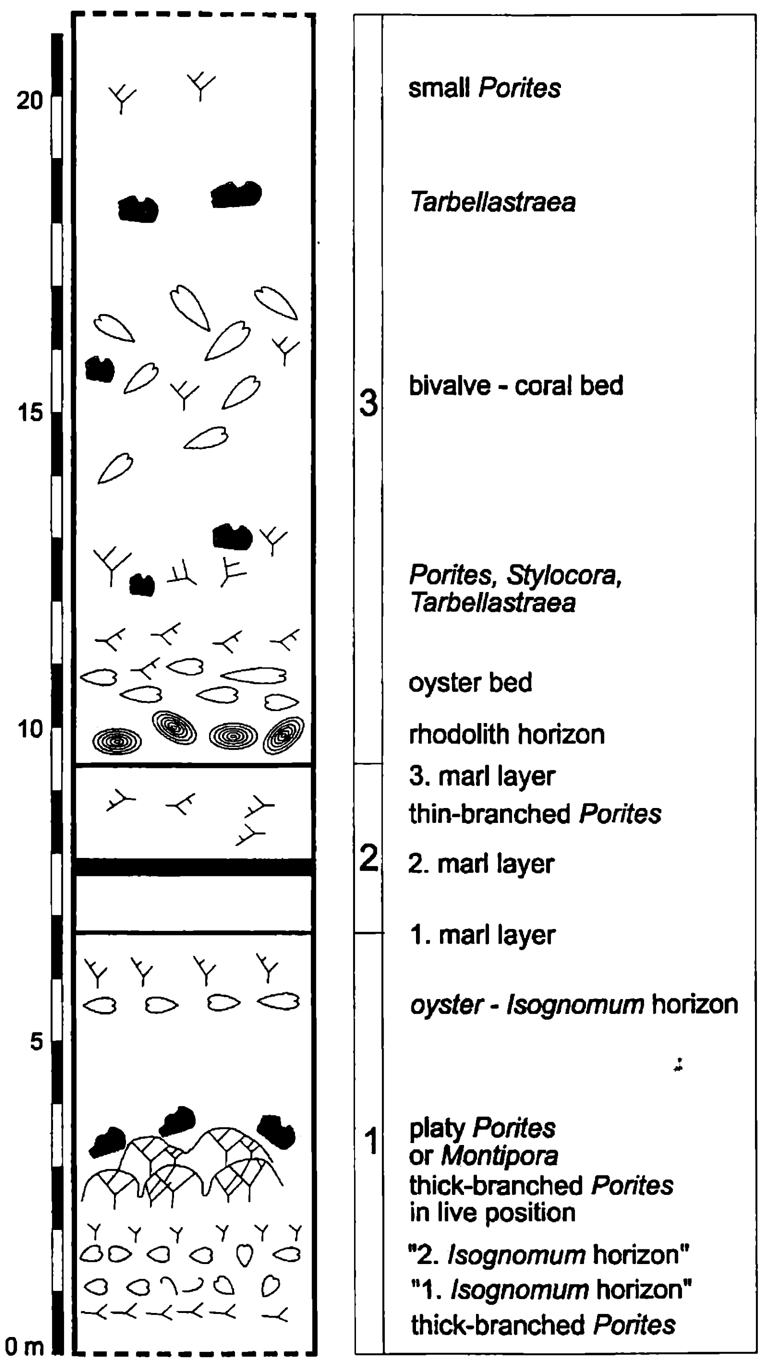


Fig. 18: Section of the faciostratotype of the Leitha Limestone of the "Fenk"-quarry.

colonies of c. 20 cm occur in live position. In the uppermost part the abundace of *Isognomum* increases again.
b) The following subunit (ca. 350 cm) is characterized by thick branched (12 - 22 mm) *Porites*-colonies in live position (up to 90 cm in height). Aside and particulary incrusting these large colonies thin platy corals occur, usually denominated as *Porites incrustans*, which, however, have probably be assigned to the genus *Montipora*. In addition, also *Caulastrea* and *Tarbellastraea* occur (comp. PILLER & KLEEMANN, 1991).
c) Above follows a subunit with abundant double-valved oysters and rare *Isognomum* overlain by a bed with thin branched *Porites* in live position. Their branches are incrusted by relatively thick coralline algal crusts. The subunit ends with a coralline algal-bryozoan calcarenite with chaetetids.

2) a) The base of this unit is marked by a (1.) marl bed (1 - 2 cm) which is overlain by a
b) bioclastic bryozoan-coralline algal limestone with bivalves.
c) This limestone continuously grades into a (2.) brown marl with coralline algae (branch fragments and rhodoliths) (25 cm) which is obverlain by a
d) coralline algal - bryozoan limestone (130 - 160 cm) with thin branching *Porites* cf. *leptoclada* REUSS and chaetetids.
e) A thin (3.) marl layer (1-5 cm) marks the boundary to unit 3.

3) a) The basal 90 cm are charcterized by abundant crustose coralline algal rhodoliths overlain by a limestone (90 cm) rich in ostreids, corals, bryozoans, chaetetids, and serpulids. The aragonitic shells are represented only as steinkerns, the ostreids are double valved. This zone grades into a bioclastic coralline algal limestone (70 cm) dominated by branch fragments; also fragments of thin *Porites* branches occur. Above follows a coral limestone (150 - 160 cm) with predominantly *Porites*-branches and thin branched *Stylocora exilis* REUSS. The latter is represented by parautochthonous debris material of a few decimenters in thickness. Massive coral colonies are represented by *Tarbellastraea reussiana* (EDWARDS & HAIME). Besides the corals also big bivalves are present.
b) The latter conduct over to a thick unit (450 cm) with abundant thick-valved bivalves and corals. Besides very large and thick ostreids large venerids, e.g, *Pitar*, *Venus (Periglypta)*, and carditids are remarkable.
c) The final sequence (400-450 cm) is represented by abundant rhodoliths at the base, followed by a coral limestone (*Tarbellastraea*) and topped by a bryozoan dominated limestone.

Interpretation:

The high abundance of corals in live position, particularly in the lower parts of the upper section (B), favoured an interpretation for this outcrop as a coral reef (e.g., STEININGER & PAPP [in:] PAPP et al., 1978; DULLO, 1983; TOLLMANN, 1985). Whether a true coral reef, with depth and energy related zonation, or a coral carpet is developed cannot be decided due to the limited outcrop situtation. The basal part with the *Isognomum* horizons and the huge upright standing *Porites* colonies which are overgrown by crustose corals and coralline algae followed by massive corals, shows at least a clear vertical ecological succession (comp. PILLER & KLEEMANN, 1991). The repeatedly occurring bivalve horizons may be better interpretated as bivalve biostromes. The entire sequence with its various microfacies types and the intercalated marly layers point to rapidly changing sedimentation condition at least with weak terrigenous input.

The short section in the lower part of the quarry area (A) with its relatively thin bedded limestones and weak terrigenous influx can be interpreted as slope environment. The fine grained, silty layers represent the autochthonous sedimentation; its open marine influence is

documented by the high abundance of planktic foraminifera, the greater water depth by the occurrence of uvigerinid foraminifera. Intercalated with these open marine sediments are bioclastic grainstones allodapic in origin. The coarse grained bioclastic limestone bed with its laterally variable thickness can be interpreted as debris to grain flow deposits locally producing channel fillings where shallow water sediments were transported basinwards gravitatively.
The relatively rich coral and diverse molluscs fauna as well as some larger foraminifera (*Borelis, Planostegina, Amphistegina*) together with a diverse coralline algal flora prove the tropical/subtropical climate in the Vienna Basin during the Late Badenian.

STOP 5: Gravel pit St. Margarethen - Gemeindewald (N-Burgenland)
(Mathias Harzhauser & Oleg Mandic)

Subject: Biostratigraphy and paleoecology of molluscbearing, nearshore sediments of the younger Middle Sarmatian and Pannonian (Middle - Late Miocene)

Regional biostratigraphic unit: *Mactra* - beds (late Middle Sarmatian), Pannonian - zone B, Pannonian - zone C/D

Locality: The locality is positioned about 50 km south of Vienna, near the NW shore of Lake Neusiedl (Fig. 19). At the first crossroad after Eisenstadt, on the federal road 16, follow the signpost to St. Margarethen and Rust. At the crossroad on the eastern edge of St. Margarethen choose the road on the right to the Hungarian border. In about 4 km on the left side you'll find a road to the Erwin Käufer gravel pit. The sections are located on the eastern pit wall.

Historical outline: The description on the geology of the gravel pits of the communal forest of St. Margarethen (Burgenland) was made by W. Fuchs (1965). According to its typical molluscs fauna the sequence was dated into the Sarmatian.

A monograph on the Miocene melanopsids (Gastropoda) of the Pannonian Basin (unpublished Ph. D. Thesis by Geary (1986)) brought descriptions of two *Melanopsis* species found in the gravel pit St. Margarethen. These were regarded as early Pannonian variations by Steininger (in: Geary, 1986).

Piller & Vavra (1991) and Piller et al. (1996) briefly described the gravel pit St. Margarethen for a field guide. Herein the sedimentology and fossils had been introduced and two biostratigraphically distinct horizons were recognised - the Sarmatian "*Mactra* beds" and *Melanopsis* bearing Pannonian - Zone D.

In summer 1996 an undergraduat student fieldcourse was organised by the Institute of Paleontology of the University of Vienna under the supervision of P. Pervesler and R. Roetzel. The data on the paleontology, sedimentology and topography achieved there created the basis for the present description. At the same time the tectonic structures have been measured and analysed by Decker & Peresson (1996).
The presented taxonomic identifications and biostratigraphic interpretations are based mainly on the publications of the serial "Chronostratigraphie und Neostratotypen": M5-Sarmatien (Papp et al., 1974) and M6-Pannonian (Papp et al., 1985) (Fig. 20).

Lithology and fossils: Lithologically the section can be subdivided into six units (Fig. 21):
Unit I: basal gravel
In section A about 4 m layered, evenly laminated fine-, middle- and coarse gravel with sandy matrix are exposed. An intercalated marly silt layer shows convolut bedding.

Especially at the southern and western wall of the pit this thick basal sedimentary sequence with its extensive crossbedding, faults and synsedimentary tectonics is exposed very well. Fossils are rare, *Pirenella disjuncta* (SOW.), *Pirenella picta* (BAST.) and *Irus gregarius* (GOLDF.) occur sporadically.

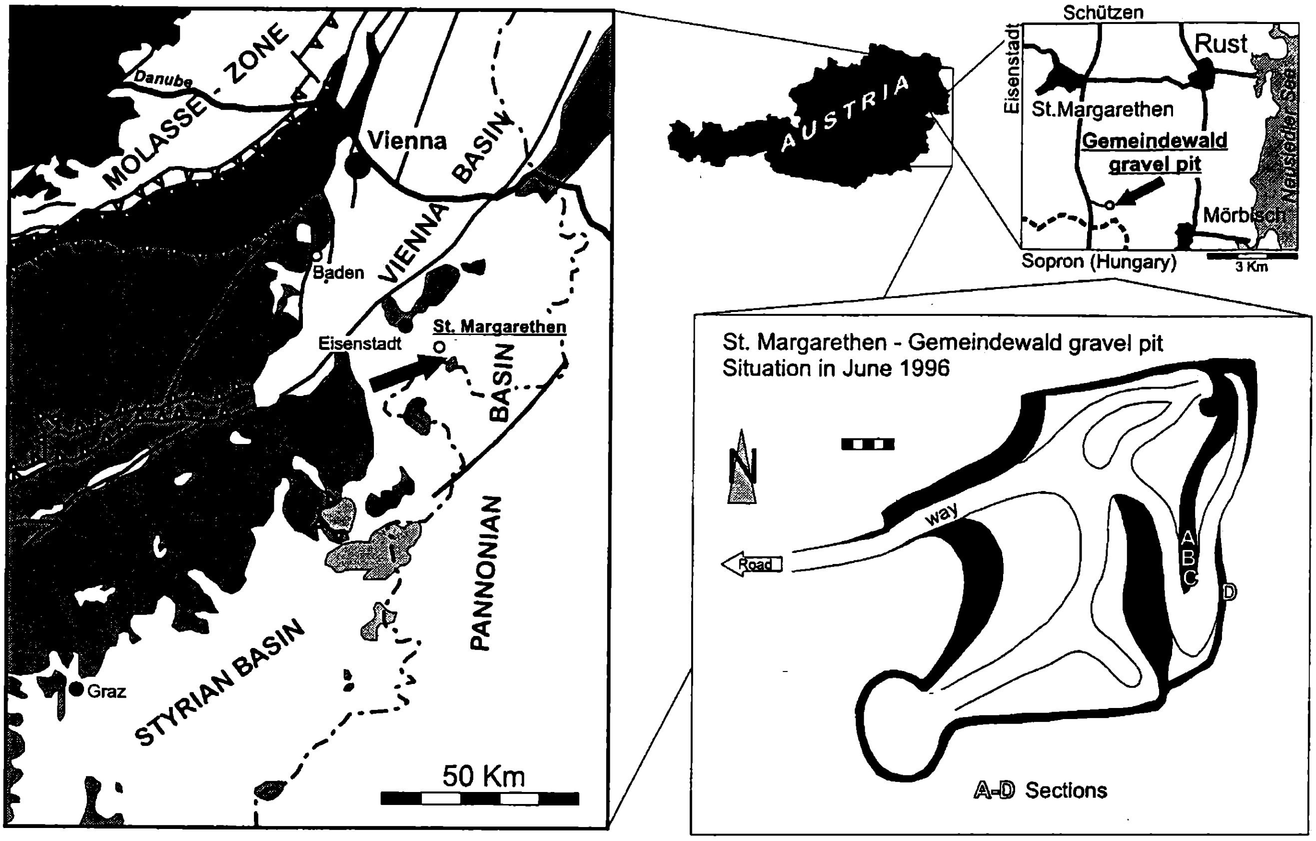


Fig. 19: Tectonic and geographic position of the St. Margarethen-Gemeindewald sections (Location map of the pit with courtesy of P. Pervesler, Inst. of Paleontology, University Vienna

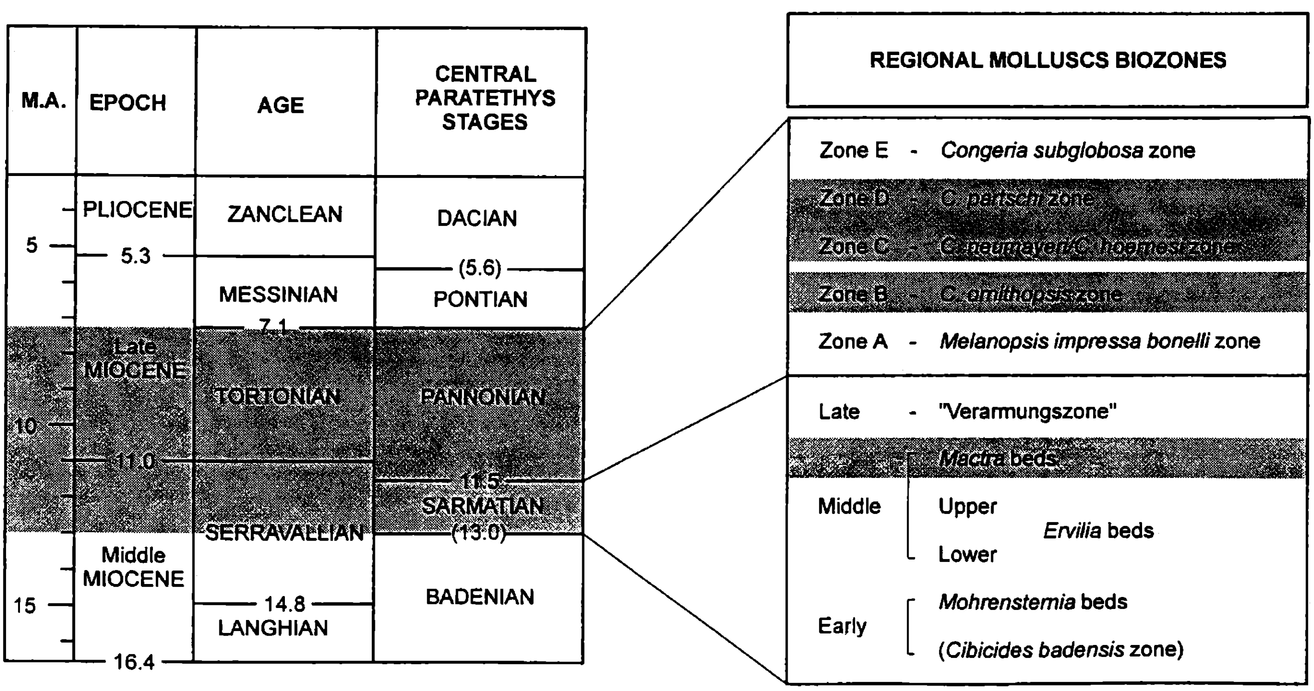


Fig. 20: Chronostratigraphic correlation and regional biozonation of the Paratethys stages Sarmatian and Pannonian (Rögl, 1996; Papp, Marinescu & Senes, 1974). Shaded areas correspond to the biozones determined in the section.

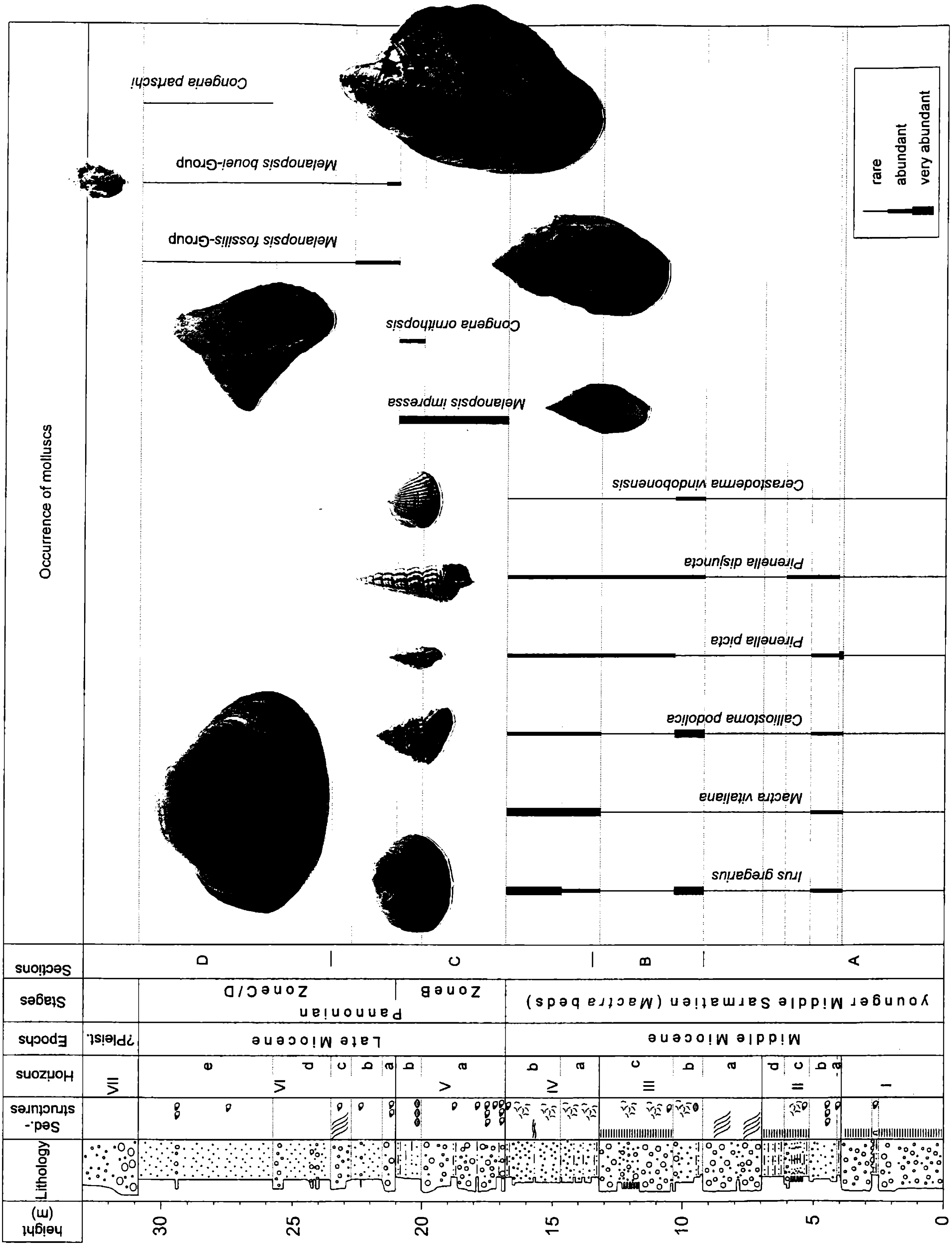


Fig. 21: Occurrence of molluscs in the section of the gravel pit St. Margarethen-Gemeindewald (loging by R. Roetzel, Geological Survey Vienna)

Unit II: sands and clays

a) About 10 cm dark-brown clay and silt with abundant bone fragments (up to 3 cm) and terrestrial and freshwater gastropods (*Lymnaea* sp., *Planorbis* sp., Helicidae indet.) are overlain by thin greyish-brown silt (5 cm) characterised by masses of *Pirenella picta* (BAST.), additionally *Hydrobia* sp. and *Modiolus incrassatus* (ORB.) are found.

b) Approx. 1 m bright, yellowish-grey sand and gravel with large sized shells of *Pirenella disjuncta* (SOW.) at the base; the following marly finesand layer bears a diverse mollusc fauna consisting of *Pirenella disjuncta* (SOW.), *Calliostoma podolicum podolicum* (DUB.), *Modiolus incrassatus* (ORB.), *Musculus sarmaticus* (GAT.), *Hydrobia stagnalis* (BAST.), and *Dorsanum duplicatum* (SOW.), seldom appear *Pirenella picta* (BAST.), *Acteocina lajonkaireana* (BAST.), *Cerastoderma vindobonensis* (LASK.), *Mactra vitaliana pallasi* (BAILY), and *Irus gregarius* (GOLDF.). In addition accumulations of small sized serpulids and a single artiodactylan bone are worth mentioning.

c) Approx. 95 cm interbedded, indurated clayey silt and medium sand with mollusc grit and evenly laminated to slightly wavy layers; in the top 10 cm gravel occurs.

d) About 85 cm yellowish-grey, partially indurated clayey silt, topped by 7 cm clay.

Unit III: gravel

a) Approximately 220 cm crossbedded, badly sorted medium and coarse gravel with sandy ground mass. The shell surfaces of *Dorsanum duplicatum* (SOW.) and *Irus gregarius* (GOLDF.) are abraded.

b) About 105 cm succession of silt, sand and gravel. 25 cm mollusc detritus bearing clayey silt at the base are overlain by middlesand molluscgrit passing into coarsesand. This section exhibits a thin *Irus gregarius* coquina with many articulated valves, a marker horizon observed all over the gravel pit. Besides this striking accumulation the mollusc fauna consists mainly of *Calliostoma podolicum podolicum* (DUB.), *Pirenella disjuncta* (SOW.) and lense-like layers of *Musculus incrassatus* (ORB.), *Modiolus sarmaticus* (GRAT.), *Cerastoderma vindobonensis vindobonensis* (LASK.), and *Cerastoderma vindobonensis jekeliusi* (PAPP). Towards the top the number of *Hydrobia* div sp. and *Pirenella picta* (BAST.) increases, finally the bed passes into 10 cm greyish-brown silty sand with bone fragments, terrestrial - and limnic-fluvial gastropods (*Pomatias conica* (KLEIN), *Lymnaea* sp., *Klikia* sp.).

c) 270 cm interbedded gravel and sand consisting of about 120 cm evenly bedded gravel with sandy matrix and platy, well rounded components; the top becomes sandy with *Pirenella picta* (BAST.) and *Pirenella disjuncta* (SOW.).

About 85 cm interbedded, evenly bedded fine- to coarse gravel and middle sand with sporadic *Pirenella:*

Approximately 70 cm evenly- to crossbedded gravel with sandy matrix and mollusc detritus; shells of *Pirenella* are aligned parallel to the bedding.

Unit IV: sands

a) Approximately 150 cm thick yellowish-grey layer of interbeded marly silt and middlesand with mollusc detritus and serpulids. The thickness of the siltlayers decreases towards the top.

b) About 200 cm bright yellowish-brown partially indurated sand with a layer of 10 cm flaser bedded sandy silt in its middle part. This unit ends with a 27 cm thick layer of calcareous marls exhibiting a diverse mollusc fauna consisting of *Irus gregarius ponderosus* (ORB.), *Calliostoma podolicum podolicum* (DUB.), *Cerastoderma vindobonensis vindobonensis* (LASK.), *Pirenella disjuncta* (SOW.), *Pirenella picta* (BAST.), *Dorsanum duplicatum* (SOW.), *Ervilia* cf. *dissita* (EICHW.), and *Hydrobia stagnalis* (BAST.). The top of the section (30 cm) is characterised by a marker horizon of bivalved *Cerastoderma latisulcum*

latisulcum (MÜNST.) and *Mactra vitaliana* ORB. accompanied by *Pirenella picta* (BAST.) and *Hydrobia* sp.

Unit V: Gravels and sands

a) Approximately 320 cm, the unit starts with 12 cm fossiliferous coarse- to medium gravel, the components (2-5 cm) are well rounded and platy. The mollusc fauna consists only of abraded, large sized *Melanopsis impressa* KRAUSS and probably redeposited Sarmatian and rare Badenian shells. 20 cm silt with gastropods are overlain by three layers of gravel with *Melanopsis impressa* KRAUSS separated by thin silty, calcareous sheets. The first layer is inversly graded, including *Melanopsis* shells, which are orientated parallel to the bedding. The second layer displays normal grading, the third one again is inversly graded with platy components orientated parallel to the bedding plane and redeposited marl clasts which cavities were populated by smallsized *Congeria ramphophora* BRUS.

b) Approximately 100 cm normal graded finesand-silt succession, at the base a marker horizon with *Congeria ornithopsis* BRUS. is developed, additionally *Melanopsis impressa* KRAUSS and mollusc detritus appear in scattered gravel intercalations.

Unit VI: finesands

a) About 50 cm gravel with sandy matrix, the lowermost 5 cm consist of abraded *Melanopsis impressa* KRAUSS the following gravel layer bears a highly evolved *Melanopsis* fauna with *Melanopsis fossilis* (MART.-GMEL.), *Melanopsis bouei* FER. and *Melanopsis pygmaea* HOERN.

b) Approximately 120 cm yellowish-grey finesand with a thin gravel layer bearing *Melanopsis fossilis* and several small-sized shells of *Melanopsis bouei* FER., *Melanopsis inermis* HANDM. and *Melanopsis varicosa* HANDM..

c) About 80 cm crossbedded gravel developing from a 20 cm thick sand layer. The mollusc fauna corresponds to VI b.

d) About 2 m yellowish-grey finesand with gravel layers with a diverse *Melanopsis* fauna topped by 40 cm gravels.

e) About 5 m finesand with rare but large sized *Melanopsis fossilis* (MART.-GMEL.) and *Congeria partschi* CZJZEK. On the soft sediment surface the gastropods apertures sometimes acted as secondary hardground for the byssate *Congeria ramphophora* BRUS., more seldom *Limnocardium* cf. *spinosum* LÖR. and abraised shells of *Psilunio* ex gr. *atavus* PARTSCH occur.

Unit VII: Quaternary debris

a) The Pannonian sedimentary sequence is covered by 2-3 m quaternary debris consisting of crystalline boulders (mica slate), middle Miocene limestones (Leithakalk) and quartz or crystalline pebbles.

Molluscs

Units I-IV:

This fauna corresponds to the regional Central Paratethys **Mactra beds** Biozone (Middle Sarmatian).

Calliostoma podolicum podolicum (DUBOIS, 1831)
Calliostoma podolicum wiesenensis PAPP, 1954
Theodoxus crenulatus KLEIN, 1853
Hydrobia stagnalis (BASTER, 1765)
Hydrobia sp.
Pseudamnicola (Staja) cf. *inflata* JEKELIUS, 1944
Mohrensternia sp.
Pirenella picta picta (BASTEROT, 1825)
Pirenella picta mitralis (EICHWALD, 1830)

Pirenella disjuncta disjuncta (SOWERBY, 1831)
Dorsanum duplicatum (SOWERBY, 1829)
Acteocina lajonkaireana (BASTEROT, 1825)
Planorbis sp.
Lymnaea sp.
Pomatias conica (KLEIN, 1853)
Klikia sp.
Modiolus incrassatus (ORBIGNY, 1844)
Musculus sarmaticus (GATUJEV, 1916)
Cerastoderma vindobonensis vindobonensis (PARTSCH-LASKAREV, 1903)
Cerastoderma vindobonensis jekeliusi (PAPP, 1954)
Cerastoderma latisulcum latisulcum (MÜNSTER, 1834)
Mactra vitaliana ORBIGNY, 1844
Mactra vitaliana pallasi BAILY, 1858
Solen subfragilis EICHWALD, 1850
Ervilia cf. *dissita* EICHWALD, 1850
Irus gregarius gregarius (GOLDFUSS, 1834)
Irus gregarius ponderosus (ORBIGNY, 1844)

Unit V:
This fauna corresponds to the regional Central Paratethys **"Zone B"** (Early Pannonian)
Melanopsis impressa KRAUSS, 1852
two morphotypes: *M. impressa impressa* KRAUSS, 1852
M. impressa posterior PAPP, 1951
Congeria ornithopsis BRUSINA, 1892
Congeria ramphophora BRUSINA, 1892

Unit VI:
This fauna corresponds to the regional Central Paratethys "Zone C/D" (Middle to Late Pannonian)
Melanopsis fossilis (MARTINI-GMELIN, 1790)
three morphotypes: *M. fossilis fossilis* (MARTINI-GMELIN, 1790)
M. fossilis constricta HANDMANN, 1887
M. fossilis rugosa HANDMANN, 1887
Melanopsis bouei FERUSSAC, 1823
two morphotypes: *M. bouei bouei* FERUSSAC, 1823
M. bouei rarispina LÖRENTHEY, 1902
Melanopsis vindobonensis FUCHS, 1870
Melanopsis inermis HANDMANN, 1882
Melanopsis varicosa HANDMANN, 1882
Melanopsis pygmaea HOERNES, 1856
Congeria ramphophora BRUSINA, 1892
Congeria partschi CZJZEK, 1849
Psilunio ex gr. *atavus* (PARTSCH, 1837)
Limnocardium cf. spinosum LÖRENTHEY, 1902

Biostratigraphy
Sarmatian
As a consequence of the beginning isolation of the Central Paratethys from the Mediterranean during the late Badenian (Middle Miocene) most of the stenohaline-marine species became

extinct and a diverse, endemic Sarmatian mollusc fauna evolved at salinity conditions of about 17 per mille. Few marine genera as *Ocinebrina*, *Turritella* or *Solen* persisted, producing small sized relict-forms.
The typical Sarmatian fauna is characterized by genera as *Irus, Mactra, Ervilia, Cerastoderma, Calliostoma* or *Mohrensternia*, which settled in large numbers the littoral and shallow sublittoral. Increasing in size as well as high variability and a striking evolutionary tempo allow the separation of distinct assemblage zones (SENES, 1972).
The units I-IV bear a characteristic Sarmatian mollusc fauna. Large sized, thick-shelled morphotypes of *Calliostoma podolicum podolicum* (DUB.), *Irus gregarius ponderosus* (ORB.), *Mactra vitaliana pallasi* BAILY, and *Pirenella disjuncta disjuncta* (SOW.) are typical representatives of the younger Middle Sarmatian *Mactra*-beds. Marker fossils of the stratigraphically older *Ervilia*-beds as *Calliostoma poppelacki* (HOERN.) and *Calliostoma podolica enodis* (TOULA) are absent or rare like *Ervilia dissita* (EICHW.).

Pannonian
Local tectonics and worldwide regressive tendencies at the Sarmatian/Pannonian boundary result in the final isolation of the Pannonian Basin from the Eastern Paratethys (STEININGER & RÖGL, 1985). Salinity decreases 3-10 per mille causing the extinction of the reduced-marine Sarmatian mollusc fauna and the take-over by limnic-fluvial and oligohaline molluscs. Especially the genera *Melanopsis* and *Congeria*, recorded since the lower Miocene, show a remarkable radiation, developing numerous species and subspecies, whereas a diverse *Limnocardium* fauna evolves from the Sarmatian *Cerastoderma*. Based on this mollusc radiation PAPP (1951) subdivided the Pannonian of the Vienna and Pannonian basin into five zones (Zone A-E).
In unit V the occurrence of *Melanopsis impressa* KRAUSS together with the marker fossil *Congeria ornithopsis* BRUS. correspond well to Zone B.
Because of the regression at the beginning of the Pannonian, only few nearshore sediments have been deposited in the Vienna - and Eisenstadt basin, thus the upper Sarmatian "Verarmungszone" and the Pannonian zone A are missing in the section of the gravel pit St. Margarethen.
The diverse fauna of unit VI consists of large specimens of the *Melanopsis fossilis* -group and numerous representatives of the *Melanopsis bouéi*-group which characterise the Zone C/D; *Congeria partschi* CZJZEK, *Melanopsis pygmaea* HOERN. and *Psilunio* ex gr. *atavus* PARTSCH are most abundant in Zone D.

Paleoecology
Unit I: The fluvial transported and submarine deposited gravel bears scattered molluscs from the littoral and shallow sublittoral.
Unit II: The rich terrestrial and limnic-fluvial gastropod fauna at the base of unit II is evidence for strong freshwater influence.The following muddy, clayey sediment was developed in the intertidal, where *Pirenella picta* (BAST.) - an organic detritus and algae browser - appeared in masses. With the rising of the relative sea-level the intertidal fauna was replaced by infaunal bivalve associations (*Irus, Mactra, Cerastoderma*), some epifaunal suspension feeders as *Musculus* and *Modiolus*, and a herbivorous gastropod fauna of the shallow sublittoral like *Calliostoma podolicum podolicum* (DUBOIS, 1831).
Unit III: The shallow sublittoral mollusc fauna of this unit is dominated by infaunal bivalvia, accompanied by gastropods from nearshore communities as *Calliostoma podolicum* (DUB.) or *Pirenella disjuncta* (SOW.). Towards the top the increasing number of *Hydrobia* as well as terrestrial and freshwater gastropods correspond to fluvial influence.The fauna of the following layer (*Pirenella disjuncta* (SOW.), *Irus grgarius* (GOLDF.)) reflects the re-established marine conditions.

Unit IV: In the uppermost, sandy-marly Sarmatian section, a rich and diverse, marine, infaunal bivalve community appears together with littoral and shallow sublittoral gastropods and a large number of fluvial-estuarine *Hydrobia* specimens.
Unit V: The predominating species of this less diverse unit is *Melanopsis impressa* KRAUSS, which lived herbivorous in fluvial-estuarine and brackish-littoral environments. Abrasion and sorting of the shells point to transport, as do the disarticulated valves of *Congeria ornithopsis* BRUS. which were epifaunal, suspension feeders, lying on firm ground (PAPP,1951). In this high-energy environment small holes and cavities in redeposited Sarmatian marlclasts have been settled by small *Congeria ramphophora* BRUS.
Unit VI: The diverse, highly evolved *Melanopsis* fauna of this horizon reflects nearshore conditions with fluvial input. In the freshwater-influenced littoral zone large sized epifaunal byssate *Congeria partschi* CZJZEK and infaunal Limnocardiidae occured. The gracile *Congeria ramphophora* BRUS. lived attached in the apertures of *Melanopsis fossilis* shells. Rare *Psilunio* valves were transported from fluvial environments.

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