Berichte der Geologischen Bundesanstalt, Band 49, ISSN 1017-8880, 113 S., 43 Abb., Wien 1999

Forum of the European Geological Surveys Directors

FOREGS ´99 Vienna

150 Years Geological Survey of Austria

Field trip guide

Vienna - Dachstein - Hallstatt - Salzkammergut (UNESCO World Heritage Area)

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Preface

Hans-Peter SCHÖNLAUB

The Annual FOREGS'99 Meeting held in Vienna, Austria, is concluded by an excursion to the Unesco Cultural Heritage Landscape of Hallstatt-Dachstein. The decision to establish this region as a World Heritage Site was accompanied in December 1997 with the following remarks: "*The Hallstatt-Dachstein/Salzkammergut Alpine region is an outstanding example of a natural landscape of great beauty and scientific interest which also contains evidence of a fundamental human economic activity, the whole integrated in a harmonious and mutually beneficial manner.*"

According to Article 1 of the Unesco World Heritage Convention such a landscape represents the *"combined works of nature and of man"* or - expressed in a simple way - a region in which the local population is strongly dependent on the surrounding nature. During the excursion we will try to demonstrate this intimate relationship.

This Guidebook provided by Earth scientists is intended as a starting point to complement the formal political decision to nominate parts of the Salzkammergut as a World Heritage Site. It has specifically been compiled for this event and benefits from contributions from various authors and sources who contributed published and unpublished data from different fields of expertise including historical and applied geology, archaeology and research in karst speleology. Primarily, however, the recently published new Geological Map of the Dachstein Region at the scale 1:50.000 should be mentioned which had been compiled by Gerhard Mandl from the Geological Survey of Austria with support from the Federal Environment Agency. Both the Guidebook and the Map should stimulate further research, relevant PR products and the necessary infrastructural measures to fulfill the aims of the Convention and the expectations of the wider public.

In the Salzkammergut region geoscientific research has a long tradition. In fact, the area represents one of the key areas for the understanding of Triassic and Jurassic stratigraphy and the corresponding facies development of the whole Alps, having further implications for the broader Tethys realm of almost global significance. Besides others, this fact is reflected by the currently used ammonite biostratigraphic zonation based on the Salzkammergut area. Presumably, during the 5th International Cephalopod Symposium taking place shortly after the FOREGS '99 Meeting in Vienna this linkage will be discussed at length.

The majority of visitors to the Hallstatt-Dachstein region are equally impressed by the surrounding mountains and the beauty of the villages with its traditionally styled houses decorated with many flowers. Such a truly sustainable development is the result of a long lasting economic development based on salt mining since Celtic times when the so-called "Hallstatt Culture" flourished in this region. Later on, beginning in the 19th century also forest industry and tourism became a major source of wealth for this region.

Economic geology, i.e. salt mining, general geology, hydrogeology, palaeontology and archaeology may guarantee further welfare in this region if treated carefully and responsibly. The declaration as a "cultural landscape" and its strong relationship with geology provides a first step in this future direction.

The organizers of this excursion greatly acknowledge the generous help of all authors who contributed to this Guidebook including general reviews on road-side geology. In particular, we are indebted to Gerhard MANDL and co-workers from the Geological Survey for their authorship and guidance during the excursion.

Hans Peter Schönlaub (Director)

1. Excursion itinerary

Monday, August 30, 1999

12:30 - 18:00:	Bus tour Vienna-Gmunden-Hallstatt (310 km) For explanations of road-side geology see chapter 3.
about 18:00:	Arrival at Hallstatt (Hotel Bergfried)

Tuesday, August 31, 1999

8:30 - 9:30:	Boat tour on Lake Hallstatt with an introduction to the regional geology. For additional information see chapters 2.5 and 4.2
10:00:	Congress Center Hallstatt: Welcome by Mr. Scheutz, Mayor of Hallstatt
10:15 - 12:30:	Presentations by local representatives on "The Hallstatt-Dachstein region as UNESCO Cultural Heritage Landscape" and by GBA representatives on "Marketing geology in the Hallstatt-Dachstein region"
10:15 - 12:30:	Partners Programme: Guided tour in Hallstatt
14:00 - 17:00:	Ascent by cable-railway to the world's oldest underground saltmine, still operating since the year 1.000 BC, with a special prehistoric tour of where the "Man in Salt" was found over 300 years ago For additional information see chapter 5. Panoramic view from the Rudolf Tower over the idyllic community of Hallstatt and the Salzkammergut

Wednesday, September 1, 1999

8:30 - 10:00:	Bus tour from Hallstatt via Bad Aussee to Loser Mountain with panoramic view at altitude 1600 m and presentation of regional & local geology. For additional information see chapter 6.
11:00:	Departure for Grundlsee and Toplitzsee
12:00 - 14:00:	Lunch at Fischerhütte/Toplitzsee with optional boat tour
14:00 - 15:00:	Bus tour to Obertraun/Dachstein Cable Car Ascent and a 10 minutes walk to the entrance of the Ice Cave
15:30 - 17:00:	Visit to Giant Ice Cave (1 hour; be ready for a temperature of + 2°C only!) For additional information see chapter 7.
17:00:	Descent and return to hotel

Thursday, September 2, 1999

8:30:	Departure from Hallstatt to the village of Gosau and Gosau Lake
9:30 - 10:30:	Ascent by cable car to Gosaukamm (1475 m)
10:30 - 12:30:	Panoramic view from Gablonzer Hütte to Dachstein and Gosaukamm. Introduction to local geology and short walk to fossiliferous Triassic strata. For additional information see chapter 8.
13:30:	Return and departure for Vienna
about 18:00:	Arrival in Vienna. End of FOREGS '99 Excursion

2. Introduction to selected geological main units of Austria

2.1. The Bohemian Massif - a short introduction

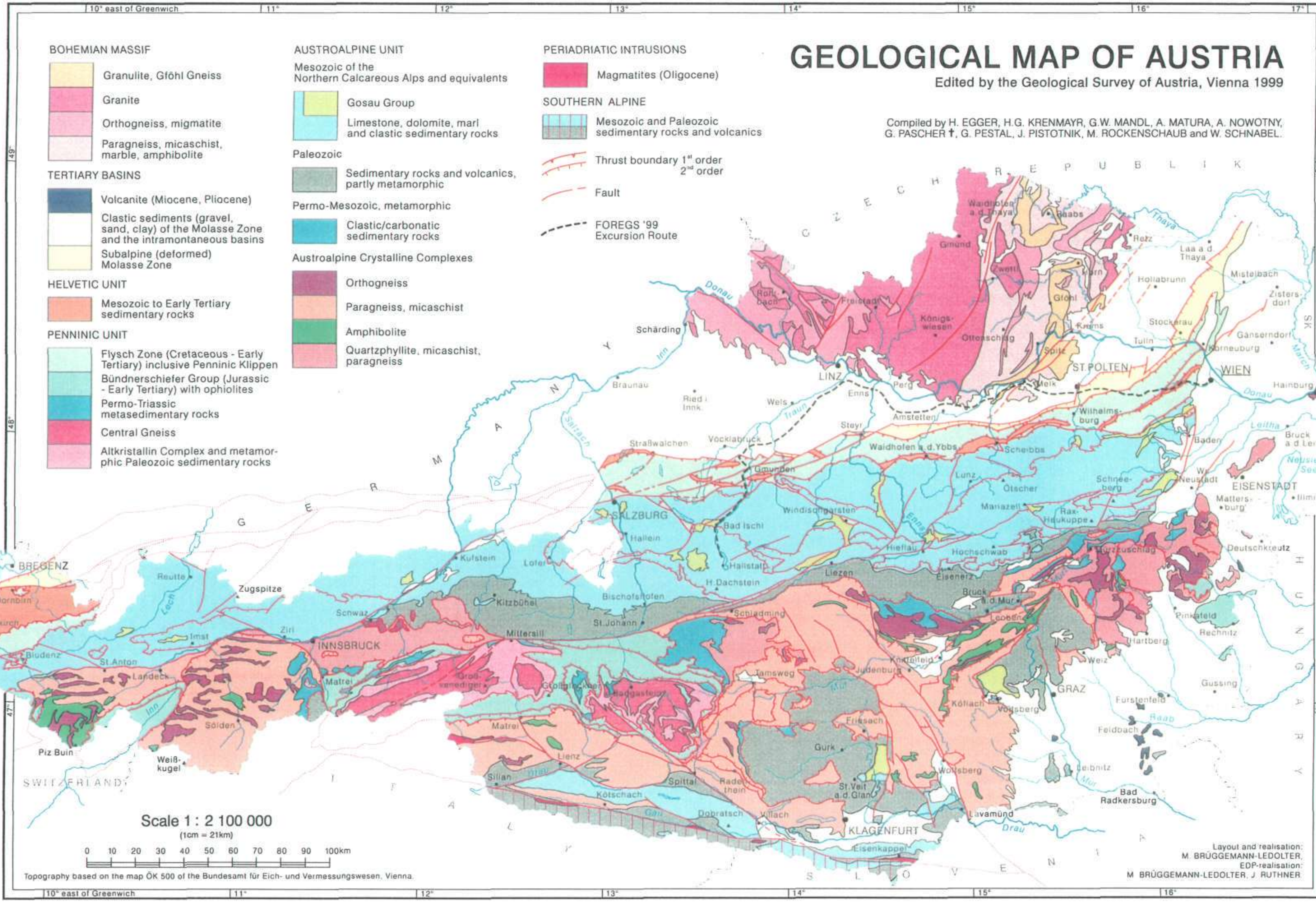
Thomas HOFMANN

The Bohemian Massif is part of the Variscan orogenic belt of Europe which comprises different metamorphic units and granitic intrusions. The surface outcrops North of the river Danube belongs to the Bohemian Massif which extends as well to the South below the Rhenodanubian Flysch Zone and the Molasse Zone. It represents a former fragment of Northern Gondwana that split off during early Paleozoic time and collided with Avalonia and Baltica during middle Paleozoic time. This block is essentially composed of medium-grade metamorphic rocks derived from early to late Proterozoic and early Paleozoic precursory and extensive granites of Variscan age.
Structurally, the Bohemian Massif of Austria consists of two units, the Moldanubian Zone in the west and the Moravian Zone in the east. The former consists of paragneisses overlain by a complex of variegated crystalline rocks, granulites, and orthogneisses while the latter exhibits low- to medium-grade micaschists, metasedimentary rocks, orthogneisses and a cadomian granite (Thaya Batholith). During the Variscan Orogeny the Moldanubian Zone was thrust upon the Moravian Zone. Their complex lithologies and different evolutionary histories suggests, that originally the two zones may have represented two separate microplates.

The Moldanubian Zone

The Moldanubian part of the central European Variscan Belt shows characteristics of a collisional orogen. Nappe tectonics and high-P/high-T metamorphism have been identified. In the southeastern part of the Moldanubian zone, the development of the early Variscan metamorphism with subsequent nappe piling can be observed. The late orogenic development in the Moldanubian zone is dominated by high-T/low-P metamorphism within the lowermost structural units. The high temperatures led to regional migmatisation and the generation of granitoid magmas which formed the South Bohemian Batholith and other plutons.
The Moldanubian nappe pile consists, from top to bottom, of three major units: the
Gföhl nappe complex (or Gföhl unit), the
Drosendorf unit and the
Ostrong unit (= Monotonous Series).
The Gföhl nappe complex consists of an internal framework of different units (granulites, Raabs unit, Gföhl gneiss and Meisling unit), of generally high-grade (up to granulite-facies) metamorphism. The Meisling unit composed of amphibolites, orthogneisses and metasediments separates the Gföhl unit and the Drosendorf unit.

Fig. 2.: Geological Map of Austria and ➔
----- FOREGS ´99 Excursion route


GEOLOGICAL MAP OF AUSTRIA
Edited by the Geological Survey of Austria, Vienna 1999
Compiled by H. EGGER, H.G. KRENMAYR, G.W. MANDL, A. MATURA, A. NOWOTNY, G. PASCHER †, G. PESTAL, J. PISTOTNIK, M. ROCKENSCHAUB and W. SCHNABEL.
BOHEMIAN MASSIF
Granulite, Gföhl Gneiss
Granite
Orthogneiss, migmatite
Paragneiss, micaschist, marble, amphibolite
TERTIARY BASINS
Volcanite (Miocene, Pliocene)
Clastic sediments (gravel, sand, clay) of the Molasse Zone and the intramontaneous basins
Subalpine (deformed) Molasse Zone
HELVETIC UNIT
Mesozoic to Early Tertiary sedimentary rocks
PENNINIC UNIT
Flysch Zone (Cretaceous - Early Tertiary) inclusive Penninic Klippen
Bündnerschiefer Group (Jurassic - Early Tertiary) with ophiolites
Permo-Triassic metasedimentary rocks
Central Gneiss
Altkristallin Complex and metamorphic Paleozoic sedimentary rocks
AUSTROALPINE UNIT
Mesozoic of the Northern Calcareous Alps and equivalents
Gosau Group
Limestone, dolomite, marl and clastic sedimentary rocks
Paleozoic
Sedimentary rocks and volcanics, partly metamorphic
Permo-Mesozoic, metamorphic
Clastic/carbonatic sedimentary rocks
Austroalpine Crystalline Complexes
Orthogneiss
Paragneiss, micaschist
Amphibolite
Quartzphyllite, micaschist, paragneiss
PERIADRIATIC INTRUSIONS
Magmatites (Oligocene)
SOUTHERN ALPINE
Mesozoic and Paleozoic sedimentary rocks and volcanics
Thrust boundary 1st order
2nd order
Fault
FOREGS '99 Excursion Route
CZECH REPUBLIK
GERMANY
SWITZERLAND
ITALY
SLOVENIA
HUNGARY
SK
WIEN
LINZ
ST.PÖLTEN
SALZBURG
INNSBRUCK
GRAZ
KLAGENFURT
EISENSTADT
BREGENZ
Scale 1 : 2 100 000
(1cm = 21km)
0 10 20 30 40 50 60 70 80 90 100km
Topography based on the map ÖK 500 of the Bundesamt für Eich- und Vermessungswesen, Vienna.
Layout and realisation:
M. BRÜGGEMANN-LEDOLTER
EDP-realisation:
M. BRÜGGEMANN-LEDOLTER, J. RUTHNER
10° east of Greenwich
11°
12°
13°
14°
15°
16°
17°
47°
48°
49°

The Drosendorf unit has a Proterozoic basement (Dobra gneiss) overlain by mainly metasedimentary units (Variegated unit) of probable Palaeozoic primary age. It consists f para- and orthogneisses, amphibolites, calcsilicates and marbles. The depositional environment was probably a passive continental margin. The mafic layers within the Dobra gneiss are interpreted as former basaltic dikes, while those in the Variegated unit are derived from synsedimentary volcanics.

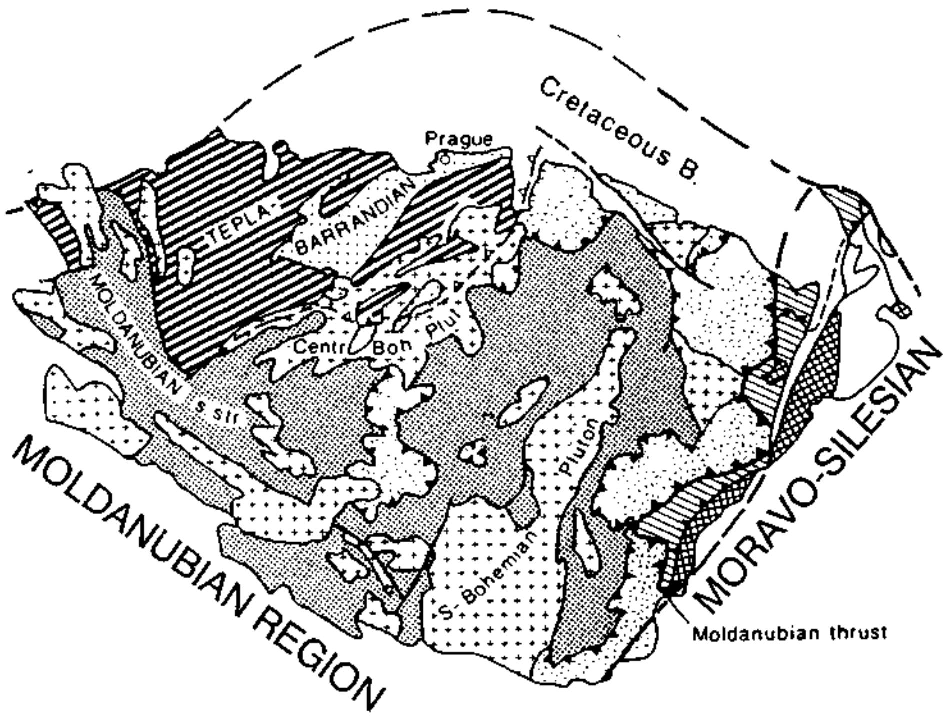


Fig. 2.1.: Tectonic map of the Bohemian Massif in Austria and adjacent areas (modified from FRANKE, 1989)

The lowest structural unit in the southeastern Moldanubian zone is the Ostrong unit, which is separated from the Drosendorf unit by a tectonic contact. Metapelitic rocks with cordierite and sillimanite dominate in the former called Monotonous Series. In addition, garnet-bearing ortho- and paragneisses and amphibolites occur. The protoliths of the metapelites and paragneisses were most probably pelites and greywackes.

The igneous rocks of the eastern part of the South Bohemian Batholith cut the Moldanubian nappe system. The South Bohemian Batholith extends for 160 km from Jihlava (Czech Republic) in the north to the Danube river in the south, and forms large areas in the Austrian part of the Bohemian Massif. The granitoids are late-orogenic plutonic complexes within the Variscan orogenic belt. The are emplaced at mid- to upper-crustal levels into hot country rocks shortly after the thermal peak of regional metamorphism. Clockwise P-T paths in the country rocks suggest that granite formation, low-P/high-T metamorphism and extensional thinning was preceded by a phase of intense crustal thickening which occurred within the framework of the late Palaeozoic continent-continent collision between Baltica and Gondwana. Apart from subordinate basic and intermediate rocks related to the granitoids the South Bohemian Batholith consists of different types of granites.

1. The Rastenberg Granodiorite intruded along the tectonic contact between the Drosendorf and the Monotonous unit. The pluton is granodioritic to quartzmonzonitic in composition. A typical feature of this pluton is the occurrence of dioritic enclaves due to magma mingling. These mafic bodies are more frequent than in any other granitoids of the South Bohemian Batholith.
2. The coarse grained Weinsberg Granite is the most widespread. In general the Weinsberg granite shows a large geochemical variation partly as I-type and partly as S-type granite. Like the Rastenberg granodiorite, it is coarse grained and contains idioblastic K-feldspar of up to 12 cm in size. S-type material, such as amphibolite-facies metasediments, particularly metagreywackes, were the possible protoliths for the Weinsberg granite. Post-plutonic aplites, fine-grained granites and porphyrites cut the Rastenberg granodiorite and the Weinsberg granite. Both granitoids were classified as members of the "older plutons" in the succession of the South Bohemian Batholith.
3. The Eisgarn Granite, which is commonly a muscovite rich granite with clear S-type characteristics. Andalusite is a typical accessory mineral and indicates a crystallisation at a relative small P-T-field formed by the intersection of the andalusite stability field and the granite minimum melt curve. It is obviously contemporaneous with the Weinsberg Granite.
4. The Mauthausen Granite varies from granodioritic to granitic composition and most of the fine-grained biotite granites have been related to this group. They form dikes and irregularly stocks within or in the vicinity of the Weinsberg granite. They are characterized by a clear I-type geochemistry. Inclusions of xenoliths and K-feldspar xenocrysts derived from the Weinsberg type granite are a common phenomenon for Mauthausen granite. In some parts it is considerably younger than the above mentioned types.

The Moravian Zone

The Moravian Zone is regarded as former western marginal zone of the so called Bruno-Vistulian Block, which is an old, at the latest Cadomian consolidated continental micro plate in the eastern part of the Bohemian Massif. Today the Moravian Zone is dissected from the Bruno-Vistulian Block by post-Variscan sinistral strike slip movements along the Diendorf-Boskovice wrench-fault system, which amounted at least 25 km.

During Variscan orogeny the western marginal parts of the Bruno-Vistulian Block were overthrusted by a hot nappe pile of the Moldanubian mobile belt. Thrusting occurred in connection with a strong dextral transpression between the Moldanubicum and the western flank of the Bruno-Vistulian Block. This transpression is responsible for the very charakteristic North-South-trending elongation of the westernmost Moravian lithological units and demonstrates the strong indentation that occurred within the Variscan continent-collision zone of Central Europe. The transpressional movements are followed by local updoming. All these Variscan events together are responsible for the distinct metamorphic and structural style of the Moravian Zone: a high degree of deformation and medium grade metamorphism on top, continously decreasing towards the east and towards the northern and southern ends of the Thaya Dome.

The deepest structural unit of the Moravian Zone is the weakly metamorphosed and deformed granitoid complex of the Thaya Batholith of Cadomian Age. With regard to its petrographical and geochemical characteristics the granitiods of the Thaya Batholith broadly fit the definition of I-type granitoids.

Based on field mapping and chemical work four major lithologies could be distinguished within the Thaya Batholith: the "Hauptgranite"-type (=main granite type) comprises medium-grained light granites and granodiorites with low biotite, the "Gumping"-type defines a more or less gneissic biotite-rich granodiorites and quartz-monzodiorites with blocky K-feldspar phenocrysts and amphibole altered to biotite, the"Passendorf"-type comprises essentially fine- to medium-grained tonalites and meta-tonalites or their gneisses and the "Gauderndorf"-type is a fine grainde granitic to granodioritic rock with somewhat higher biotite contents than the "Hauptgranite" type.

Therasburg Formation

Toward the west the Thaya Batholith is overlain by the Therasburg Formation. It consists of micaschists partly with a considerable amount of albite and/or oligoclase leading to fine grained gneisses. The assumed stratigraphic position is inferred from some preserved intrusive contacts and migmatites of the Cadomian Thaya Batholith as Precadomian.

Stengelgneis of Weitersfeld

This distict gneisss body separates the Therasburg Formation from the tectonical higher sequence of the Pernegg formation. The Weitersfeld gneiss sensu stricto is restricted to the northern part of the Moravian Zone showing a granitic composition with a partly well developed Augen-structure, but seems to be in most parts derived from metaarkoses.

Pernegg-Formation

The Pernegg-Formation comprises micaschists, calcschists and pure marbles, which grade into each other. The marbles prevail in the upper part of the sequence as coherent layers, partly as elongated lenses. The uppermost part of the marbles is formed by a very distict horizon of calcsilicate schists, the so called "Fugnitzer Kalksilikatschiefer". It is an only several meters thick layer, sometimes also found as small layers and lenses in the above lying Bittesch Gneiss.

Bittesch Gneiss

The Bittesch Gneiss is the uppermost unit of the Moravian Zone. It is a highly deformed orthogneiss with well developed Augen structure. Dark ampibolite layers up to 50cm thick are restricted to the uppermost 20 to 30 meters.

Acknowledgement

The author wants to express special thanks to Susanna SCHARBERT for critical reading and constructive comments.

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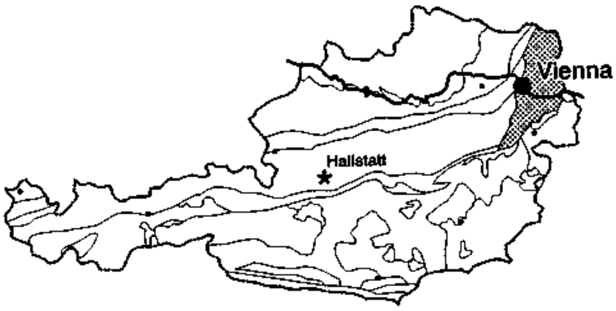
2.2. The Neogene of the Vienna Basin

WERNER E. PILLER



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 stratigraphic, sedimentologic and tectonic knowledge of the basin during the last 60 years. The different fields of interest 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.

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 km. The subsurface separation from the Vienna Basin is represented by the continuation between the Rosalien- and Leithagebirge; its tectonic and sedimentary history, however, is very similar and the Eisenstadt Basin is therefore considered as a subbasin of the Vienna Basin.

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 rhombohedral shape and the left-stepping pattern of en-enchelon faults firstly ROYDEN (1985) interpreted the basin as pull-apart structure. This idea was strengthened later on (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. 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 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. 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.

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) 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 forth 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.

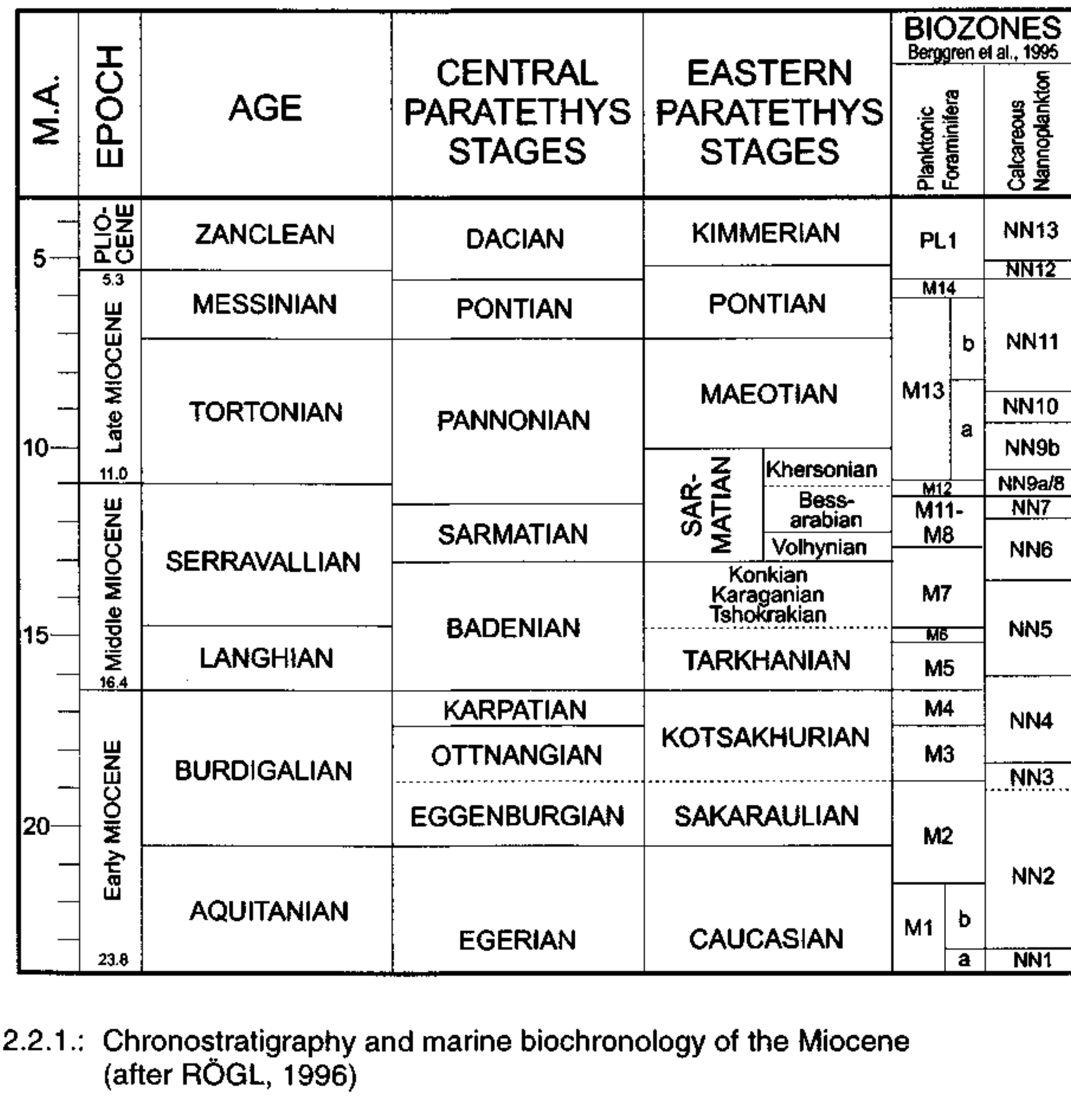


Fig. 2.2.1.: Chronostratigraphy and marine biochronology of the Miocene (after RÖGL, 1996)

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.

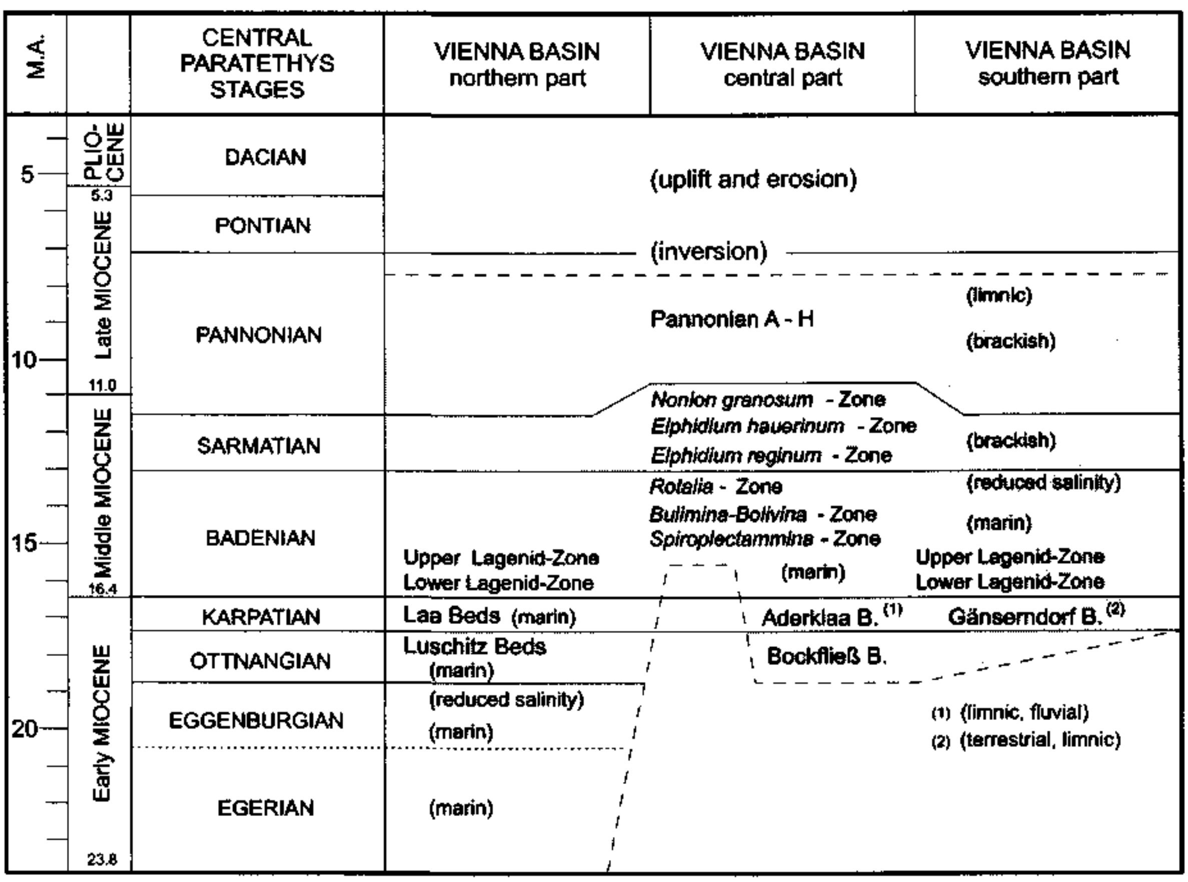


Fig. 2.2.2.: Facial development and stratigraphy of the Vienna Basin with schematic representation of the spannberg ridge in the central part of the basin (after WESSELY, 1988, changed).

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, 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.

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 thickness 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)

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).

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Oil and Gas Occurrences of the Vienna Basin
Godfrid WESSELY

The oil- and gas provinces of the Vienna Basin (FRIEDL, 1957; KRÖLL, 1980; LADWEIN, F. SCHMIDT, SEIFERT & G. WESSELY, 1991, BRIX & SCHULTZ 1993) are connected to distinct structural features. A concentration occurs over the depocenter of deeply buried autochthonous Malmian marls below the northern Vienna Basin.
The structural trapping features are the large fault systems of the northern Vienna Basin in Austria, in particular the Steinberg Fault system, the median highzones of Matzen - Aderklaa - Enzersdorf including the Preneogene Calcareous Alpine floor, and the southern and southeastern fault systems.
The northern and central provinces contain oil and gas of thermocatalytic origin. Gas of biogenic and mixed origin was found in the southern and southeastern regions.
Lower and Middle Miocene transgressive and regressive sandstone cycles resulted in a stack of multiple productive zones (KREUTZER, 1986). As a result nearly every field in the Neogene floor produces from several horizons. At Matzen field, for example, at least 9 Lower Miocene, 16 Badenian, 9 Sarmatian and 4 Lower Pannonian horizons contain hydrocarbons. The best productive zone is the transgressive 16th Badenian horizon in the Matzen field.
The trapping mechanism is primarily structural. Tilting along flanks of structures also causes combined stratigraphic and structural traps, particularly in the Lower Miocene.
Along the faulted zones, accumulations of hydrocarbons have been found in parallel striking, often rather narrow faultblocks. Along the downthrown block complex of the Steinberg Fault, classical drag- and rollover structures have been found. The rollover structures have downfaulted crests in some cases. In the upthrown block anticlines cause trapping. Along the median highzones, traps are extended anticlines, such as at Matzen, Aderklaa and Zwerndorf.
The Flysch Zone below the Neogene is only productive in the area of the Steinberg High and neighbouring structures. Like the Neogene, it has multiple productive zones in Paleocene to Eocene turbiditic sandstones.
The oil- and gas fields of the Calcareous-Alpine floor of the Vienna Basin are mainly situated along the median highzones. The reservoirs are thick Upper Triassic dolomites (Hauptdolomit) and, in one case, dolomitic limestones (Dachstein Limestone). The hydrocarbons are trapped in flat to very steep dipping structures. In the latter case, vertical gas columns of several hundred meters occur, as in the Schönkirchen area.
Two types of traps can be distinguished: relief and internal. In the first, Neogene marls act as a caprock, whereas for the second, tight sediments within the Calc Alpine complex (for example Cretaceous to Paleocene shales and sandstones) unconformably cover the dolomites. The Schönkirchen Tief, Prottes Tief oil fields and the Aderklaa and Baumgarten gasfield are relief pools, while the Schönkirchen Übertief, Reyersdorf and Aderklaa Tief gas fields are internal ones. All gas is sour gas. Schönkirchen Tief is the second largest oil reservoir in Austria and Schönkirchen Übertief is the second largest gas reservoir.
The Vienna Basin has played a leading role in the development of oil and gas production in Austria first from the Neogene floor, and later from the Calcareous Alpine dolomites of the second floor.

In the Austrian part of the Vienna Basin, at least 46 fields have been found. The largest cumulative oil production (till the end of 1991) was achieved in Matzen (Neogene, 65.6 Mio t), Schönkirchen Tief and Prottes (Hauptdolomit, 8.8 Mio t) and Mühlberg (Neogene, 5.5 Mio t). The largest cumulative production of gas has been in Matzen (Neogene, 24.9 Bill m^3n), Schönkirchen Übertief (Hauptdolomit, 6.6 Bill. m^3n) and Zwerndorf (Neogene, 12.2 Bill m^3n).

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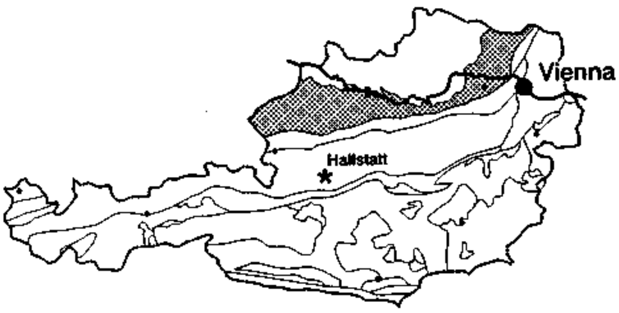
2.3. The Austrian sector of the North Alpine Molasse: A classic foreland basin

Hans Georg KRENMAYR



The North Alpine Molasse extends from the French Maritime Alps to the area of Vienna, where the Alpine nappe pile largely disappears below the intra-orogenic Vienna Basin. The "North Alpine" Molasse extends northeastward from the Danube west of Vienna and farther into the Carpathian Foredeep.

The term "molasse" was introduced into the scientific literature by H.B. DE SAUSSURE in 1779. Etymologically it can either be inferred from the latin „mola" (whetstone or grindstone) or from the french "molasse" (slack or very soft), which refers to the widespread occurrence of soft sandstones and loose sands.

The Austrian Molasse is of considerable scientific interest due to the occurrence of hydrocarbons, which created the somehow paradox situation, that the subsurface of the basin is partly better known than the surface geology. In recent times special attention has been paid to the Molasse Basin because of its mirror function of Alpine uplift history.

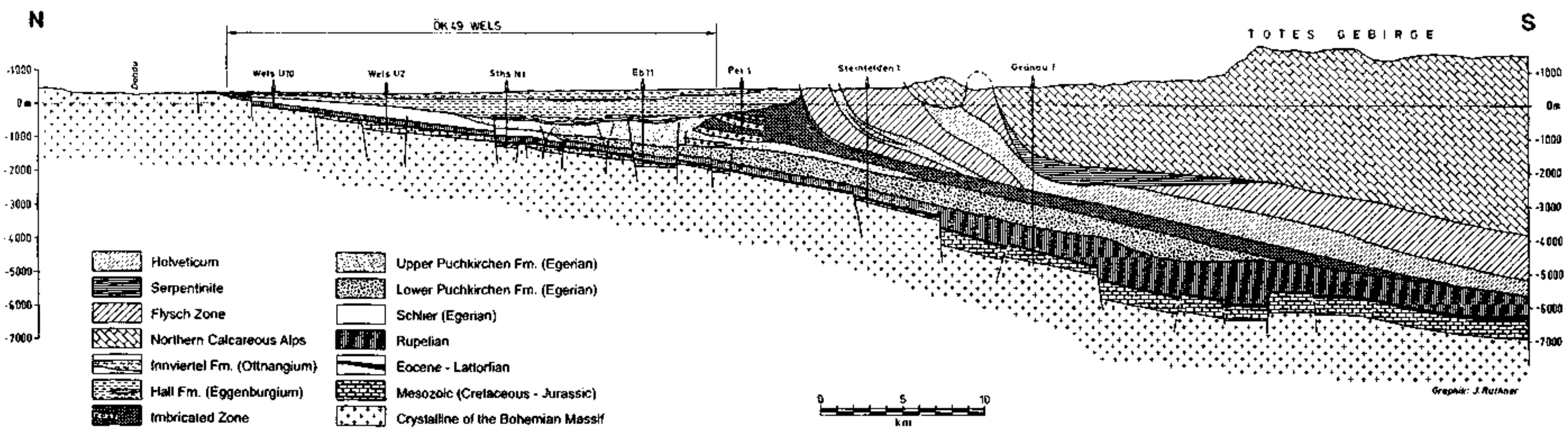
Throughout the Austrian sector of the Molasse Basin the southern edge of the Variscan Bohemian Massif forms the northern bordering zone of the Tertiary basin fill. The metamorphic and magmatic basement rocks continue far below the Alpine nappe wedge to at least 50 km behind the northern thrust front. Structural depressions of the basement locally contain relicts of Late Carboniferous (?) to Permian molasse-type sediments of the Variscan orogenic cycle, whereas wide regions of the basement to the west and east of the southward extending so called "spur" of the Bohemian Massif are covered with epi-continental Jurassic and Cretaceous sedimentary rocks.

The Austrian Molasse Basin is strongly assymetric in two respects. There is a marked increase of basin depth and thickness of Tertiary strata towards the south, with a maximum value of >4000 m at the Alpine thrust front, which is a typical feature of foreland basins (Fig. 2.3.1.). Secondly, in a W-E profile the basin is shallowing and narrowing (~500 m deep and ~10 km wide in the region of the town of Amstetten) towards the spur of the Bohemian Massif.

Southern parts of the Molasse Basin have been overthrusted by the Alpine nappe wedge. A palinspastic reconstruction of the area northeast of Salzburg shows that the present zone of outcropping Tertiary strata between the Alpine thrust front and the Bohemian Massif, which is about 60 km wide, corresponds to less than a quarter of the former basin width. This situation requires the definition of three tectonic settings of Tertiary Molasse deposits:

1. The Authochthonous Molasse: comprises mainly flat-lying Molasse sediments underneath and in front of the Alpine body.

Fig. 2.3.1.: Geological Cross-section of the Molasse Zone in the region of map sheet GÖK 49 Wels from the Bohemian Massif to the Northern Calcareous Alps (from WAGNER, 1996). ➔


N
S
ÖK 49 WELS
TOTES GEBIRGE
Donau
Wels U10
Wels U2
Sths N1
Eb 11
Pet 1
Steinfelden 1
Grünau 1
+1000
0m
-1000
-2000
-3000
-4000
-5000
-6000
-7000
Helveticum
Serpentinite
Flysch Zone
Northern Calcareous Alps
Innviertel Fm. (Ottnangium)
Hall Fm. (Eggenburgium)
Imbricated Zone
Upper Puchkirchen Fm. (Egerian)
Lower Puchkirchen Fm. (Egerian)
Schlier (Egerian)
Rupelian
Eocene - Lattorfian
Mesozoic (Cretaceous - Jurassic)
Crystalline of the Bohemian Massif
0
5
10
km
Graphik: J. Rulsner

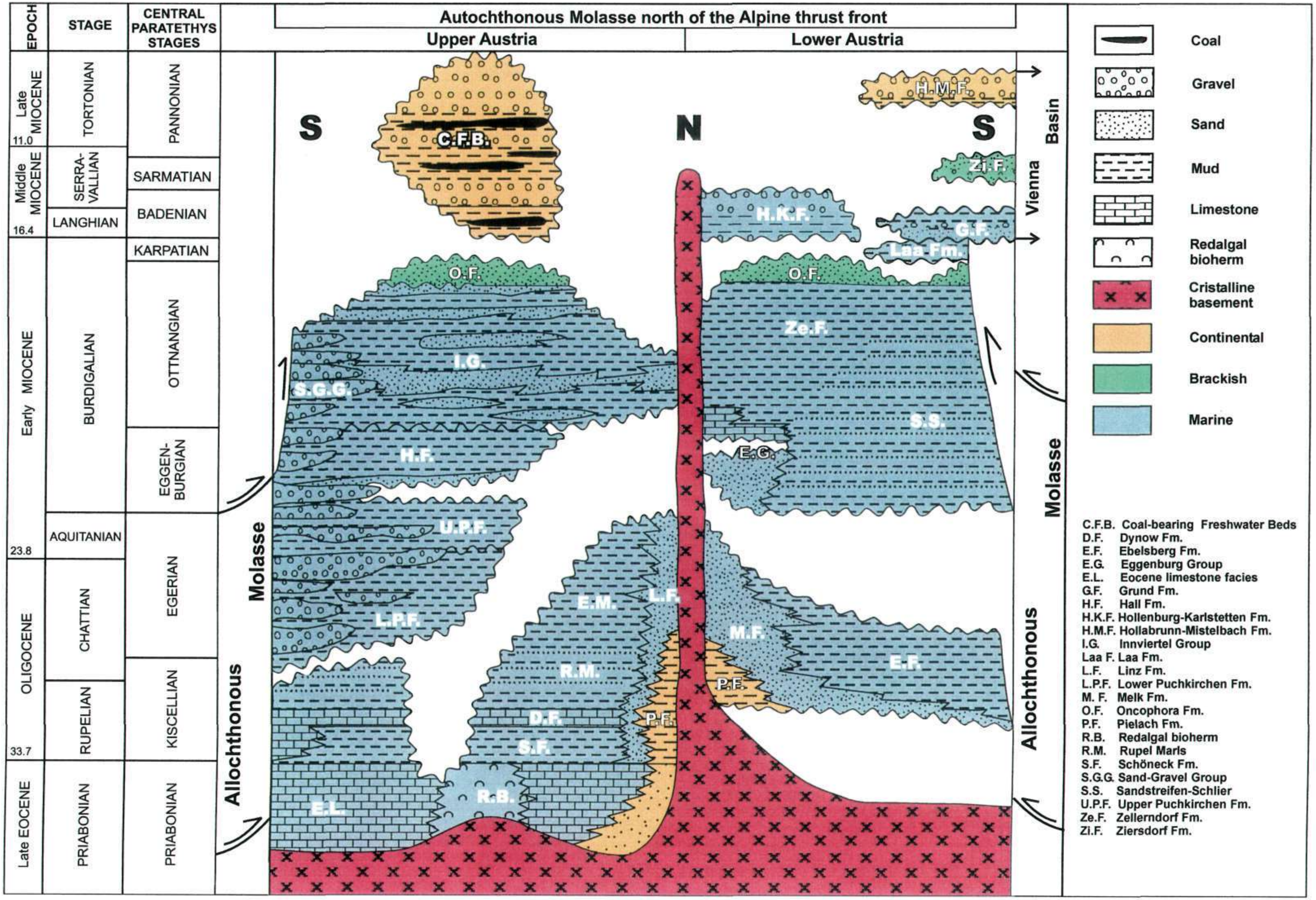
2. The Allochthonous Molasse: comprises folded and/or imbricated Molasse sediments underneath and in front of the Alpine body, which have been sheared off from the subalpine Autochthonous Molasse. Regionally (e.g. in the Waschberg Zone, N of Vienna) slices of the Mesozoic basement cover are incorporated within the imbricates. Along the strike of the Alpine thrust front the imbricates are partly covered by sediments postdating the Authochthonous Molasse. This is especially the case in the provinces of Upper Austria and Salzburg, where the Molasse imbricates form text-book-like triangle zones on seismic lines.
3. The Parautochthonous Molasse: this term refers to rare erosional relics of Molasse deposits resting on top of the Alpine nappe wedge (e.g. the „Unterinntal Tertiär", SW of Kufstein in the Northern Calcareous Alps). They have been subjected to block-faulting, northward transport and wrench-faulting together with their stratigraphic basement units in partly synsedimentary to postsedimentary times.

Post-Cretaceous sedimentation in the area of the Molasse Basin (Fig. 2.3.2.) started with a Late Eocene (Priabonian) transgression, as a consequence of a major tectonic event of the evolving Alpine orogen, which resulted in the partial elimination of the Penninic flysch troughs and integration of their sedimentary infill into the northward advancing nappe pile. Sedimentation at that time was still dominated by shallow to deep-marine carbonate facies, including red-algal bioherms. In Late Eocene times large parts of the East Alpine realm were below sea-level.

The onset of „Molasse-sedimentation", which coincides with the emergence of the Paratethys-bioprovince, can be defined with the appearance of the typical deep-marine anoxic facies of the "Fish Shale" (= Schöneck Fm.; source rocks for hydrocarbons!) in the lowermost Oligocene. Isolation of the basin can be explained by the further advance of Alpine nappes across the relictic Penninic as well as Helvetic realm and uplift of southern parts of the Alpine body above sea-level. The simultaneous subsidence of the foreland basin was triggered by tectonic loading and flexural downbending of the European lithosphere by the Alpine nappe body. Additionally a pronounced eustatic sea-level rise (Tejas A 4.4) at that time may have enhanced this process. The Fish Shale is overlain by a thin package of nannoplankton ooze (Dynow Fm.). Sedimentation of thick terrigenous units, already influenced by turbidites commenced only in Late Kilcellian (Late Rupelian) times („Rupelian Marls").

A first pulse of imbrication of Molasse sediments, caused by another northward shift of the Alpine nappe complex correlates with a distinct eustatic sea-level fall (Tejas A 4.5/B 1.1) and the incision of a slope-parallel, deep-marine trough by strong bottom currents. The sedimentary infilling of this depression (Lower Puchkirchen Fm.; Early Egerian [~Chattian]) was largely achieved by huge slump masses from both the passive northern and tectonically oversteepened southern slope of the basin. Sandy turbidites play only a minor role, however, they display important reservoir rocks for natural gas. After another re-gression (Tejas B 1.3/ B 1.4) and northward shift of the Alpine nappe pile around the Oligocene/Miocene boundary the described processes repeated once again, documented in the Upper Puchkirchen Fm. of Late Egerian (~Aquitanian) age and the lowermost part of the Hall Fm. of Eggenburgian (lowermost Burdigalian) age. Contemporaneous sediments of the Lower and Upper Puchkirchen Fm., representing the northern margin-facies of the basin comprise coal-bearing continental to brackish clays and sands (Pielach Fm.), shallow-marine sands (Linz Fm., Melk Fm.) and dark, partly diatomit-bearing offshore shales (e.g. Ebelsberg Fm.). In Bavaria, west of the Inn river, the Paratethys is nearly totally dominated by continental sedimentary successions within the same time interval.

Fig. 2.3.2.: Stratigraphic chart of the Austrian sector of the North Alpine Molasse Basin ➔



EPOCH
STAGE
CENTRAL PARATETHYS STAGES
Autochthonous Molasse north of the Alpine thrust front
Upper Austria
Lower Austria
Late MIOCENE
Middle MIOCENE
Early MIOCENE
OLIGOCENE
Late EOCENE
11.0
16.4
23.8
33.7
TORTONIAN
SERRA-VALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
PRIABONIAN
PANNONIAN
SARMATIAN
BADENIAN
KARPATIAN
OTTNANGIAN
EGGEN-BURGIAN
EGERIAN
KISCELLIAN
PRIABONIAN
Allochthonous Molasse
S
N
S
Vienna Basin
Molasse
Allochthonous
C.F.B.
H.M.F.
Zi.F.
H.K.F.
G.F.
Laa Fm.
O.F.
O.F.
Ze.F.
I.G.
S.G.G.
S.S.
E.G.
H.F.
U.P.F.
E.M.
L.F.
L.P.F.
M.F.
E.F.
R.M.
P.F.
P.F.
D.F.
S.F.
R.B.
E.L.
Coal
Gravel
Sand
Mud
Limestone
Redalgal bioherm
Cristalline basement
Continental
Brackish
Marine
C.F.B. Coal-bearing Freshwater Beds
D.F. Dynow Fm.
E.F. Ebelsberg Fm.
E.G. Eggenburg Group
E.L. Eocene limestone facies
G.F. Grund Fm.
H.F. Hall Fm.
H.K.F. Hollenburg-Karlstetten Fm.
H.M.F. Hollabrunn-Mistelbach Fm.
I.G. Innviertel Group
Laa F. Laa Fm.
L.F. Linz Fm.
L.P.F. Lower Puchkirchen Fm.
M. F. Melk Fm.
O.F. Oncophora Fm.
P.F. Pielach Fm.
R.B. Redalgal bioherm
R.M. Rupel Marls
S.F. Schöneck Fm.
S.G.G. Sand-Gravel Group
S.S. Sandstreifen-Schlier
U.P.F. Upper Puchkirchen Fm.
Ze.F. Zellerndorf Fm.
Zi.F. Ziersdorf Fm.

This might be due to an existing mountainous relief in the western part of the Eastern Alps and the resulting strong clastic input during the Oligocene.
This is followed by the Eggenburgian-Ottnangian (Early to Late Burdigalian) transgressive cycle (Tejas B 2.1) across a basinwide erosional surface which was created by deep-marine bottom currents and strong tide-induced currents. Possibly an uplifting event in the northern part of the basin is jointly responsible for the prominence of this surface. The uplifting event could be due to the evolution of a foreland-bulge, which can develop as a result of a visco-elastic relaxation of the lithosphere, when the thrust front of the orogen remains largely stationary. This was the case in Upper Austria since Eggenburgian (Early Burdigalian) times, whereas in Lower Austria even Carpathian (Late Burdigalian) strata are affected by imbrication processes. Sediments of the Eggenburgian-Ottnangian transgressive cycle are characterized by a multiple change of complexely interfingering, mostly shallow-marine sands and offshore muds (e.g. Hall Fm., Innviertel Group, Zellerndorf Fm., "Sandstreifen-Schlier"). These include the famous fossil-rich strata of the facially strongly diversified Eggenburg Group, which rest on the eastern margin of the Bohemian massif. Storm-influenced and tide-influenced deposits play a dominant role throughout the basin. Coarse-grained fan-delta sediments are known from the area northeast of Salzburg ("Sand-Gravel group").
In Late Ottnangian (Late Burdigalian) times fully-marine sedimentation ceased in the major part of the basin documented by brackish sands and silts (Oncophora Fm.). Following above a major hiatus, which includes the Carpathian (Latest Burdigalian) a thick succession of continental coal-bearing clays and fluviatile gravels and sands was deposited from Badenian to Pannonian (Langhian and Tortonian) times in Upper Austria ("Coal-bearing Freshwater beds"). No more relation to eustatic sealevel changes can be recognized in this succession. However, in Lower Austria (north of the Danube) a transgressive cycle (Tejas B 2.2) of Carpathian (Latest Burdigalian) age is evidenced by shallow-marine sands, muds, and gravels (Laa Fm.). The early Badenian (Early Langhian) sediments are again transgressive in character (Hollenburg-Karlstetten Fm., Grund Fm.) and a short incursion from the intra-alpine Vienna Basin reached the Molasse Basin in the Early Sarmatian (Upper Serravallian) for the last time (Ziersdorf Fm.). The latter sedimentary cycles do not satisfactorily match the eustatic sea-level chart. Sediments of the Pannonian (Tortonian) north of the Danube correspond to the limnic-fluviatile deposits of Upper Austria and can be ascribed to a Proto-Danube discharge system (Hollabrunn-Mistelbach Fm.).
Significant uplift of the Rhenodanubian Flysch and the Northern Calcareous Alps in the eastern part of the Eastern Alps did not start before the Pannonian (Tortonian), as is expressed by the gravel material in the foredeep. In the corresponding time interval the eastward directed drainage-pattern of the Danube developed. Widespread erosion of Molasse deposits commenced in Pliocene times. During the Quaternary both glacial and periglacial processes operated in the North Alpine Molasse Basin leaving huge masses of moraines, fluviatile gravels, loess, solifluidal material and a strongly overprinted landscape.

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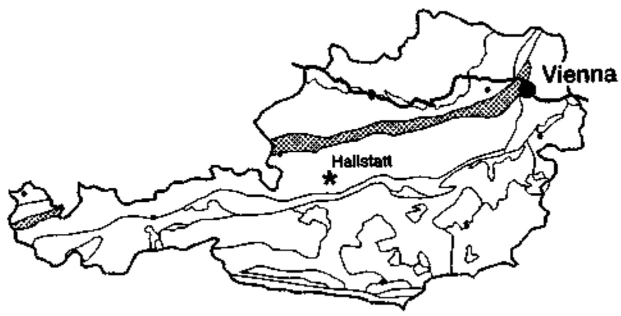
2.4. The Flysch Zone of the Eastern Alps

Wolfgang SCHNABEL



The zone along the northern front of the Northern Calcareous Alps, designated as 'Flysch Zone', is a comparatively narrow zone. Nevertheless two major Alpine palaeogeographic zones (Helveticum and Penninicum) are still preserved in it and are represented mainly by sequences from the Lower Cretaceous to the Paleogene. Older (Upper Triassic - early Lower Cretaceous) substrata are present in the Klippen Zones (Fig. 2.4.1., 2.4.2.).

The predominant unit is the East Alpine Flysch ("Rheno-Danubic" or "Rhenodanubian Flysch" after OBERHAUSER, 1968; RDF in the following). It is a supergroup of formations dominated by flysch facies from the Lower Cretaceous - middle Eocene, widely considered to be part of the Penninic realm. It extends from the west-east Alpine border to western Lower Austria more or less as one nappe (Main Flysch Nappe). Although admittedly sliced and tectonically disturbed, the entire sequence could well have had an average original thickness of about 2000 m (EGGER, 1987; BRAUNSTINGL, 1988).

In the easternmost section (Wienerwald), the Flysch Zone widens and has a more complex structure. It can be divided into three nappes with different facies, the Greifenstein Nappe to the north, the Laab Nappe to the south and the Kahlenberg Nappe to the southeast. A separate narrow imbricated zone, the 'Northern Zone', occurs at the northern edge of the Flysch Zone.

The second main unit within the narrow Flysch Zone is assigned to the Helvetic System *sensu lato.* On the surface it extends along strike from Switzerland through Vorarlberg and Bavaria and can be traced north of the Flysch Zone approximately to the area of Salzburg (South Helvetic Zone in Bavaria). It continues in Upper Austria, where it crops out in numerous elongated thrust slices ('strip windows') within the Flysch Zone. This northern Ultrahelvetic Zone consists chiefly of red and variegated marls and is late Lower Cretaceous to Eocene in age (upper slope). Tectonically it underlies the RDF.

East of the River Enns a new situation arises as the Rheno-Danubic Flysch has almost completely overthrust the Ultrahelveticum. In a complicated system of windows, half windows and double windows, which even include sequences of the oldest Molasse Basin (Inner Alpine Molasse - late Eocene to Oligocene), Helvetic units appear at the surface. The Cretaceous-Tertiary sequences here are termed "Buntmergelserie" (Variegated Marl Series) and present the southern Ultrahelvetic Zone. The increase in clay-content and agglutinated Foraminifera points toward deposition below the calcite compensation level on the continental slope. Contrary to the situation in the west, the pre-mid-Cretaceous substratum is present here (Gresten Klippen Zone, see below). During the Paleocene and Eocene, coarse chaotic sediments occur as a 'Wildflysch'-like facies, possibly derived from a marginal basement high. They may have accumulated as debris-flow or rock-fall deposits originating from escarpments or as the sedimentary fill of submarine canyons. Its most prominent exposure is the exotic granite of the Leopold-von-Buch memorial in western Upper Austria. This detrital assembly, and the klippen sequence itself, bear compositional similarities to the Bohemian Massif and its sedimentary cover (FAUPL,

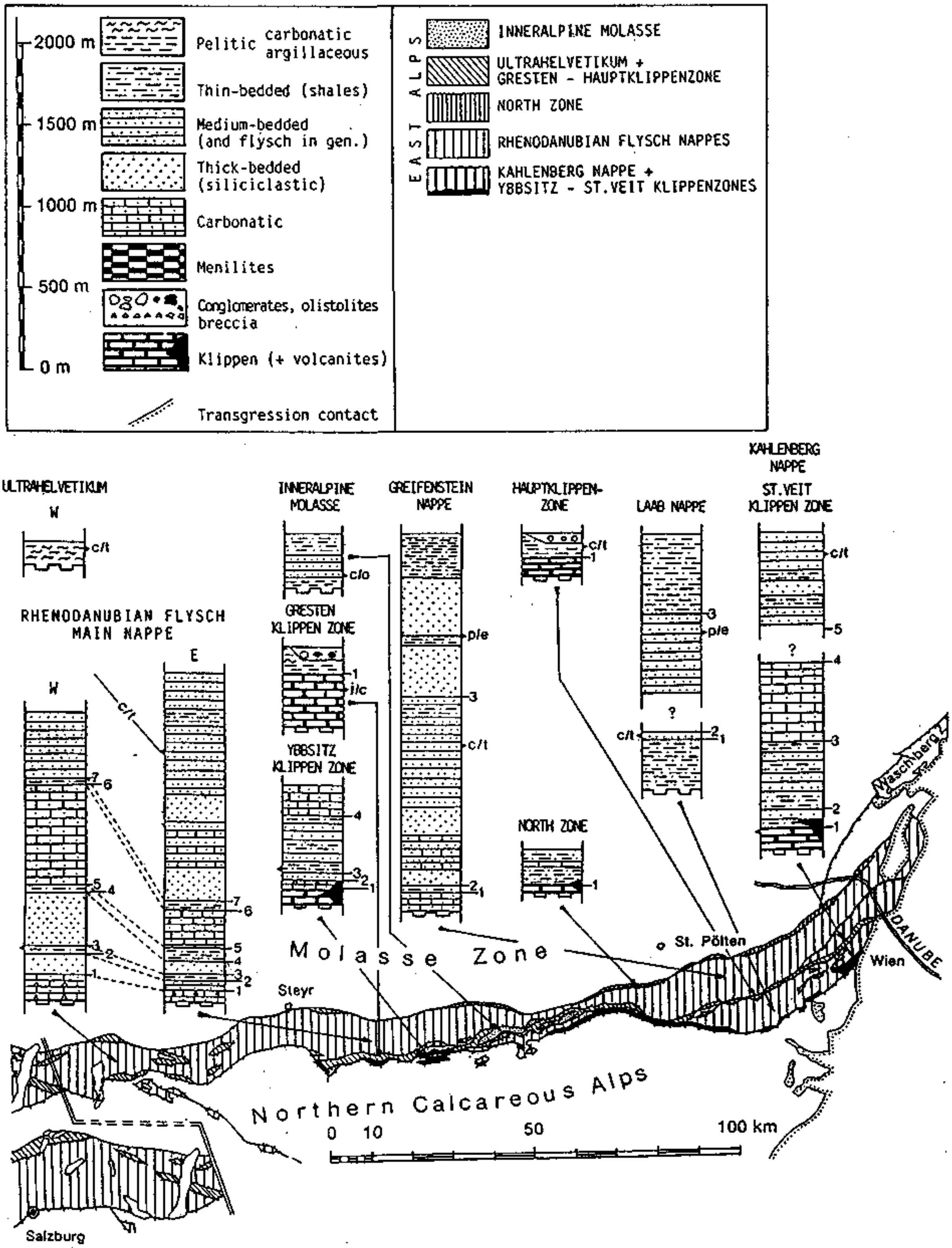


Fig. 2.4.1.: Tectonics and Facies of the Flysch Zone of the Eastern Alps (Eastern section; after ELIÁS, SCHNABEL & STRANIK,1990).

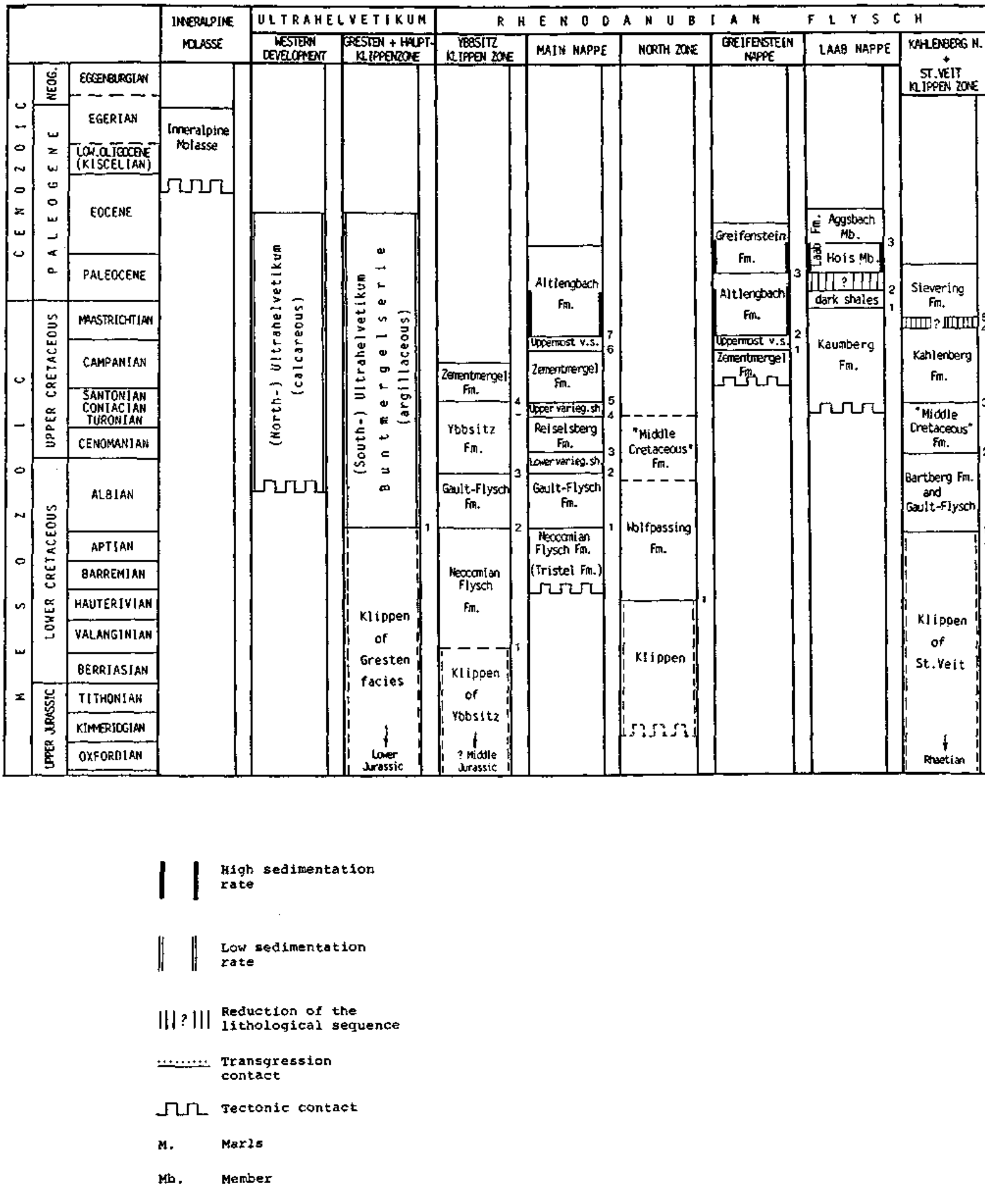


Fig. 2.4.2.: Stratigraphy of the Flysch Zone of the Eastern Alps (Eastern section; after ELIÁS, SCHNABEL & STRÁNIK,1990).

1975a, 1978), but also display their own individual features (FAUPL & SCHNABEL, 1987, WIDDER, 1988).
Further east, in the area of the Wienerwald, this zone continues into the so-called "Hauptklippenzone" (Main Klippen Zone) in the same facies. Nevertheless, here it is no longer a window like the Gresten Klippen Zone, but a nappe separator, a suture separating two flysch nappes of different facies (the Greifenstein Nappe to the north from the Laab Nappe to the south). It is a long and distinct tectonic slice and not a window.

The Klippen Zones

The original base of the Rheno-Danubic Flysch (Penninic) and of the Buntmergelserie (Ultrahelvetic) is found in the Klippen Zones. These zones consist of Jurassic-Lower Cretaceous sequences in their cores. Their younger sedimentary cover consists of Buntmergelserie or Flysch.
Depending upon their tectonic positions, facies, ranges and types of cover, several different klippen zones can be identified, of which the Gresten Klippen Zone in the pre-Alpine area of western Lower Austria, the Hauptklippenzone (Main Klippen Zone) of the Wienerwald and the St. Veit Klippen Zone in the western outskirts of Vienna are the well known classic klippen zones. New investigations have shown that, to the west, the Ybbsitz Klippen Zone, a zone with deep-sea facies in the Jurassic and a cover of flysch, must be separated from the Gresten Klippen Zone with characteristic Lower Jurassic coal-bearing, shallow-water facies (Gresten facies) and a cover of Buntmergelserie.
In the Gresten Klippen Zone, two different facies can be distinguished: the Waidhofen Facies, with a distinct shallow-water Jurassic facies, and the Scheibbs Facies, with a deep-water facies (SCHNABEL, 1983). In this manner a continuous deepening along the southern European continental margin is evident (Fig. 2.4.3.).
Based mainly on their sedimentary cover (either Buntmergelserie or Flysch), the klippen zones can be assigned to the main tectonic systems as follows:
1) Helvetic (Buntmergelserie): Gresten Klippen Zone and Main Klippen Zone and
2) Penninic (Flysch): Ybbsitz Klippen Zone and St. Veit Klippen Zone.

The Flysch Successions

Main Flysch Nappe and Greifenstein Nappe:

The principal stratigraphic and sedimentological features of the Main Flysch Nappe and the Greifenstein Nappe, which is the eastern continuation of the former in the area of the Wienerwald, are outlined in Fig. 2.4.4.
The entire sequence could have had an average thickness of about 2000 m (HESSE, 1982; PREY in OBERHAUSER, 1980, pp. 191-199). In Bavaria it embraces the late Lower Cretaceous to the Maastrichtian; towards the east the sequence becomes increasingly younger and extends into the early Eocene (nannoplankton-zone NP12) in the Greifenstein Nappe. Recently, a predominantly marly facies of nearly the same age (NP11) was established in Upper Austria (EGGER, 1989b).
There is a considerable lateral change in thickness insofar as lower formations (late Lower Cretaceous - Campanian) thin towards the east, whereas the higher ones beginning with the Maastrichtian, thicken in the same direction. This corresponds generally with current directions, which are predominantly longitudinal parallel to the axis of the elongated basin and switch to petrographically different sources (HESSE, 1965, 1982). These directions

are from west to east in the Lower Cretaceous (carbonate and quartz-arenite flysch), variable in the mid-Cretaceous and again from west to east in the Turonian-Campanian Zementmergel Formation (carbonate flysch). In the Maastrichtian-Paleocene (terrigenous flysch), current directions are from the east again (Bleicherhorn Formation in Bavaria and Altlengbach Formation, the predominant formation in the eastern Austrian sector), and heavy-mineral associations are garnet-dominated. In the easternmost section, the dominant directions indicate transport from west to east and northwest to southeast, beginning with nannoplankton zone NP3, and dominated by heavy-mineral associations with zircon/tourmaline/rutile. These results, including the data of coarse-grain analysis of the Greifenstein Formation, indicate a source area composed of acid crystalline and autochthonous Mesozoic rocks similar to the Bohemian Massif and the basis of the Molasse Zone (HÖSCH, 1985; RAMMEL, 1989).

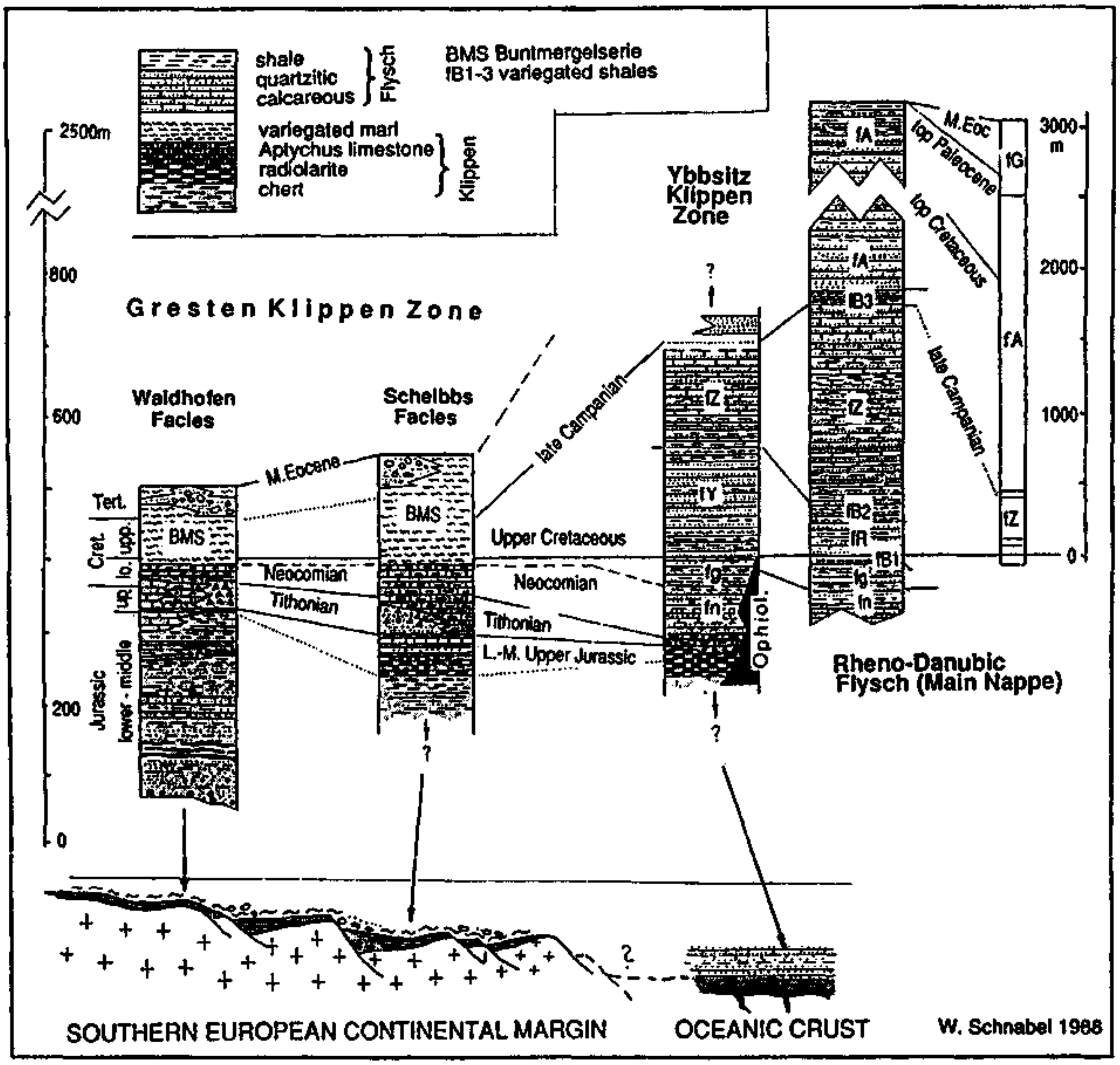


Fig. 2.4.3.: Paleogeographic position of the Klippen Zones along the Southern European Continental Margin (Helvetic domain) into the oceanic basin of the Penninic realm (after SCHNABEL, 1992).

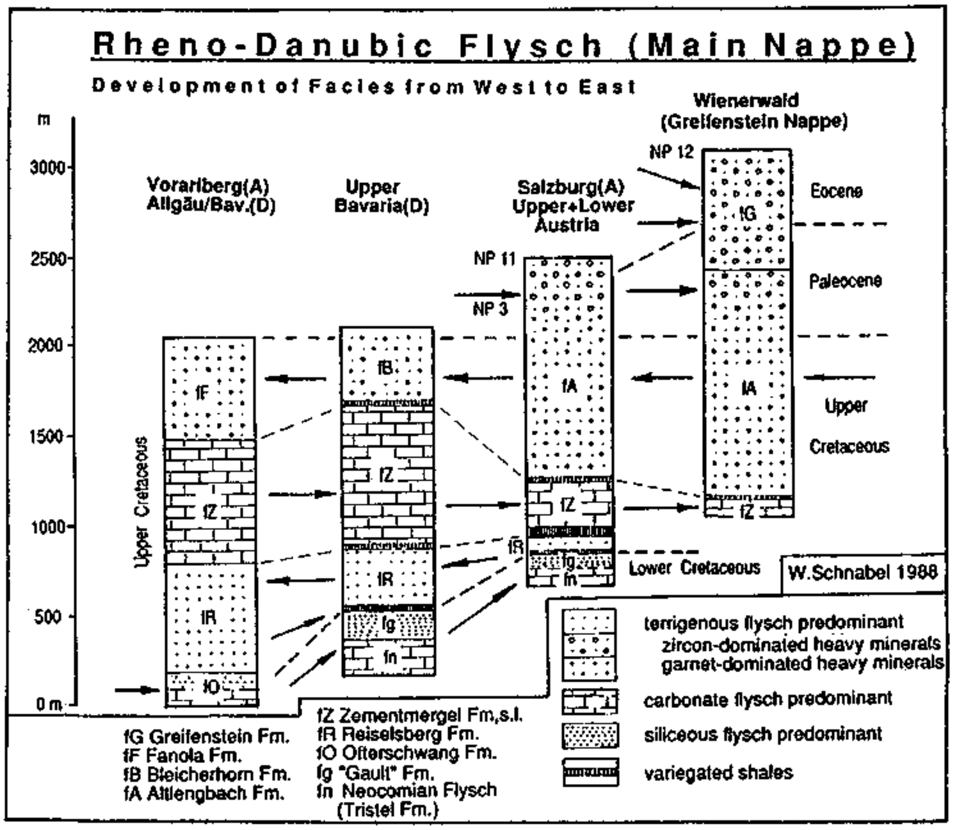


Fig. 2.4.4.: Rheno-Danubic Flysch; Main Nappe. Essential features of facies development from west to east. It should be mentioned, that particularly in the western part (left) the facies also changes from north to south. Arrows indicate predominant paleocurrent directions (after SCHNABEL, 1992).

Laab Nappe (Fig. 2.4.5.):

In the Laab Nappe a flysch with variegated shales dominates the Upper Cretaceous from the Turonian onward (Kaumberg Formation). Current directions from northwest to southeast suggest an internal basement high within the flysch domain in late Cretaceous time. Traces of chrome spinel in the heavy mineral spectra point toward ultramafic rocks (FAUPL, 1975). Following a gap, the Laab Formation continues with thick-bedded terrigenous flysch in the late Paleocene (Hois Member) and clayey flysch in the Eocene (Agsbach Member). Current directions indicate transport from northwest to southeast in the Hois Member and from east to west in the Agsbach Member (RINGHOFER, 1976).
A normal sedimentary transition between the Kaumberg Formation and the Laab Formation has not been proven. Considering the different tectonic style and the stratigraphic gap, a tectonic contact (overthrust, as argued by FUCHS, 1985) remains a possibility, although an assignment of the Kaumberg Formation to the Helvetic realm (Buntmergelserie) is not feasible.

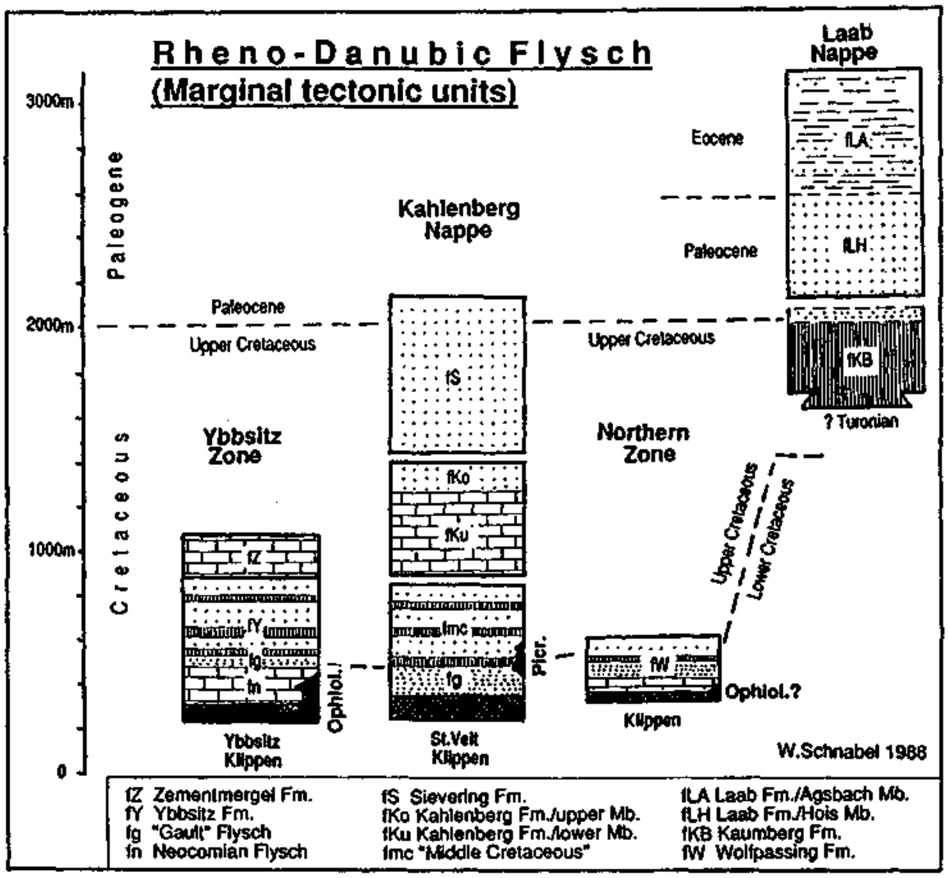


Fig. 2.4.5.: Rheno-Danubic Flysch; Marginal tectonic units. For legend see Fig. 2.4.4. (slightly modified after SCHNABEL, 1992).

Kahlenberg Nappe (Fig. 2.4.5.):

The Kahlenberg Nappe includes the Klippen Zone of St. Veit, which presumably represents the Upper Triassic to early Lower Cretaceous substratum of the flysch formations (TOLLMANN, 1963, p. 134; PREY, 1975). The flysch cover comprises sequences from the Aptian/Albian up to the Paleocene. The Kahlenberg Nappe is extensively dismembered tectonically owing to progressive, possibly gravitational sliding to the north over the other flysch nappes (PREY, 1971, 1979). In essence, the older parts (klippen and basal flysch) are accumulated in the south, the younger parts in the north. Only the mid-Cretaceous variegated shale formation is present everywhere as a tectonic lubricant and is thus the common link, which provides a good reason to consider all these dismembered slices as of common origin.

Apart from its klippen substratum (St. Veit Klippen Zone), the flysch sequence itself begins with Aptian/Albian/Cenomanian-Coniacian variegated shales and intercalations of sandstone. Owing to the scarcity of marker fossils and the consequent difficulties in precise dating, this time span is often referred to as 'Mid-Cretaceous.' The occurrence of sporadic picritic volcanic rocks of the same age is worth noting. The Kahlenberg Formation (Santonian-Maastrichtian) is a carbonate flysch with transition to terrigenous flysch in the

hanging wall. Its palaeocurrents reflect east-west transport. It contains garnet-dominated heavy-mineral suites (MÜLLER, 1987); on the other hand, the thick terrigenous turbidites of the Maastrichtian Sievering Formation contain acidic crystalline rock fragments and zircon-dominated heavy minerals, also coming from the east in the same direction (FAUPL et al., 1970).
Although there is evidence for a separate basin differing from the depositional conditions of the other flysch nappes, the sequence of the Kahlenberg Nappe is undoubtedly part of the Rheno-Danubic Flysch in its eastern sector and likely to be derived from the southern part of the original flysch trough. Tectonically it is the highest nappe, since outliers have been proven to overlie the Laab Nappe tectonically (PREY, 1983).

North(ern) Zone (Fig. 2.4.5.):

In the eastern sector, the Flysch Zone is bordered in the north by a zone which mainly consists of Lower Cretaceous flysch sediments (Wolfpassing Formation). It continues towards west, at least to the area of the town of Steyr, highly imbricated and intersliced with Helvetic Buntmergelserie (EGGER, 1989a). The 'Neocomian Flysch' in the Haunsberg area (Salzburg) could belong to the same zone. An olistostromatic horizon and isolated boulders at that locality provide valuable clues to the nature of the basement of the flysch. Here at its northernmost rim, these wildflysch-like sediments contain a rock assembly similar to that of the European plate at its southern margin (FRASL & FLÜGEL, 1987).
The presence of serpentinites near the village of Kilb has been noted. These are embedded in basal flysch sequences (Aptian/Albian-Cenomanian, [PREY, 1977]). The continuity of the Northern Zone along the northern edge of the Flysch Zone clearly shows its tectonic independence within the Flysch Zone. It is not part of the Main Flysch Nappe, contrary to previous interpretations (see also GRÜN et al., 1972).

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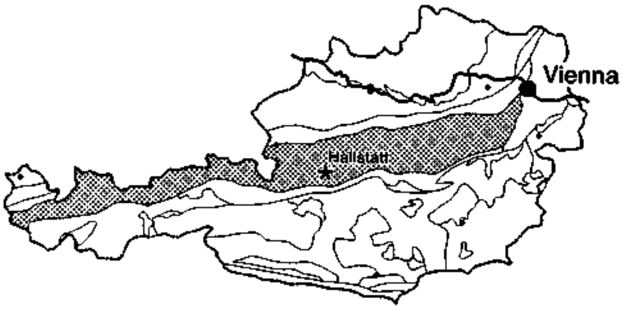
2.5. Geology of the central and eastern sector of the Northern Calcareous Alps (NCA)

Gerhard W. MANDL



General features

One of the most prominent units of the Eastern Alps are the Northern Calcareous Alps, which extend for about 500 kilometers from the Rhine valley in the west to Vienna in the east, forming a 20 to 50 kilometer wide belt. The NCA consist of mountain ranges with considerable plateau mountains, the latter being a remnant of the late Lower Tertiary peneplain, faulted and uplifted since the Miocene. In the western and middle part the highest peaks reach altitudes of up to 3.000 meters and are locally glaciated (Dachstein area). In the eastern part elevations are up to 2.000 meters.
At their eastern end the NCA are bounded by the Vienna Basin, which subsided during Neogene times. In the basement of the Vienna Basin, however, the NCA continue in principle into equivalent units of the Western Carpathians even if the details are still in discussion. For example the uppermost tectonic unit of the NCA - the Juvavic Nappe System - ends in the Slovakian part of the Vienna Basin. Equivalent units occur again only far in the east of the Western Carpathians (Stratena-, Muran-, Silica-, Aggtelek- and Rudabanya-Mountains).
In the Northern Calcareous Alps Mesozoic carbonates are predominating, but also clastic sediments are frequent at several stratigraphic levels. The sequence begins in the Permian and extends locally into the Paleogene (Gosau Group), but the Triassic rocks are the most prevailing ones, details of stratigraphy and facies see below.

Principles of structural evolution

The sequence of Mesozoic sediments of the NCA has lost its former crustal basement during Alpidic Orogeny. During Upper Jurassic to Tertiary times several events of folding and thrusting have created a complex pile of nappes which rests with overthrust contact in the north on the Rhenodanubian Flysch Zone and in the south on the Greywacke Zone - see Fig. 2.
The following nappe scheme of the Northern Calcareous Alps can be given today (Fig. 2.5.1.): The northern (= frontal) part of the NCA is built by the Bajuvaric nappes, which one show narrow synclines and anticlines. They dip down toward the south below the overthrusted Tirolic nappe system. Due to their widespread dolomitic lithology the Tirolic nappes exhibit internal thrusting and faulting and only minor folding. The Greywacke Zone is thought to represent the Palaeozoic sedimentary substratum of the Tirolic nappes, remaining several kilometers in the south during the nappe movements. The Juvavic nappes represent the uppermost tectonic element, overlying the Tirolic Mesozoic in the north and the Greywacke Zone with its Tirolic transgressive Permoskythian (Werfen

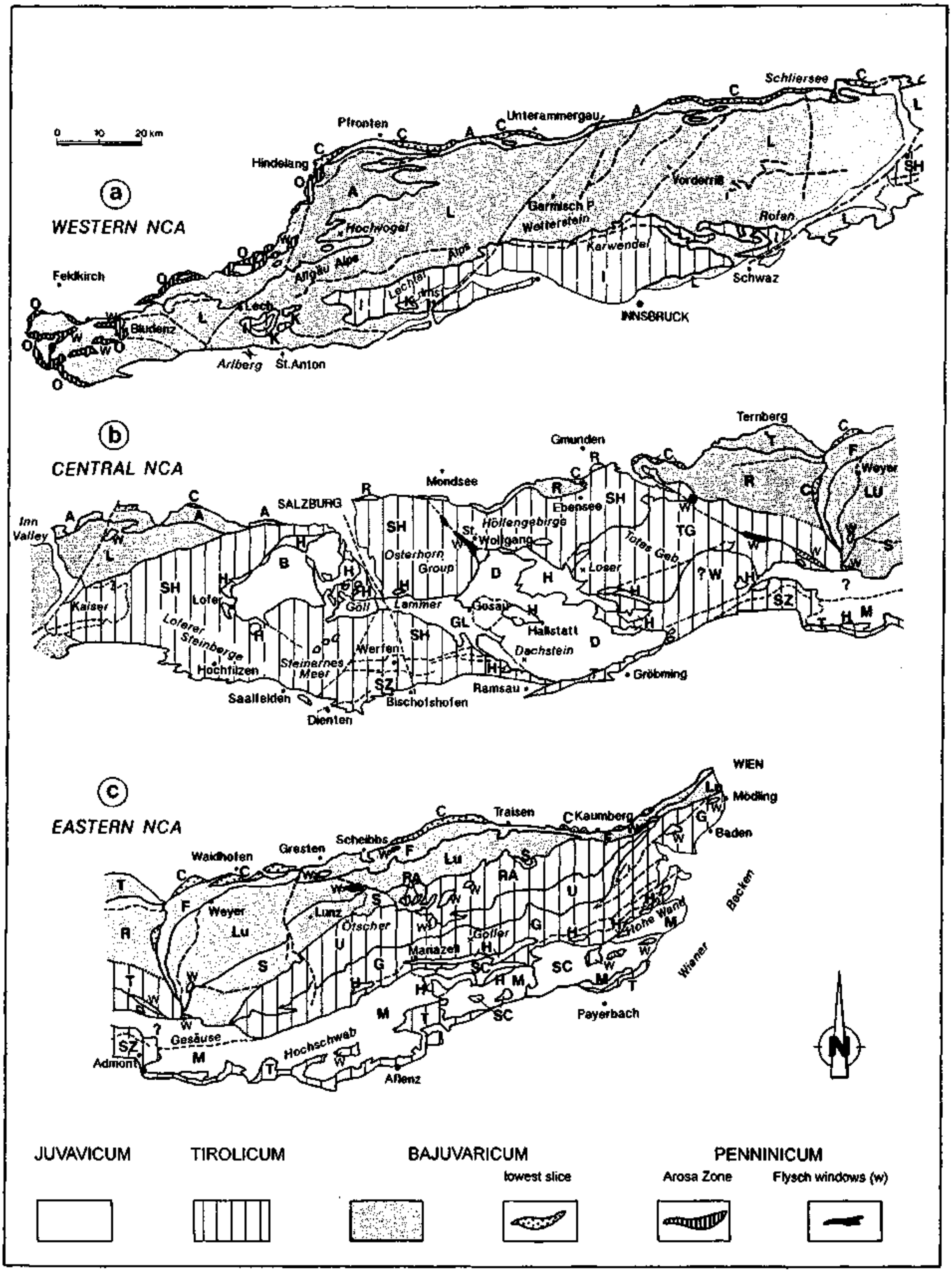


Fig. 2.5.1.: The Nappe System of the Northern Calcareous Alps; after PLÖCHINGER, 1995.

Schuppen-Zone) in the south. An additional subdivision into a "Lower" and an "Upper" Juvavicum has been used in literature; these terms seem not to be useful anymore. They had a mixed facial and tectonic meaning: "Lower" means pelagic Hallstatt facies and a tectonic position below the "Upper"Juvavic carbonate platforms of Wetterstein-/Dachstein facies. Recent mapping has shown that also an opposite configuration is existing frequently.
Apart from slightly metamorphosed beds at the basal parts - mainly within the siliciclastic Permo-Skythian rocks - it was assumed that most parts of the NCA do not exhibit any metamorphic overprint - see KRALIK et al. (1987). Investigations of Conodont Color Alteration Index during the last years have revealed a considerable thermal event in parts of the Juvavic nappes, predating the oldest (Late Jurassic) overthrusts (GAWLICK et al.,, 1994, KOZUR & MOSTLER, 1992, MANDL, 1996).
Today there is a common agreement that the NCA depositional realm during the Permotriassic was a passive continental margin between Variscian (= Hercynian) consolidated Pangäa and the Tethys ocean, Fig. 2.5.2. That sector of the ocean that bordered the NCA and the Western Carpathians was also named "Hallstatt-Meliata-Ocean" by KOZUR, 1991 and it is thought to be closed by plate tectonics during Jurassic times. The position of this geosuture in the today visible nappe stack as well as the original arrangement of the tectonic mega-units to each other is still a matter of discussion and major disagreement (HAAS, KOVACS, KRYSTYN & LEIN, 1995, KOZUR, 1991, KOZUR & MOSTLER, 1992, SCHWEIGL & NEUBAUER, 1997, TOLLMANN, 1976, 1981).

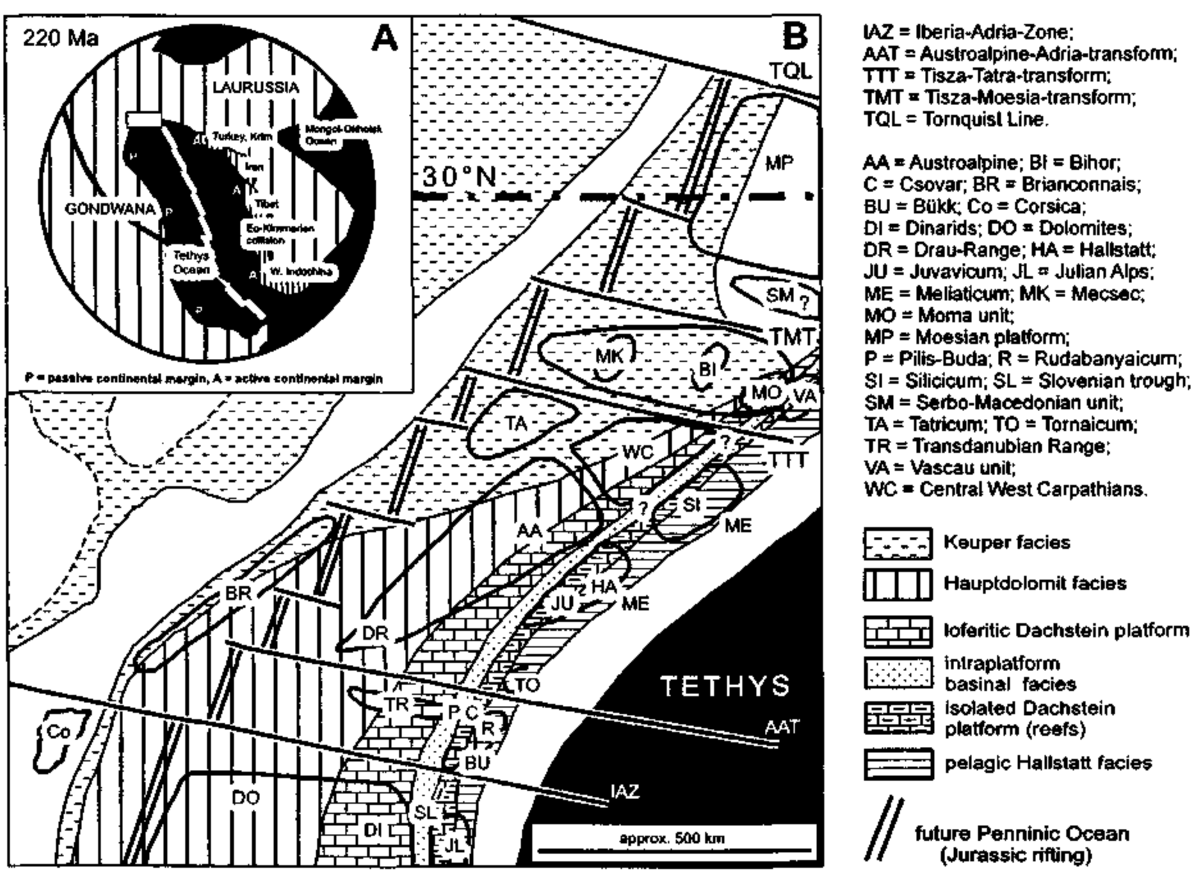


Fig. 2.5.2.: The Alpine-Carpathian sector of the Triassic Tethyan shelf.
After HAAS et al., 1995, modified.

Beginning in the Jurassic the Austroalpine realm (including the NCA) became separated from its European hinterland by the birth of the transtensional basin of the Penninic Ocean, which was linked by large transform faults with the opening of the Northern Atlantic Ocean. Contemporaneous compressional tectonics have affected the Tethyan ocean and the adjacent shelf of the Austroalpine realm, causing the first displacements of the Juvavic Nappe System.

Subduction processes at the southern margin of the Penninic Ocean have started in the Cretaceous, accompanied by heating and crustal shortening within the Austroalpine crystalline basement and by synorogenic clastics and nappe movements in its sedimentary cover (DECKER et al., 1987, FAUPL & TOLLMANN, 1979). For details of metamorphic evolution of the Eastern Alps and controversial discussions see FRANK (1987).

Upper Cretaceous clastic sediments of the Gosau-Group transgressed after a period of erosion over the NCA nappe stack. The sediments of the Gosau-Group show a facies change in time from shallow water clastics to flysch-like deep water sediments, WAGREICH & FAUPL, 1994. The latter ones are also typical for the adjacent Penninic trough, where beside other structural units (e.g. ophiolite-bearing metamorphic Bündner-schiefer-Group of the Tauern-Window) the Rhenodanubian Flysch Zone originates from.

Ongoing subduction of the Penninic realm toward the south below the Austroalpine units led to the closure of the Penninic Ocean. The sediments of the Rhenodanubian Flyschzone became deformed, lost their oceanic basement (only preserved in form of some Klippen) and became partly overthrusted by the nappes of the NCA, beginning in the late Eocene.

The remaining sea between the alpine orogenic front and the european foreland was during Oligocene and Miocene the depositional site of the Molasse Zone, which collected the erosional debris of the uplifting Alps. The southernmost part of the Molasse Zone became also incorporated into the alpine orogeny due to the youngest subduction pulses.

The large scale overthrusts of the NCA, Flysch- and Klippen Zone over the Molasse Zone and the European Foreland (crystalline basement of the Bohemian Massive with autochthonous sedimentary cover) is proven today by several drillings, which penetrated all units and reached the basement in depth of about 3.000 to 6.000 meters.

The uplift of the central part of the Eastern Alps in the Miocene was accompanied by large strike slip movements on its northern side (sinistral Salzach-Ennstal- and Mur-Mürz-fault systems; responsible also for the genesis of the Vienna Basin and also dissecting the NCA) and on its southern side (dextral Periadriatic faults) - see for example LINZER et al. (1995), DECKER et al. (1994).

Permotriassic Stratigraphy and Facies of the NCA

Overviews as well as detailed data and further literature to this topic are given by TOLLMANN, 1976, LEIN, 1985, 1987, KRYSTYN & SCHÖLLNBERGER, 1972, MANDL, 1984, SCHLAGER & SCHÖLLNBERGER, 1975, ZANKL, 1971, FLÜGEL, 1981. A schematic representation of the Triassic sedimentary sequences is shown in Fig. 2.5.3.

The sedimentary sequence of the NCA starts in the Permian with continental red beds, conglomerates, sandstones and shales of the Prebichl Formation, transgressively overlaying the Lower Paleozoic rocks of the Greywacke Zone (Noric nappe). The Permian age is assumed due to local intercalations of acid tuffs and pebbles of quartzporphyr, which are widespread in the European Permian (Saalic tectonic phase). A marine facies of Permian sediments is the so called Haselgebirge, a sandstone-clay-evaporite association

containing gypsum and salt. This facies is frequent in the Juvavic units, exposed for example in the Hallstatt salt mine. The Upper Permian age is proved paleontologically by pollen/spores at several localities and confirmed by sulfur isotopes.
The Lower Triassic is characterized by uniform shallow shelf siliciclastics of the Werfen Formation, containing limestone beds in its uppermost part with a poor fauna including Scythian ammonoids.
In the Middle Triassic carbonate sedimentation became dominant. The dark Gutenstein Limestone and Dolomite is present in most of the NCA nappes. It can be laterally replaced in its upper part by light dasycladacean bearing carbonates, the Steinalm Limestone / Dolomite. During the Middle Anisian a rapid deepening and contemporary blockfaulting of the so called Reifling Event caused a sea floor relief, responsible for the following differentiation into shallow carbonate platforms (Wetterstein Formation and lateral slope sediments) and basinal areas. The basins can be distinguished into the Reifling/Partnach basins and the Hallstatt deeper shelf, the latter one was bordering the open Tethys. The transition from the Hallstatt depositional realm into oceanic conditions with radiolarites is not preserved in the NCA. We have hints on the existence of such an oceanic realm only in form of olistolites of Ladinian red radiolarite in the Meliata Klippen in the eastern Sector of NCA.
The Wetterstein platforms in general show a platform progradation over the adjacent basinal sediments until the Lowermost Carnian ("Cordevolian"). Then carbonate production decreased rapidly due to a sealevel lowstand. The platforms emerged, the remainig basins received siliciclastics from the European hinterland. The Reifling basin has been filled completely by marine black shales (Reingraben shale) and marine to ?brackish Lunz Sandstone, containing coal seams. Local intraplatform basins and the Hallstatt realm toward the south received also finegrained siliciclastics (Reingraben shale) interbedded with dark cherty limestones and local reef debris ("Leckkogel facies"), derived from small surviving reef mounds at the basin margins.
As sealevel started rising up again in the Upper Carnian, rather slowly in the beginning, carbonate production increased, locally filling a relief in the drowning platforms with lagoonal limestones (Waxeneck Limestone). The relief (several tens up to about 100 meters) may be caused by erosion during the lowstand time and/or by tectonic movements. More toward the north, in the Lunz - Reifling area, partly hypersalinar conditions led to the deposition of limestones and dolomites with evaporitic (gypsum) intercalations (Opponitz Formation).
A transgressive pulse just below the Carnian/Norian boundary caused an onlap of pelagic limestones over the shallow water carbonates and initiated the rapid growth of the Norian carbonate platform.
Due to local differences in platform growth conditions we can distinguish two different developments, see Fig. 2.5.4. In the central part of the NCA (Hochkönig, Tennengebirge, Dachstein area etc.) the pelagic onlap represents only a short time interval and became covered by the prograding Dachstein carbonate platform - see example of the type area below. In this areas the Upper Triassic reefs approximately are situated above the Middle Triassic ones.
An other situation characterizes the eastern sector of the NCA. There the Uppermost Carnian pelagic transgression continues until the Upper Norian and has been termed Mürztal Type of Hallstatt facies by LEIN (1982). Dachstein reefs are only known from the Upper Norian and this ones are situated above the former platform interior, several kilometers behind the former Wetterstein reef front. Such a configuration seems to be also typical for the Western Carpathians (Slovakian karst and the Aggtelek Mountains). This "backstepped" reefs show transitions into the basinal facies of the black Aflenz Limestone at the eastern Hochschwab / Aflenz area and at the Sauwand- and Tonion Mountains. The

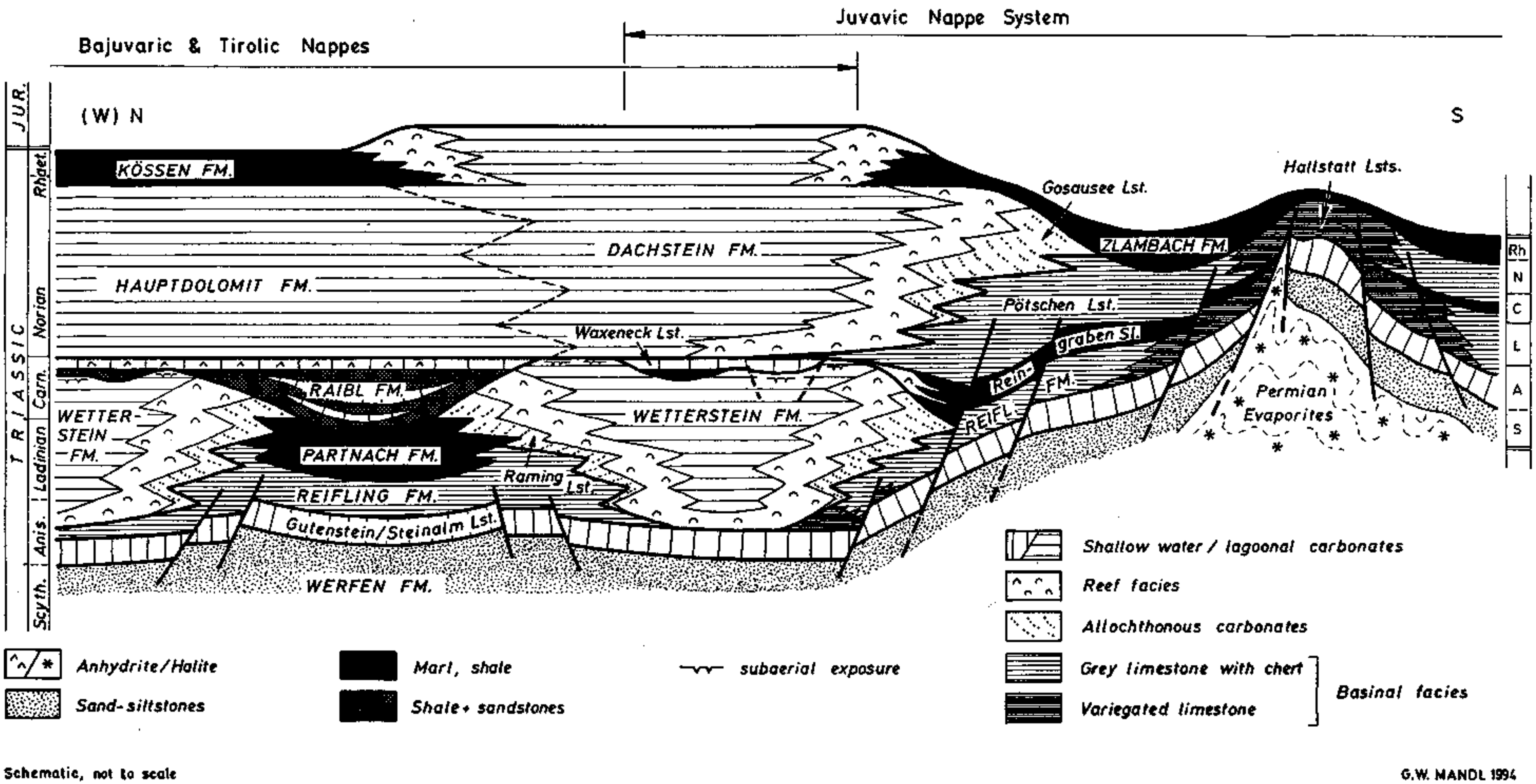


Fig. 2.5.3.: Triassic depositional realms of the middle part of the northern Calcareous Alps (Austria)

Fig. 2.5.4.: Triassic Depositional Realms of the Juvavic Domain (Northern Calcareous Alps, Austria).

„Middle Triassic": Wetterstein Interval (Upper Pelson - Lower Julian); platform, margins, intraplatform basin

1 Wetterstein Facies; interior of carbonate platform, lagoonal subfacies.
2 Wetterstein Facies; carbonate platform, marginal reef subfacies.
3 „Northern" slope facies; facing toward restricted intraplatform basin; reef debris.
4 Grafensteig Facies; restricted intraplatform basin; bedded black limestones, containing distal turbidites of platform origin; connecting seaways to open marine realm are not preserved; central parts of basin may persist into Upper Triassic (Carnian shales; Norian sediments are not preserved).
5 „Southern" slope facies; reef debris interfingering with open marine pelagic carbonate mud facies.
6 Distal „southern" slope facies; pelagic variegated carbonate mud facies mixed with finegrained platform derived debris.
7 Margin of basinal facies; grey limestones with chert nodules and intercalated carbonate turbidites.

Upper Triassic: Reingraben and Dachstein Interval (U. Julian to Rhaetian); platform, margins, drowned platform

Middle- and Upper Triassic carbonate platforms are separated by the Reingraben event (sealevel fall). Platforms emerged; locally bypassing siliciclastics (mainly shales) reached the remaining basinal areas, onlapping the former Wetterstein platform slopes. Sealevel rise during Upper Carnian initiated a next platform growth:

8 Dachstein Facies; carbonate platform, cyclic bedded lagoonal subfacies; toward north transition into intertidal Hauptdolomit.
9 Dachstein Facies; carbonate platform, marginal reef subfacies situated above Wetterstein reef, facing toward Hallstatt deeper shelf.
10 Mitteralm Facies; Dachstein carbonate platform, backstepped margin above drowned interior of Wetterstein platform, facing toward Aflenz intraplatform basin.
11 Tonion Facies; backstepped platform like 10, separeted from drowned Wetterstein platform by pelagic Mürztal facies; platform progradation during Upper Norian, older parts of platform are not preserved.
12 Hohe Wand Facies; backstepped platform, prograding during Upper Norian over red Hallstatt limestone facies and reaching again a reef position above Middle Triassic platform margin.
13 Gosausee Facies; (distal) slope toward Hallstatt deeper shelf; carbonate turbidites of platform origin interfingering with pelagic grey mud facies (Pötschen facies).
14 Aflenz Facies; intraplatform basin over drowned Wetterstein platform; connection into a persisting depression above Middle Triassic intraplatform Grafensteig Facies questionable (sediments eroded).
15 Mürztal Facies; variegated pelagic limestones on „pelagic plateau" of drowned Wetterstein platform; transitions to Aflenz facies are not preserved (eroded).

Middle- and Upper Triassic (Upper Pelsonian to Rhaetian) in basinal facies, Hallstatt deeper shelf

16 Pötschen Facies; basinal realm of Hallstatt deep shelf; bedded grey limestones with chert.
17 Siriuskogel Facies; few occurrences of massive grey pelagic limestone, depositional site questionable.
18 Salzberg Facies; variegated Hallstatt limestones s. str.; intrabasinal rises due to synsedimentary diapirism of Permian evaporites and/or tectonics (mobile shelf margin) are the reason for reduced sedimentation, condensed sequences, block tilting and fissure fillings.

The Upper Triassic sedimentary history was terminated by increasing input of terrigenous material, in the Juvavic realm represented by the Zlambach Formation, covering the basinal areas as well as the platform slopes.

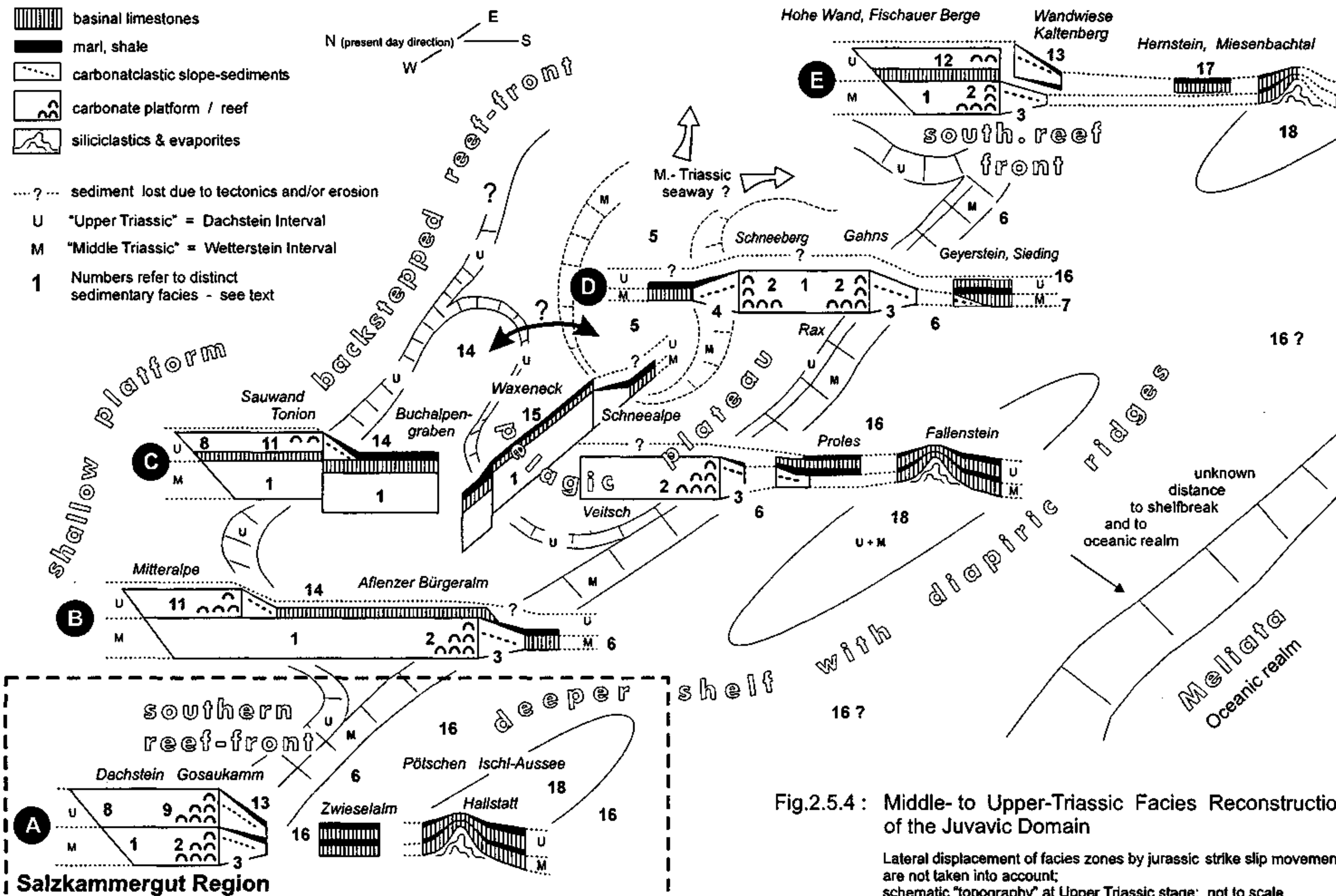


Fig.2.5.4 : Middle- to Upper-Triassic Facies Reconstruction of the Juvavic Domain

Lateral displacement of facies zones by jurassic strike slip movements are not taken into account;
schematic "topography" at Upper Triassic stage; not to scale

"Southern Marginal Reefs" of central NCA are connected by the allodapic Pedata Limestone to the Pötschen Limestone of the Hallstatt facies s.str.
The Hallstatt-Group shows a great variability of variegated limestones often with rapidly changing sedimentary features due to its mobile basement (diapirism) of Permian evaporites - details see below.
Behind the Dachstein reefs a large lagoonal environment extended all over the NCA with Dachstein bedded limestones near to the reefs and the intertidal Hauptdolomit in distal parts.
In the Uppermost Triassic ("Rhaetian") once again increasing terrigenous influx has reduced the carbonate platforms. The Hauptdolomit area and parts of the Dachstein lagoon became covered by the marly Kössen Formation, borderd by Rhaetian reefs.
In the Hallstatt realm as well as in the intraplatform basin of Aflenz Limestone the marly Zlambach Formation has been deposited onlapping and interfingering with the Dachstein platform slope.

Jurassic to Early Cretaceous sediments

At the beginning of Jurassic the Austroalpine shelf drowned completely, basinal conditions prevailed until the Lower Cretaceous with the only exception of local Plassen carbonate platforms (Late Malm - Earliest Berriasian) in southern parts of the NCA, especially in the realm of Juvavic nappes.

Irregular drowning and synsedimentary faulting caused a complex seafloor topography with reddish/grey crinoidal limestones (Hierlatz Lst.) and red ammonoid limestones (Adnet Lst., Klaus Lst.) mainly above former carbonate platforms and grey marly/cherty limestones (Allgäu Fm.) in the troughs between.
Parts of the Hettangian are often missing at the base of Hierlatz and Adnet Limestone - e.g. at the type locality. The reason - subaereal exposure or submarine non-deposition - is still in discussion. Neptunian sills and dykes filled with red or grey Liassic limestones are frequent, cutting down into the Norian shallow water carbonates up to more than 100 meters.
According to BÖHM (1992), BÖHM & BRACHERT (1993) Adnet and Klaus Limestones are bioclastic wackestones, mainly made of nannoplankton (*Schizosphaerella*, coccoliths) and very finegrained biodetritic material. After globigerinids had evolved in the Middle Jurassic, they also became a major component of these sediments along with the tiny shells ("filaments") of the probably planctonic juvenile forms of the bivalve *Bositra*. The macrofauna mainly consists of crinoids and in some places very abundant brachiopods and ammonites. Strong condensation, Fe/Mn stained hardgrounds and deep-water stromatolites are frequent.
The type locality of Klaus Limestone - also nearby Hallstatt - and its ammonites have been reviewed by KRYSTYN, 1971. According to him the Klaus Limestone unconformably covers the Upper Norian Dachstein Limestone and contains an ammonite fauna indicating Late Bajocian.

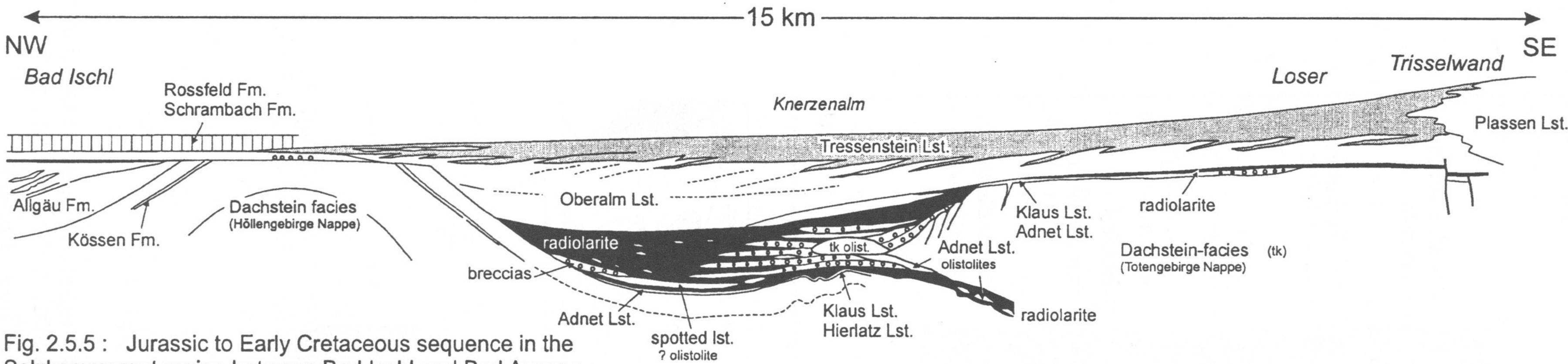


Fig. 2.5.5 : Jurassic to Early Cretaceous sequence in the Salzkammergut region between Bad Ischl and Bad Aussee, according to SCHÄFFER & STEIGER 1986.

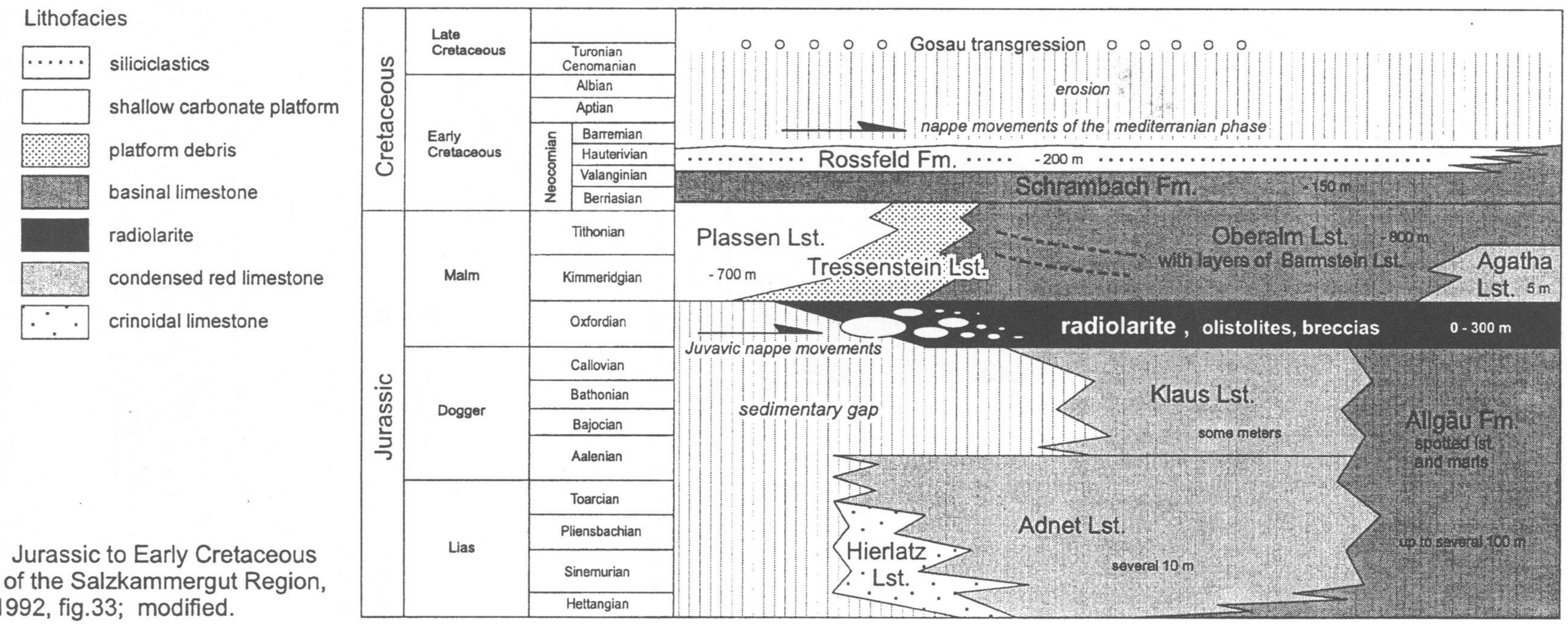


Fig. 2.5.6 : Jurassic to Early Cretaceous stratigraphy of the Salzkammergut Region, after BÖHM 1992, fig.33; modified.

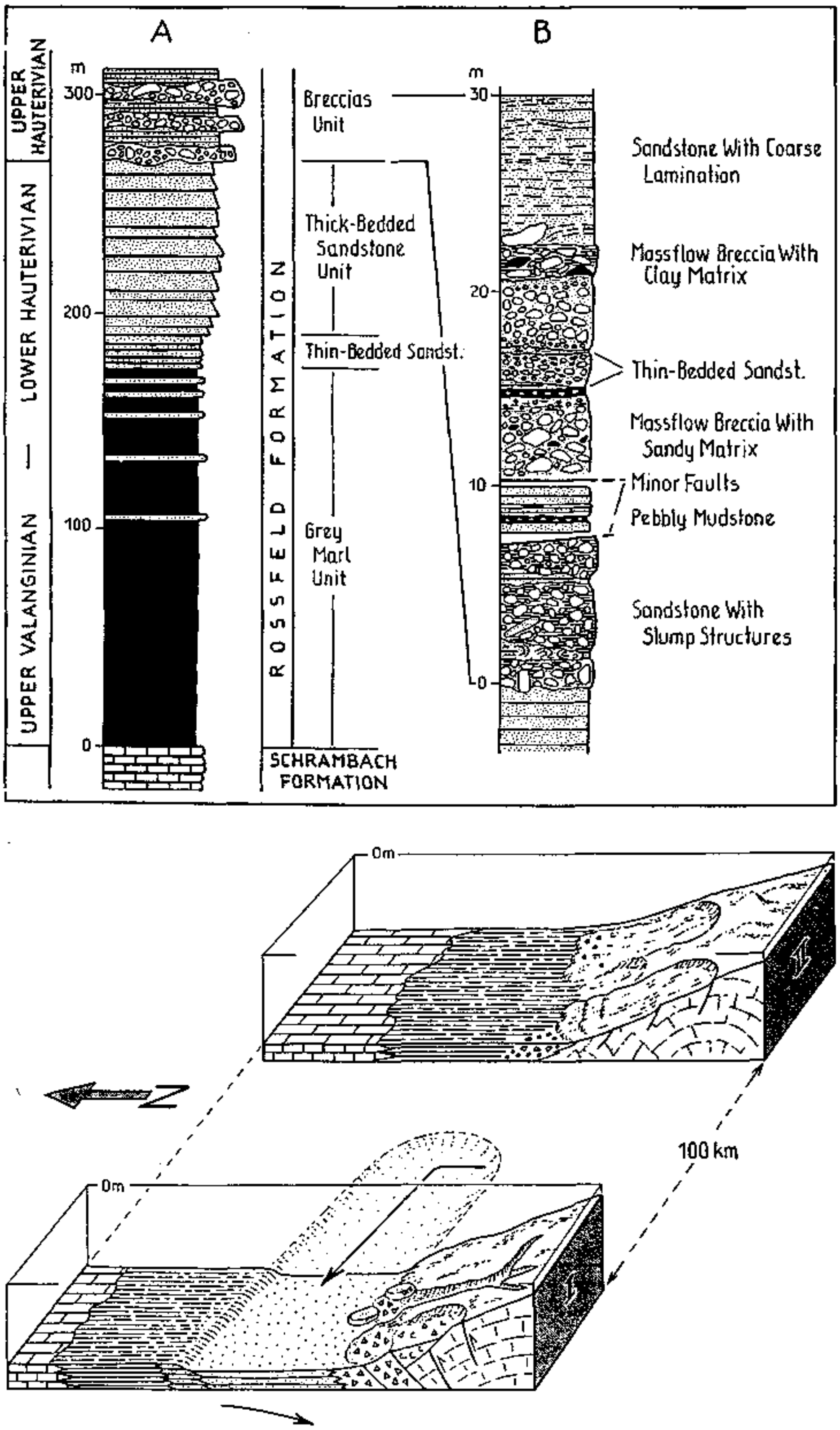


Fig. 2.5.7.: Lithology and depositional model of the Rossfeld Fm.
After DECKER, FAUPL & MÜLLER (1987).
A: Schematic profile at the Rossfeld area. Coarsening upward trend in front of advancing Juvavic nappes; B: Detailed section of the breccias unit.
Block diagramm of sedimentary environments (out of scale):
I: Locality Rossfeld area (west); II: Locality Reichraming area (east)

The greatest water depth has been reached in Oxfordian, characterized by widespread radiolarite deposits, the Ruhpolding Formation and equivalents (DIERSCHE, 1980). Contemporaneously breccias, olistolites and large sliding blocks occur as a consequence of the Juvavic gravitational nappe movements. This first pulse of alpine orogeny caused a new seafloor topography in the Late Jurassic. Especially above large Juvavic "sliding units" shallow water conditions led to the deposition of platform carbonates (Plassen Lst., Tressenstein Lst.) whereas pelagic limestones (Oberalm Lst.) have filled the basins in between (FENNINGER & HOLZER, 1972, STEIGER & WURM, 1980).
As indicated by microfossils, the facies of Late Jurassic carbonates persists into the Early Cretaceous. Deepening and increasing terrigenous input caused a gradual transition into the marly aptychus limestones of the Schrambach Formation. The terrigenous facies of the Rossfeld Formation replaced the deep water carbonates since the Late Valanginian (DECKER et al., 1987). The Rossfeld Fm. consists of grey marls, turbiditic sandstones and breccias partly associated with huge slide blocks. In the central NCA a coarsening and thickening-upward sequence is developed, while toward the northeast a transition into contemporaneous deep water limestones is preserved. At the Rossfeld area the synorogenic clastics filled a trench-like structure in front of the advancing nappes - see FAUPL & TOLLMANN (1979).
The deposition of the Rossfeld Fm. took place during the crustal shortening within the Austroalpine basement. This tectonic process caused an uplift of southern parts of the NCA, overthrusting of Juvavic Nappes and metamorphism in the Austroalpine crystalline nappes below. The clastic material of the Rossfeld Fm. is a mixture of two different kinds of components. The coarse grained material mainly consists of carbonates, derived from uplifting parts of the NCA (e.g. Hallstatt limestones from the south). In contrast to this locally derived material the sand sized components contain siliciclastics, including quartz, feldspar, chlorite and heavy mineral spectra with "exotics" as actinolitic amphibols, rare kaersutite and dominating chrome spinel. These constituents are derived from an ophiolitic belt situated south of the NCA, which is interpreted as the suture zone of the Late Jurassic orogenic front.

Late Cretaceous to Eocene sediments of the Gosau Group

Palaeogeographically the NCA were situated during Upper Cretaceous at the northern margin of the Apulian microplate within the western Tethys realm, facing toward the Penninic oceanic realm in the northwest.
During the Cretaceous orogeny the sedimentary succession of the Northern Calcareous Alps and their Palaeozoic substratum (Greywacke Zone) had been sheared off from their crystalline basement. North-verging folds, thrusts and nappe structures developed. The unconformable deposition of the Gosau-Group began after this tectonic event, sealing folds and thrust structures. A second phase of compressive deformation affected the NCA during the end of Eocene, terminating the sedimentation. Finally in Miocene large scale strike-slip movements dissected the whole nappe stack.
Today only relatively small remnants of the formerly widespread Late Cretaceous to Eocene sedimentary cover of the NCA are still preserved. As a consequence of the complex deformation history the paleogeographic relationships between individual Gosau occurrences are often obscured.
The Gosau-Group can be divided into two subgroups (WAGREICH & FAUPL, 1994): The Lower Gosau Subgroup comprises alluvial fan deposits passing into a shallow-marine

succession. Reviews of lithofacies and sedimentary environment are given by HERM (1977), BUTT (1981), POBER (1984), HÖFLING (1985), GRUBER (1987), WAGREICH (1988, 1989a,b), FAUPL et al. (1987) and LEISS (1988, 1990).
The Upper Gosau Subgroup is characterized by deep-water deposits. Descriptions of these sediments are given by HESSE & BUTT (1976), BUTT (1981), FAUPL (1983), ORTNER (1992), LAHODYNSKY (1992) and KRENMAYR (1999).
The thickness of the whole succession reaches up to 2500 m at the type locality, the area around the village of Gosau in the middle part of the NCA.
Despite the very early knowledge of rich macrofaunas in the sediments of the Gosau-Group the biostratigraphic framework for modern investigation is mainly based on planktonic foraminifera - e.g. HERM (1962), OBERHAUSER (1963), KOLLMANN (1964), WILLE-JANOSCHEK (1966), Butt (1981), WAGREICH (1988, 1992), - and calcareous nannoplankton - e.g. WAGREICH (1988, 1992), WAGREICH & KRENMAYR (1993).
In the Lower Gosau Subgroup, a zonal refinement has been attained by ammonite and inoceramid stratigraphy - e.g. SUMMESBERGER (1985), IMMEL (1987), TRÖGER & SUMMESBERGER (1994), SUMMESBERGER & KENNEDY (1996).
A comprehensive description of stratigraphy and facies was recently given by FAUPL, POBER & WAGREICH (1987), WAGREICH & FAUPL (1994), FAUPL & WAGREICH (1996), also including paleogeographic maps and geodynamic/palaeotectonic conclusions.
After a period of non deposition or erosion sedimentation has started diachronously from the Late Turonian onwards, see Figs. 2.5.8. and 2.5.9.
The Lower Gosau-Subgroup can be subdivided into 5 formations (WAGREICH, 1988):
The basal Kreuzgraben Formation consists of reddish conglomerates and subordinate sandstones and pelitic sediments. An alluvial fan environment can be reconstructed with debris flow and braided stream sedimentation. Within the lower part of the overlying Streiteck Formation several coarsening upward marl-sandstone-conglomerate cycles of a fan-delta facies are preserved. The cycles are interpreted as progradational sequences of a fan into a shallow marine environment to the south. The upper part of the Streiteck Formation indicates a deepening with sedimentation of marls with sandstones and fossiliferous beds. The Grabenbach Formation consists of marls of the middle to outer shelf with storm layers of sandstone. Within the following Hochmoos Formation a regressive tendency is observed, resulting in local fan-delta sedimentation. The sediments of the Bibereck Formation mark a renewed subsidence from the shelf to bathyal depth with turbiditic influence.
Heavy mineral studies indicate both local sources of detritus with apatite-turmalin-garnet and "exotic" source areas with chromian spinels.
During the Campanian, tectonic activities caused a considerable facies change. In some places striking unconformities can be observed. Simultaneously with this facies change a new spectrum of clastic material arrived, dominated by metamorphics. The source area was situated south of the NCA. K-Ar dating give evidence of its affection by early Alpine metamorphism. The Upper Gosau-Subgroup comprises deep-sea fan sequences - Ressen Formation, Zwieselalm Formation - deposited partly below the CCD, as well as a marl-dominated slope facies - Nierental Formation. South of the northward dipping slope - mainly outside of the NCA nappe-stack - a carbonatic shallow-marine shelf facies was developed, serving as a source of bio- and lithoclasts during Maastrichtian to Paleocene.
A special highlight in the investigation of the Gosau Group was the discovery of an undisturbed and complete sedimentary sequence of the Cretaceous/Tertiary boundary at the locality „Elendgraben" (PREISINGER et al., 1986). The outcrop in a steep creek exposes a more than 30 m thick sequence of flyschoid sediments of the Zwieselalm Formation. The sequence across the boundary consists of marly limestone and silty marl and is not disturbed by turbidites. The 2 mm thick boundary clay differs from the

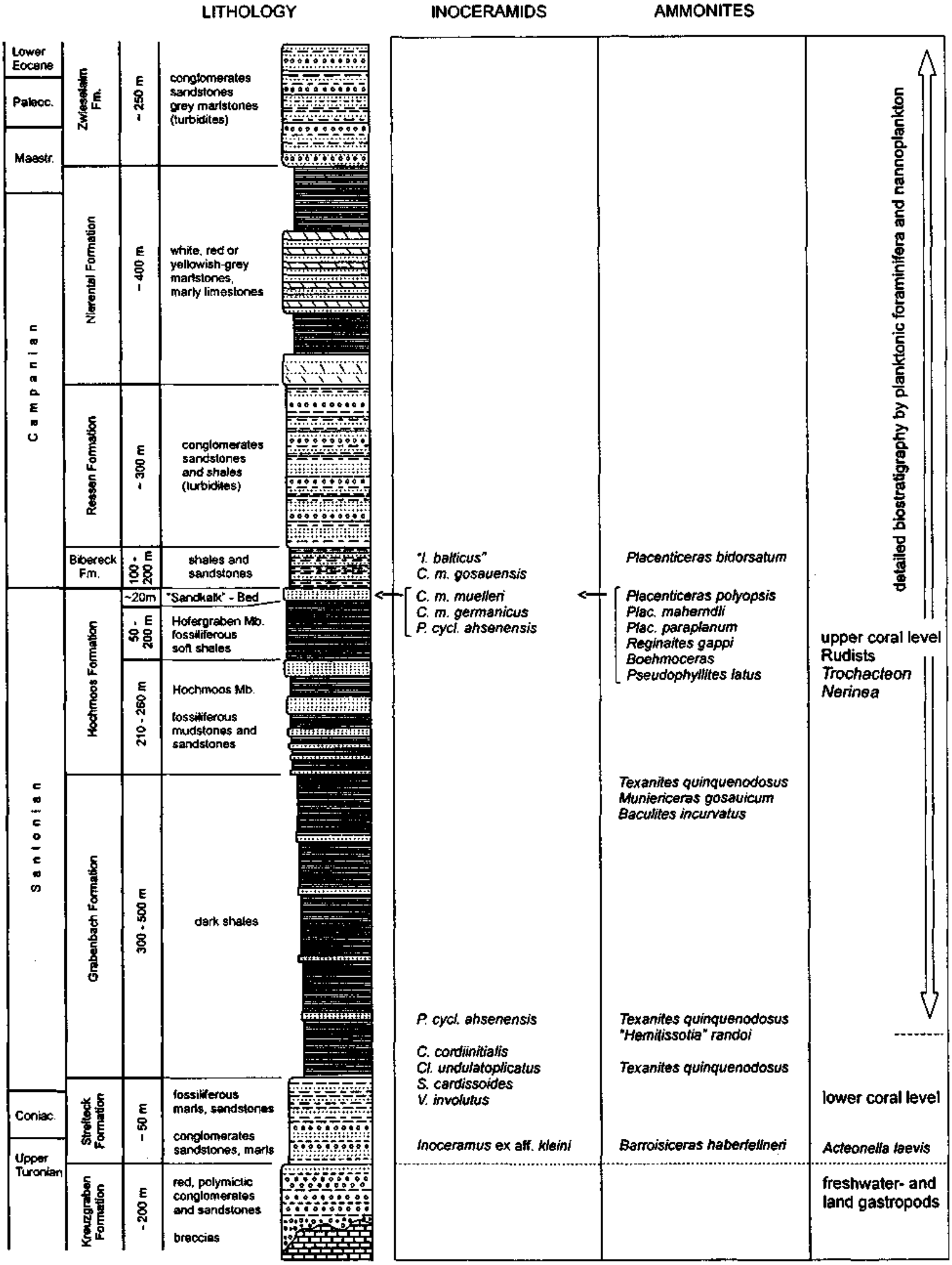


Fig. 2.5.8.: Idealized lithostratigraphic sequence of the Gosau-Group in the Gosau Basin according to KOLLMANN (1980). Fauna after SUMMESBERGER (1992), TRÖGER & SUMMESBERGER (1994) and SUMMESBERGER & KENNEDY (1996)

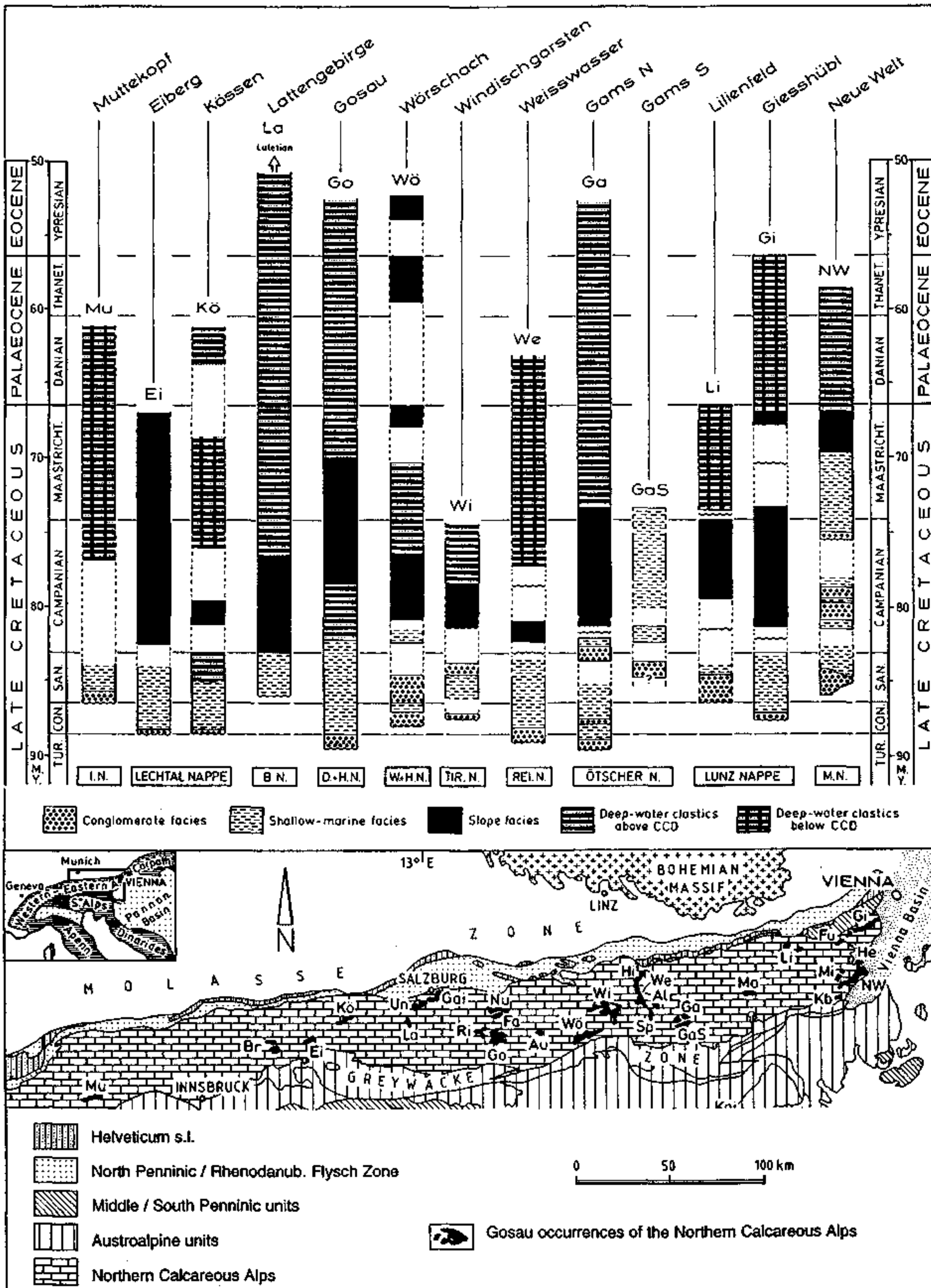


Fig. 2.5.9.: Selected lithological sections of the Gosau Group of the NCA (after FAUPL & WAGREICH, 1996)

surrounding sediment in having significant light-brown colour, no biogenic calcite, an enrichment of Ir, Cr, Co and Ni and a different content of rare-earth and siderophile elements, carbon and magnetic minerals. The clay also contains shocked quartz and plagioclase grains as well as glass particles. Micropalaeontological investigations have shown mass extinction of foraminifera and nannoplankton. All data fit to the impact-hypothesis of ALVAREZ et al. (1980).

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3. Road side geology - from Vienna to Hallstatt
Th. HOFMANN & H.G. KRENMAYR

3.1. Bus tour Vienna - Gmunden

The Westautobahn (Highway A1) runs from Vienna, the capital of Austria, in a western direction towards the Austrian-German Border. The Highway connects from east to west the federal countries of Lower Austria, Upper Austria and Salzburg. The main cities which can be reached by the A1 are Vienna, where the Highway starts, then St. Pölten, the capital of Lower Austria, Linz, the Capital of Upper Austria and Salzburg, the capital of the federal county of Salzburg.

Tectonic overview

Geologically the A1 runs more or less parallel to the east-west striking tectonic units of the alpine orogenetic belt. Nevertheless some main tectonic units are crossed on the way from Vienna to Salzburg.
In Vienna the A1 starts at the eastern border of the Vienna Basin, then crosses the complex nappe system of the Rhenodanubian Flyschzone, which was overthrusted over the Molassezone, which is the next zone in a western direction. Then some parts of the southern Bohemian Massif are crossed including the Diendorf Fault - one of the greatest fault systems in the outer Alpine regions of Austria. From the western parts of Lower Austria onwards the A1 runs within the Molassezone. Sometimes the Flyschzone comes very close to the Highway, as well as the Northern Calcareous Alps which also are close to the highway, especially near Salzburg. For the western part of the A1, especially in Upper Austria and Salzburg, the A1 passes various accumulations (Terraces, ...) of the glaciers which existed in the Alps during the Pleistocene.
Looking at the geological units of Vienna, the capital of Austria, with an area of 414 km² 79% represent the Vienna Basin, 20% the Rhenodanubian Flyschzone and 1% the Northern Calcareous Alps (KÜPPER, 1968).

The route

The Geological Survey in the Palais Rasumofsky is situated in the Vienna Basin right at the edge of the Hochterrasse (Riß) (FUCHS, 1985). Going towards Schwarzenbergplatz, we find there the Hochstrahlbrunnen. This fountain has provided water since the emperor Franz Josef opened the „1. Wiener Hochquellenwasserleitung“ which was erected based on the ideas of Eduard Sueß in the years 1870-1873. This water supply brings karst water through a 118 km long pipeline (without using any pumps!) in 16 hours from the Northern Calcareous Alps (Rax) to Vienna. Today 20.000 m³/day come to Vienna by the „1. Wiener Hochquellenwasserleitung“. In 1910 the „2. Wiener Hochquellenwasserleitung“ was finished, which brings another 200 Million Liters/day from the Hochschwab Area (Northern Calcareous Alps) via a 170 km long pipeline in 36 hours to Vienna.

Continuing to Karlsplatz we pass „Karlskirche". This church is dedicated to St. Karl Borromäus after the great plague in 1713. This famous baroque church with the two towers was started by Johann Bernhard Fischer von Erlach in 1716-1722, then the church was completed - after changing the dome - by his son Joseph Emanuel from 1724 to 1739. At the right side of the Curch, there is the Vienna University of Technology. At the right corner of the building, which dates back to 1816, we find the Institute of Engineering Geology. At this Institute worked among others Franz von HOCHSTETTER, Franz von TOULA, Karl TERZAGHI, Josef STINY and Franz KIESLINGER.

The Seccession at the Beginning of the Naschmarkt and the Wienzeile is an important Exhibition Hall for Contemporary Art.
The erection of its own exhibition building was one of the guiding principles of the "Association of Visual Artists Vienna Secession" that was discussed in the foundation meeting. The Secession members commissioned the hardly 30-year-old architect Joseph Maria Olbrich, who was at the time a member of Otto Wagner's atelier, to design the building, which was to become a key work of Viennese Art Nouveau. A site along the Ringstraße was originally chosen, but Olbrich's designs met with violent reaction on the part of the Municipal Council. It was only after the site was transferred to a plot on Friedrichstraße that the Municipal Council granted permission for "the erection of a provisional exhibition pavilion for the period of the next ten years" (minutes of the meeting of the Municipal Council of 17 November, 1897). The necessary financial resources for construction was partly supplied by patrons, especially the industrial magnate Karl Wittgenstein, and partly from the proceeds of the first exhibition in the k.k. Gartenbaugesellschaft (Royal and Imperial Gardening Society). The Municipality of Vienna allocated the site along the Wienzeile.
Joseph Maria Olbrich designed the building over the course of ten months, continually modifying his designs to correspond to new requirements, while reviewing and refining them at the same time. The cornerstone was laid on 28 April 1898 within the framework of a small celebration. Only six months later, on 29 October 1898, the construction was complete.
The Secession building, which is now recognised as one of the high points of any visit to Vienna, was heaped with derision at the turn of the century. The building was described as "Temple for Bullfrogs", "A Temple of the Anarchic Art Movement", a "mausoleum", a "Pharoah's Tomb", "The Grave of the Mahdi" and a "crematorium", the dome was known as "a head of cabbage", the whole building dismissed as a "a bastard between temple and warehouse" and "a cross between a greenhouse and a blast furnace".
The Secession differs fundamentally from other galleries of modern art in the way in which its program and individual exhibitions are determined. The artists elected to the board decide the program of the Secession and which artists will be invited to mount exhibitions (http://www.secession.at/).

Continuing along the Linke Wienzeile, we follow the Naschmarkt, which is the most famous market in Vienna, and we also see the stations of the metro U4 which where built by Otto Wagner. For constructing the regulation system of the Wien river he used sandstones from quarries of the Flyschzone, which were from nearby quarries.
The next prominent stop is the castle of Schönbrunn at the right side.
This castle was recently attributed to the world heritage list of the UNESCO. Two obelisks surmounted by golden eagles tower above the elaborate portal. Through its wrought-iron bars glows the yellow of Schönbrunn Palace. A first castle was owned by emperor Maximilian II. in 1559. During the invasion of the Turkish Army the castle was destroyed in 1683. In 1688 Johann Bernhard Fischer von Erlach presented a huge project according to

Versailles in France with a castle at the top of the hill. Finally he changed his plans and in 1695 to 1711 the castle was built at the actual position. Between 1695 till 1699 the garden was designed in French stile.
The Baroque style predominates on the outside of the Palace, yet the inside opens out into the world of the rocaille (the flourishes typical of the Rococo style). The decoration of the apartments is a perfect example of Austrian Rococo from the second half of the 18th century. The splendour of the rooms, which today essentially represent the taste of Empress Maria Theresia, who renewed the castle between 1744 and 1749 exceeds all expectations. After the death of her husband Franz I. in 1765 some rooms were adapted in the stile of Austrian Rococo. Between 1817 and 1819 the castle, where even Napolean lived in, was renewed again in some parts. On August the 18th 1830 Emperor Franz Joseph was born there, he lived there and died on November, 21st of 1916 also in this castle. In 1918 his son Karl I. resigned here.
In some of the rooms the Imperial predilection for the exoticism of the Far East is evident in the oriental lacquer ware, Chinese vases, porcelain and gilded paintings depicting scenes of Indian and Mogul life which dominate the rooms' splendour.
Among many attractions like the Gloriette at the top of the hill, attention should be laid on the Zoo, which was founded in 1752 as the oldest still existing Zoo of the world.
(http://www.schoenbrunn.at/e/tour/rundS00.html)

Following the indication of kilometers, which can be read on little blue signs at the right side of the Highway some points of geological interest are passed on the way from Vienna to Salzburg:

EXIT: „Auhof":
Under the alluvial deposits of the river Wien a railway tunnel has recently been built. Thus sequences of the Rhenodanubian Flysch Zone within the Kahlenberg Nappe and the St. Veit Klippen Zone are evident: grey marls of the Kahlenberg Formation (Upper Cretaceous) and variegated marls and claystones (Hütteldorf Formation, Cenomanian-Santonian)
From "Auhof" onwards the A1 runs more or less along the Hauptklippenzone. This narrow zone separates the Kahlenberg Nappe in the north from the Laab Nappe in the South.

KM 20,5: "Bihaberg":
Leaving the Hauptklippenzone and the Kahlenberg Nappe, the highway enters the Greifenstein Nappe. This is the largest nappe in the Rhenodanubian Flyschzone and can be split up in four thrust sheets ("Schuppen").
At Bihaberg the A1 cuts to the North an overturned sequence within the second "Schuppe" of the Greifenstein Nappe. The section consists of Campanian marls of the Zementmergelserie, variegated marls and claystones of the Perneck Formation (= Oberste Bunte Schiefer") from the Upper Campanian and thick bedded sandstones of the Altlengbach Formation (Maastrichtian).

KM 27,5: "Großram":
This large outcrop to the North of the A1 is situated in the upper part of the third "Schuppe" of the Greifenstein-Nappe. It shows thick bedded sandstones of the Greifenstein Formation (Lower Eocene).

KM 43,5: Close to "Josef Weinheber-Brücke":
At Josef Weinheber Brücke, the A 1 crosses the tectonic contact between the Rhenodanubian Flyschzone in the South and the Molasse Zone in the North. The Flysch Zone

has been overthrusted upon the Molassezone during late orgenetic movements in the Lower Miocene.
This is evident by many drillings within the Flyschzone and the Northern Calcareous Alps (NCA). One important drilling is BERNDORF 1 situated in the eastern part of the Northern Calcareous Alps 35 km from the Alpine thrust front.
After penetrating the NCA the drilling reached at 5640 m a sequence of 200 m with sediments of the Rhenodanubian Flysch. At 5840 m, the overthrusting of the Molasse Zone by the Rhenodanubian Flyschzone, was documented by an Upper Oligocene Nannoflora (NP 24). Finally, at 5945 m, crystalline rocks of the Bohemian Massif were reached (SAUER et al.)

KM 53,0: Route to St. Pölten in direction S 33 to Krems:
This point at the eastern border of the Traisen Valley shows a sequence of terraces which are due to Pleistocene accumulations of the Traisen.
Following the classic ideas of PENCK and BRÜCKNER from the beginning of our century: four main levels of pleistocene fluviatile gravels (= terraces) are distinguished generally along the major rivers in the foreland:
The "Ältere Deckenschotter" (Günz),
the "Jüngere Deckenschotter" (Mindel),
the "Hochterrasse" (Riss) and
the "Niederterrasse" (Würm). Finally there is
the "Zone of recent Mäander", which reflects the Holocene.

All of them - except the "Niederterrasse" - may have thick Loess accumulations, the gravels may also be intensively weathered, so crystalline components of some older/ higher Terraces can be totally altered to Kaolin.

At the level of the “Ältere Deckenschotter” there is a panoramic view:
In a southern direction the hilly landscape is part of the Flyschzone, whereas the horizon is part of the Northern Calcareous Alps. In the north the Dunkelsteiner Wald as a part of the Bohemian Massif is visible.

KM 55,0: “Hochterrasse” of the Traisen-Valley:
Coming down from the level of the “Ältere Deckenschotter” the wide area of the “Hochterrasse” is passed, which was deposited during the Pleistocene (Riss). The material of the terrace consists of sandy gravels derived from the Northern Calcareous Alps and - to some extent - by the Rhenodanubian Flysch Zone.

KM 56,0: “Niederterrasse” of the Traisen-Valley:
The next lower part of the terraces are the gravels of the "Niederterrasse" (Würm) which are also dominated by material from the Northern Calcareous Alps.

The skyline of St. Pölten shows the tower of a baroque church as well as the so called "Klangturm" which is in the Center of the recently built Center of the government of Lower Austria. St. Pölten is so far the youngest capital in Austria. Since an election in 1986 Vienna was the Capitel of Austria, of Lower Austria and an autonomous Federal Country. After the peoples decision in 1986 all institutions of the government of Lower Austria went to St. Pölten, after a totally new governmental Center was built.

KM 58,0: View to "Muckenkogel" (1248 m):
The Muckenkogel (1248m) south of Lilienfeld within the Northern Calcareous Alps is the place where skiing began in Austria. On the 19^{th} of March 1905 the first down-hill slalom in the world with 24 men and women was organised by Mathias Zdarsky (1856-1940), the

pioneer of alpine skiing. Later on he organised a lot of courses to make skiing more popular, among the participants were also earth scientists such as Julius v. Pia (1875-1947).

KM 59,0: "Schlier":
The route up the hill brings us from the Pleistocene reformed depression of the Traisen to the "Jüngeren Schlier", which is covered here (KM 60,5 - 61,5) by the "Ältere Deckenschotter" which forms the wide plain north of the highway.
"Schlier" is a common word for pelitic sediments of the Molassezone, which were deposited during the Oligocene and the Miocene. Following a rough classification which was established by mapping geologists at the beginning of our century, "Schlier" may be divided into "Älterer Schlier" (= older Schlier) which is a brown clay to silt of Oligocene age and into the "Jüngeren Schlier" (= younger Schlier), which is grey, more sandy and of Miocene age.

Raststation St. Pölten: View to the Ötscher (1893 m):
From the position of the "Raststation St. Pölten", still at the level of the "Ältere Deckenschotter", there is an excellent view to the south towards the Ötscher (1893 m). The Ötscher is situated within the Northern Calcareous Alps. The peak of the Ötscher consists of Upper Triassic Dachstein Kalk and Dachstein Dolomite (BAUER & SCHNABEL, 1997).

KM 64,0: Pielach Valley:
In the Pielach Valley there is the same sequence of pleistocene deposits as in the Traisen: First we follow the "Niederterrasse", then from Km 65,5 till 66,0 the "Hochterrasse". Older Pleistocene deposits are eroded and so are evident only in small relictic areas.

KM 73,0: View to the north to "Lochau":
Some outcrops at the "Lochau" show a miocene olisthostrome which is intercalated in the "Schlier". Components are derived from the Bohemian Massiv in the North.

KM 76,5: View to the Wachberg (300 m):
The Wachberg shows a distinct plateau at the top (300 m) which is covered by gravels of the Danube during the pleistocene. In this region FUCHS established in 1964 for the first time a detailed sequence of terraces of the Danube (Fig. 3. ?).

The basis of this „Wachberg-level“ sensu FUCHS is at 285-290 m. The gravels of this terrace are rich with quartz (apx. 70%) and crystalline components (30%), most of them are weathered; there are no carbonates (BUCHHAMMER, 1989).

KM 77,5: View to the south: Schallaburg:
The Schallaburg is the most famous castle in Lower Austria in the style of the renaissance. It was built in this style in 1572 from a medieval castle, then after heavy bombing during the Second World War, it was totally restored in 1974. Now the Schallaburg hosts many great exhibitions.

KM 80,0: Sandpit of "Melker Sande", Stift Melk:
At the western part of the Wachberg there is a great sand pit within the "Melker Sande" which could be traced within the whole Wachberg.

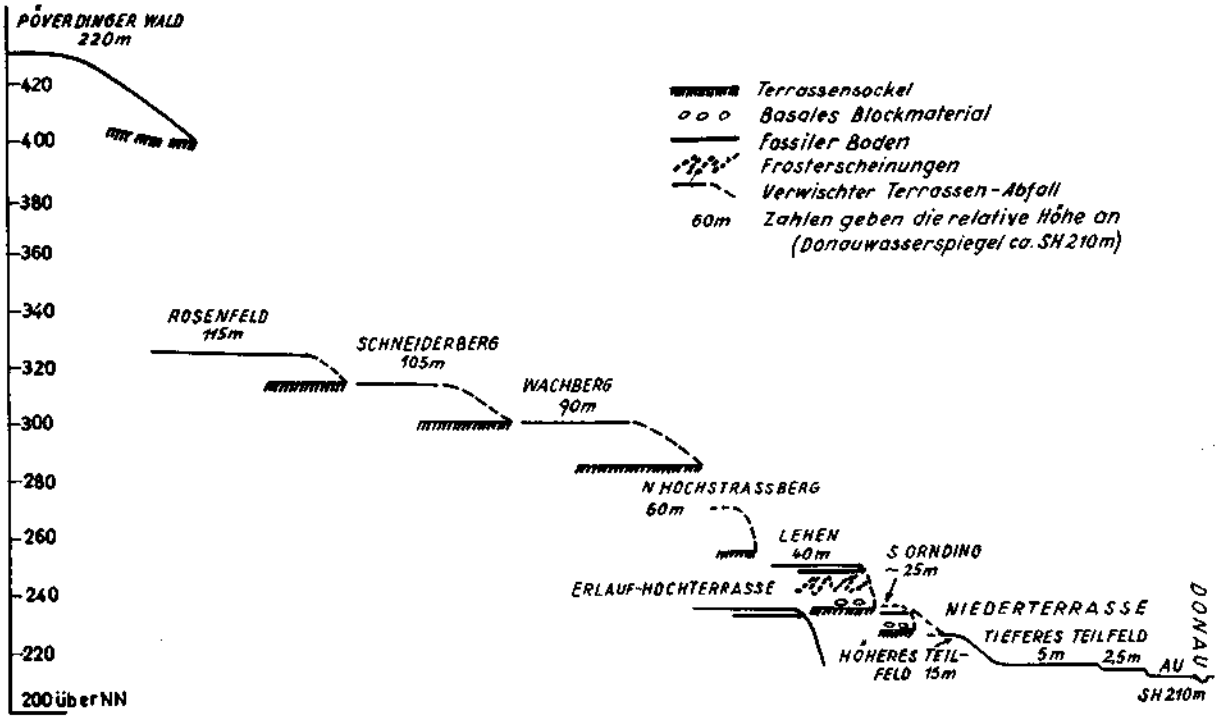

Fig. 3.1.1.: Sequence of Terraces in the Region of Melk (from FUCHS, 1964).

The white Melk Sands are according to ROETZEL (1983), deposited in the wash zone to breaker zone. The spectrum of heavy minerals points to a transport of the sediments from the Bohemian Massif. The poor roundness of the grains makes a short distance of transport probable. Heavy minerals and feldspar seem to be partly influenced by presedimentary weathering processes and the climatic changes from early Oligocene to Middle Oligocene.
The Melk Sands are pure quartz-sands used for the glass industry in nearby Pöchlarn. During late Oligocene and early Miocene the south eastern part of the Bohemian Massif was a wide coastal area with many bays. Due to the changing sea-level we find brackish sediments with coal horizons (Pielach Clays) at the Lower Oligocene, as transgression proceeds coastal sands (Melk Sands) are deposited. Later on - in the lowest Egerian - a regression with the deposition of lagoonal sediments takes place. During the following new transgression reworked coarse sands were deposited on submarine sandbars in the transition zone. In protected nearshore areas the sedimentation of fine coastal sand continues. In the Late Oligocene the deposition of shelf sediments starts with the deposition of „Älterer Schlier", which covers the sequence.

The monastery of Melk is one of the most prominent buildings of baroque style in Europe. It is built on cristalline rock (schists). The building with its 362 m long front and 1188 windows was erected in the period of 1702-1726 according to the plans of Jakob Prandtauer. The monastery is still inhabited by benedictine monks, and is very famous for the rich library (more than 80.000 books, and 1850 handwritten books and documents). Inside, the church and the monastery is decorated with colourful, baroque frescos.

The town of Melk also marks the southern end of the Wachau area which extends to Krems. This 30 km long valley of the Danube is famous for its beautiful landscape, fine wine (since Roman times) and apricots. The latter products of the Wachau can be found in the eastern part and reflect the mild climate. Geologically the Wachau follows to a large extent the Diendorf Fault, a southwest - northeast striking fault. The eastern part of the Wachau is wider and was a bay of the Paratethys during the Middle Miocene.

KM 83,5-84,0: Diendorfer Fault and Hiesberg (558 m):
The river Melk here follows strictly the Diendorf fault. The sinistral NE-SW-striking Diendorf fault dissects the basement into two blocks which are displaced by up to 25 km. Before these movements the granulite Masses of Pöchlarn - Wieselburg in the west and of the Dunkelsteinerwald in the east formed a unit.
The Hiesberg (558 m) in the south is mainly formed by steeply inclined N-S striking paragneisses with intercalations of migmatitic granite gneisses and amphibolites. The coarse grained Zelking Granit is identical with the Weinsberg Granite of the South Bohemian Pluton in the Moldanubian Unit of the Bohemian Massif. (MATURA, 1984)

KM 90,0: Pöchlarn: View to the North:
At the edge of the northern side of the Valley of the Danube, there is the Church of "Maria Taferl" at 443 m. This baroque church was built between 1660 and 1710. It is visited every year by 250.000 to 300.000 pilgrims.

KM 91,5 - 92,0: View to Pleistocene terraces of the Danube:
According to Werner FUCHS (1964) the lower terrace belongs to the „Niederterrasse", whereas the upper one is attributed to the „Hochterrasse".

KM 93,5 - 94,0: Granulite of the Bohemian Massif:
The granulite belongs to the Moldanubian zone in the Bohemian Massif. This zone is divided into three main lithological units (from bottom to top):

the Monotone (= Monotonous) Series,
the Bunte Series (= Variegated) and
the Gföhl Unit.

The latter is predominantly composed of amphibolites, the widespread Gföhl gneiss and granulite. The granulite forms tectonically emplaced klippen such as the Dunkelsteiner Wald at the top of the Moldanubian zone. The granulite comprises pyroxene-free assemblages, which are in a few places intercalated with pyroxene bearing rocks. Kyanite is a common relict phase, either enclosed in garnet or transformed laterally to sillimanite in the rock matrix. The protolith of the pyroxene-free granulite was an acid igneous rock that crystallized close to the wet-granite minimum whereas the less acidic, pyroxene-bearing granulite is most probabley derived from calcalkaline magmatic differentiates (PETRAKAKIS, 1997).

KM 98,0: View to the North to the "Loja-Quarry":
This quarry is situated in a small, apx. 100 m wide slice of the Bunte (= Variegated) Series. Dominating rocks in the quarrry are graphitic schists, garnet rich amphibolites and marbles, which show reaction zones with paragneisses. The whole series of rocks is penetrated by discordant dykes.

KM 99,5: View to the North "Power-station of YBBS":
This power-station was the first of nine powerstations on the Austrian part of the Danube. It was built between 1959 - 1964.

EXIT: „AMSTETTEN OST":
At the northern side of the highway the crystalline of the Bohemian Massif occurs once again.

KM 109,0 - 146,5: Landscape:
Following the route in an eastern direction we pass the so called „Strengberger Hügelland": This hilly landscape is characterised by individual farmhouses („Vierkant-höfe"). We typically find apple and pear trees around the houses. The fruits are used to produce "Most", which has a low content of alcohol and may be to some extent compared to the British "cider".
Geologically the landscape is built of "Schlier" (both types) which is covered by intensively weathered layers of early Pleistocene gravels ("Ältere Deckenschotter") and loess.

KM 146,5: "Schlier":
We cross the contact between the "Älteren" and "Jüngeren Schlier"

KM 149,5: Enns-valley:
We are at the "Niederterrasse" (Riss) of the Enns river. This level is according to VAN HUSEN (1971), divided into three levels (Obere Niederterrasse, Untere Niederterrasse and Oberes Hochflutfeld), which corresponds to the terraces of the Danube.
The River Enns, 254 km with ist source in Salzburg, enters Styria through the east-west striking "Ennstal" which follows one of the major tectonic faults in the Eastern Alps.

EXIT: "ENNS":
The town of Enns with its distinctive Tower (59 m, built between 1564-68) is situated on the „Hochterrasse" and dates back to Roman times ("Lauriacum"). Here the "Hochterrasse" (Riss) begins and continues till KM 157,5, where the level of "Niederterrasse" begins again.

KM 163,0: View to the „VOEST"
Here we have an overview of the steel industry of Linz, which is known as „VOEST" or - in full name VOEST-ALPINE STAHL LINZ GmbH (http://www.voest.co.at)

Turnover:	ATS 19.762 million
Delivered volume:	3,290,000 metric tons flat rolled steel products,
	3,345 metric tons smith hammer forming and forming work pieces,
	5,111 metric tons boiler bottoms.
Employees:	7,917.

Short history of the „VOEST":
1945: Eisen- und Stahlwerke Österreichs" (United Austrian Iron and Steel Works) During the same year the company changed its name to "Vereinigte Österreichische Eisen- und Stahlwerke AG" (VÖEST) (United Austrian Iron and Steel Works, Inc.)
1946: Resolution of the 1st Nationalization Law: Nationalization of VÖEST.
1947: 1st Blast Furnace (No. 5) of VÖEST is started up , Blast furnace bricked, 1st Open-hearth furnace in the steel works is started up.
1948: Blast Furnace No. 3 and 4 are started up, Thin sheet rolling mill becomes operational.
1955: The annual production of pig iron in the 3-Blast-Furnace operation reaches one million metric tons for the first time.
1970 : The start-up of a Sendzimir-4 Roll-Cold Rolling Stand makes the production of very thin sheets possible. The 4-Blast Furnace Operation surpasses an annual production of two million metric tons of pig iron.
1992. Inauguration of Europe's most modern plate testing center in Linz.

1995: In preparation for the listing of the share on the stock exchange, VOEST-ALPINE STAHL AG restructures its portfolio, in some areas extensively, by spinning-off areas of the Group of companies that are not part of the Group's core activities;, among other events, VOEST-ALPINE STAHL JUDENBURG GmbH was sold as well as the majority interest in VOEST-ALPINE INTERTRADING AG.

1997: As a part of the ATS 11 billion capital investment program, the new continuous casting line CC 5 of the Linz steel plant with an annual capacity of 1.2 million metric tons is started up in February. In April the first phase of the expansion of the hot dip galvanization plant 2 Linz is completed on schedule, capacity increases from 240,000 metric tons annually to 280,000 metric tons annually. The final expansion to 350,000 metric tons annually is scheduled for 1998. In the middle of the year, the production plant for laser welded sheet bars is started up. An annual production of approximately 1.1 million steel sheet bars for the automobile industry is scheduled. The wide strip mill in Linz is further modernized extensively.

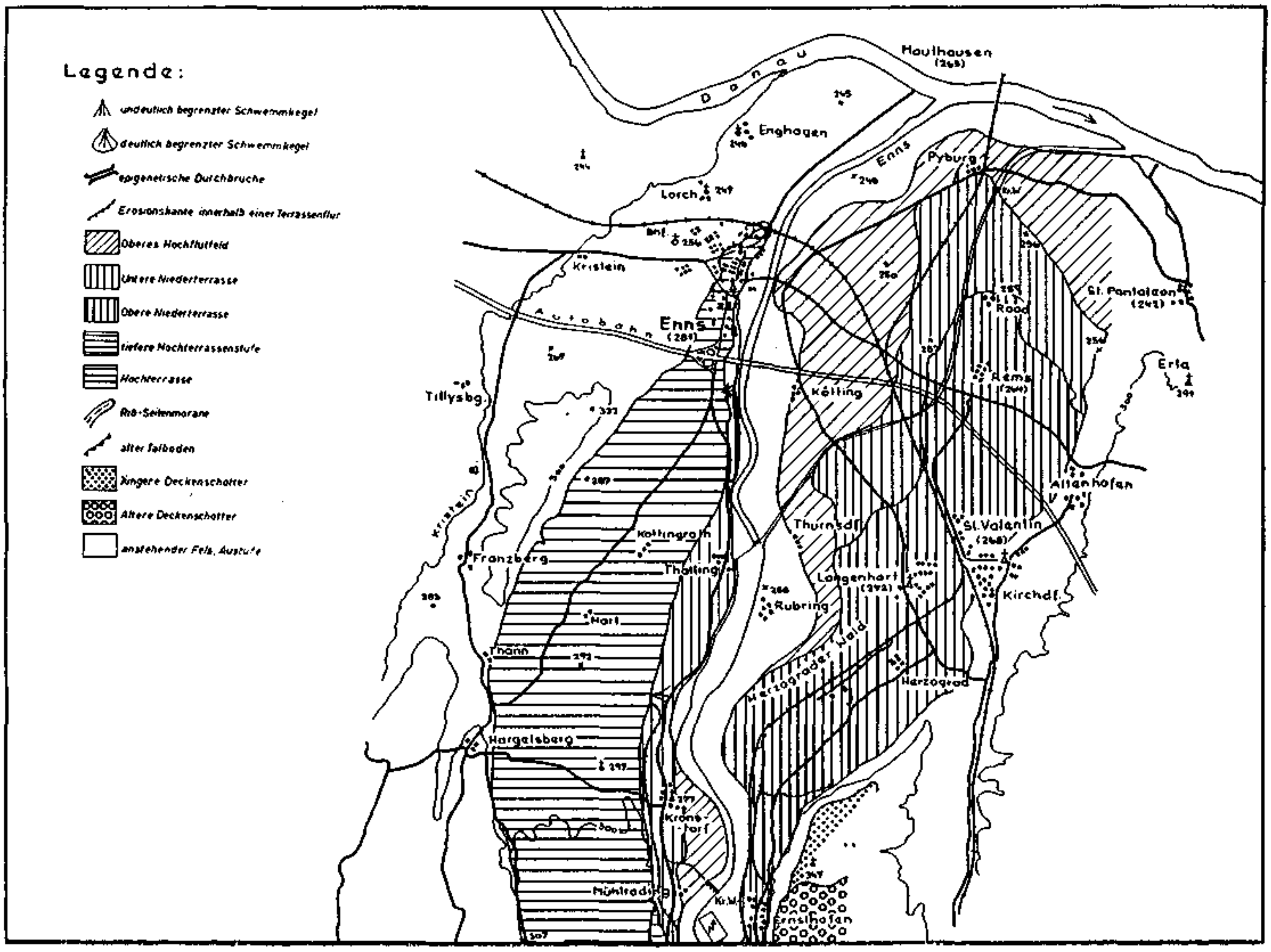

Fig. 3.1.2.: Quarternary geological map of the lower Enns valley (VAN HUSEN, 1971)

KM 164,0: Conglomerates:
The conglomerates belong to the "Ältere Deckenschotter" deposited upon "Schlier".

EXIT: "ANSFELDEN":
In Ansfelden, a town south of Linz, the composer Anton Bruckner was born in in 1824 and died in 1896 in Vienna.

KM 183,0: View to the front: Traunstein (1691 m):
Here we see the Traunstein (1691 m) for the first time. It is built of Mid Triassic Wetterstein Limestone. The Traunstein is close to the northern border of the Northern Calcareous Alps at the east side of lake Traunsee near the town of Gmunden in Upper Austria.

KM 187,0 -189,0: Crossing the "Traun-Enns Platte":
The "Traun-Enns Platte" is named after the River Traun which is the western border and the river Enns in the east. This plain is covered with huge deposits of pleistocene gravels brought from the Alps by several rivers such as the Traun, the Alm, the Krems and the Enns. At the surface the most widespread sediments are „Ältere Deckenschotter". This is due to the great extension of the glaciers during the Günz period. Terminal moraines of later periods (Mindel, Riss, Würm) are found more in the south.
In southern parts there are also several outcrops of the „Kremsmünsterer Nagelfluh", a white breccia which was deposited in a colder period (?Haslach) within the intervall of Günz and Mindel (KOHL, 1996). This 4 to 10 m thick sediment has been a common building stone since Roman times.

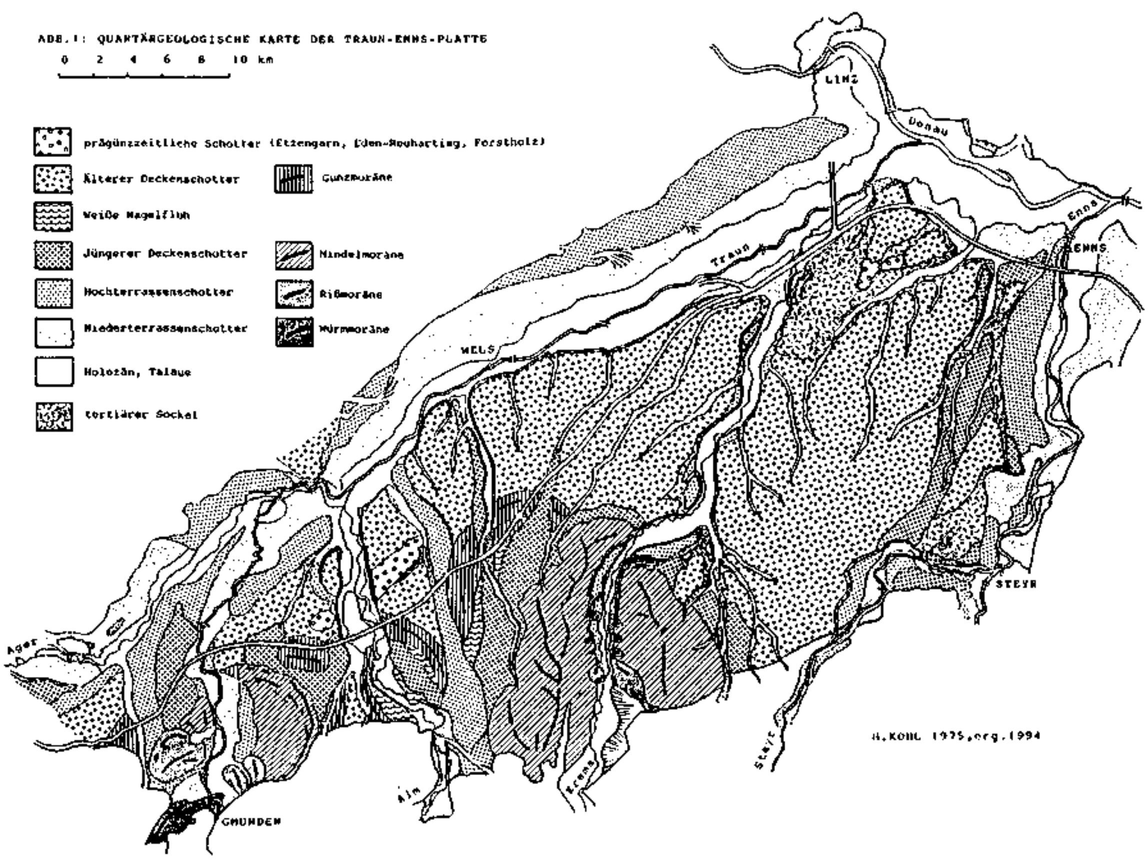

Fig. 3.1.3.: Quarternary geological map of the Traun-Enns-Platte (from KOHL, 1994)

KM 194,0: Oil-Field Sattledt:
This field produces oil from autochtonous Eocene sands and limestones from depths of 1700-1750 m covering the crystalline of the Bohemian Massif. The field belongs to the "Rohölaufsuchungs AG (= RAG)", which is operated by SHELL.

EXIT: SATTLEDT and VORCHDORF:
Here we are at the level of the Günz-Moraine. These deposits could be identified from large artifical outcrops during the building of the highway in the fifties. These deposits come from Pleistocene glaciers of the Steyr and Krems-Valley and the Alm-Valley.

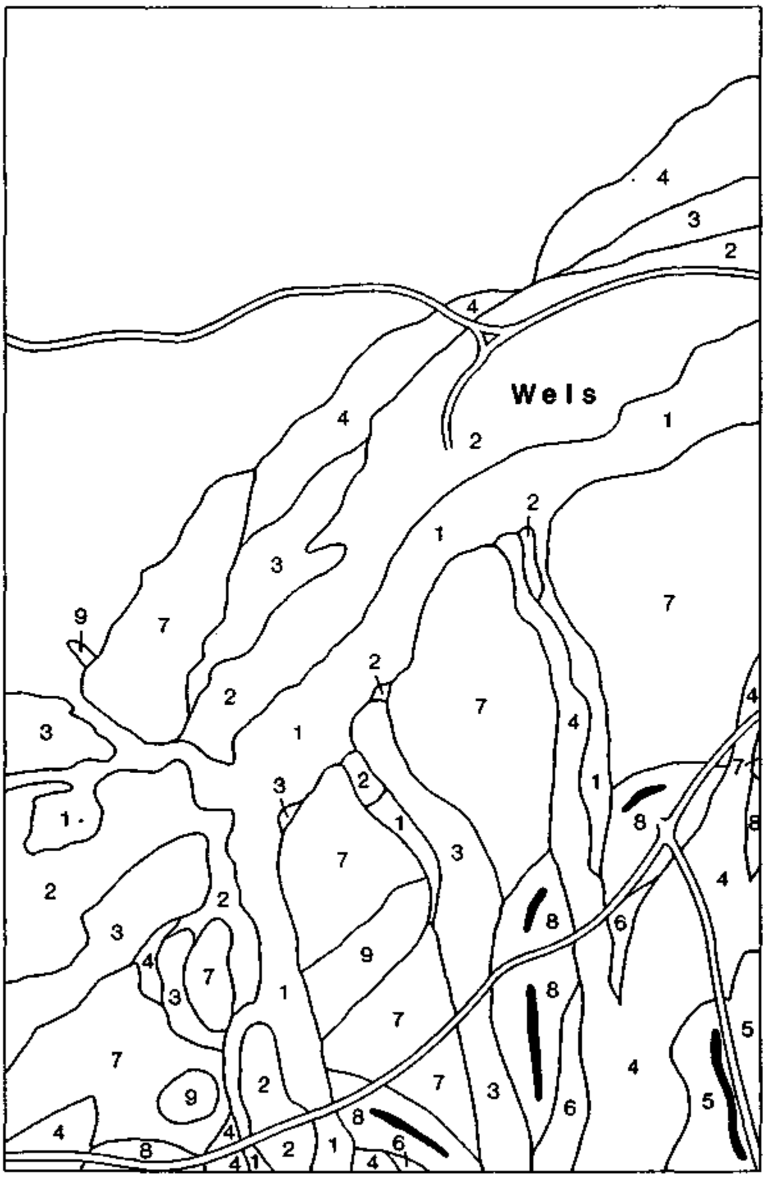

Fig. 3.1.4.: Overview of Pleistocene sediments on map sheet 49 Wels (from: KOHL et al, 1997)
1 = Holocene deposits, 2 = Gravels of the Niederterrasse (Würm), 3 = Gravels of the Hochterrasse (Riß), 4 = Jüngere Deckenschotter (mindel), 5 = Mindelmoraine, 6 = Weiße Nagelfluh (?Haslach), 7 = Ältere Deckenschotter (Günz), 8 = Günzmoraine, 9 = Gravel from Reuharting-Schnelling (oldest Pleistocene to Pregünz)

KM 202,5: Panoramic view to the south
To the east we see Totes Gebirge (2093 m, Upper Triassic Dachstein Limestone) on the horizon, then there is the depression of the lake Traunsee, the peak of Traunstein (1691 m) and then the Höllengebirge (1862 m, Middle Triassic Wetterstein Limestone) which lies between the lake Traunsee in the east and the lake Attersee in the west. All the mountains at the horizon are part of the Northern Calcareous Alps.

KM 220,0: View to the south
The mountain of Hongar (943 m) close to the highway belongs already to the Flysch Zone and is built of the Altlengbach Formation, which is dominated by sandstones of the Late Cretaceous (Maastrichtian) and early Tertiary (Paleocene) and the marly Zementmergelserie, (Upper Cretaceous Campanian) (EGGER et al., 1996).

EXIT "REGAU":
Leaving the Highway at Regau we turn south towards Gmunden. Here we cross several moraines. An outer circle is divided into two parts and attributed to the Riss, the inner circle, where the town of Gmunden is situated, to the Würm (EGGER et al., 1996).

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3.2. Stop Gmundner Berg

Panoramic view to the eastern side of Lake Traunsee
Thomas HOFMANN

Lake Traunsee covers an area of 25,6 km², has a maximum depth of 191 m (average 89,7 m) with a water volume of 2.300,000.000 m³ and a catchment area of 1417 km².
The profile from the North to the South (from TOLLMANN, 1985, Fig. 93) shows a sequence from the Rhenodanubian Flyschzone and the Northern Calcareous Alps.
The Grünberg (984 m) is built of Altlengbach Formation (Maastrichtian to Late Paleocene), which is rich in sandstones and the Campanian Zementmergelserie dominated by marls.
The smooth depression north of the Traunstein (1691 m) is the Gschliefgraben which represents in a tectonic window the Ultrahelvetic Zone. The Gschliefgraben has been famous for landslides and debris flows since the 15th century. An area of apx. 5 km² is affected by the slowly downhill slipping debris flows. The triggering factor is the loose „Buntmergel" (= marls) of the Ultrahelvetic Zone in combination with the tectonic position at the front of the Northern Calcareous Alps (NCA). The front is composed of small tectonic slices (Bajuvaric part of the NCA) which include Haselgebirge (a sandstone-clay-evaporite association, containing gypsum and salt of the Permian-Skythian), the most mobile horizon in the Northern Calcareous Alps. Towards the north some beds of the southern parts of the Rhenodanubian Flysch Zone occurs the Perneck Formation (Campanian-Maastrichtian) - which is also very mobile, due to the geological material (slates and marls).

The Traunstein (1691 m) and the Schönberg (895 m) already belong to the Tirolic part of the NCA, that consists of Mid-Triassic Steinalmkalk.

In the depression of the Eisenbach we find Cretaceous Sediments of the „Gosau-Group". In a quarry at Karbach, right at the eastern side of Lake Traunsee, we find a sequence of Upper Triassic (Platten Limestone, Dachstein Limestone), Lower Jurrassic (Hierlatz Limestone), Middle to Upper Jurassic [?] (Grünanger Beds), Upper Jurassic (Plassen Limestone, Tressenstein Limestone, Oberalmer Beds) and Cretaceous Sediments („Gosau-Group").

The peak of Erlakogel (1575 m) is formed of the Liassic Adnet Formation (red limestones) which is underlain by the Upper Triassic at the slopes of the Mountain. The Rindbach-Valley with beautiful waterfalls, which are protected as a Natural Monument, show the deepening of the water within the Upper Triassic Platten Limestone and the Lower Jurrassic Hierlatz Limestone.

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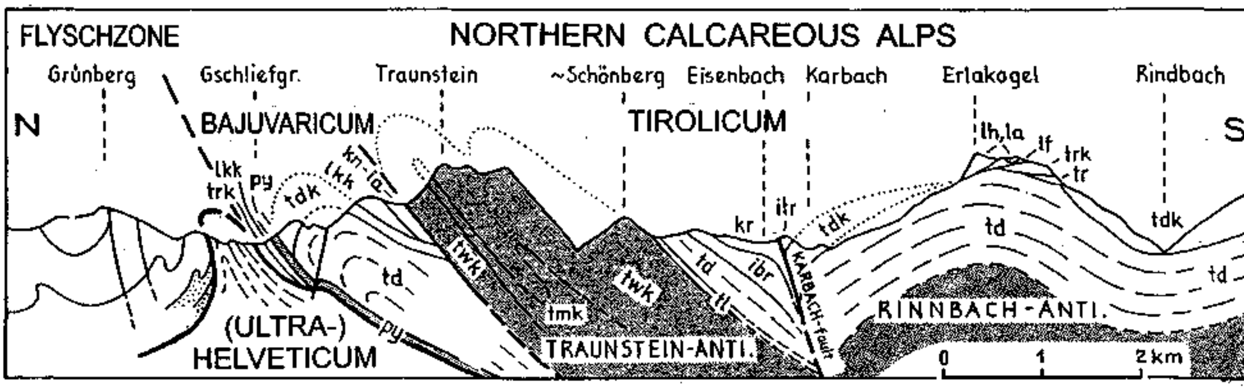

Fig. 3.2.: Geological section of the eastern border of Lake Traunsee (from TOLLMANN, 1985)

3.3. Bus tour Gmunden-Hallstadt

Along the road on the western side of the lake the Calcareous Alps are crossed to reach the town of Bad Ischl. During the second half of the 19^{th} and the early 20^{th} centuries, this lovely town was the favourite place of Emperor Franz Josef I. for recreation.

After passing Bad Ischl the road continues southward for some further 25 km to Hallstatt. For explanatory notes concerning the history of research, stratigraphy, tectonics and the overall implications of this classical region for Triassic-Jurassic geology of the Alps see chapter 2.5., 4.1., 4.2., 5.1. and 5.2.

4. The Dachstein-Hallstatt-Salzkammergut Region

4.1. A brief history of geological research of the Dachstein-Hallstatt-Salzkammergut Region

Harald LOBITZER & Gerhard W. MANDL

Besides its unique scenic beauty, the area around Hallstatt is well known for its long tradition in salt mining. Underground mining of rock salt - the "white gold" - commenced around 4500 years ago. Also the name "Salzkammergut" refers to the traditional economic resources of this region, the salt mining. In addition, the Salzkammergut - and in particular the region around Hallstatt and Bad Aussee - has been a classical area for geoscientific research in the Tethyan Mesozoic for over 200 years. It is recorded in early travel reports, that the salt miners of Hallstatt collected ammonites and sold them to tourists and also to museum collections. Most of the ammonites were collected in the famous red limestones of Upper Triassic age ("Hallstatt limestone"), close to the Hallstatt salt mine or from Liassic red limestones ("Hierlatz Limestone"), more rarely from "Klauskalk", a red limestone of Dogger age, both also from the surroundings of Hallstatt. Already in 1782 the Bohemian naturalist J. BOHADSCH mentions the nearby fossil-rich rock formations, in particular in the area of Gosau. Gastropods, corals, ammonites and other petrefacts from this Upper Cretaceous Gosau Group could be purchased from local commercial collectors; this is true even for today !

Leopold von BUCH

The first remarkable geognostic study of the Salzkammergut dates back to the year 1802, when the renowned German naturalist Leopold von BUCH published his 2-volume booklet *"Geognostische Beobachtungen auf Reisen durch Deutschland und Italien"* (volume 2 was published in 1809). An extensive treatise in Volume 1 entitled *"Geognostische Uebersicht des Oesterreichischen Salzkammerguths"* deals with observations in this region, which he carried out in part together with his fellow and mentor Alexander von HUMBOLDT in the years 1797-1799. BUCH noticed the dominance of limestone and speculated on its striking colour variations. He attributes the variations of colour to different levels in altitude of the exposed limestones: "The red colour of limestones seems more common in the deep valleys, it disappears uphill and on the summits of the mountains only white limestones are exposed, while in the intermediate altitudes they show mostly a pale smoky greyish hue". This "phenomenon" is explained by BUCH by the fact that the metal solutions which extensively stained the lower part of the limestone masses - were either not sufficient quantitatively or too heavy to follow the newly formed limestone masses to the higher altitudes. BUCH also realized the abundance of fossils in the red limestones, which never occur as individual specimens but always as clusters. As a consequence of the aforementioned concentration of red limestones in the valleys, BUCH draws the conclusion, that the rich "Fossil-Lagerstätten" are concentrated in the red limestones of the valleys, while the white limestones are widely devoid of fossils. However, besides these odd hypotheses, BUCH identified already coquinas of *Pecten*-like bivalves in the region of the Hallstatt salt mine (named by BRONN 1830 *Halobia* and *Monotis*) and mentions orthoceratids, ammonites and nautiloids.
BUCH also deals with the origin of limestone bedding and the reasons for varying dipping directions, the latter he attributes to variable underground conditions, which force the beds

to change their striking and dipping directions. There is no evidence, that BUCH understood already the primary sedimentary or diagenetic origin of limestone bedding, respectively the effect of tectonic forces in respect to mountain building.
Of course BUCH dealt also extensively with the origin, mineralogy and the age of the Hallstatt salt mine. The discussion about the origin and age of the Haselgebirge persists up to the present and only due to more sophisticated geochemical and paleontological methods has a better understanding been obtained during the last decades. The key questions, tectonic versus sedimentary origin, respectively Permian versus Lower Triassic age will be discussed in extent during our trip to the salt mine!
BUCH showed also interest in hydrogeological questions, such as the water balance of Lake Hallstatt, where he considers hidden subsurface springs as important contributors. Last but not least, he records an earthquake in Hallstatt on March 12, 1789, which lasted 4-5 seconds. It started with a bang, while the shock wave spread from south to north, accompanied by sonorous humming.
Astonishingly enough, the pioneer paper by Leopold von BUCH (1802) did not trigger immediate further research activities, but only almost twenty years later were the next studies on this region published, showing already the considerable progress made in our science.

1821-1845: Laying the foundation-stone

The following period of research in Salzkammergut was largely dominated by the excellence of British geoscientists. William Buckland´s *"Uebersicht über die Struktur der Alpen"* (1821) is one of the first attempts to subdivide the "Alpenkalk" into several lithologic units. According to him the Alpenkalk comprises the complete stratigraphic sequence from the Magnesian Limestone (Upper Permian) till the Chalk (Upper Cretaceous). The evaporitic sediments of the Haselgebirge are already considered to be of Upper Permian age, the red marly sandstones (Werfen Formation) from Hallstatt are equivalent to the New Red Sandstone, while the ammonites from Hallstatt represent the Liassic.
The famous Bavarian geologist Ch. KEFERSTEIN edited a journal entitled *"Teutschland, geognostisch-geologisch dargestellt"*. In volume 5 of this journal, KEFERSTEIN (1828) describes in detail a walking tour from Hallstatt over the Salzberg to Gosau. For him the formation of the salt and gypsum deposits occurred due to "osmotic respiration processes" within the clays. Besides this odd hypothesis, KEFERSTEIN gains merit in that he introduces the comparison of fossils as a new stratigraphic method. He studied and compared especially the fauna of Gosau with stratigraphically well dated faunas from abroad. This approach represents an enormous step forward! However, his main error was, that he considered the "Sandstone Formation" (Gosau Group) as older/underlying rock unit superimposed by the "Limestone Formation" of the Alpenkalk.
In 1828 the Bohemian born Carl Lill von LILIENBACH published his paper on *"Allgemeine Lagerungsbeziehungen der Steinsalz-Lagerstätten in den Alpen"*. He lists many fossils, however, is very cautious about their stratigraphic significance. Subsequently there was a rapid series of publications. In 1829 the famed British geologists SEDGWICK & MURCHISON published their paper *"On the Tertiary deposits of the Vale of Gosau in the Salzburg Alps"*, followed in 1830 by the papers by the French born Ami BOUÉ entitled *"Description du Basin de Gosau"* and by C. Lill von LILIENBACH *"Ein Durchschnitt aus den Alpen mit Hindeutungen auf die Karpaten"*. SEDGWICK & MURCHISON´s paper represents the first detailed stratigraphic study of the Gosau locus classicus, however, they considered the sequence as being Tertiary in age. BOUÉ considers the Gosau Group as stratigraphically coeval with the Greensand. Lill von LILIENBACH´s paper from 1830 represents the first attempt to subdivide the sequence of the Northern Calcareous Alps

into clearly defined rock units, comparable to the present "Groups". For instance he coined the name "Werfen Shales", into which he also placed the evaporitic Haselgebirge. Lill´s paper is also fundamental as a first attempt to compare rock units of the Northern Calcareous Alps with coeval ones from the Carpathians.

The paper by SEDGWICK & MURCHISON from 1831 *"A sketch of the structure of the Eastern Alps"* can be considered a real milestone in the history of research of the Austrian Alps. It demonstrates the progress in the application of new methods, as for instance using fossils as useful tools in biostratigraphy, or the comparison of sequences on an European wide scale. In addition, SEDGWICK & MURCHISON were drawing a series of geo-traverses through the Eastern Alps perpendicular to the striking direction of geological units. The main axis of the Eastern Alps ("Zentralzone") was already recognized, as well as the existence of the Northern and Southern Calcareous Alps. In the Salzkammergut the British in cooperation with Lill von LILIENBACH (who accompanied them in the field), continued the subdivision of the rock units, in particular of the Alpenkalk. The red shales of the Werfen Formation were seen in close association with the evaporitic Haselgebirge. Furthermore they introduced terms such as Lower and Upper Alpine Limestone and Greensand respectively Cretaceous Deposits; all these terms were later replaced by new and more precise ones.

1846-1853: Disenchanting the Alpenkalk

For a long period the Alpenkalk was considered to be of Liassic age by some workers (especially the formation called Dachstein Limestone from 1847 onwards) and by others as being Jurassic in general. The famous German geo-scientist F.A. QUENSTEDT still believed in 1845, that the Alpenkalk represents the Neocomian - based on (incorrect) ammonite determination. The breakthrough came closer, when HAUER started detailed systematic studies of the ammonite fauna of the Hallstatt Limestone in 1846. It became more and more evident that Triassic formations contribute substantially to the sequence of the Northern Calcareous Alps. The first definite short references, regarding the important role of the Triassic in the sequence of the Northern Calcareous Alps, we owe to the Swiss geologist A.v. MORLOT, 1847 and also to HAUER, 1848. Following these initial findings, new lithostratigraphic units were defined in the following years, replacing the obsolete term Alpenkalk. In his classical paper from 1853 "Ueber die Gliederung der Trias-, Lias- und Juragebilde in den nordöstlichen Alpen" Franz von HAUER presents the following sequence for the Triassic of the Northern Calcareous Alps: Werfen Formation (including the Haselgebirge) = Buntsandstein, Guttenstein Formation = Lower Muschelkalk, Hallstatt Formation = Upper Muschelkalk, Dachsteinkalk = Lower Liassic. The Liassic age of the Hierlatz Limestone was confirmed by Eduard SUESS in 1852 while the Upper Jurassic age of the Plassen Limestone was already recognized by HAUER in 1850. The fauna of the Plassen Limestone was described by MOJSISOVICS in 1868.

The Haselgebirge - source of the "white gold"

The so called Haselgebirge is represented by a mélange of evaporitic minerals - mostly rock salt - and clays. For a long time it was argued, that the primary sediments of this mélange represent an environment, where biota cannot live, respectively cannot be preserved, and therefore the stratigraphic age of the Haselgebirge remained speculative. Due to the mobility of this clay/salt mixture - diapirism included - the question of stratigraphy was still more obscured. The mineralogy of the Haselgebirge has been well studied since the last century and a tremendous amount of papers deal with genetic questions, i.e. tectonic versus sedimentary origin of the mélange. Also tholeitic basalts have been found in association with the Haselgebirge (FOULLON, 1889, C.v. JOHN, 1899, GÖRGEY, 1914, SEIDL, 1927, AMPFERER, 1928, HIMMELBAUER, 1931, PETRASCHECK, 1947, SCHAUBERGER, 1949 f., ZIRKL, 1957, MEDWENITSCH, 1968, a.o.).

Concerning the stratigraphy of the Haselgebirge, a breakthrough was achieved by Wilhelm KLAUS (1953, ff.). It was already known since 1913, that in salt-clays of the North-German Zechstein sporomorphs had been found and also PETRASCHECK (1947) reports the first findings of palynomorphs in washing residues from the Haselgebirge in Hallstatt. Finally KLAUS systematically investigated all Alpine salt deposits for pollen and spores. He found, that the preservation of palynomorphs is best in pure salt and also still acceptable in the salt-clays, however, in the latter strong fragmentation of the palynomorphs can be occasionally observed. Already in his first paper concerning these investigations (1953), KLAUS proudly stated: "In the Eastern Alps palynology became the paleontology of the salt". Later on, sulfur-isotope studies (e.g. HOLSER & KAPLAN, 1966, PAK, 1974 ff.) confirmed the Upper Permian age, which KLAUS postulated, for a large part of the Haselgebirge. Recently Christoph SPÖTL was also successful in confirming, that the main part of the Haselgebirge is of Permian age and only a comparatively small portion shows an early Triassic age (SPÖTL & PAK, 1996).

Hallstatt - The Standard for the Upper Triassic Substages

The region around Hallstatt and Bad Aussee is famous for its "Fossil-Lagerstätten" in the Hallstatt Limestone Group. The Hallstatt Limestone Group comprises variegated coloured (mostly red) micritic limestones from the Upper Anisian (Schreyeralm Limestone) till the Upper Triassic Carnian and Norian Hallstatt Limestones sensu strictu. Franz von HAUER with his famous paper from 1846 *"Die Cephalopoden des Salzkammergutes aus der Sammlung seiner Durchlaucht des Fürsten von Metternich"* opened the Austrian participation in Mesozoic biostratigraphic research. With HAUER and later on by his contemporary, the brilliant Eduard SUESS, an incredible story of success started. In 1849, the Geologische Reichsanstalt was established and soon HAUER and SUESS jointly established a Mesozoic working group, which later on became famous as the "Viennese School of Paleontology/Geology", among them scientists such as M.V. LIPOLD, Edmund von MOJSISOVICS, Alexander BITTNER, Ferdinand STOLICZKA, Melchior NEUMAYR, Moriz HOERNES, Dionys STUR, Georg GEYER, Gustav von ARTHABER, (later also Carl DIENER), and others. However, also German scientists contributed a substantial share to early stratigraphic research in the Triassic and Liassic of Salzkammergut, as for instance GÜMBEL, KOKEN, OPPEL, ZITTEL, FRECH, and others. Even though grave stratigraphic errors still persisted, the monographic studies on Triassic ammonites by MOJSISOVICS remain unrivaled to the present day (e.g. *"Das Gebirge um Hallstatt"*, 1873 ff. and *"Cephalopoden der mediterranen Triasprovinz"*, 1882). However, also the facies relations of various rock units were attracting attention, as for example in the spectacular paper by MOJSISOVICS from 1868 *"Faunengebiete und Faciesgebilde der Trias-Periode in den Ostalpen"*. It was only about 30 years ago, that the classical profiles by MOJSISOVICS were re-investigated (e.g. KRYSTYN et al., 1969, 1971; KRYSTYN, 1973; SCHLAGER, 1969, a.o.). Since these modern studies, the complex interplay of sedimentation and synsedimentary tectonics is evident and many of the classical sections in the Hallstatt Triassic and Liassic have been shown to represent not concordant sequences, but neptunian dykes. More recently Tim TOZER from Canada has studied this fascinating period of research, which can be apostrophized as a high point in systematic-paleontological research, however, which was somehow overshadowed by insufficient understanding of the sedimentological parameters. At present, out of 13 Upper Triassic

Tethyan ammonite zones, 10 are described from the Salzkammergut, respectively all Upper Triassic substages, except the Lower Carnian ones, are also defined in this region (KRYSTYN, unpubl. Manuscript). The Salzkammergut also contains the richest Upper Triassic ammonite sites in the world. From the Feuerkogel nearby Bad Aussee more than 500 ammonoid taxa of Carnian to Norian age have been described (HAUER, 1846 f., MOJSISOVICS, 1873 f., DIENER, 1923) and from the Sommeraukogel an additional 100 Norian ammonoid species have been described by MOJSISOVICS, 1873 ff. (KRYSTYN, l.c.).

The Dachstein Limestone

The determining rock formation of the Hallstatt region, however, is the Dachstein Limestone, which shows exposures in the Hallstatt environs of more than 1500 m thick (e.g. Hierlatz-Wand). The classical region of the Dachstein Limestone is the large karst plateau of Mt. Dachstein (2996 m). The Dachstein Limestone is represented for the main part by well bedded "lagoonal" limestones (see chapter cy), which are bordered to the south by a reef development (we will visit the reef-tract of the Gosaukamm and the lagoonal facies along Loser panorama road).
The plateau of Mt. Dachstein is not only the classical region of the Dachstein Limestone (name coined by Friedrich SIMONY, 1847), but is also a spectacular area of Alpine limestone karst research. Also the geomorphological studies of the Dachstein limestone karst, which represents an important water resource, are closely bound to the name Friedrich SIMONY, who dedicated his life to the study of the glacial phenomena and the influence of the atmosphere on limestone weathering in higher altitudes.
The most characteristic fossils of the Dachstein Limestone are the heart-shaped cross-sections of megalodontid bivalves. Depending on the area, these conspicuous bivalve sections are called in vernacular language "lithified hearts" or "cow traces" or "red deer traces". The famous Bavarian geologist C.W. GÜMBEL (1862) was the first to give a detailed description of these characteristic bivalves in the Northern Calcareous Alps. It was also GÜMBEL, who pleaded for an Upper Triassic (Norian/Rhaetian) age of the Dachstein Limestone; before a Liassic age seemed already generally accepted!
The question, which bivalve genus or species did the "Dachstein-bivalve sensu strictu" represent started already in the 18th century, when HACQUET (1781) and WULFEN (1793) gave the first systematic descriptions. The next generation, which dealt intensively with this "causa prima", were geo-scientists from Lombardy and Veneto, especially CATULLO, CURIONI and STOPPANI. In Switzerland Escher von der LINTH and MERIAN participated in this discussion and SCHAFHÄUTL in Bavaria. In Austria the French born all-round scientist Ami BOUÉ and later on Franz von HAUER dealt with this question. Finally Leopold von TAUSCH pleaded in his monography from 1892 *"Über die Bivalvengattung Conchodus und Conchodus Schwageri n.f. aus der obersten Trias der Nordalpen"* for this genus to represent the one and only "Dachsteinbivalve" - the real thing sensu strictu. Several of the specimens described and figured by TAUSCH were collected in the vicinity of Hallstatt, in particular in Echernthal, Wiesberg Höhe, Mitterwand and Hierlatz. Also in modern papers by ZAPFE (1957, 1964), TICHY (1974) and VÉGH-NEUBRANDT from Budapest, the species *Conchodus infraliasicus* is considered one of the main representatives of the "Dachstein-bivalves". Probably the last word has not yet been spoken on this (local) key question for geosciences.

Studies on carbonate facies

Two phenomena of eminent importance drew the attention of many sedimentologists to the Dachstein region, i.e. the origin of the bedding, respectively cyclicity of the lagoonal Dachstein Limestone and the phenomenon of neptunian dykes. The latter caused tremendous long lasting misinterpretations in Triassic and Liassic stratigraphy, because many of the classical ammonite localities in the Hallstatt region are bound to neptunian dykes or - in some cases - represent stratigraphic condensation of faunas (Feuerkogel).
Eduard SUESS (1888) explained the bedding, respectively cyclicity of the Dachstein Limestone, as a consequence of subaerial exposition of the beds and subsequent weathering of the bedding planes. In 1928 Kurt LEUCHS assumed, that the variegated coloured thin intercalations in the Dachstein Limestone represent a rudimentary Hallstatt facies, while SCHWARZACHER (1948) studied the Norian Hallstatt Limestone of the Steinberg- und Sommeraukogel. The well-known study by Alfred G. FISCHER (1964) on the cyclicity of the Dachstein Limestone is explained in detail in the chapter on Loserstraße road cuts.
In addition, the working group led by Alfred G. FISCHER also carried out early studies of deeper water limestones by means of electron microscope in the Salzkammergut region (e.g. paper by HONJO, GARRISON & FISCHER), which opened a new dimension in lithogenetic studies.

Early micropaleontological studies

The study of rock thin-sections was probably established in England as a consequent follow-up of microtomic botanical and medical studies. In the Austrian Northern Calcareous Alps Karl PETERS was the first geoscientist to apply these new techniques. In his classical study from 1863 *"Über Foraminiferen im Dachsteinkalk"*, PETERS reports on planktonic foraminifers ("Globigerinas") in the Dachsteinkalk of Echerntal in the vicinity of Hallstatt. Later on, the finding of these early Globigerinas was thought to be dubious by KITTL (1903), who considered the limestones to be Upper Jurassic Plassenkalk. In 1913 A. HEINRICH reports on Globigerinas in the Carnian Hallstatt-Limestone of Feuerkogel/Rötelstein, close to Bad Aussee. In more recent times Rudolf OBERHAUSER (1960) and Edith KRISTAN-TOLLMANN (1964) describe early "Globigerinas" from the Rhaetian Zlambach Marls of Salzkammergut and finally Werner FUCHS (1967, 1969, 1975) provides a systematic description of this rather neglected group of planktonic foraminifera from material from the Italian Dolomites and from the Salzkammergut region. One of the systematic groups (family Oberhauserellidae) is currently under revision by Donato DI BARI from Modena.
The region around Hallstatt and Bad Aussee is also a classical area for Triassic conodont research. The first review paper was published by the German R. HUCKRIEDE in 1958: *"Die Conodonten der mediterranen Trias und ihr stratigraphischer Wert"*, followed by the papers by the American L. MOSHER in 1968. MOSHER succeeded in using the evolutionary trend of platform conodonts for worldwide stratigraphic correlation. His reference sections also include the classical Upper Triassic ammonite localities Sommeraukogel and Steinberg-kogel, nearby Hallstatt, which were previously described by MOJSISOVICS. Later on, Walter C. SWEET and especially Leopold KRYSTYN successfully continued this challenging work on a worldwide scale, including also the classical key sections in the Salzkammergut.
MOJSISOVICS (1903) in one of his last papers summarized his ideas of the palaeo-geographic position of the Hallstatt zones. He postulated an in situ position of the sedi-

ments of Hallstatt type deposited in "channels" cutting through the Dachstein Limestone platform.
One year later the paper of HAUG & LUGEON (1904) marks a fundamental break through in the history of geological research in the Salzkammergut area: the concept of nappe tectonics was established. In the sequel the "nappists" entered into competition with the "autochthonists". KOBER and his school (e.g. MEDWENITSCH, 1958, TOLLMANN, 1960 and others) plead for an extreme nappism. On the other hand DIENER, LEUCHS, TRAUTH and in modern time ZANKL and SCHLAGER followed a modified version of the autochthonous concept of MOJSISOVICS. PLÖCHINGER, 1974, 1976 and SCHÄFFER, 1976 revealed the significance of Jurassic gravitative nappe movements in the Salzkammergut area for the geodynamic history of the Northern Calcareous Alps. TOLLMANN, 1976, 1981 has briefly summarized all the contradictory models (see Fig. 4.1.), which have been suggested to explain the complex geology of this exciting part of the Northern Calcareous Alps.

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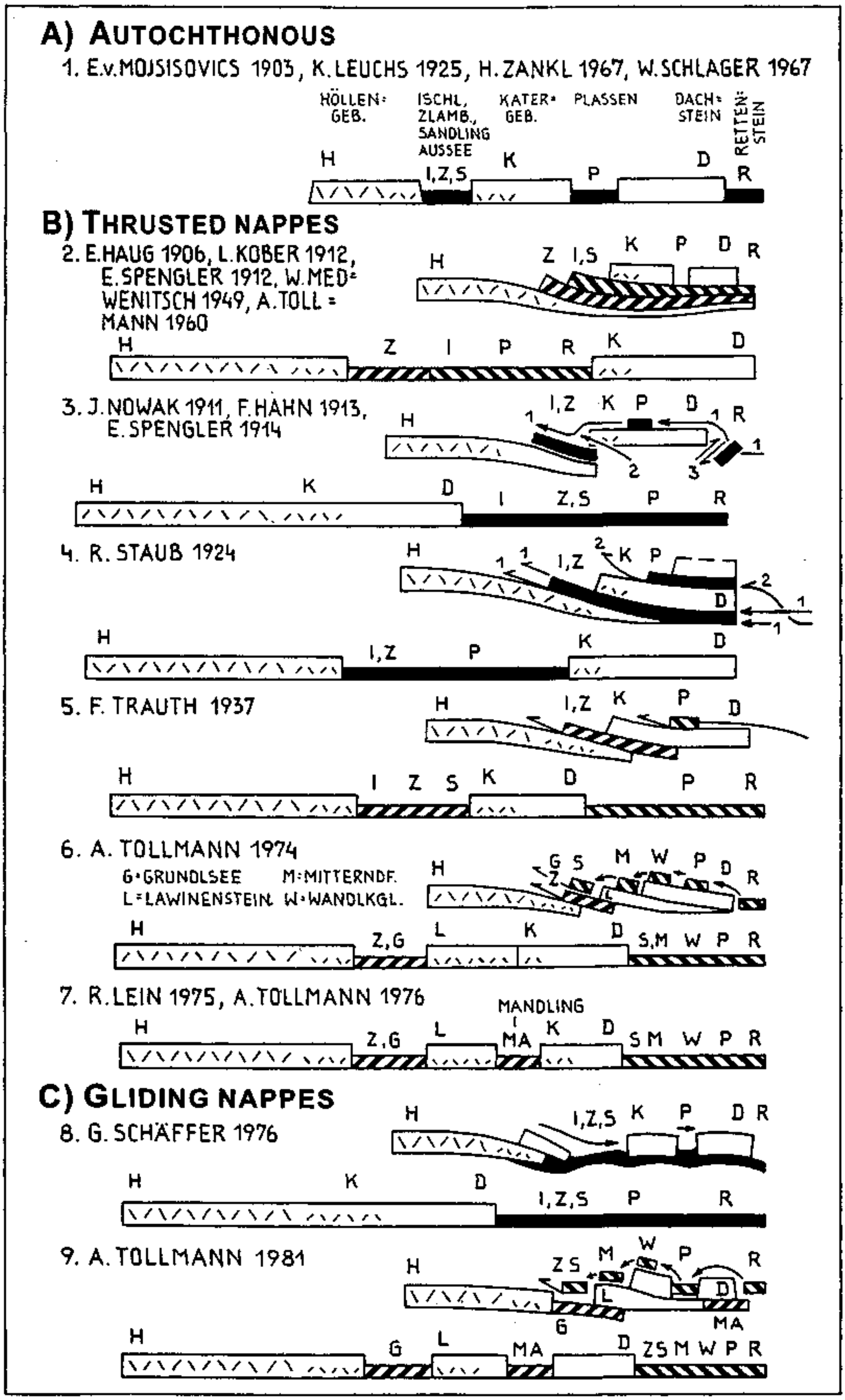

Fig. 4.1.: Schematic representation of different models of the palaeogeographic and/or tectonic relation between Triassic platforms and basinal sediments of the Salzkammergut. After TOLLMANN (1981).

4.2. Geological overview of the "Juvavic" Realm
Gerhard W. MANDL

The uppermost tectonical elements of the Northern Calcareous Alps are traditionally summarized under the term Juvavicum (Juvavum was the Latin name of Salzburg). From our recent point of view they represent those parts of the Austroalpine distal shelf area, which became firstly detached from its basement during the Upper Jurassic („Eohellenic" phase of Alpine Orogeny), caused by the plate-tectonical closure of the westernmost part („Hallstatt-Meliata ocean") of the Tethys ocean. Repeated compressional tectonics affected the NCA additionally between Upper Neocomian to Eocene, large strike slipe faults dissected the nappe pile during the Miocene.

Due to this deformation history a complex pattern of tectonical units has been created in the Juvavic realm. The dissection of the Triassic sediments mainly has followed facies boundaries, often resulting in „unifacial" tectonic bodies. Therefore especially the original configuration of platforms and basinal areas has been a matter of long lasting and controversial discussion.

Careful mapping of facies distribution within distinct tectonic units, accompanied by biostratigraphic control, has revealed a lot of information about general facies trends and the relation between different facies types. This polarity of facies can be used as a tool for palinspastic reconstruction.

The orientation of platform to basin transitions within the larger Juvavic units provides a frame for palinspastic restoration of the Juvavic realm. As shown in Fig. 2.5.4. all transitions from platform to open marine conditions are oriented in a similar manner, facing toward the south. A „Dual Shelf Model" - as it has been proposed recently by some authors (KOZUR & MOSTLER, 1992, SCHWEIGL & NEUBAUER, 1997) - is in contradiction to the visible facies patterns and has to be rejected. If the Juvavic units would originate from an opposite southern shelf, separated from the Tirolic shelf by an ocean (Meliata realm), the Juvavic units should exhibit facies gradients of also opposite orientation.

The NCA represent the carbonatic shallow shelf area and its transition into deeper pelagic conditions - see Fig. 4.2.1. The adjacent oceanic realm seems not to be preserved in Austria to a larger extent. Only a few small "exotic klippen" of such an origin have been discovered - MANDL & ONDREJICKOVA, 1991,1993, KOZUR & MOSTLER, 1992. But the Triassic deep-water sediment (red radiolarite) is preserved there only as olistolites in a Jurassic matrix of dark shales and greenish radiolarite. Representatives of the Triassic oceanic crust are not proven. Candidates for such an origin are the tholeiitic pillow basalts and serpentinite fragments within the melange of Permian evaporites along the basal thrust-planes of several Juvavic nappes. Unfortunately we have no clear evidence of their extrusion age until now.

Toward the north the carbonatic NCA shelf changes into a siliciclastic one ("Keuper facies") which is represented today by the cover of metasediments of the Austroalpine crystalline nappes.

The tectonical detachment of the Triassic to Jurassic shelf sediments from their basement has started about the end of the Middle Jurassic ("Eohellenic phase"). Jurassic syntectonic clastics as well as the "sandwich" of Juvavic units demonstrate a first displacement from Hallstatt deeper shelf (Pötschen- and Salzberg-Facies) and gravitative transport onto and across the drowned Triassic shallow shelf. Rocks derived from the Meliata oceanic realm should have been mobilized also before oder during this phase. With time the detachment encroached on the Triassic platform margins and at last on the platforms themselves - creating the large „Upper" Juvavic nappes like Dachstein or Mürzalpen nappe. These large

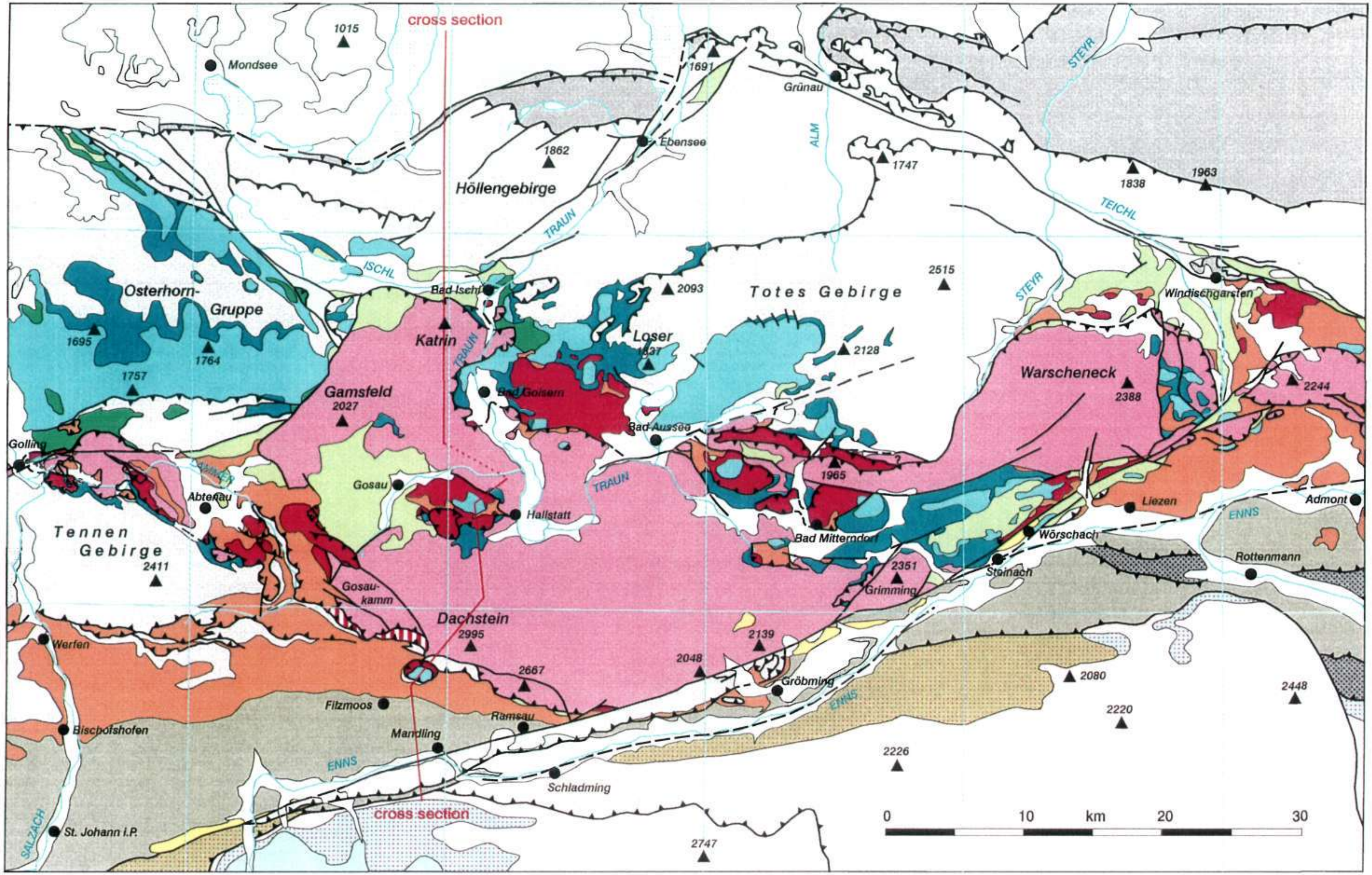

Fig. 4.2.1. : Geological map of the Salzkammergut Region.

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nappes carry tectonical outliers of Hallstatt facies on the one hand, on the other hand they have been transported onto similar Hallstatt outliers, resting in Jurassic basins of the future Tirolic nappes. Such a multiple stacking of triassic rocks of different depositional realms is a common feature of the Juvavicum, the time of stacking is restricted to the Ruhpolding Interval (Lowermost Upper Jurassic). After this first phase of intensive movements a period of tectonic quiescence lasted until Lower Cretaceous. The Juvavic units became covered by marine Upper Jurassic to Lower Cretaceous carbonate sediments of platform and basinal facies.
A next phase ("Austroalpine phase") of tectonics mobilized western parts of the Juvavicum again: the Dachstein nappe, the Reiteralm nappe and accompanied Hallstatt outliers have been transported onto the Upper Neocomian clastics of the Roßfeld trough, which contain also ophiolitic detritus (chromite). A subsequent uplift exposed large parts of the Eastern Alps to weathering and erosion before the Upper Cretaceous Gosau transgression. Intra- and Post-Gosau compressional tectonics and Miocene strike slip faults additionally affected the NCA nappe pile.

The Dachstein Nappe - an example for facies transitions from platform to basin in the Juvavic realm

The Dachstein Nappe represents a sector of the Triassic distal shallow shelf, bordering the open marine deeper Hallstatt shelf of the Tethys ocean. Along its southern rim transitions from platform to basin are preserved, which are used as connecting links in palinspastic models (SCHLAGER, 1967, LEIN, 1976, MANDL, 1984, 1987).
Anisian carbonates are followed after the Pelsonian drowning event by pelagic limestones (Reifling Lst., Hallstatt Lst.). The initial stage of Wetterstein carbonate platform growth is nowhere exposed, but progradation of the platform toward the basin during Ladinian to Lower Carnian is well preserved. Typical sedimentary features are reef breccias, platform derived massive to bedded allodapic limestones (Raming Limestone) and distal carbonate turbidites. Secundary dolomitization has affected large parts of the platform carbonates, especially the lagoonal interior.
During the Lower Carnian sea level drop the platform emerged. Framebuilding organisms (mainly calcisponges) became restricted to a narrow belt (Leckkogel Facies of the Reingraben Group) along the former platform slope, their detritus can be found within adjacent dark limestones and shales (FLÜGEL et al., 1978). As suggested by facies distribution and age data of superimposing strata the emerged platform has been exposed to a remarkable erosion, creating a relief of several 10 meters.
Sea level rise in the Upper Carnian led at first to lagoonal conditions (Waxeneck Lst.) mainly in local depressions of the eroded Wetterstein platform. Dolomites with relictic reef structures are thought to represent Waxeneck marginal reefs. Adjacent bedded dark dolomites with breccia layers and pelagic intercalations are interpreted as slope sediments of this interval. In the contemporaneous basin (Pötschen Limestone) breccias („Cidaris breccia“) of distal slope origin occur.
In the Uppermost Tuvalian a distinct transgressive pulse led to widespread pelagic conditions, covering the drowning platform. The prevailing relief caused a complex pattern of local reef patches, separated by depression, where massive micritic limestones have been deposited. They exhibit a mixture of components from the platform interior, of reef debris, crinoids and pelagic biogenes (ammonoids, conodonts, radiolarian, „filaments“). A

deeper depression (Plankenalm area) contains bedded allodapic limestones similar to Gosausee Limestone.
This initial stage of Dachstein platform growth has been rapidly terminated within the Middle Lacian by lagoonal limestones, the reefs became concentrated at the platform margin. The open platform situation changed into a rimmed platform configuration, characteristic for the Dachstein Facies:
The lagoonal platform interior exhibits cyclic bedded, inter- to subtidal „Lofer Facies", which changes toward the north by an increase of intertidal dolomites into the Hauptdolomit Facies (FISCHER, 1964, ZANKL, 1971).
Back reef areas are showing massive to thick bedded limestones with ooids, oncoids and other coated grains, grapestones, algae and reef debris (sometimes black stained, „black pebbles").
The massive reef limestone is composed of reef patches (frameworks built by calci-sponges, corals, solenoporaceans and encrusting organisms) and bio-/lithoclastic debris. At the Gosaukamm reef breccias predominate (WURM, 1982).
Slope sediments are represented by the allodapic Gosausee Limestone (in literature mostly referred to as „Pedata Schichten") which gradually passes into Pötschen Limestone of the basinal realm. Locally the terrigenous Rhaetian Zlambach Formation is preserved, onlapping and interfingering with the uppermost Dachstein Limestone.

The Central Salzkammergut Region - an example for facies diversity of the Hallstatt basinal realm.

Attention has been drawn to the variegated limestones of Hallstatt since the beginning of the research in the Northern Calcareous Alps (NCA) in the 19th century due to its local richness in cephalopodes; about 500 species have been firstly described from these strata. MOJSISOVICS's ammonite chronology (Monographs 1873 to 1902) based on this fauna was widely used as a standard for Triassic time.
Despite this importance of Hallstatt limestones no general lithostratigraphy existed until SCHLAGER (1969). He established firstly a subdivision of the Hallstatt sequence based on distinct lithological features. Additionally work like reinvestigation of classical ammonite sites (KRYSTYN, SCHÄFFER & SCHLAGER, 1971), correlation of lithostratigraphy and conodont zonation (e.g. KRYSTYN, 1980) and studies on the lithological variability of Hallstatt sequences (e.g. MANDL, 1984) led to a picture shown (with some improvements) in Fig. 4.2.5.
It became also clearly visible, that the two subfacies types as there are Pötschen Facies (grey cherty limestones, marls, shales) and Salzberg Facies (variegated Hallstatt limestones) do not belong to two different nappes as suggeested in previous works. Lateral transitions between these subfacies can be demonstrated nearly at each stratigraphic level. Syndepositional blockfaulting and local uplift due to salt diapirism of the Permian evaporites are thought to be the reason for the differentiation into basinal areas and intrabasinal ridges with reduced sedimentation. Syndepositional faulting is well documented (SCHLAGER, 1969) by numerous sedimentfilled fissures at several stratigraphic levels at a scale of millimeters to some meters in width and up to 80 meters in depth, cutting down at a maximum from Sevatian red limestone into Anisian dolomites. Faulting is sometimes accompanied by block tilting and rotation, causing remarkable differences in sediment thickness of nearby sequences. Additionally the normal sequence can be superimposed by sedimentary gaps and discontinuities with breccias.

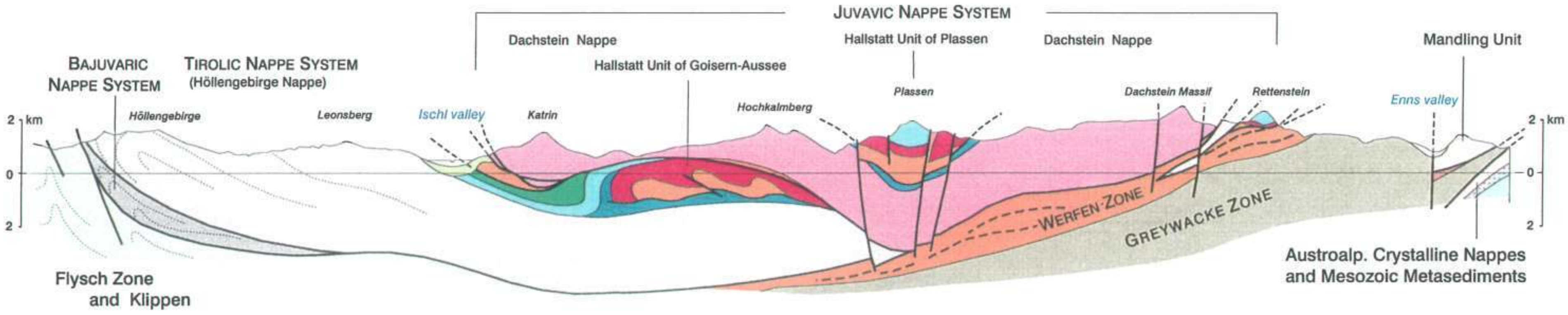

Fig. 4.2.2.: Cross Section of the Nappe System of the Northern Calcareous Alps in the Salzkammergut Region.

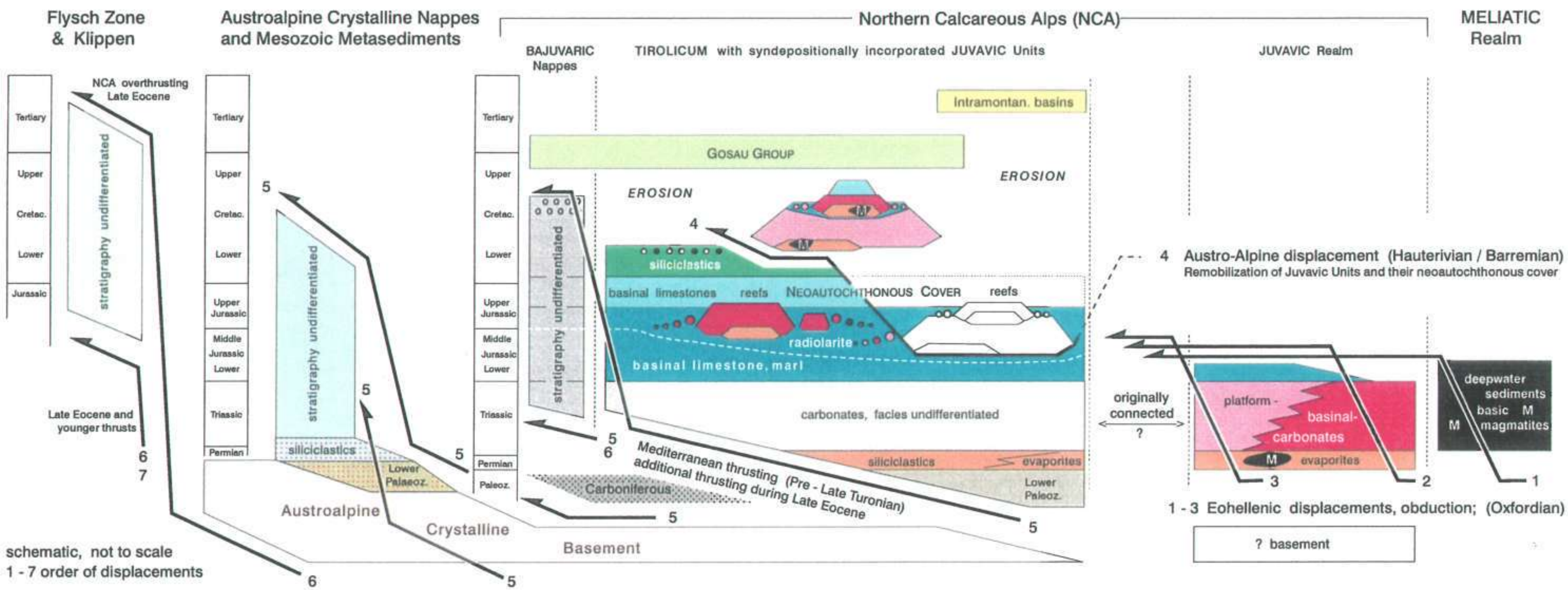

Fig. 4.2.3.: Interaction of sedimentation and tectonical displacements in the Middle Sector of the Northern Calcareous Alps.

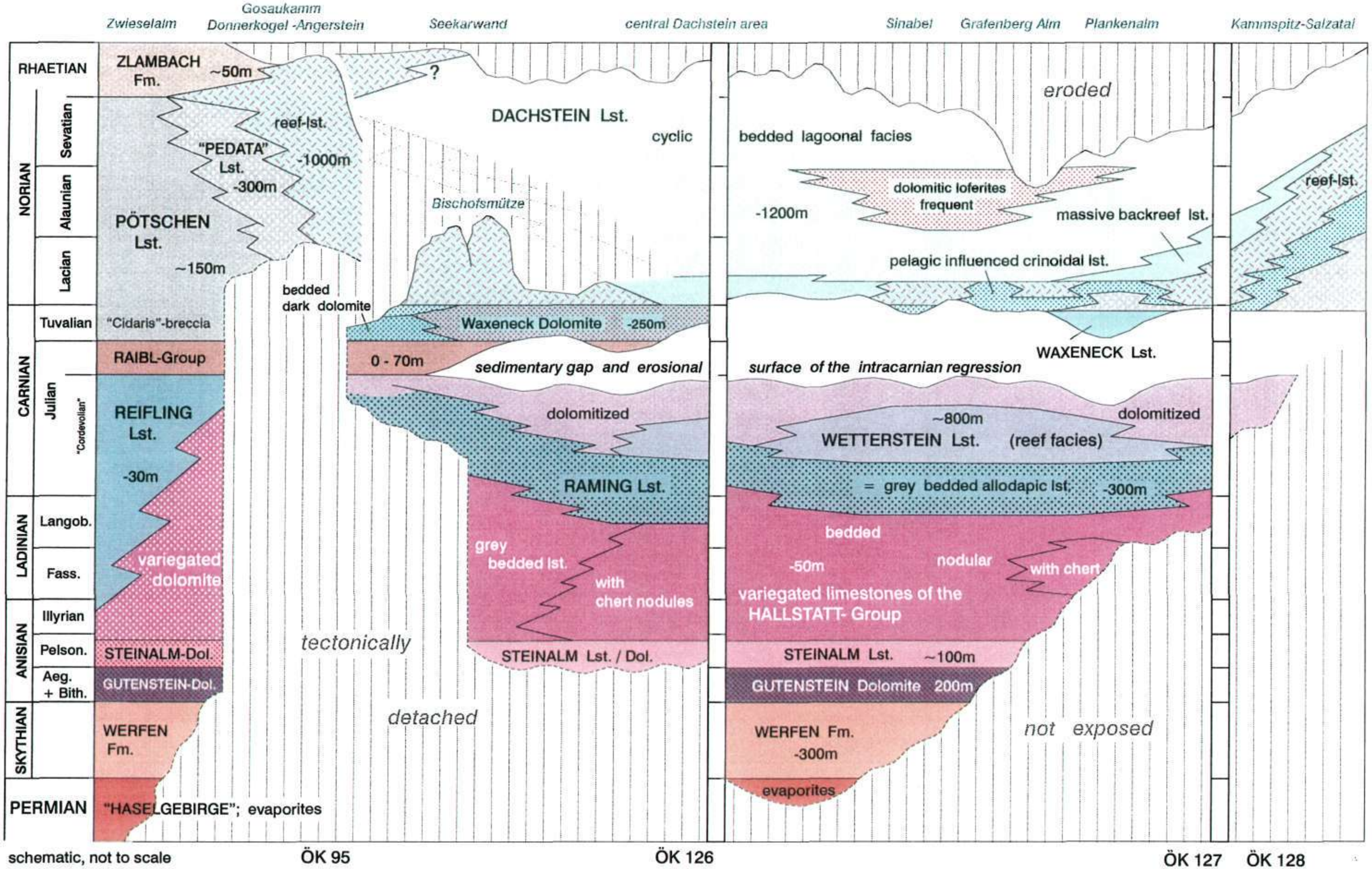

Fig. 4.2.4.:
Stratigraphy and Facies of the Dachstein Nappe (Triassic Carbonate Platform; Juvavic Nappe System)

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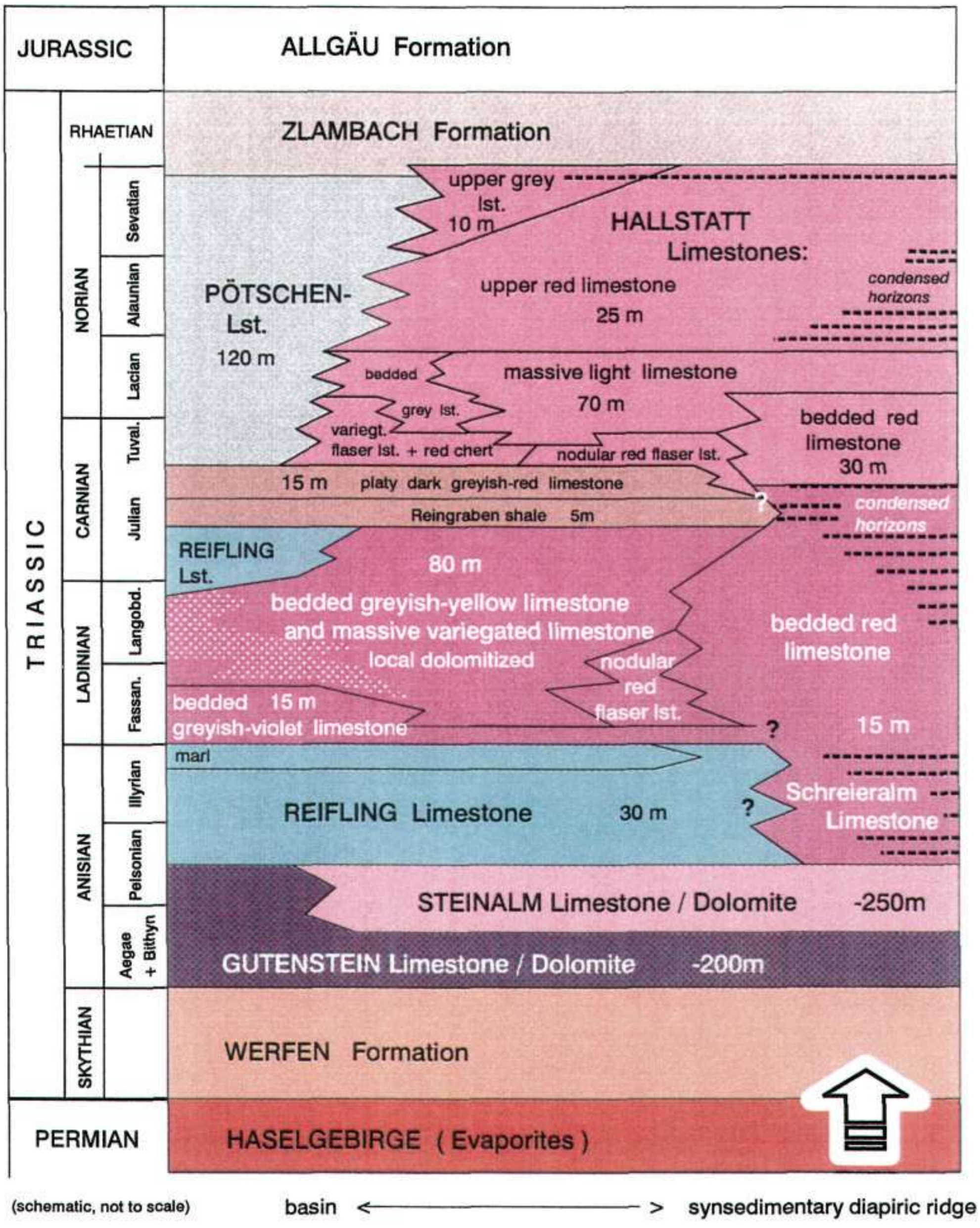

Fig. 4.2.5.:
Lithological diversity of the Hallstatt Limestone sequence,
according to MANDL 1984, modified. Numbers refer to maximal reported thicknesses.

The pelagic sedimentation of the Hallstatt Facies has started with the drowning of the Steinalm shallow platform (dasycladaceean limestone) during Pelsonian. This stratigraphic event is widespread also in other parts of the NCA. Grey cherty limestone (Reifling Lst.) represents the deeper basin, whereas red Schreieralm Lst. covers shallower horst structures; transitional types are not known yet. In Upper Anisian a marl horizon of a few meters in thickness is frequent in the basin.
Beginning with the Ladinian a characteristic lithological succession has developed which is repeated in a similar manner after the terrigenous Reingraben event also in the Upper Triassic: Within the basin the deposition of grey cherty limestones has continued (Reifling Lst. Pötschen Lst.); toward the ridges they pass laterally either via variegated cherty limestones into bedded red limestones or via bedded grey transitional types into light colored massive limestones. The red Hallstatt limestones, covering the top of the diapiric ridges, frequently show subsolution horizons and condensation. For example the thickness of the upper red limestone can be reduced within a lateral distance of 200 meters from about 25 meters to zero (KRYSTYN, SCHÄFFER & SCHLAGER, 1971).
The Lower Carnian Reingraben shales and accompanied platy limestones are missing in some profiles of red limestone. They are replaced there by thick ferromanganese crusts, containing condensed cephalopod faunas.
Most of the classical ammonite sites are situated in red limestones within layers with reduced sedimentation and subsolution. Beside the cephalopods certain lumachelle layers („styriaca beds“, „monotis beds“) can be used as lithostratigraphic as well as chronostratigraphic marker beds in the Lowermost and the Uppermost Norian.
The Hallstatt limestone sequence is terminated by increasing terrigenous input in the Uppermost Norian and Rhaetian (Zlambach marl). Lower to Middle Jurassic sediments (spotted marls of the Allgäu Formation) are preserved only at a few localities. Upper Jurassic radiolarite and limestones, resting on Hallstatt sequences, do not belong to the sequence in a strict sense, because they represent a matrix and a sealing „neoautochthonous“ cover during and after displacement and gravitational transport of Hallstatt units during the Eohellenic (Oxfordian) tectonic event.

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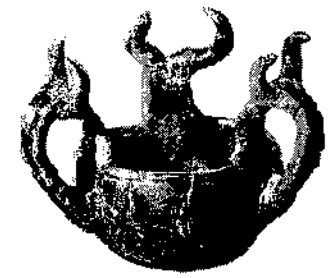
5. The Hallstatt Salzberg



5.1. Archaeological heritage of the Hallstatt region

Fritz E. BARTH

This text is part of the Austrian application to the World Heritage Committee of the UNESCO, to get the "Hallstatt - Dachstein Salzkammergut - Region" inscribed as Cultural Landscape on the World Heritage List

Hallstatt, set in the Upper Austrian lake district known as Salzkammergut, justifiably claims world-wide fame not just for its scenic beauty but also as the site of prehistoric finds. Particularly two places have yielded major finds: the necropolis that gave the Hallstatt culture its name, and the salt mine. Both are located high above the present market town of Hallstatt in the inaccessible Salzberg valley, and they are joined by a causal relationship: salt mining provided the economic base for a wealth which found its expression in an abundance of burial offerings in the graves.

Large-scale salt mining was already an established industry in Hallstatt in the middle of the Bronze Age. Then the brine spring was caught in large deep basins and the water boiled special vessels. The ceramic material used for these vessels is found only in Hallstatt and Bad Reichenhall, another ancient salt mining town.

Right at the start of modern mining, workers must have come across traces of their predecessors' labour in the underworld, naming them *Heidengebirge* ("Heathen Hills"). So far, more than 60 underground sites have been discovered, primarily on three spots known as Western, Northern an Eastern Group respectively. The groups are viewed as consecutively and independently worked mines.

Salt mining in Hallstatt started towards the end of the Bronze Age. Steep pits were driven down to extract the salt rocks, applying a method on loan from copper mining and not adapted to the features of a saline deposit. Copper miners had to follow the seam and cut wide, deep shafts that sloped with the mineral vein. The same happened in the Northern Group of the Hallstatt mine even though the more or less homogeneous deposit would have permitted other methods. Major find sites in the Northern Group are the *Appoldwerk,* where workers cut across an ancient shaft in 1879, and the *Grünerwerk,* where a large system of shafts and trial pits was investigated in recent years. The largest known shaft width is 17 m *(Flechnerwerk)* the lowest depth is 215 m below ground *(Colloredokehr).*

At all exposures of the Northern Group - to the extent known - the old cavities were filled in with very fine sediments. The material, slipped in from the surface, indicates that the late Bronze Age mine had been shut down systematically and over time filled up with sediments. The closure was probably due to events external to Hallstatt, perhaps trading routes blocked by fighting or political events or a slump in sales.

Salt mining in Hallstatt however, was not suspended for long. Production started again already in the 8th century B.C., although miners now developed new district (the Eastern Group) and employed a fundamentally different method. They still strove to reach the body of salt through steeply slanting shafts with as little detour as possible; but once there, they drove almost horizontal drifts to mine the salt. One site yielded some interesting details: through some fortunate circumstances, an ancient opening was preserved at the *Stügerwerk* which clearly shows that a horizontal tunnel was first driven and its roof raised at various points so that several crews could work at the hanging wall simultaneously. The broken material was no longer conveyed but remained in place, and the floor rose to the same extent as the roof, guaranteeing that the working level would stay the same. Efforts were made to mine larger rocks, which was achieved by the following method: curved channels facing each other were carved and linked by a short central to form a heart-shaped structure which was then cut out in whole. Tests using emulated tools found that a medium-sized structure could be shaped by a crew of two in about nine hours; at the tests, however, it was not possible to cut out the halves of the heart-shaped structure in one piece although the method appears useful only in the light of this goal. But a piece found in the *Stügerwerk* shows that it was basically feasible. The prehistoric miners must have used a trick that we have not yet discerned. As a consequence of the mining method, the roofs and side walls of the prehistoric section in the *Stügerwerk* are covered with heart-shaped cutting traces - rows of pick-axe marks. Similar marks were also found in the *Katharina von Edlersbergwerk*.

Finds give us a clear idea of the tools used in the Eastern Group: they were bronze lobed pick-axes with a short, thick handle sharply tapering in the upper third. The head is large and lobe-shaped, the prongs are short, thick and conical. The handle's tapered shape must have caused considerable springiness in the pick-axe. The mines were lit with wide, very flat splints. At working level, large fires appear to have been kindled, as is evidenced by charred logs. Digs at the salt dilution works yielded broken pieces of large clay bottles with tapered necks and a beech cooking spoon encrusted with pap - proving that the large fires were also used for cooking.

The miners wore clothing made of fur or leather and carefully woven woollen fabric. On their heads they had pointy caps with the fur worn inside and berets which were made by pulling at the edge of a circular piece of fur. Their shoes were made of a single piece of leather. The heel was sewn with much care, while the three lobes of the front and sides were folded and tied with a string. The sacks used for hauling, also found in the Eastern Group, were similarly characterised by practical thinking. The hide of a large animal was skinned without abdominal incision and sewn together at the back. The neck was used as a filling funnel, the stumps of the front legs served as handles. A second model had its neck sewn together and fitted with a loop. This model was filled from below, closed by folding and - probably carried with two belts slung across the shoulders: the original model of an alpine rucksack.

Work at the flourishing mine in the Eastern Group was terminated abruptly by a local accident, when a landslide, probably laying waste to the entire alpine valley, penetrated deep into the mountain through the air shafts. The disaster appears to have killed the miner whose body was found in the *Kilberwerk* in 1734 and who attained posthumous fame as the "Man in the Salt". It probably happened in the middle of the 4th century B.C. when the necropolis became disused. The survivors attempted to get the mine back in operation, driving new air shafts *(Katharina von Edlersbergwerk,* prospecting in the *Christina* tunnel), but their efforts were not crowned with success. The settlement was moved to the Dammwiese, a meadow at the southern foot of the Plassen, where no repetition of the disaster, was feared, and a new district was opened up: the Western Group. The highest-lying of the three groups, it became the first to be worst, with few finds and usually just short references to the *Heidengebirge* in the work reports. Nevertheless number and location of finds indicate that the mine was successfully worked for a long time.

The necropolis, second archaeological dig in the Salzbergtal, gives us evidence that the pains and risks of salt mining were found to be worthwhile. There is hardly any other place which yielded finds of similar quantity and quality. The Hallstatt necropolis was discovered by master miner Johann Georg RAMSAUER in 1846. He was the first to recognise the graveyard character and decided to start a dig. By 1863 he had excavated 980 graves and documented them with the support of the Museum Francisco Carolinum in Linz and the Vienna Museum of Art History. RAMSAUER thought that the dig was exhausted, but his successors were able to discover another 290 graves. Friedrich MORTON dug up 62 more graves in 1937-39, which had been the last to be filled. A penstock laid through the Salzbergtal in the last two years unearthed the - so far - last graves. They provide an indication of the wealth of pottery which must have been there and was missed by the digs of the previous century.

Ever since the discovery (the first publication appeared in 1848), scientists have been working to analyse and interpret the abundance of finds. The first comprehensive presentation was furnished by Eduard von SACKEN. Moritz HOERNES, who first inventoried the prehistoric department of the Vienna Museum of Natural History, where the finds were brought and who in the course of his work acquired an intimate familiarity with the material, attempted an in-depth analysis. He selected 240 graves, categorising them in two stages and breaking them down into men's and women's graves. In his opinion, the composition of the necropolis was perfectly typical. Karl KROMER, who finally did the full presentation (a task frequently demanded and attempted) in 1959, arrived at an entirely different conclusion. He found a clear predominance of men's graves, inferring a very specific population structure governed by the purpose of the settlement. According to him, the necropolis was filled in line with distinct rules, with graves furnished with arms encircling those without arms, so that the buried "warriors" continued faithfully to do their duty of protecting the community against enemies even beyond the grave. His theories were fiercely disputed but also used as underpinnings for further speculation. Thus, Imma KILIAN-DIRLMEIER accepted the specific population structure but still views the mingling of rich and poor, young and old graves as an indication that those associating in life wanted to continue their closeness after death. Systematically pursuing this idea, she guesses that communities interested in salt mining sent working parties to Hallstatt who had sections of the necropolis allotted to them. According to her, the necropolis was thus structured not by clan or family, nor by social status, but rather by provenance. Recently, Frank Roy HODSON reconsidered the old model developed by HOERNES, believing that, on the basis of his computer analysis, he can see graves of men, women and children.

The Hallstatt necropolis is at the entrance to the Salzbergtal valley, at the steep slope of the Niederer Sieg. Estimates put the number of dead originally buried here at 2000, but only 1270 graves are under museum administration and open to research today. About half of the dead (45%) were cremated before burial. Nevertheless more than 70% of the bronze vessels - surely an indication of the dead person's wealth and power - were found in cremation graves. Cremation burial thus was reserved to a higher social stratum and was less dependent on the time of burial. It should be noted in this connection that the bronze vessels are not so much cooking pots but are rather connected to drinking habits, as witnessed by the large buckets used for mixing and the bowls. Similarly, weapons are found primarily in cremation graves. A special accessory for the rich graves were clay vats, described by the excavator as oval clay coffins without lids. Their incidence is so far restricted to the Hallstatt necropolis, and even there they are a rare sight. Normally, the bottom of the grave was simply levelled or perhaps compressed.

There have been repeated complaints that the documentation of the Hallstatt graves, in spite of the good quality of depiction and undisputed pains taken by the excavator, is not quite satisfactory by today's standards, harbouring many an uncertainty. Yet recently so many previously untapped sources have been discovered by a careful search that there is a fair chance of clarifying many issues. But an irretrievable loss was caused by RAMSAUER when he disposed of the skeletal remains and clay vessels - digging for precious antiquities as dictated by the spirit of his time - as being shabby and therefore useless. The more valuable are the few clay vessels that have survived, a pointer to the splendid variety that was lost.

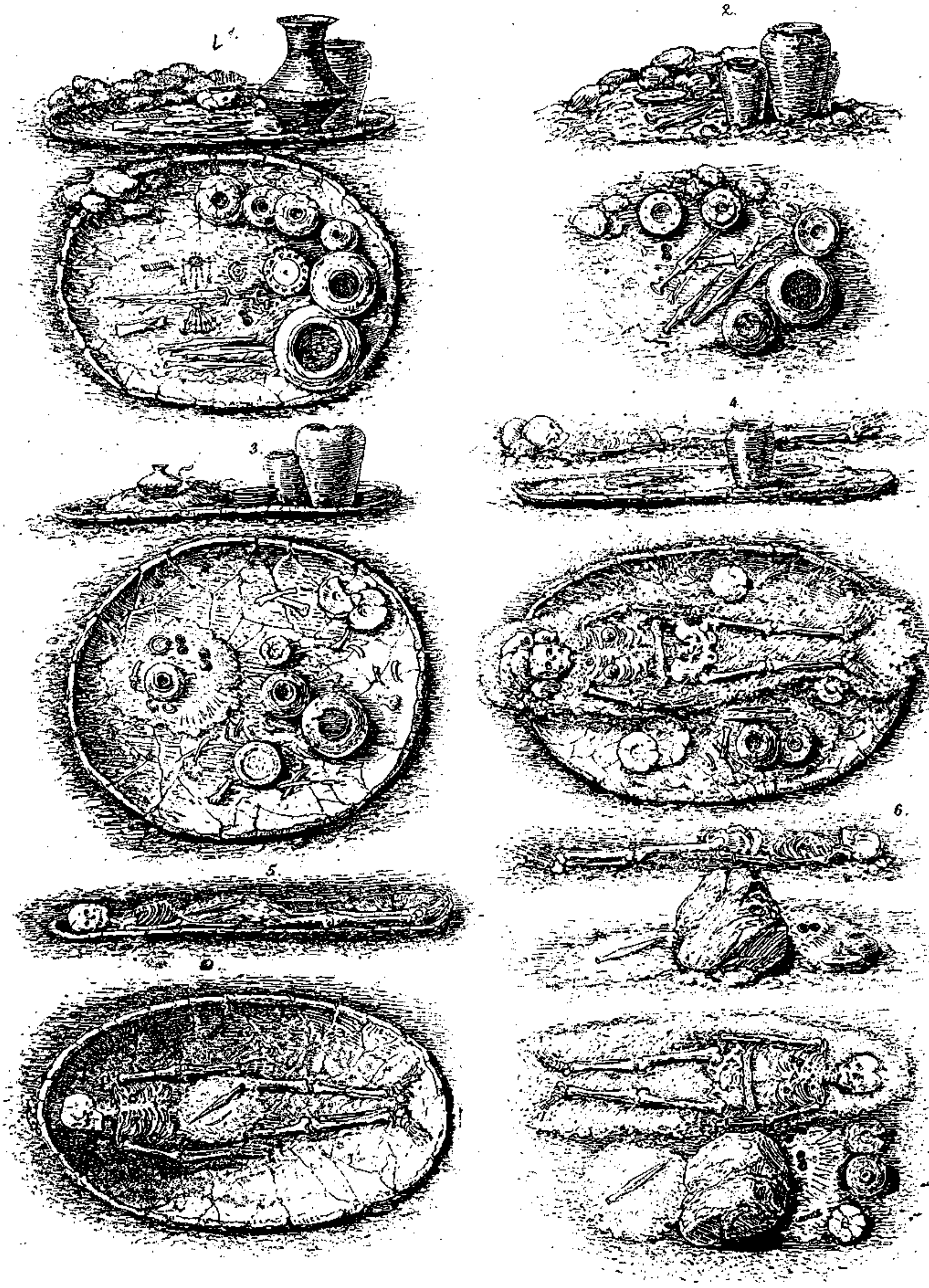


Fig. 5.1.1.: Examples of RAMSAUER´s documentation, after SACKEN (1868).

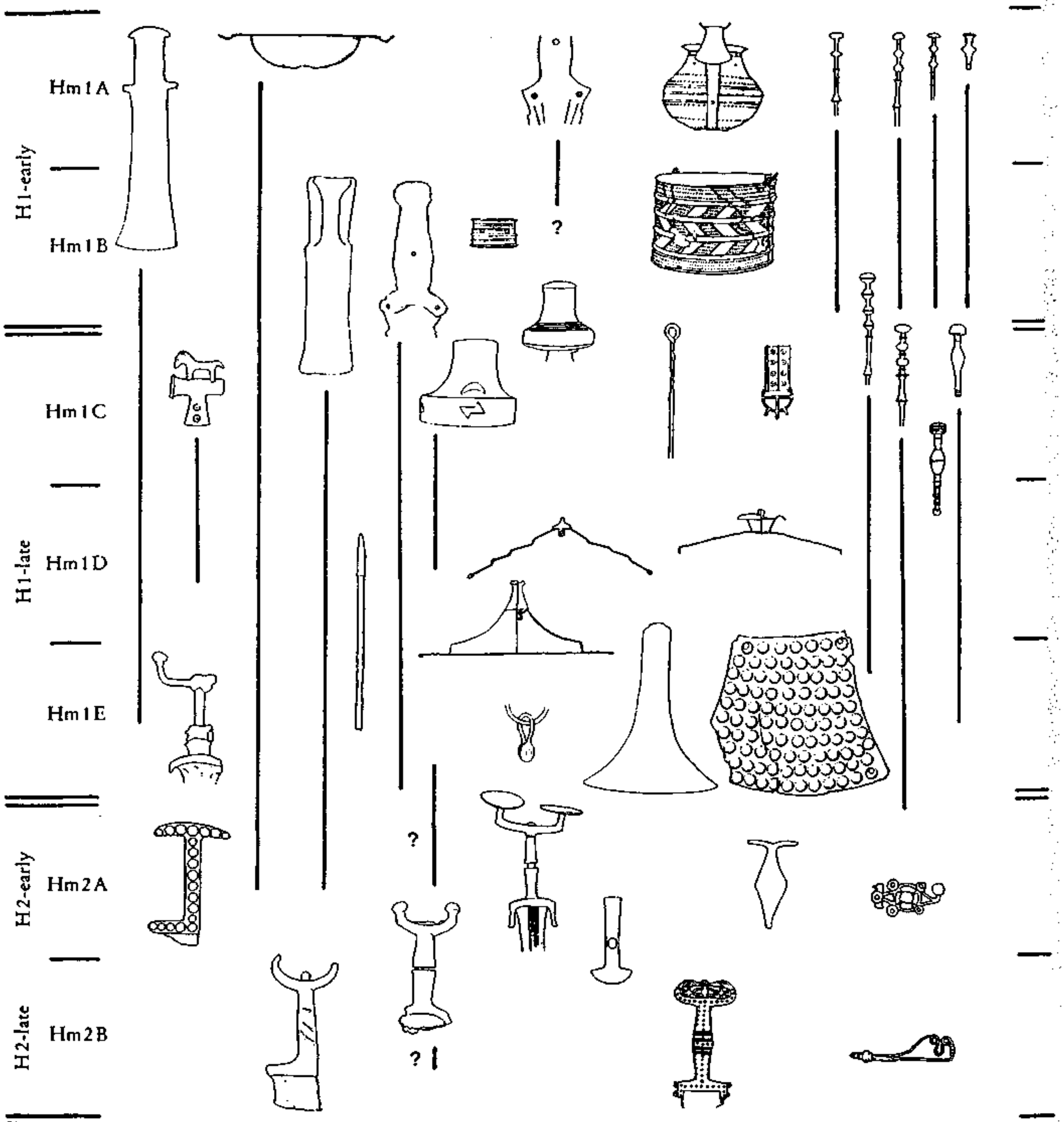


Fig. 5.1.2.: Summary of the proposed sequence of male types, after HODSON (1990).

RAMSAUER was also frequently reproached for leaving finds to celebrity visitors. With the Vienna imperial court resident in Bad Ischl during the summer months, the Hallstatt digs were soon becoming a popular destination for excursions. Emperor Francis Joseph visited the site several times. As a mine employee, RAMSAUER was not in a position to refuse requests for finds, may have felt flattered even - and many a find was lost. Yet in many cases RAMSAUER at least recorded the find in his protocol and had reproductions made for major pieces (as was the case with the cattle figurines).

The Hallstatt necropolis was mainly filled in two periods: the older one in the 8^{th} and 7^{th} centuries B.C. and the younger one in the 6^{th} century B.C. A more detailed categorisation in line with the Southern German chronology is not fully feasible. A few graves demonstrated that the graveyard was still used in the 5^{th} and early 4^{th} century B.C. The main phases (known as "Hallstatt C" and "Hallstatt D") can be excellently visualised by the graves furnished with weapons, because of a change in fighting techniques. Typical for the older phase was a long cutting sword made of bronze or iron, which later changed to a short dagger with antennae, which probably did not play much of a role in actual fighting but is perceived by experts as a symbolic weapon marking out the leader, a theory bolstered by the magnificent workmanship of some specimens.

An iron sword from grave no. 573 serves as an example for the far-reaching trading links of the time. The hilt and pommel are cut from ivory and richly inlayed with amber. Neither material was indigenous to the region where the sword was almost certainly made. The ivory was probably imported from Africa, and the amber from the beaches of the Baltic Sea. Trading over large distances was not restricted to raw materials, but extended to finished products. The glass jars found at the Hallstatt necropolis (actually the oldest glass vessels to the north of the Alps) were manufactured around caput Adriae, an area which also yielded the bucket lid in grave no. 696. The type of figural representation is typical for the Este region in Upper Italy.

Even people appear to have come from afar. Marktus Egg pointed out that the furnishings of the man buried in grave no. 259 were largely similar to those of a man lying in Vace/Slovenia. Brisk trading with this region is evidenced by numerous objects, e.g. the many pieces of armour found in the older weapons graves.

When we attempt an overall assessment of prehistioric Hallstatt, visualising life in the narrow valley, mining experts will tell us that it probably was a well-considered and strictly managed organisational structure. "Laborious burrowing" alone certainly did not enable men to do down 300 metres below ground and keep pits open for centuries. Recent digging has shown that mining was very extensive. Thus at the Kilbwerk, gravelly Heidengebirge, i.e. bottom settlings, was exposed which had a substance of three metres without reaching the top or bottom. Recent excavations at the salt dilution works supplied evidence of a prehistoric pit with a clearance of 15 metres. Such a production-driven enterprise would not have depended on traders passing through by chance, especially since Hallstatt probably had to rely on outside supplies. It is thus likely that they themselves organised the salt transport. Trading in the vicinity appears to have been done by pack animals and predefined counterfreight, as suggested by Ludwig Pauli for the trade between Hallein and Bohemia; it certainly was not an uncontrolled chance business.

It is more difficult to find out the reach of Hallstatt at the height of the culture that took its name. It is noticeable that the place is included in almost every map showing the range of the Hallstatt culture: maps of western incidences indicate it as one of the easternmost sites while on their eastern counterparts it is one of the westernmost sites. The intense ties to the south and south-east have already been noted. It appears Hallstatt was linked by trade directly or indirectly to almost the entire culture.

In the valley near Hallstatt, archaeologists are still faced with major challenges. Current work concentrates on the salt mine because modern miners have already penetrated to larger depths beyond the reach of prehistoric miners and access to the few underground sites still open today cannot be ensured for an unlimited period. The work is thus of an emergency excavation type that is performed under pressure of time. The situation is aggravated by the difficulties of archaeological mining and the high costs associated with it. The fact of prehistoric pits being of a rambling type excludes short-term examinations and quick results. Findings so far have provided answers to some questions but raised new ones just as quickly. The reconstruction of the mining technique in the Northern and Eastern Groups is largely based on assumptions, still to be confirmed by excavations. The preliminary chronological interpretation similarly needs to be verified, although it is highly likely that salt was mined in Hallstatt throughout the last millennium B.C. It can thus be concluded that many surface finds are still awaiting discovery. Houses and graves of the late Bronze Age, the settlement and graves of the Eastern Group, and the graves of the people who lived on the Dammwiese and worked in the Western Group are still hidden in the narrow valley. Many a discovery may still remain buried in the ground to surprise future archaeologists.

Romans too left their traces in Hallstatt. Although no evidence of Roman mining has yet come to light, it is difficult to find any other reason than salt for their massive presence in this remote spot. The Celtic mine of the Weastern Group may have continued to operate far into the Roman era.

The Roman settlement was located in the Echerntal valley, at the foot of the sunny Echernwand mountain face. The extensive vicus included all the blessings of Roman civilisation: window panes made of glass have been documented as well as hot-air heating systems and luxury tableware from the Rhine. The Roman cemetery has not yet been fully explored, and rich archaeological horizons can be found in the cellars of modern houses. Recently a Roman layer was discovered in the Markt quarter on the debris cone of the Mühlbach rivulet. Even here in the valley, the soil of Hallstatt has not yet yielded all of its secrets.

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5.2. Short notes on the Hallstatt salt rock - the "Haselgebirge"

Gerhard W. MANDL

The salt-bearing rocks of the Northern Calcareous Alps are summarized under the term „Haselgebirge", a term of old miner´s language origin, which means salt rock. The term has been introduced into the geological literature by L. v. BUCH (1802).

Nowadays the geological term Haselgebirge comprises variegated claystones, gypsum, anhydrite, halite and accessoric evaporitic minerals. Breccia structure is prevailing, undisturbed sedimentary successions are mostly preserved in some „inclusions", huge rock bodies within the breccia.

Haselgebirge in a strict sense, as it is used by miners, is a breccia with a matrix of salt and components of clay/siltstone, gypsum, anhydrite and rare dolomite.

The origin of the brecciation was a matter of long lasting discussions - synsedimentary versus tectonical brecciation. Both factors seem to be of importance.

Fluidal tectonical processes accompanied the diapiric ascent of the evaporites, starting in the Mid-Triassic. Due to its position near the basal detachment plane of the NCA sedimentary sequence the Haselgebirge underwent additionally strong shearing during alpine orogeny. On the other hand, however, marker beds visible within some breccias point at a synsedimentary origin.

Based on detailed mapping inside the salt mines SCHAUBERGER developed a subdivision of the Haselgebirge according to colour and mineralogical composition, summarized in SCHAUBERGER (1986):

„Rotsalzgebirge" - reddish/grey salt, anhydrite, polyhalite, glauberite, Na/Mg-sulphates, red and black claystone, grey/brown sandstone.

„Grüntongebirge" - white salt, muriazite, rare K/Mg/Na-sulphates, green claystone, greygreen sandstone, rare Fe/Cu-ores.

„Bunttongebirge" - brown salt, black, green, grey and red claystone, accessoric local volcanites („Melaphyr") and volcanic tuffites.

„Grausalzgebirge" - grey/white salt, cherty anhydrite, dolomitic anhydrite, grey claystone, accessoric magnesite.

The sedimentary environment is interpreted as shallow depressions within a Graben system. Occasionally marine ingressions from the open Tethys led to hypersalinar conditions, causing evaporitic mineral deposition. Alluvial fans from the hinterland and sand/mud flats bordered gypsum flats of a sabkha facies and a central „basin" with halite precipitation.

Evaporitc „shoaling upward" sequences have been demonstrated by SPÖTL (1988) a,b - see Fig. 5.2.2. The so called Northern Inclusion of the Hallstatt salt mine represents a clastic/evaporitic red-bed succession, which is thought to represent the transitional facies between the depositional realm of the Haselgebirge and the siliciclastic hinterland - SPÖTL (1987).

Due to the lack of macrofossils and the tectonically disturbed contact to the surrounding rocks also the age of the Haselgebirge was uncertain for a long time. KLAUS (1953, 1955, 1963, 1974) established an Upper Permian age, based on palynology. Characteristic taxa are *Nuskoisporites*, *Gigantosporites*, *Lueckisporites* and *Klausipollenites schaubergeri*.

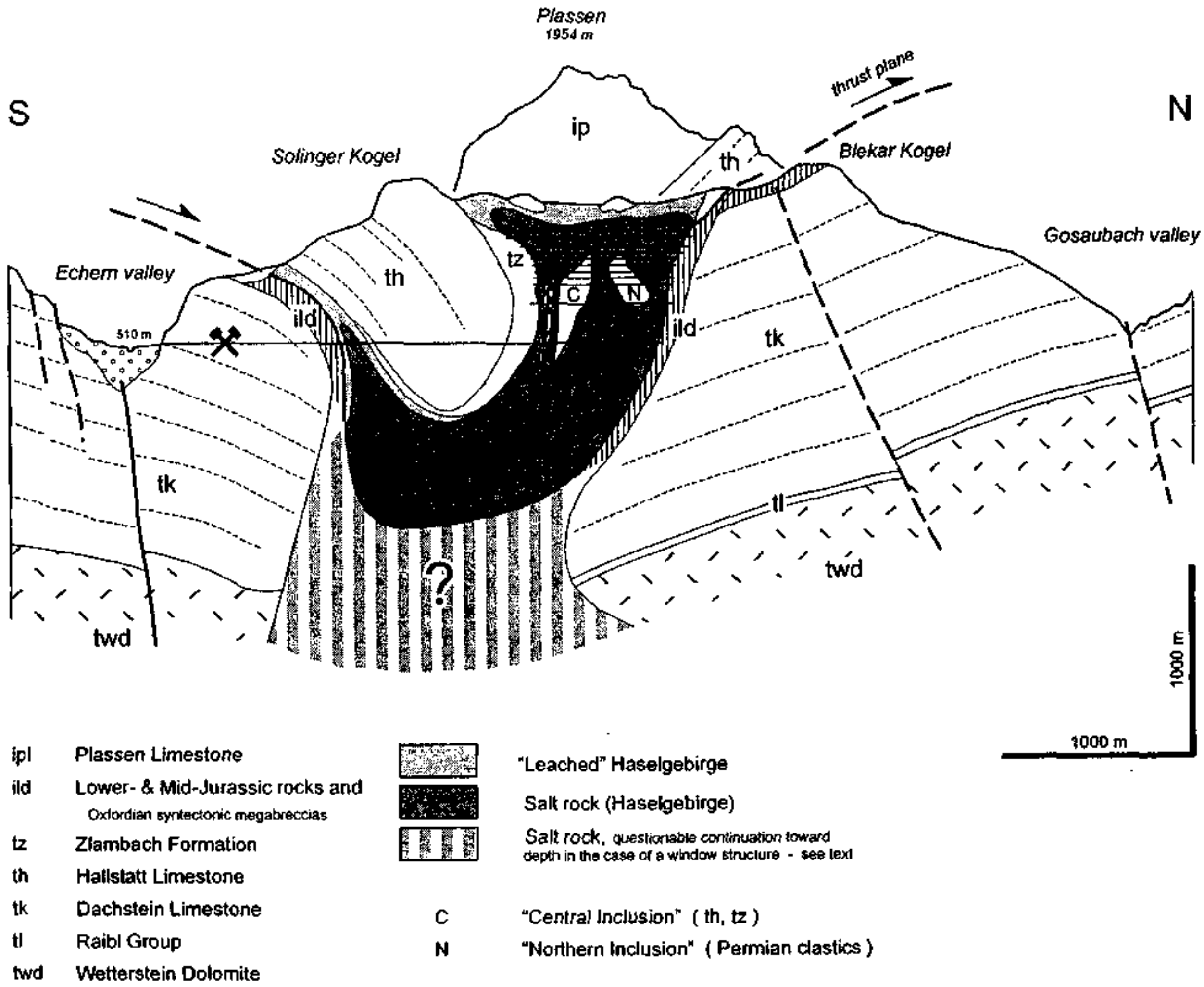

Fig. 5.2.1.: Schematic cross-section of the Hallstatt salt mine, according to SCHAUBERGER (1955).

Bituminous dolomites and anhydrites from the Grausalzgebirge surprisingly contained floral elements of late Lower Triassic.
Several sulphur isotope determinations supported the Upper Permian age as well as the Lower Triassic one (PAK, 1974, 1978, 1982, PAK & SCHAUBERGER, 1981, SPÖTL, 1988a,b).
Special attention has been directed in the last years to the basic magmatites, which are associated with the Haselgebirge at many localities. They are well known since long ago (JOHN, 1899, ZIRKL, 1957). Investigations of KIRCHNER (1977, 1979, 1980) have revealed indications of a possible ophiolitic origin due to the coexistence of tholeiitic pillow lavas, tuffites and lenses of serpentinite. Minerals as *pumpellyite* and *sodium-amphiboles* within the magmatites as well as in the surrounding sediments point at a low grade metamorphic overprint. Recent analysis by VOZAROVA et al. (in press) give hints for a high pressure metamorphism of basalts in the Haselgebirge of Bad Ischl.

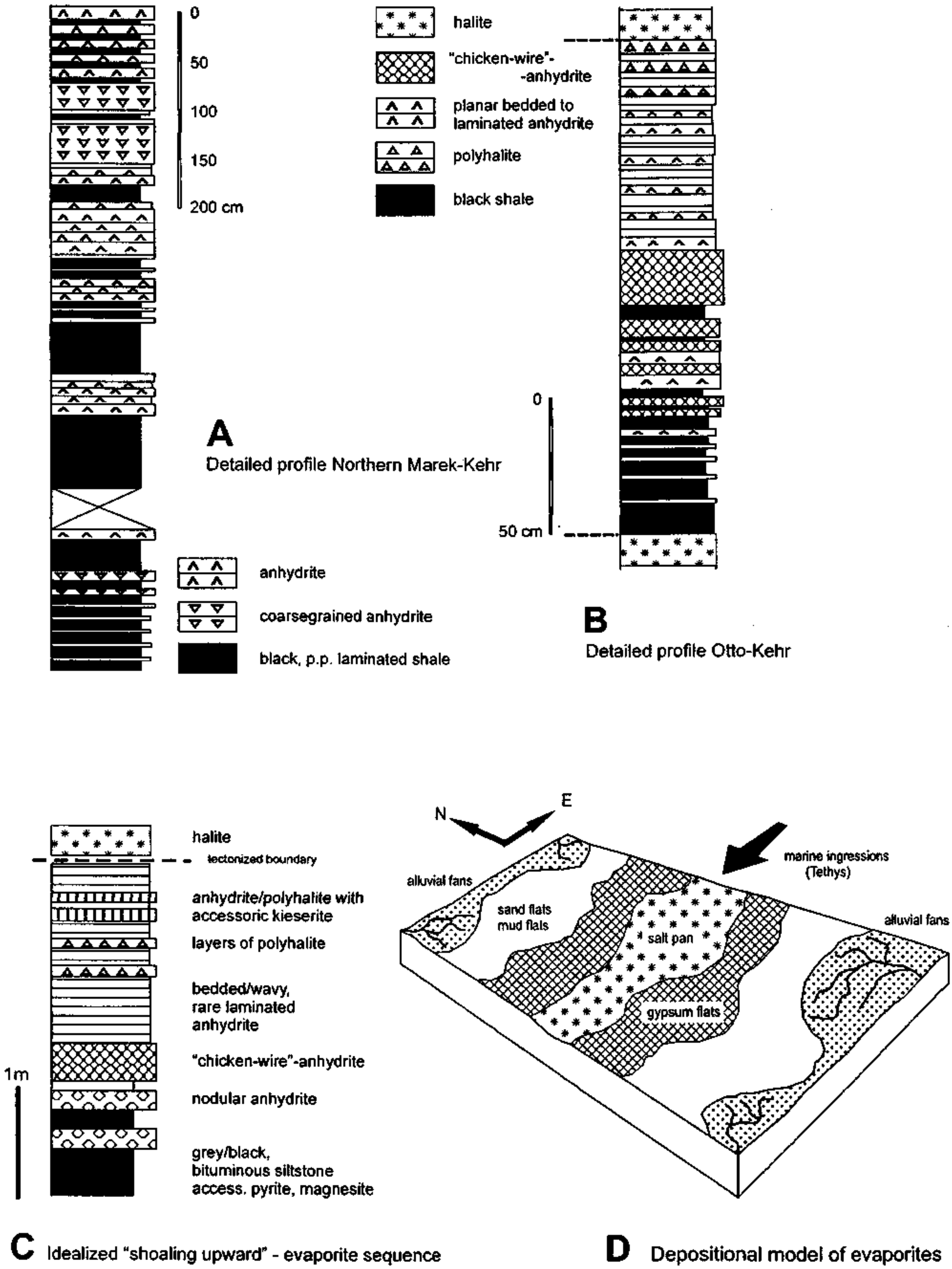

Fig. 5.2.2.: Sedimentary sequences of the Permian evaporites (Haselgebirge, evaporitic melange) of the Hallstatt salt mine, according to SPÖTL (1988 a,b).

All these data are of interest in so far as similar volcanites within Permian evaporites in a comparable tectonic position in the North Hungarian Carpathian mountains have been dated micropaleontologically by associated radiolarites as Middle Triassic. They are interpreted as a remnant of the Tethyan oceanic crust, which has been incorporated in an evaporitic melange during the Jurassic subduction of the Meliata segment of the Tethys ocean. KOZUR (1991), KOZUR & MOSTLER (1992) insist on an equivalent origin of the magmatites of the Austrian Haselgebirge.

SPÖTL et al. (1998) and SPÖTL & HASENHÜTTL (1998) studied the metamorphism of mudrock/dolostone components in the evaporitic melange of several Austrian localities. Illite crystallinity, vitrinite reflectance and fluid/rock reactions record a complex deformation- and thermal history, changing between and within individual outcrops. IC values vary between diagenesis and anchizone, vitrinite data point at temperatures of 160-180 °C. $^{40}Ar/^{39}Ar$ analysis of authigenic K-feldspar at the locality Moosegg yielded step-heating spectra which suggest Late Jurassic cooling. This supports again the concept of Jurassic initial detachment of the Juvavic nappes.

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6. The Loser panorama road

Harald LOBITZER & Gerhard W. MANDL

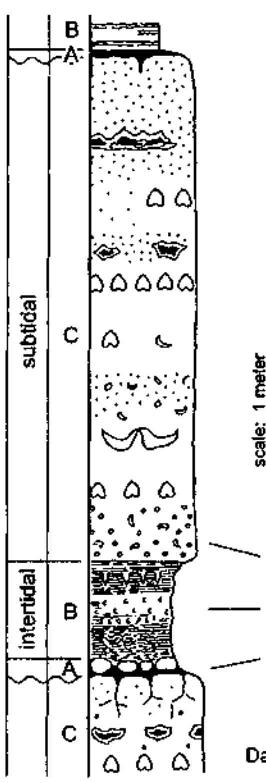
6.1. Cyclicity of the Dachstein Limestone - the dominant feature of the Dachstein landscape

A characteristic morphological feature of the southern parts of the NCA is the distinct meter-sized bedding of the Dachstein Limestone, well visible along the steep slopes as well as on the karstified top of the large plateau mountain ranges.

First attention from a sedimentological point of view has been drawn to this sedimentary structure by SANDER (1936) and SCHWARZACHER (1949, 1954). ZAPFE (1959) supposed a very shallow depositional environment, based on biota and similarities to the recent carbonates of the Bahamas.

FISCHER (1964) has given a still classical description of this phenomenon called "Lofer cycle", based on sequences from the plateaus of Dachstein and Loferer Steinberge. The cyclicity is caused by an interbedding of lagoonal limestones, thin layers of variegated argillaceous material and intertidal/supratidal dolomites and dolomitic limestone.

An ideal representation of the Lofer cycle is shown in Fig. 6.1.: The main sediment is a generally unbedded light limestone (layer C), containing oncoids, dasycladacean and codiacean algae, foraminifera, bryozoa, gastropoda, large megalodontid and other bivalves. A weathered and solution-riddled surface of this limestone is overlain and/or penetrated by reddish or greenish argillaceous limestone (layer A), which may include limestone clasts and which is interpreted as a former terrestrial soil. Layer B consists of intertidal carbonates of a variety of rock types like "loferites" or birdseye limestone of laminated



	Lithic composition						Biota														Shrinkage structures		
	Homogenous carbonate lutites	Laminated carbonate lutites	Pellet lutites	Algal mats	Carbonate arenites	Intraformational conglomerates	Filamentous algae in mats and crusts	Filamentous algae in oncoids	Rhodophytes, dasycladaceans, codiaceans	Foraminifera	Porifera	Corals	Bryozoa	Brachiopoda	Gastropoda	Pelecypoda	Cephalopoda	Ostracoda	Echinodermata	Fecal pellets	Prism cracks	Sheet cracks	Shrinkage pores
C	+				+			+	++	++	+	+	+	(+)	+	++	(+)	+	+	+	+	+	
B	+	+	+	+		+	++			+					+			+		++	++	++	++
A	+		+			+												+		++		+	

Dachstein Limestone, lagoonal facies - idealized "Lofer cycle" according to A.G. FISCHER 1964.

Fig. 6.1.: Dachstein Limestone, lagoonal facies - idealized "Lofer cycle" according to FISCHER (1964).

or massive type, nonloferitic lutites and intraclasts. The flat or crinkled lamination represents filamentous algal mats, characteristic also for modern tidal flats. Fenestral pores and mud cracks seem to be the result of shrinkage of unconsolidated sediment due to desiccation. All types of layer B are more or less dolomitic, some of it formed as contemporaneous brittle surface crusts as shown by intraclasts demonstrating the intertidal/supratidal setting.
A theoretical complete sequence of such a transgressive-regressive cycle might be expected to show a succession A-B-C-B-A. The real Lofer cycle generally lacks the regressive phase of B, probably because of the succeeding erosion. If a phase of total emergence is missing, the succession is C-B-C-B. Layer A is commonly not developed as a distinct bed, because of its erosional origin; however, remnants of A are abundant fillings in veins, cavities and biomoldic pores (gastropod and megalodontid shells).
FISCHER explains the formation of the cyclothems by periodic fluctuations of the sea-level which is superimposed on the general subsidence. An amplitude of up to 15 m and 20.000 to 100.000 years is assumed for one cycle. Because this model does not explain the gradual lateral transition into the Hauptdolomit Formation and the lateral wedging of intertidal and supratidal sediments on short distance, ZANKL (1971) proposed an alternative model: Current activity and sediment producing and binding algae produced mud mounds and tidal mud flats. Subsidence and eustatic sea-level fluctuations of centimeter amplitudes and in several hundred years may have modified growth pattern and shape of the tidal flats by erosion and transgression.
Along the upper part of the Loser panorama road Dachstein Limestone of lagoonal facies is well exposed. The "Megalodontid Limestone" is the main sediment type containing a variety of biota like large shells of *Conchodon, Rhaetomegalodon, Dicerocardium* and other molluscs as well as echinoderms, calcareous algae, rare corals, hydrozoans, bryozoans and some problematic organisms like *Cheilosporites tirolensis.* Components are sometimes black stained - "black pebbles" - indicating subaerial exposure prior to redeposition. The sediment is characterized dominantly by grainstones and biomicrites.
The foraminiferal fauna contains *Involutina*-associations. The algal flora consists of *Heteroporella crosi* (OTT), *Heteroporella zankli* (OTT), *Macroporella* sp., *Palaeodasycladus* sp., *Cayeuxia alpina* FLÜGEL, *Garwoodia* sp., *Solenopora endoi* FLÜGEL.

Fissure fillings

A very interesting phenomenon are neptunian dikes and sills within the Dachstein Limestone, filled by Lower Jurassic limestones and coquina of brachiopods. The fissures occur both diagonally and parallel to the bedding planes of the host rock. Diagonal fissures sometimes display an interaction of submarine sedimentation and of vadose origin (calcareous sinter). Several types of fissure fillings can be seen - red micrites (Adnet facies), crinoidal limestones (Hierlatz facies), grey brachiopod limestone, grey micrites and others - up to 13 generations of sediment have been recognized within the fissures.

6.2. Panoramic view: Dachstein glaciers, the Pleistocene basin of Aussee and Upper Jurassic limestones of Trisselwand and Tressenstein.

The view from the mountain Loser toward south shows Upper Triassic Dachstein Limestone of the Totengebirge nappe in the foreground.
At the opposite side of Lake Aussee the impressive steep cliff of Trisselwand and the small peak Tressenstein expose Upper Jurassic limestones, which are covering the contact between Totengebirge nappe and the Hallstatt unit of Ischl-Aussee. Evaporites and siliciclastics of the latter one are expected to form the floor of the Aussee basin - a deep depression, glacially eroded during the Pleistocene and filled by a thick sequence of glacial and periglacial sediments. A recent drilling for salt prospection has penetrated more than 600 meters quaternary gravel, covered by morains of the youngest glaciation (Würm). According to the spatial distribution of morain deposits, the valleys have been filled by an ice-stream, more than 1000 meters in thickness during the maximum extent of Würm glaciation about 20.000 years BP. The quaternary history of the Traun valley is documented in detail by VAN HUSEN (1977, 1987).
The background of the panorama is built by Triassic platform carbonates of the Dachstein nappe.
The Dachstein Limestone of the Loser Mountain is covered by Jurassic rocks, formig its characteristic summit. East of the Loser Hütte outcrops of red radiolarites and thin-bedded micritic limestones with radiolaria and sponge spicules can be seen above Lower Jurassic red limestones. The siliceous sediments are overlain by a sequence consisting of bedded limestones with chert nodules and layers - the Oberalm Formation. The lower part is characterized by sedimentary structures indicating synsedimentary slidings. Intercalations of pelsparites demonstrate the transition between this deeper-water facies and the superimposing shallow-water facies of the Tressen Limestone and Plassen Limestone (Loser summit). Bioclastic intercalations near the locality Augstsee contain also aptychus fragments.
These limestones are mainly Upper Jurassic in age, according to the occurrence of the algae *Clypeina jurassica* (FAVRE), *Muniera baconica* DEECKE and *Salpingoporella annulata* CAROZZI.
The panorama view exposes also the type locality of Tressenstein Limestone (HÖTZL, 1966), at the southern side of Lake Aussee. Oberalm transition facies with carbonate-detritic intercalations of Barmstein beds interfinger with and are overlain by shallow-water Tressenstein limestone. The latter consists of intraclasts derived from high-energy environments with hydrozoans, corals, calcareous algae and partly near-coast lithoclasts. The summit of Tressenstein and the Trisselwand consist of micritic as well as sparry Plassen Limestone. The transition platform to slope is disturbed by several subvertical faults.
For additional information about Jurassic sedimentary history see chapter 4.2.

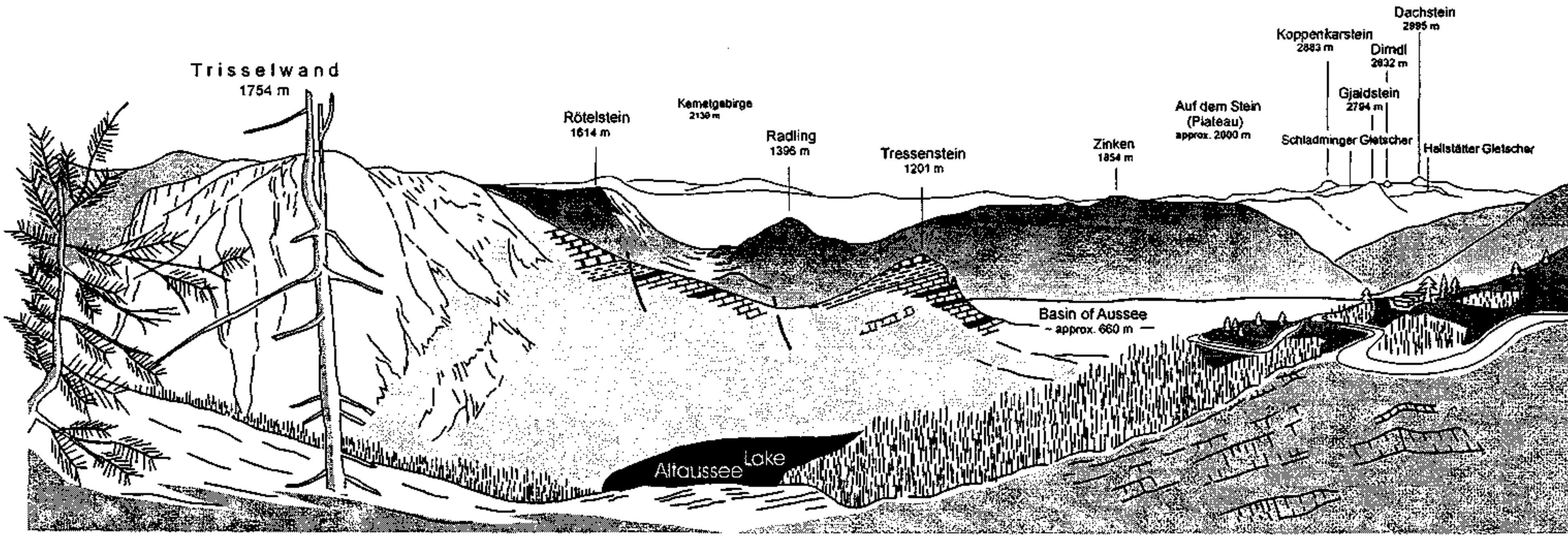


Fig. 6.2 : Loser Panorama road; view toward south:

In the foreground right: Late Triassic Dachstein Limestone, lagoonal facies with Lofer cycles.
Middle part: The Trisselwand is built up by Late Jurassic to Earliest Cretaceous Plassen Limestone (shallow platform facies), prograding over slope facies of Barmstein-/Tressenstein Limestone (type locality !) and basinal facies of Oberalm Limestone.
The basin of Aussee is a glacial eroded depression in rocks of the Ischl-Aussee Hallstatt Zone (limestones, sandy shales, evaporites) filled by thick glacial deposits (fluviatile gravel, moraine of Würm-glaciation).
The Mt. Rötelstein is an other tectonical outlier of Hallstatt rocks, resting on Triassic to Jurassic rocks of the Dachstein-Warscheneck Nappe.
Radling, Zinken, Kemetgebirge, the plateau "Auf dem Stein" and the central Dachstein massif belong to the Dachstein Nappe, consisting mainly of Triassic platform carbonates.

Plassen Limestone
Tressenstein Limestone
Barmstein beds
Oberalm Limestone

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7. The Dachstein Caves

7.1. The Dachstein Region - its karst and its caves

Rudolf PAVUZA & Günter STUMMER

Introduction

Among the karst massifs of the Northern Calcareous Alps, built mainly from Triassic and partially well-karstifiable carbonate rocks, the almost 3,000 m high glaciated Dachstein mountain range is for sure the most significant. It is known for the great number of caves, with the Hirlatzhöhle being the longest (currently 86 km) and the Dachstein-Mammuthöhle being the third longest (55 km) among Austria's explored caves, as well as for three major show caves being accessible to the public and well-suited for studies on cave development and formation, each of it representing another cave-type. Especially the ice cave, the Dachstein-Rieseneishöhle, is an outstanding example of its kind in Austria. The Dachstein-Mammuthöhle is a typical giant high alpine cave with enormous galeries and labyrinths, whereas the Koppenbrüllerhöhle down in the Traun-valley represents an active water cave at the level of the local karst water table. The Dachstein region has gained natural scientific significance through the excellent documentation work that has been going on for more than a century now. It started with the work done by Friedrich SIMONY in the 19th century and has continued almost uninterrupted up to the most recent research works. The outcome of these studies is reflected in an enormous bulk of literature. Also, the Dachstein mountains have been used for scientific comparisons and for clarifying karst-specific, cave-related and hydrogeological issues. At the same time this region has been a trailblazer in the field of cave documentation. For instance, the Dachstein-Mammuthöhle served as a model for the first presentation of an „underground atlas“ and the Hirlatzhöhle is documented by state of the art CAD-techniques.

The possibility to compare the pictures made by F. SIMONY in 1895 and those from 1950 by F. BAUER and other more recent ones is an excellent opportunity to study the changes in a karst landscape. The Dachstein region can also be considered as a model of subterranean karst drainage. It is precisely this area where a number of recent trials have resulted in a reassessment of underground drainage patterns whereby the currently well-recorded enormous horizontal and vertical insights into the underground (especially via *Hirlatzhöhle* and *Mammuthöhle*) have heightened the understanding of these drainage systems through visual and scientific information obtained from the interior of the karst massif.

The fact that the Dachstein massif is one of the few still glaciated karst regions in the Alps will enable further research approaches.

The early development of this area at the surface and underground for mountain climbing and touristic purposes, as well as its forestry and dairy farming use, enable to study the influence of man on a major Alpine karst area.

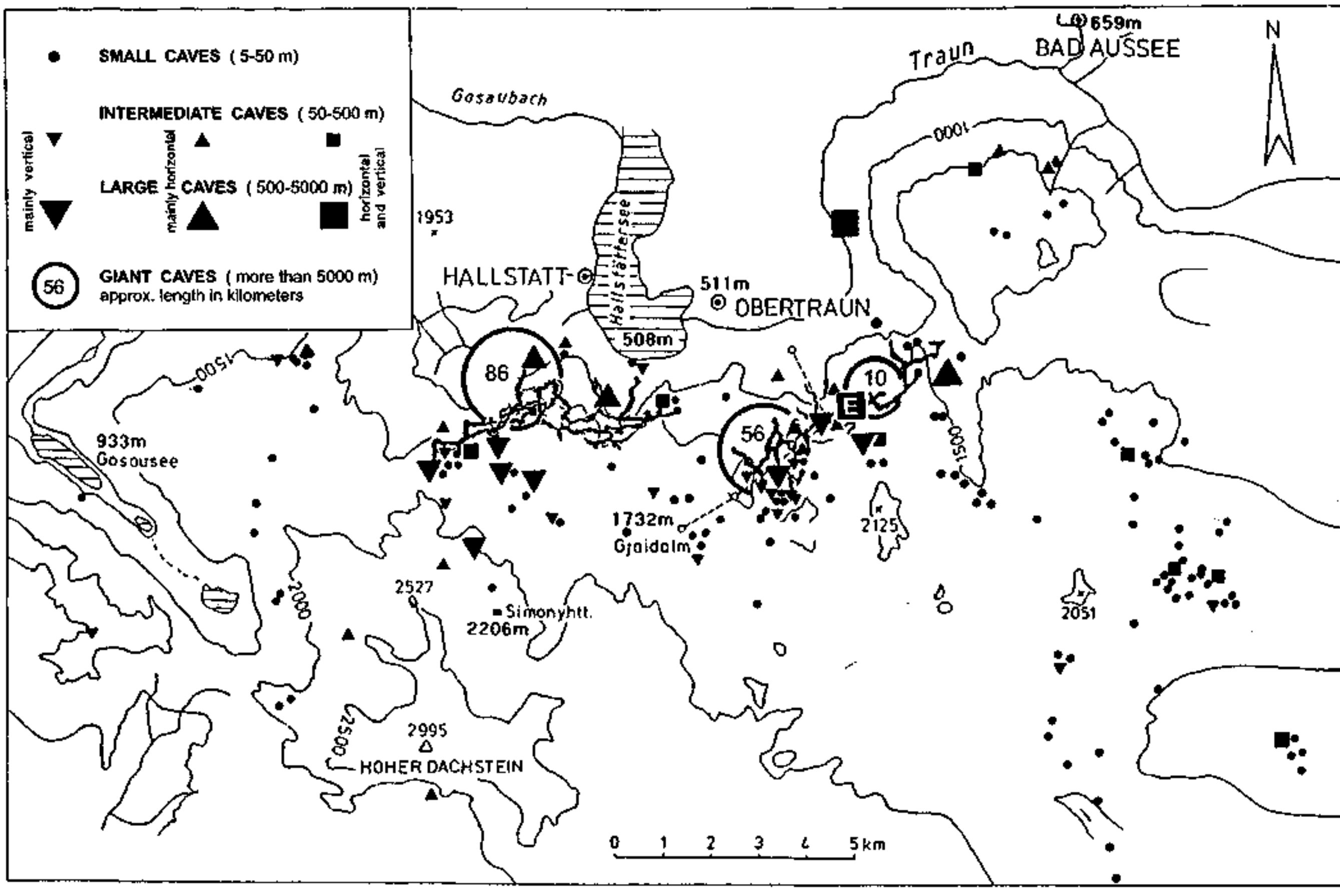

Fig. 7.1.1.: Caves and cave passages at the northern margin of the Dachstein range: Hirlatzhöhle 86 km, Dachstein-Mammuthöhle 56 km, Dachstein-Riesen-eishöhle (Ice Cave) E = 2 km, Schönberghöhle 10 km.

Geological, morphological and speleological overview

In geological terms, the Dachstein massif is comparatively simple and clear in its setup. Its central part is dominated by Upper Triassic Dachstein limestone gently dipping towards the north. The Dachstein is the „type location" of the well-banked Upper Triassic limestone of an extensive lagoon area, this limestone having been widely spread throughout the whole area of the the ancient Thetys-ocean.

Some 45 km long and 20 km wide, the Dachstein massif is quoted in literature to have a surface of 574 square kilometres. The area with subsurface drainage amounts to approximately 240 square kilometres. As compared to the 300 square kilometres of the large subterraneously drained plateau of the Totes Gebirge, the Dachstein mountain range represents the second largest karst massiv in Austria. Its glaciated peaks (Hoher Dachstein, 2995 m) rise above extensive plateaus (such as Am Stein at about 1800 to 1900 m above sea level). Especially in the south (Ennstal, 750 m above sea level) and partly in the north (Traun valley with the Hallstättersee, 508 m above sea level) the mountains drop sharply eventually yielding tremendous walls attracting mountain climbers.

Rock stratification, which is important for cave formation, is dipping slightly north / north-west towards the Traun and Echern valleys. Joints and faults - essential for for karstification - mainly strike NW-SE and NE-SW, fewer ones also W-E and N-S.
Especially along the northern edge of the mountains huge glacial valleys cut into the mountain body. An allocation of the different remnants of former surfaces to a specific age seems to be particularly difficult. There is evidence that tectonic activities have transported identical pediments to different heights. The large plateau areas are mainly characterized by a *Schichttreppen* landscape - partially sculptured by glaciers - evolved along bedding faces. Here one can often find smaller caves along the bedding planes. A more detailed study of the location of cave entrances in the Dachstein cave park has shown that most of the cave entrances are either in steep walls (mostly glacially reopened) or in the highest zones of mountain ridges. In the synclinal and deep zones we see a clear decline in the number of passable entrances, most of them probably sealed by moraine material.
The Austrian cave register refers to the Dachstein massif under figure 1540. This figure is subdivided into groups 1541 to 1549. The highest topographic point of the subgroup is the *Hoher Dachstein* (2995 m), the lowest is the Hallstättersee (508 m). The lowest cave is the *Kessel* (1546/2), 512 m above sea level in today's valley level, the highest cave is the *Nördliche Durchgangshöhle* (1543/46), 2770 m above sea level; 550 caves are currently recorded in the Dachstein mountain range.

Historic survey

Historic documents dating from the past century are mainly due to research work, drawings and publications by F. SIMONY (1895). A more systematic cave research, however, began in 1910 only in the so-called „Dachstein Cave Park" (these are caves situated in the area of the *Schönbergalpe*) when the two most important caves, the *Dachstein-Rieseneishöhle* and the *Dachstein-Mammuthöhle,* were discovered. A few years later numerous kilometres had already been surveyed and recorded. More recent research started with a theodolitic investigation into the most important parts of the *Dachstein-Mammuthöhle* in 1952.
Current speleological studies are still focused on the area of the Dachstein Cave Park and the *Hirlatz* area, with work going on both above and below the surface. In recent times tremendous discoveries have been made in the *Hirlatzhöhle*. For years the Dachstein Cave Park has also been an area for accompanying geo-scientific investigations with special emphasis on cave-sediments, -waters and -ice and cave-climate to study human influence and interference as well as natural variations of the cave ice. These studies are conducted by the Department of Karst and Caves of the Museum of Natural History in Vienna. Both the *Hirlatz* cave area and the Dachstein Cave Park are subject to active exploration and documentation of hitherto unknown cave passages by speleological societies. Our knowledge of the Dachstein caves is still far from being complete.

Karst water, springs and dye-tracing

Cave formation and the karstification of a landscape require the presence of "karstifiable rock" (such as limestone) plus corrosively acting water. In such a way karst areas become important "water reservoirs", and the knowledge of subterranean drainage patterns will help understand karstification and cave formation; it turned out to be an important factor in water management.
This aspect has been the focal point of the pioneering spore drift and dye-tracing tests in the Dachstein area since 1953. The first trials revealed mainly radially directed drainage patterns. The first series of colour tracing tests (1984-1986) however yielded maps with a general subsurface runoff from south to north following mainly the dip of the Dachstein limestone.
In 1990 more detailed studies were made in the central Dachstein area revealing minor differences to the 1984-1986 test results due to the different meteorological conditions, but basically the original findings were confirmed. The studies reasserted the necessity of introducing a comprehensive karst water conservation plan for the Dachstein so as to maintain the water quality of the major water supply systems (Gosau, Hallstatt).
The more recent results now show drainage patterns in north/north-west direction towards the *Echern* valley, the *Gosau* lakes and the *Traun* valley. All these investigations have provided evidence for a direct correlation between the waters disappearing in the karst plateau and the major springs and spring caves (with different flow times of course) along the northern margin of the Dachstein. The subsurface water streams - meanwhile discovered both in the *Mammuthöhle* and especially in the *Hirlatzhöhle* - complete the results of the dye tracing tests.

Karst and caves

Although Friedrich SIMONY has already described and documented the karst and some of the caves in his publications and notes (1895), and although Franz KRAUS lists a great number of caves in the Dachstein region in his *Höhlenkunde* (1894), a major progress in speleological terms was made in 1910 only when the *Dachstein-Rieseneishöhle* and the *Dachstein-Mammuthöhle* were discovered. A few years later some 9 km of cave passages had been explored. At the same time this region served and still serves as a forum for different cave formation theories and karsthydrogeological investigations which have resulted in a great number of publications on the Dachstein caves, karst and underground drainage systems. Owing to continuous studies some 25 km of cave passages were recorded in 1950 (at the onset of renewed and intensified research after World War II). The venture into the upper levels of the *Hirlatzhöhle* in 1983 (the cave passage length has grown since 1983 from about 8 km to more than 86 km !), the current studies of the *Dachstein-Mammuthöhle* (in 1959 some 10 km of passage were known, in 1999 about 56 km) and research in the *Schönberghöhle* have unearthed in the past decade completely new findings on the pattern of the giant cave systems at the north edge of the Dachstein. Scientists now have full information on 160 km of cave passage (of 5 major caves) including their underground horizontal and vertical extension.
A current cave register where all the well documented caves have been entered (these are approximately 70 % of all caves, the missing ones being small caves) clearly shows a

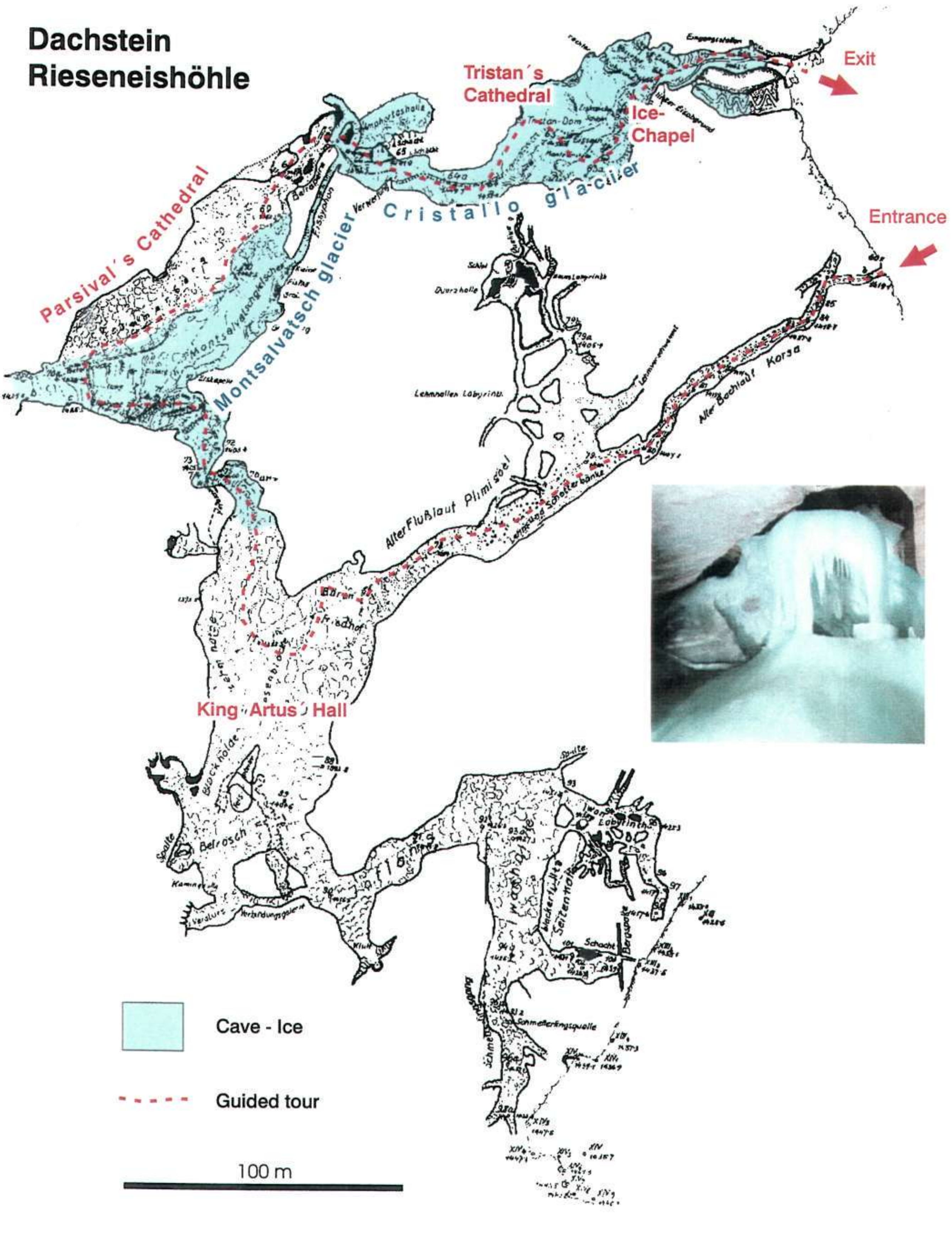

Fig. 7.1.2.: Schematic map of the Dachstein Rieseneishöhle, after F. Saar 1953, modified.

cluster of caves in the northern part of the Dachstein range which mainly houses the largest and deepest caves (Fig. 7.1.1.) stretching some 10 km W-E and some 3 km N-S. More recent cartographic and statistic evaluations have shown that the subterranean course of a major portion of this giant cave system is bound to the fault directions mentioned earlier and to the dipping of the Dachstein limestone. Whereas most of the inactive cave parts of various sizes run NW-SE and NE-SW, and also partially W-E, there are enormous (mostly active) canyons that fall steeply down north and frequently reach the phreatic zone. Here the overlying strata are only some 200-500 m, in some cases up to a maximum of 800 m. Apart from the more than 86 km long Hirlatzhöhle (i.e. the longest cave in Austria) the Dachstein Cave Park consists of the 56 km long Mammuthöhle (also one of the deepest caves in Austria featuring a level-difference of 1180 m in total and reaching from the edge of the plateau almost down to the valley floor), the 2 km long Dachstein-Rieseneishöhle (Fig. 7.1.2.) and the 10 km long Schönberghöhle (the quite exposed entrance to this cave can be seen from the cable car during the ascent to the Schönbergalpe looking to the east). This area is particularly well explored and recorded which is certainly also due to the cable railway system that enhances the accessibility of the region.

The Austrian cave register currently lists 560 caves (as of spring 1999) as compared to KRAUS's list of 16 caves (1894), BOCK's list of 30 caves (1913), ARNBERGER's list of 229 caves (1964) and the 1988 cave register that mentions 450 caves in the Dachstein region. A statistic evaluation of the data on the state of research, type and size of caves shows the comparatively fine store of knowledge (3/4 of the caves are either fully or partially explored) and the dominating feature of approximately the same number of horizontal caves (mostly in steep slopes) and shaft caves (mostly on plateaus). About 15 per cent of the caves are ice and/or water caves. If we categorise the caves by their size (length of passage) we see the great portion (about 70%) of small caves having a total passage length of 5-49 m. However, among the great number of caves there are only 3 which are „giant caves“ (more than 5 km of passages) and only 17 which are „large caves“ (500-5000 m). There are hardly any caves of 5-52 km currently known. If we add the known passage lengths of the giant caves to the mean passage length of the small and medium-size caves, there are more than 220 km of known and surveyed cave passages in the Dachstein area currently.

Allocation of the cave entrances by their altitudes reveals the maximum to lie between 1,500 m and 2,000 m above sea level. However, the altitudes recorded for most of the cave sections of the *Hirlatzhöhle* and *Dachstein-Mammuthöhle* show that the level of the entranceways is of little relevance in relation to the actual altitude of the passages inside the karst massif. For instance, the more than 86 km long *Hirlatzhöhle* currently has only one entrance at about 890 m above sea level, whereas the overall level difference of the cave amounts to some 1,000 m.

7.2. Legislative cave conservation in Austria: Experiences and results

Hubert TRIMMEL

Abstract

On June 28, 1928, the Austrian Parliament agreed a Federal Law concerning the protection of caves, one of the first laws in the world dedicated especially to the protection of geo-scientific phenomena. This etablished new dimensions of protection and preservation of Austrian caves. The most important of the criteria for declaration of a protected cave was its value for natural science. This meant that scientific studies and speleological research were vital in establishing the conservation measures. Between 1928 and 1938 and from 1945 to 1974, some 177 caves or cave areas in Austria were declared a "protected natural monument".
Since 1975, measures for the protection and preservation of caves have become regionalized. The regions ("Länder") follow their own policies in their legislative decisions but, in general, protection of caves, of the surroundings of the cave entrances and of karstic phenomena connected with caves is now a field of special legislation.
The economic development of alpine regions through tourism now makes the protection of major karst regions more important than the protection of single caves. The existing measures of cave protection form a sound basis for the active development of more extensive protected karst areas.

The Federal Law of 1928 concerning the protection of caves was supplemented by a series of decrees in the following year. One of these decrees concerned conservation-orientated rules for commercial caves and the education of cave guides; another, a scheme for continuous permanent documentation of protected caves. Scientific research as a basis for all conservation measures was undertaken before 1938 by an Institute of Speleology, and after 1945 by a Speleological Department in the Federal Bureau for the Protection of Monuments.
This was one of the first laws in the world dedicated especially and exclusively to the protection of geo-scientific phenomena. At this time the law established new dimensions of protection and preservation. The most important of the criteria for the declaration of a protected cave was its value for natural science. This meant that it was possible to declare a cave a "protected natural monument" not only because of its prehistoric or palaeontological importance, but also because of geological structures, important sediment layers or ice formations. In recognition of the relationship between the ecological development of cave chambers and conditions at the surface, the law also made it possible to protect the surroundings of the cave entrance and related karst-features at the surface. So, this law agreed 65 years ago, creates a very modern impression.
Between 1928 and 1938 and from 1945 up to 1974, in Austria, 177 caves and cave areas have been given the status "protected natural monument". In the first instance, all important show caves have been protected and the first steps have been taken to resolve the conflict between natural environment and tourism in caves. Since the Second World War, many newly discovered cave systems have been protected in collaboration with caves and caving societies. Most of the known cave systems have been explored since 1945, and it was very important to limit human influence in these systems before undertaking possible complex scientific documentation. Today, the total number of

registered caves in the central documentation system is nearly 11 000 - an important potential for future research. But this number is increasing relatively rapidly. In this situation it is more important that cavers have a proper understanding of the problems of protection than that a sound law exists.

Historically, experience with the Austrian "cave protection law" has been good. Success has been possible mainly for the following reasons:

The law has been administered by objective scientific institutions - in general well-accepted by the public and led (or regularly advised) by speleologists.

Permanent collaboration with the cave clubs by these institutions and federal authorities has guaranteed good information and documentation as well as educational measures for the cavers.

Caving is not a mass sport in Austria, and access and descent in caves, especially in the high-alpine regions, are often very difficult.

In practice, the situation regarding the protection of caves has changed for several reasons and in several ways.

First, measures for the preservation of caves by law have been regionalized. Now, the regions ("Länder") follow their own policies in their legislative decisions. In many regions, protection of caves and of karst phenomena connected with caves is now the field of special legislation; in other regions, cave protection is now part of the general legislation for the protection of nature. In many cases, problems arise because the law is administrated by local or regional authorities without any knowledge of important geo-scientific factors and often more or less in response to local economic influences.

Second, the economic development of alpine regions, especially through tourism in both sommer (mountaineering by funiculars) and winter (skiing) necessitates the protection of major karst regions including all the accessible caves. An important aspect of this need to protect regional karst landscapes is the protection of karst waters: nearly 50% of the Austrian population is supplied with drinking water from karst springs, and it seems likely that "karst water proctection" will complement the planned creation of national parks in the karstic Limestone Alps.

Thus, existing measures for cave protection in Austria form a sound basis for the active development of more extensive protected karst areas.

8. The Dachstein-reef of the Gosaukamm - An Upper Triassic carbonate platform and its margins

Gerhard W. MANDL & Harald LOBITZER

The Gosaukamm massif forms the northwestern extension of the central Dachstein mountains, separated by the deep furrow of the Gosau lakes. Both mountain ranges belong to the Dachstein nappe, which was part of the large Upper Triassic carbonate platform of the Austroalpine sector of the Tethyan shelf.
Whereas the Dachstein and the adjacent karst plateaus mainly represent the lagoonal interior of this platform, the Gosaukamm represents a marginal reef, facing toward the deeper marine Hallstatt basinal facies - similar to the palaeogeographic model of ZANKL (1971), developed for the Hohe Göll area south of Salzburg, see Fig. 8.1.

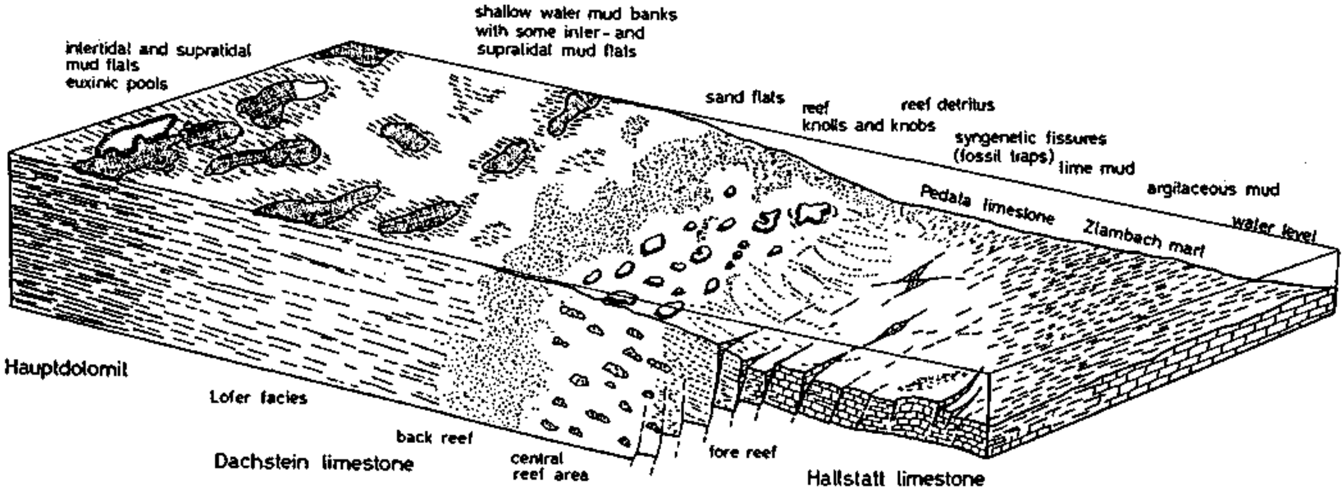

Fig. 8.1.: Palaeogeographic interpretation of the depositional environments in the Salzkammergut region during the Norian, after ZANKL (1971) (not to scale).

Transitional beds of slope- and nearby basin-facies are characterized by carbonatclastic sedimentation, derived from the platform as well as from the slope. These sediments are summarized under the term „Gosausee Limestone“, in literature often referred to as „Pedata Schichten“ according to the locally abundant brachiopod *Halorella pedata*. Exposures can be found mainly around the Gosau lakes and on the southwestern slopes of the Gosaukamm. Details of sedimentology and cyclicity of this bedded calciturbiditic limestone are given by REIJMER (1991). According to him the variations in turbidite composition can be attributed to fluctuations in sea level and resulting flooding and exposure of the platform. The so caused variation of platform sediment production could be matched with Milankovitch quasi-periodicities.
The former platform margin has been dissected during orogenesis by several dextral strike slip faults, see Fig. 8.2. The northwestern front part of the moving block was squeezed into the deformed basinal sequences of theTörleck and Zwieselalm anticlines. In this way the syncline of Roßmoos was formed, where Rhaetian Zlambach marls are preserved below a thin layer of the overturned Dachstein Limestone of the Kesselwand, Fig. 8.4.

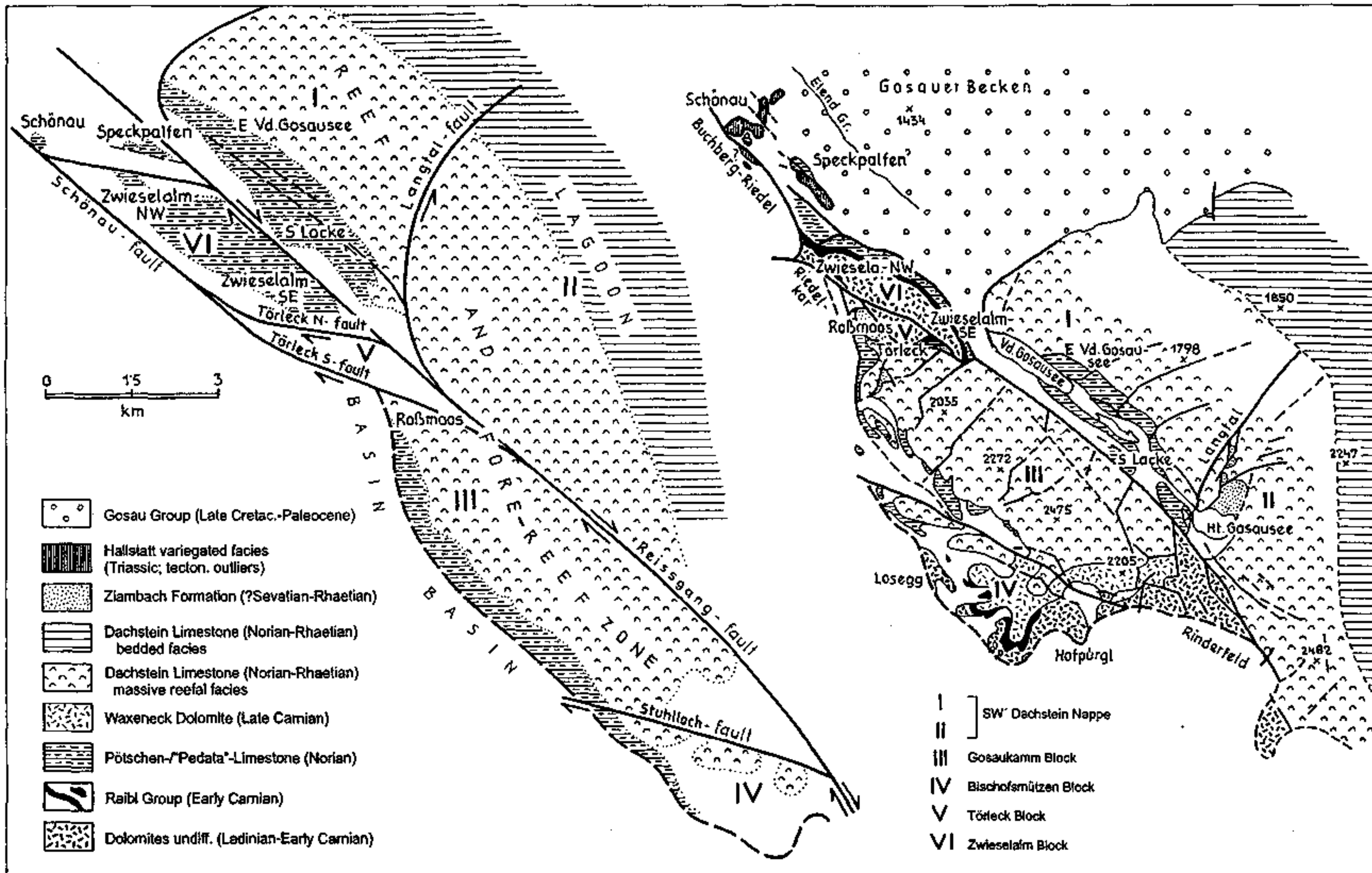

Fig. 8.2: Facies zones of the Dachstein platform margin in the Gosaukamm area. Restored geometry before strike-slip faulting After MANDL (1984).

The general investigation and mapping was done by SCHLAGER (1966, 1967), additional refinements have been contributed by TOLLMANN & KRISTAN-TOLLMANN (1970) and MANDL (1984). Palaeontological and microfacial research of the Dachstein reefs was done by the reef working group from the University Erlangen, summarized in FLÜGEL (1981); details from the Gosaukamm have been reported by WURM (1982). Short reports on the macrofauna are given by ZAPFE (1962, 1967). A recent study of corals was done by RONIEWICZ (1995).

The Dachstein reef limestone of the Donnerkogel group (localities 1-5, 19-20 in Fig. 8.3.) dominantly is composed of coarsegrained rud/floatstones and reef debris with only small, widely distributed patch reefs. The microfacies may be subdivided into up to 10 types (WURM, 1982).

A large scale bedding (some 10 meters) can be seen. The original dip of the reef slope was not 30° as today, but about 10-15° concerning displaced geopetal fabrics. The patch reefs show a dominance of non-segmented calcareous sponges as main framebuilders. Branched corals are less frequent.

Fauna and flora of the patch reefs and the detrital limestones is very rich. More than 50 species contribute to the construction of the reef framework, more than 60 species must be regarded as benthonic reef-dwellers. Pelagic elements from the open sea are known with *Heterastridium*, ammonites and conodonts.

The investigations at the Gosaukamm have shown, that the associations of foraminifera and of calcareous algae are significant for distinctive environments within the reef zone:

„Sessile foraminifera"-associations with *Alpinophragmium* and *Nubecularia* are connected with calcareous sponges and corals in patch reefs only.

„*Galeanella* - sessile foraminifera" - association with *Galeanella* and other miliolids have been recognized mostly in reef detritus of the central reef flat. A similar environment is indicated by an „*Ophthalmidium* - sessile foraminifera" - association with *Ophthalmidium*, *Quinqueloculina*, *Sigmoilina* together with *Nubecularia*.

The algal flora consists of red algae, rare dasyclads and common algal crusts around frame building organisms, often together with many tubes of *Microtubus communis*.

The marls and limestones of the Zlambach Formation at the locality Roßmoos are well known for a rich coral fauna (FRECH, 1890). Additional elements are non-segmented calcareous sponges, spongiomorph hydrozoans, bryozoans, brachiopods, ammonites (*Choristoceras haueri* MOIS.), echinoderm, serpulids, solenoporaceans.

The microfacies of Zlambach limestones is characterized by abundant reworked corals with encrusting organisms (e.g. *Nubecularia*, *Tubiphytes)* and some calcisponges and bryozoans. A packstone fabric is common, grain contacts often show stylolites. Miliolid and textularid foraminifera are found in the micritic matrix. Foraminifera have been described by TOLLMANN & KRISTAN-TOLLMANN (1970).

FLÜGEL (1962) interpreted the environment as off-reef shoals within a muddy basin somewhat deeper and near to the fore reef of the Gosaukamm reef.

The deeper and distal part of the Zlambach basin facies is not preserved at the Gosaukamm, but several kilometers to the northeast, at the type locality within the Hallstatt unit of Ischl-Aussee - for details see BOLZ (1974), PILLER (1981), MATZNER (1986).

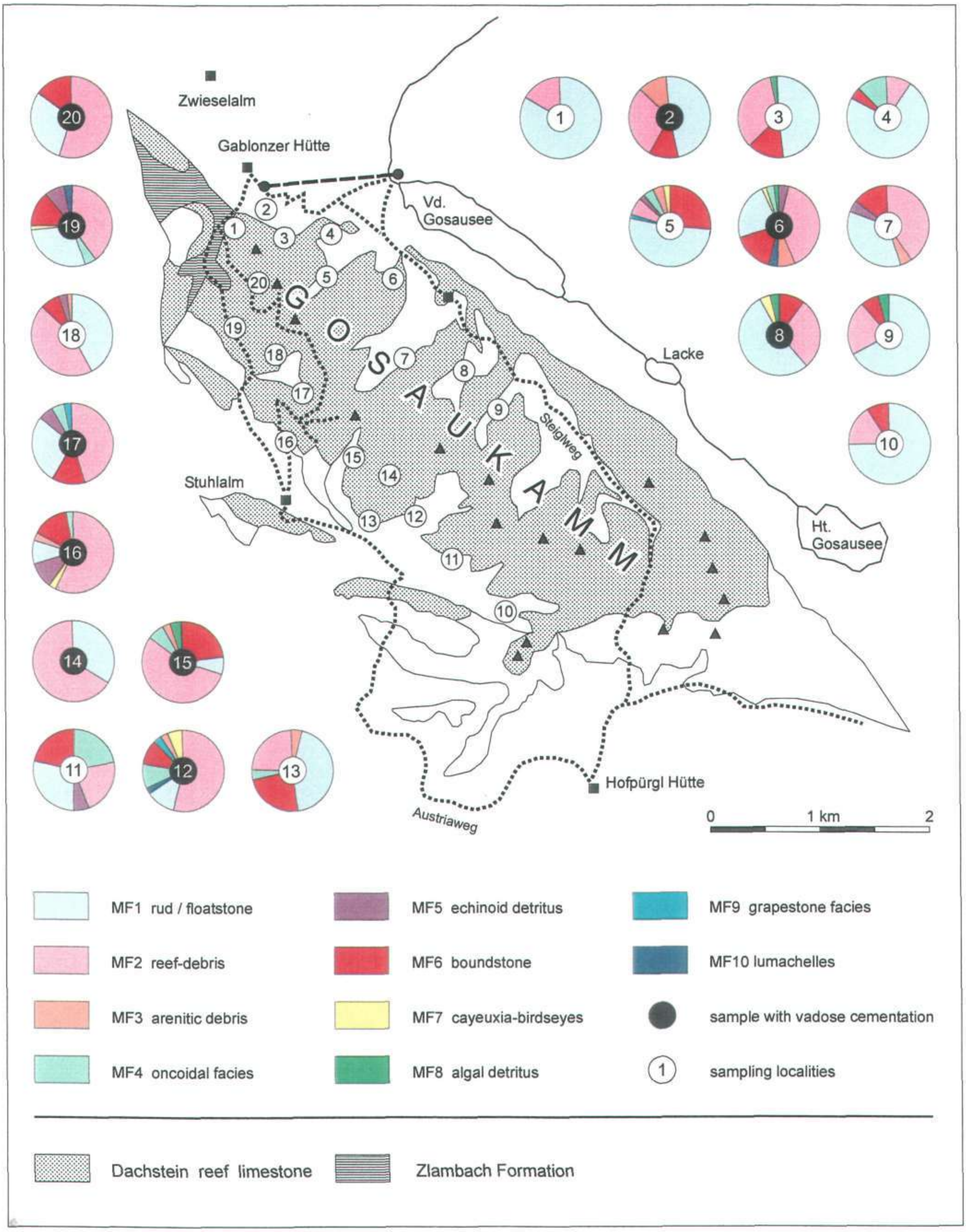

Fig. 8.3 : Microfacies composition of the Dachstein reef limestone (Upper Triassic) in the Gosaukamm area (Northern Calcareous Alps, Austria) according to WURM 1982.

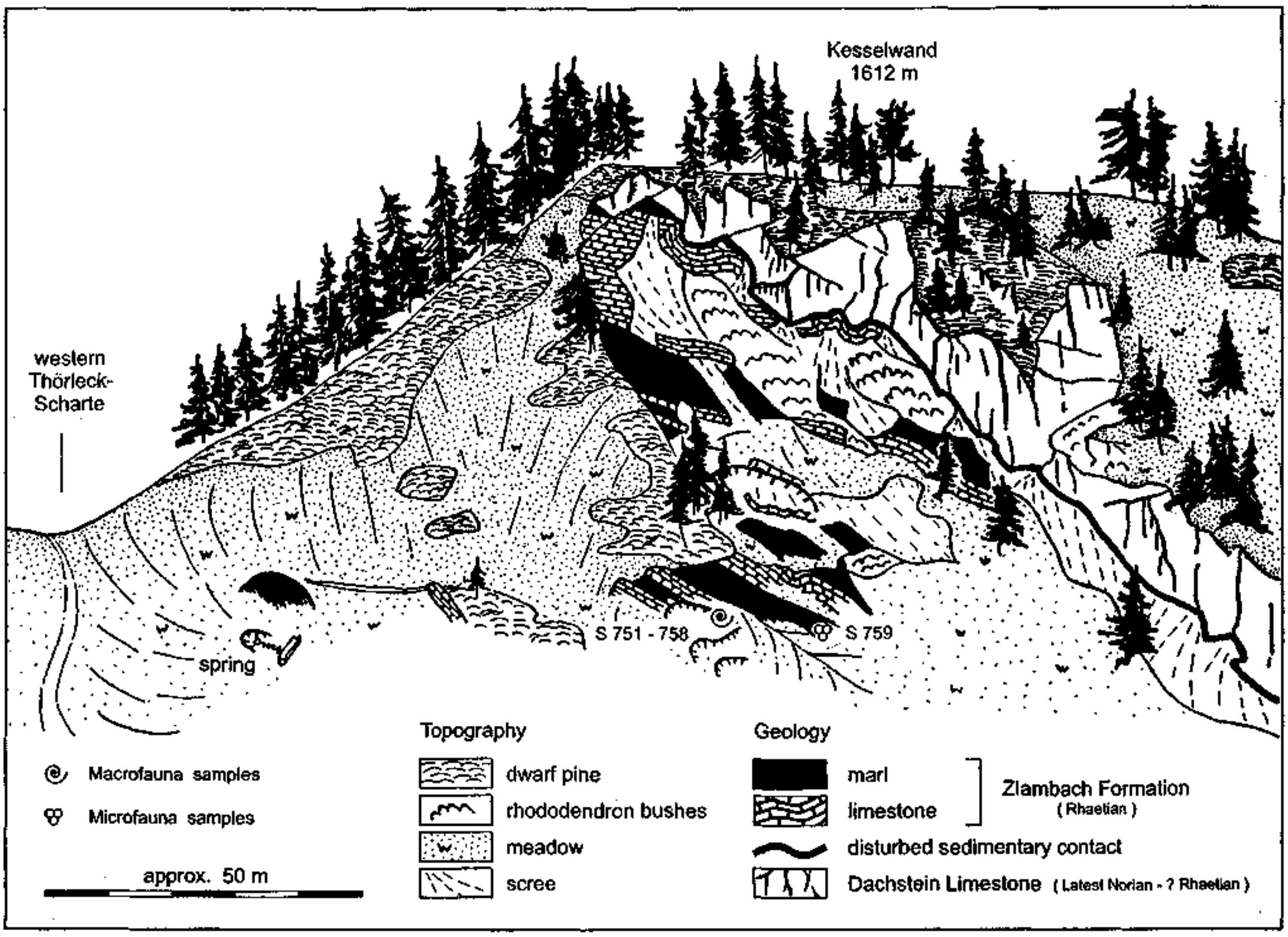

Fig. 8.4.: The localities Roßmoos (foreground) and Kesselwand.
After TOLLMANN & KRISTAN-TOLLMANN (1970), modified.

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