Outline of Sedimentation, Tectonic Framework and Hydrocarbon Occurrence in Eastern Lower Austria			
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Part I

Outline of Sedimentation, Tectonic Framework and Hydrocarbon Occurrence in Eastern Lower Austria

Geological Overview

In eastern Austria main tectonic elements of Central Europe (Fig. 1) are located and much geoscientific information has been documented since the beginning of the last century dealing with this area or parts of it. More recent compilations with an extensive bibliography may be found in monographic works, done by A. Tollmann (1977, 1985, 1986, "Geologie von Österreich, Vol. 1–3"; list of publications in vol. 3, 1986), R. Oberhauser (editor, 1980, "Der geologische Aufbau Österreichs"), W. Janoschek & A. Matura (1980, "Outline of the Geology of Austria"), H.W. Flügel & P. Faupl (1987, "Geodynamics of the Eastern Alps"), F. Bachmayer (editor, 1980, "Erdöl und Erdgas in Österreich"). Successful oil and gas exploration since 1930 has provided a great deal of important information about the Eastern Austrian basin areas and the Alps.

The basement is the Bohemian Massif which outcrops in the northwestern part of eastern Austria. Its structure was completed mainly during the Hercynian orogenesis and it represents the European Plate in the evolution of this area. The recent stage of deformation is the result of the collision of the European Plate with the African Plate. The Waschberg Zone and Helvetikum are remnants of the former margin of the European Plate, the majority of which is now dipping under the Alpine-Carpathian orogenic belt. The Central-Tethyan region is represented by the Penninic Zone, now part of the Central Alps, and the Flysch Zone north of it. In the Penninic Zone parts of an oceanic crust are preserved (V. Höck, & Ch. Miller, 1987).

The Austroalpine Nappes are parts of the African Plate and some microplates at its northern border (W. Frisch, 1978). They consist of crystalline rocks with sedimentary cover. The original setting of the units was different than todays tectonic position. South of the Penninic Zone, first the Lower Austroalpine, then

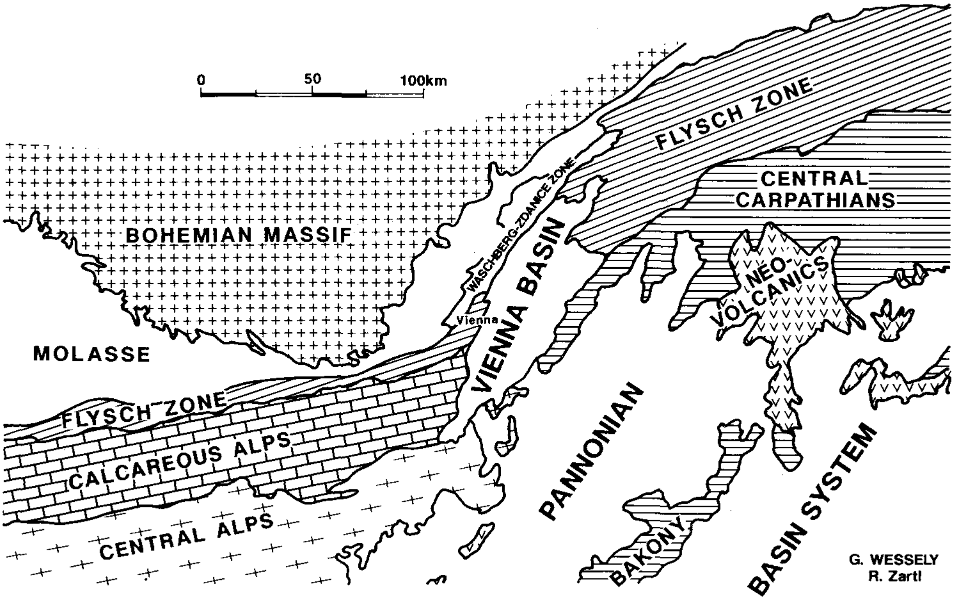


Fig. 1: Situation of the Vienna Basin within the Alpine-Carpathian thrust belt.

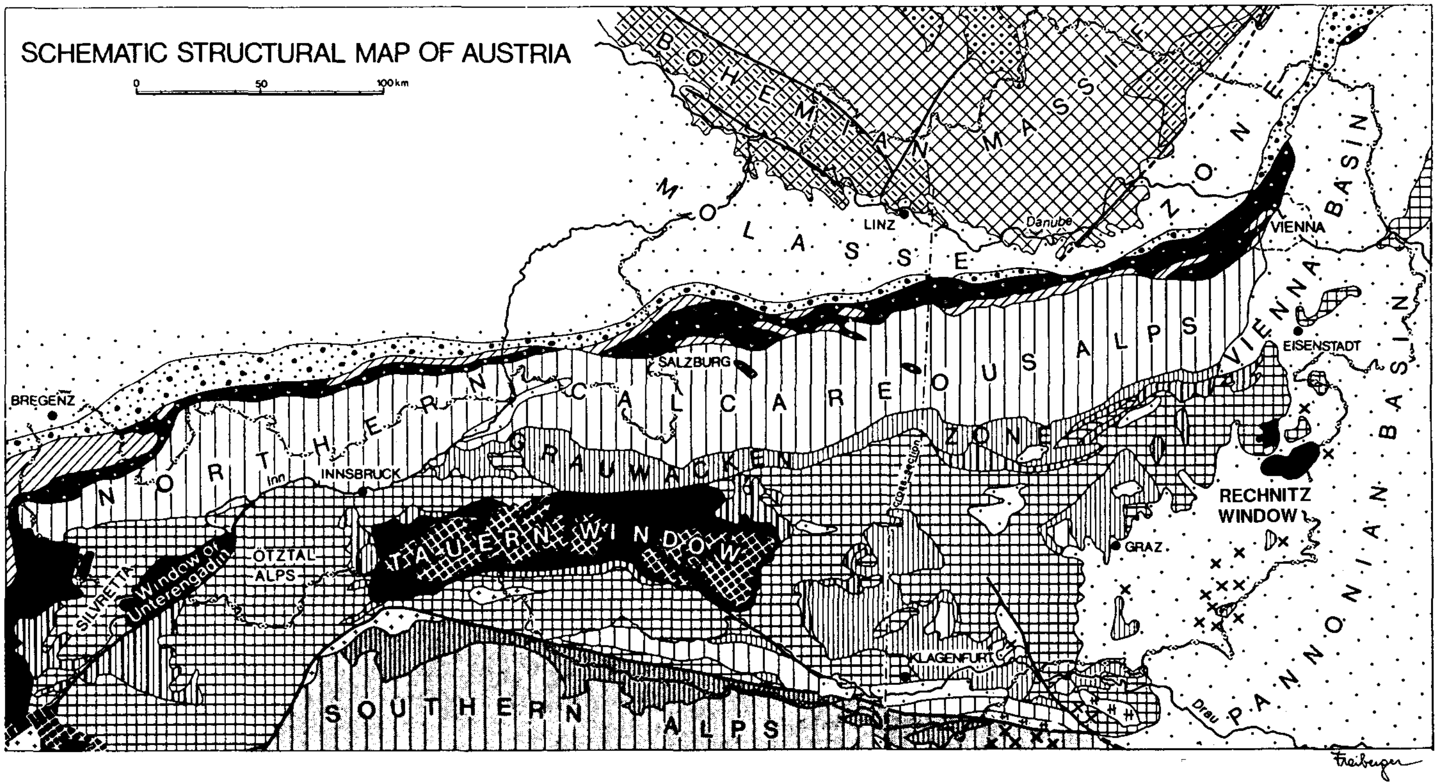
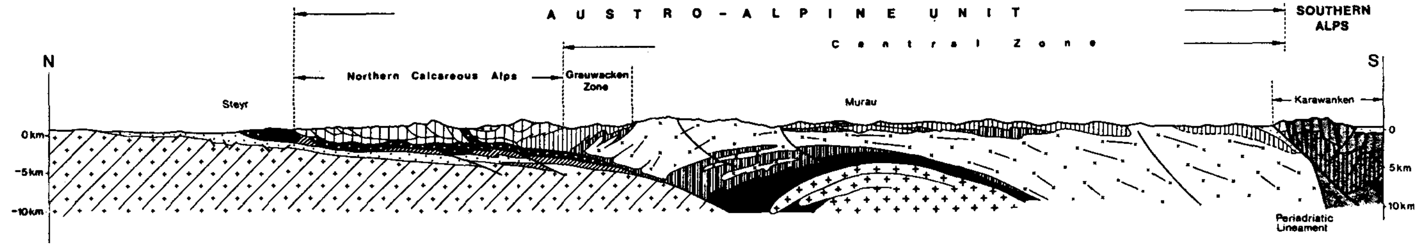


Fig. 2: Schematic structural map of Austria (W. JANOSCHEK & A. MATURA, 1980).



Bohemian Massif

- ▨ Extra–Alpine basement of the Bohemian Massif i.g. x
- ▨ Post Variscan sedimentary cover of the Bohemian Massif xx
- ▨ Moldanubian Zone xx
- ▨ Moravian Zone xx
- ▨ Bavarian Zone xx

Tertiary basins

- ☐ Molasse Zone, intramontaneous basins

External Alpine Units

- ▨ Allochthonous Molasse, Waschberg Zone x
- ▨ Helvetic and Klippen Zone
- ■ Flysch Zone

Penninic Zone

- ■ Metasedimentary rocks of the Penninic Zone
- ▨ Crystalline basement of the Penninic Zone xx
- ▨ Crystalline basement of the Penninic Zone x

x cross section only **xx map only**

Austroalpine Unit

- ▥ Permomesozoic (unmetamorphic in North Alpine facies)
- ▥ Paleozoic (low–grade metamorphic)
- ▥ Permomesozoic (low–grade metamorphic in Central Alpine facies)
- ▦ Crystalline basement ("Altkristallin") xx
- ▨ Crystalline basement ("Altkristallin") x

Southern Alps

- ▨ Permomesozoic
- ▥ Paleozoic
- ▨ Crystalline basement x

Igneous rocks

- ▨ Periadriatic intrusive masses
- ▨ Neogene andesites and basalts

Fig. 3: Cross section through the Eastern Alps (W. JANOSCHEK & A. MATURA, 1980).

the Middle Austroalpine were developed, followed by the Upper Austroalpine as the southernmost unit. In the East region of Austria the sedimentary sequence of the Lower Austroalpine and Middle Austroalpine units are represented by the Semmering Mesozoic. The Upper Austroalpine sedimentary sequences are the Paleozoic Grauwacken Zone and the Permomesozoic and Paleogene of the Calcareous Alps (Fig. 2). During the Alpine orogeny, the Austroalpine Nappes moved northwards over the Penninic Zone. Hereby the Lower Austroalpine has been overthrusted by the Middle and Upper Austroalpine. The latter now extend far to the north, represented by the Calcareous Alps. They now rest like a vessel

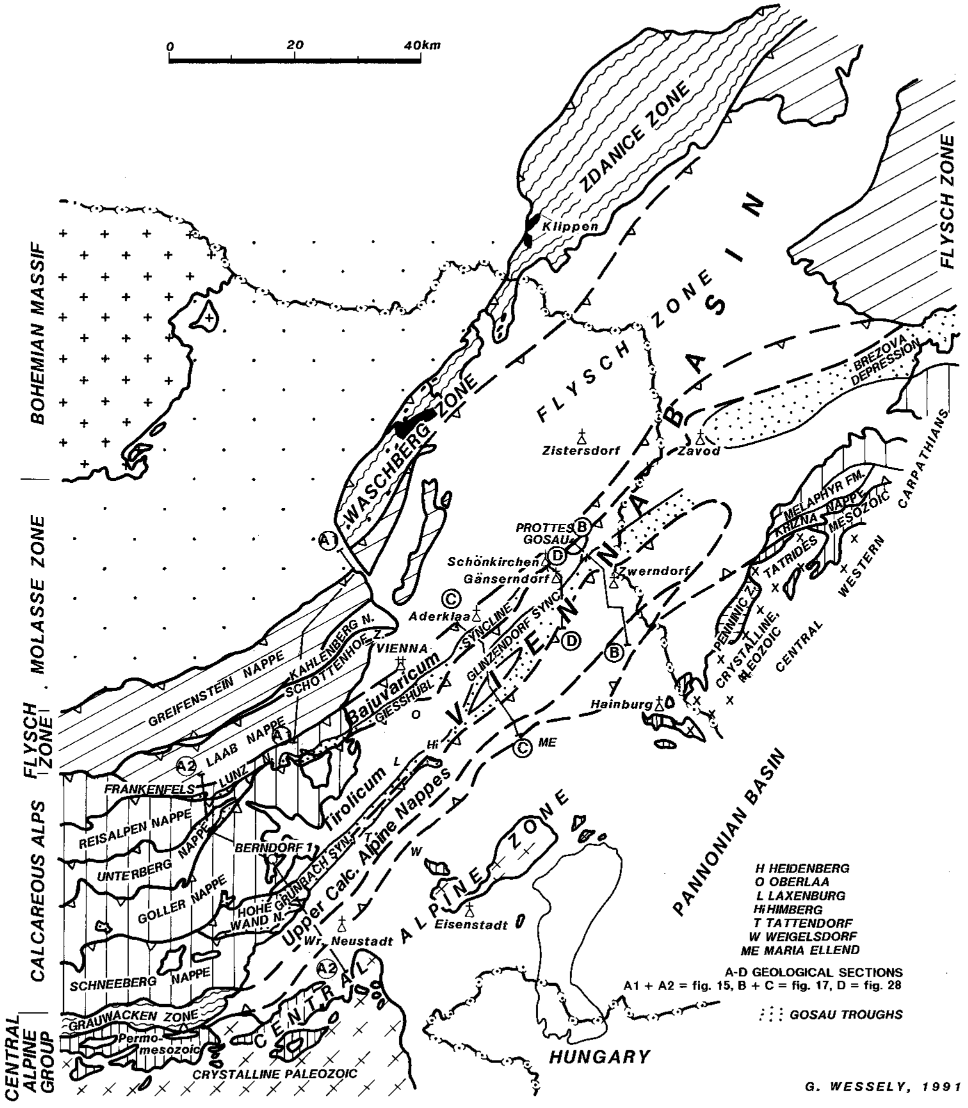


Fig. 4: Alpine Carpathian tectonic units at the border and below the Vienna Basin.
G. WESSELY (1992).

rootless on attennuated Flysch and on Lower Austroalpine units (Fig. 3). In the Vienna area the Alpine, W–E strike changes to a SW–NE orientation in the Western Carpathians (Fig. 1). This change was caused by preexisting structural patterns in the basement. Termination of thrusting in the Alpine region and continuous movement of the Carpathian nappe system led to the subsidence of the Vienna Basin by tension of the nappes in Mio–Pliocene time. The Pannonian Basin is separated from the Vienna Basin by parts of the Central Alps and Carpathians.

The tectonic units of northeastern Austria, in their present day positions from NW to SE are as follows (see Fig. 4):

○ The Crystalline complex and the Paleozoic of the Bohemian Massif.

○ The Tertiary Molasse and underlying Autochthonous Mesozoic (Middle Jurassic to Upper Cretaceous) covering the Bohemian Massif below the Molasse Zone and below the Alpine-Carpathian thrustbelt.

○ The Waschberg Zone north of the Danube river, as the external (leading edge) Alpine-Carpathian orogenic unit, consisting of strongly deformed older Tertiary Molasse beds and klippen sheared off from the Mesozoic–Paleogene Molasse base.

○ The Helvetic Zone, in its eastern part represented mainly by the "Buntmergelserie" (Cretaceous to Paleogene) and Mesozoic klippen, as exposed in the "Schottenhofzone".

○ The Flysch Zone, consisting of Uppermost Lower Cretaceous to Middle Eocene turbidites forming several nappes (Greifenstein-, Kahlenberg-, Laab Nappe including St. Veit Klippen belt).

○ The Calcareous Alps, made up of Permian to Paleocene deposits, forming several groups of nappes, the lowermost Bajuvaricum (Frankenfels- and Lunz Nappes), the Tirolicum (Ötscher Nappe s.l., including Reisalpen-, Unterberg- and Göller Nappes) and the Juvavicum (Hohe Wand-, Mürzalpen-, Schneeberg Nappes).

○ The Greywacke Zone, as the Paleozoic base of the Calcareous Alps along their southern border, divided into the Veitsch Nappe and the Noric Nappe.

○ The Central Alps, represented mainly by the Austroalpine Crystalline complexes especially the Lower Austroalpine and its cover, the "Semmering Mesozoic". The "Penninic Zone" is exposed only in the Rechnitz Window.

○ The southernmost part of the Tatrides of the Little Carpathians with crystalline rocks and a Permian to Liassic cover.

○ The Neogene Vienna Basin superimposed on Alpine-Carpathian tectonic units.

○ The westernmost part of the Pannonian Basin.

1. The Tectonostratigraphic Units

1.1. Mesozoic Cover of the Bohemian Massif (Lower Austrian Mesozoic Basin)

The Mesozoic cover of the Bohemian Massif is not exposed on the surface in Austria. The well, which first encountered it was Staatz 1. In the meantime, from many wells the stratigraphy of the Jurassic and Cretaceous sediments is known (J. KAPOUNEK, A. KRÖLL, A. PAPP & K. TURNOVSKY, 1967; F. BRIX, A. KRÖLL & G.

WESSELY, 1977). The subsidence of the Lower Austrian Mesozoic Basin (G. WESSELY, 1987), located along the southeastern margin of the Bohemian Massif (Fig. 5), began in the Early Middle Jurassic. Continental and fluviodeltaic clastics of the Gresten Group were deposited unconformably on Permo-Carboniferous sediments and the Hercynian basement complex (Fig. 6). The basal transgressive series (Lower Quartzarenite Formation) consists of Aalenian arkoses and quartzarenites containing intercalations of coal and coaly shale. In parts of the basin dark prodeltaic marine shales separate the Lower Quartzarenite Formation from the Upper Quartzarenite Formation. The latter was deposited under marine-deltaic conditions. It is overlain by marine shales of variable thickness.

These deltaic to prodeltaic sediments contain Bajocian and Bathonian ammonites, which indicate that the entire transgressive clastic cycle lasted from the Aalenian to the Late Bathonian. This series ranges in thickness from a few tens of meters up to 1,500 m depending on its position within the depositional fan and its tectonic setting. Within halfgrabens, which were caused by rifting and synsedimentary SE-dipping normal faults, the thickness is several times greater in down dip positions than on structurally high parts of the NW-dipping blocks (Fig. 6). On the crests, erosion has taken place, or the section has been condensed. A diabase flow and tuffites, which are present in the basal part of the Middle Jurassic clastics in the well Porrau 2, are connected with the rifting event.

During the Late Middle Jurassic, crustal extension apparently ceased and stable platform conditions were established. This is reflected by a more uniform thickness of the Callovian series, which is, in general, not affected by the rift faults. This series is composed of sandy dolomitic and lenticular chert layers up to 250 m thick (Höflein Formation, R. SAUER, this guide book, part II). These sediments are conformably overlain by Oxfordian platform carbonates (Vranovice Formation; M. ELIAS, 1971).

During the Oxfordian and Kimmeridgian, up to 750 m of platform carbonates were deposited along the fringe of the South Bohemian Basement Spur. The typical facies sequence of this series is the Altenmarkt Formation (W. LADWEIN, 1976), which begins with bedded, cherty carbonates and grades upward into bioclastic limestones. These beds are overlain by algal and sponge carbonates with abundant detritus. The sequence generally develops into reef build-ups, first as sponge-algal bioherms and followed by coral reefs on top.

Laterally the reef complexes are sometimes replaced by oolitic-bioclastic deposists. The above described facies sequence illustrates a progressive shallowing of depositional depth. These carbonate units are fringed basinwards by marly limestones with clastic carbonate layers (Falkenstein Formation, M. ELIAS & G. WESSELY, 1990). Laterally, these grade into dark basinal marls (Mikulov Marls, M. ELIAS, 1971, 1977), which range in thickness from 600 m to 1000 m (Fig. 7).

During the Tithonian the basin became shallower again. This is reflected by the rapid basinward progradation of coarsening upward terrigenous and bioclastic carbonates (Kurdejov Formation, M. ELIAS, 1971). These are covered, in part, by reef carbonates and dolomites (Ernstbrunn Formation, M. ELIAS & G. WESSELY, 1990).

The Early Cretaceous corresponds to a regional hiatus. The Cenomanian to Maastrichtian series (R. FUCHS & G. WESSELY, 1977) rest unconformably on truncated Tithonian carbonates. The Senonian series consists of sandy marine

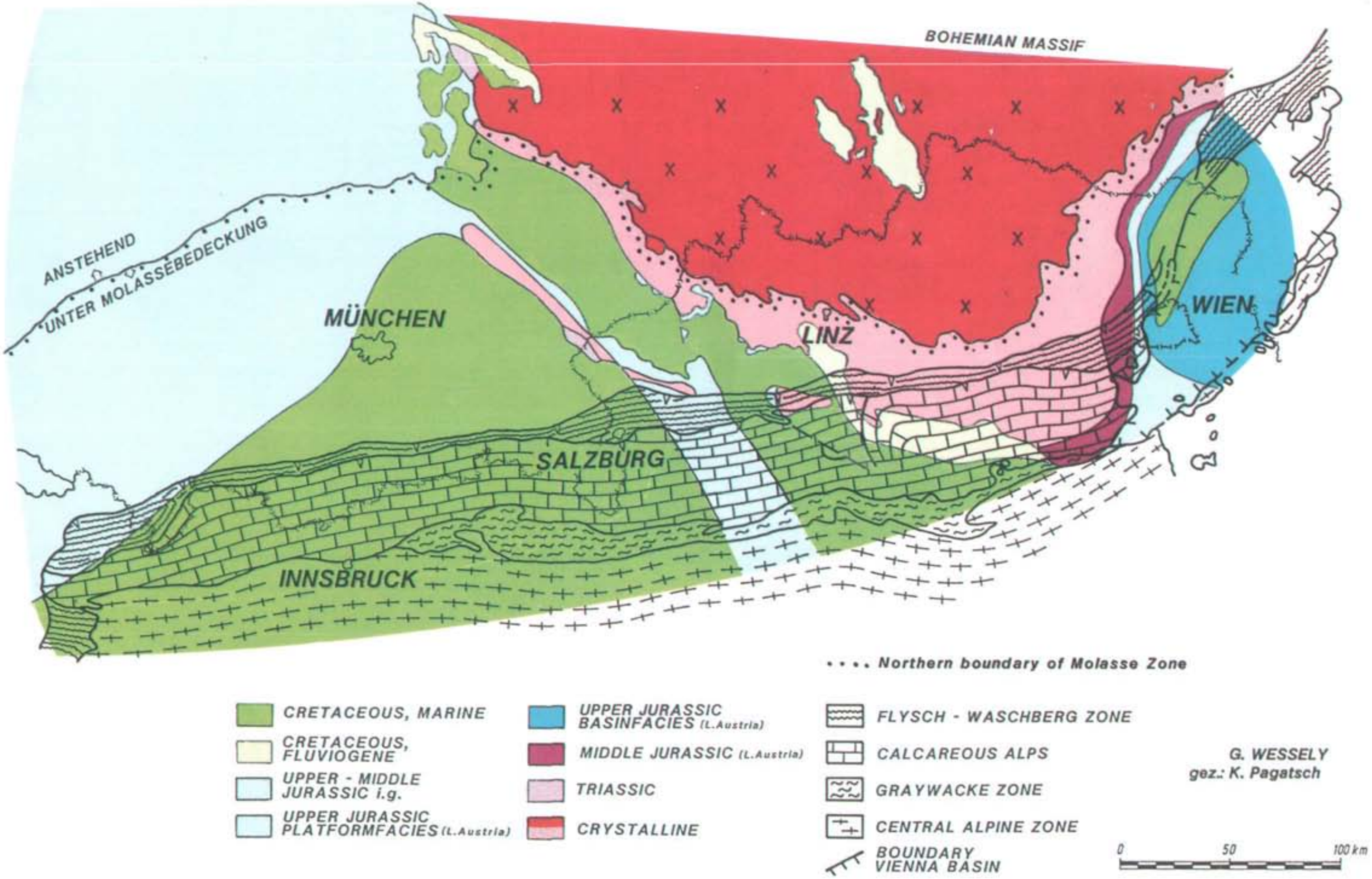


Fig. 5: Distribution of the Autochthonous Mesozoic covering the southern Bohemian massif below the Molasse and the Alpine-Carpathian thrust-belt (G. WESSELY).

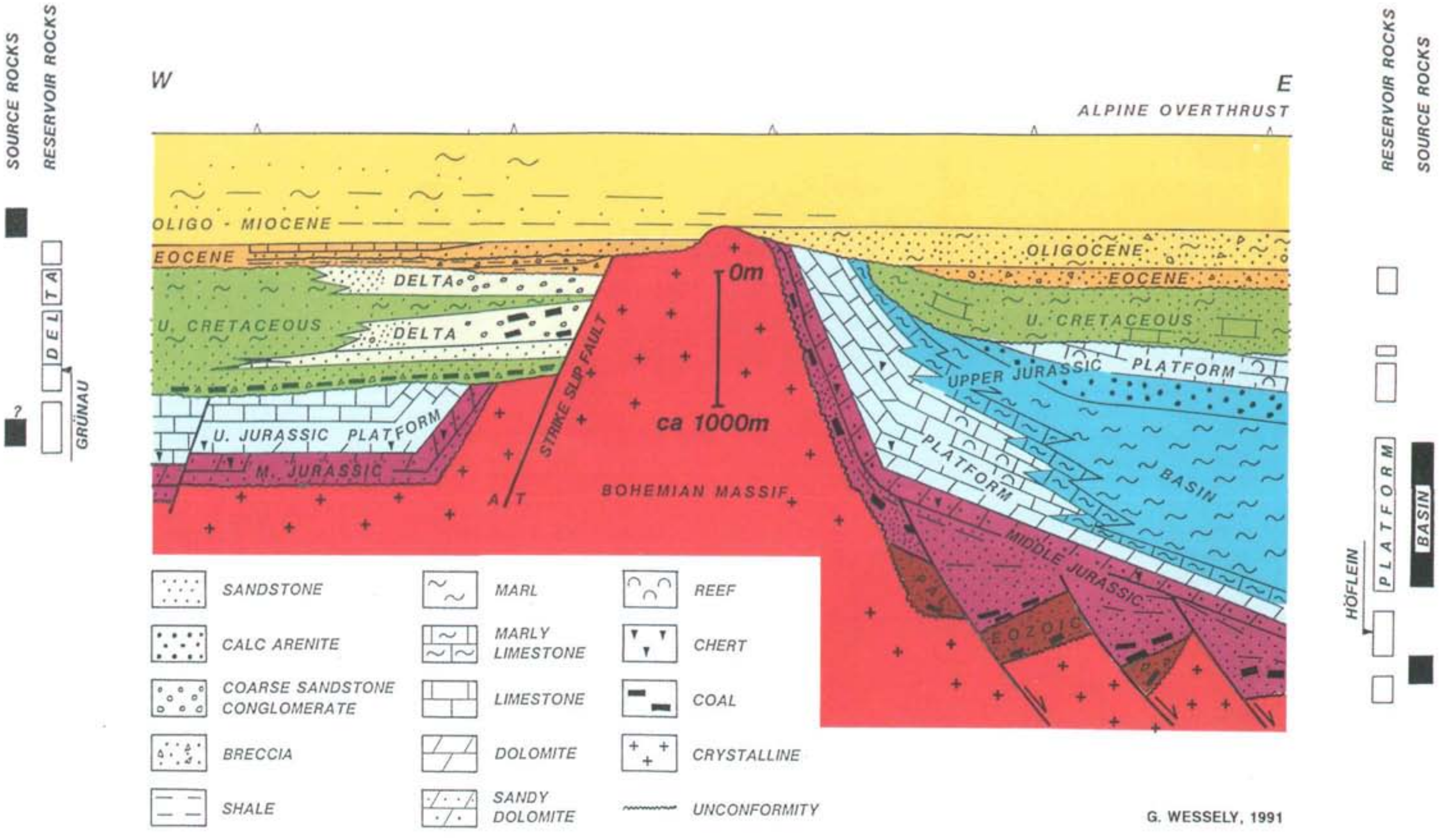


Fig. 6: Stratigraphic scheme of the Autochthonous Mesozoic and Molasse covering the southern Bohemian massif (G. WESSELY).

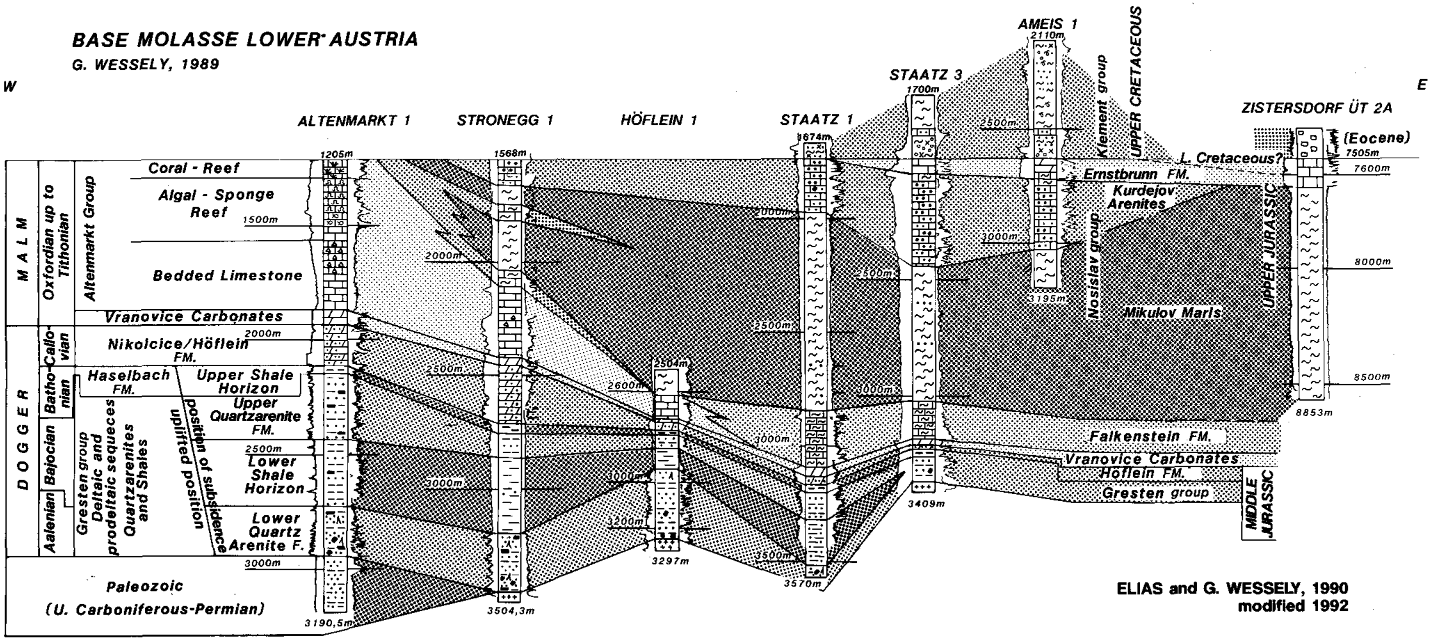


Fig. 7: Autochthonous Mesozoic below the Molasse in Lower Austria.
M. ELIÁŠ & G. WESSELY (1990, modified 1992).

marls. The entire Late Cretaceous section attains a thickness of up to 900 m, but has never been completely penetrated by a single well.

The Early Cretaceous regression resulted in karstification. The variable distribution and incomplete preservation of Late Cretaceous sediments indicate Paleogene erosion. In the well Zistersdorf ÜT2A, coarse Oligocene clastics rest unconformably on Late Jurassic limestones. The Late Cretaceous is represented only as olistolithes embedded in Oligocene clastics, which were deposited on the shelf slope.

The Autochthonous Mesozoic series of the Lower Austrian Mesozoic Basin, as known from wells extends beneath the Carpathian nappes and the Vienna Basin (G. WESSELY, 1990). In the latter, its presence at depths ranging between 6.050 and 8.553 m has been proven by several wells. The Zistersdorf ÜT 2A well penetrated 145 m of Tithonian Upper Carbonate and 893 m of Tithonian basinal shales of the Mikulov Formation. Similar series were encountered in the Maustrenk ÜT1 well between 6,050 and 6,563 m. A third well, Aderklaa ÜT1a, drilled near the city of Vienna, reached the autochthonous crystalline basement at a depth of 6,245 m, after penetration of 173 m of the Mikulov Formation and 22 m of Malmian carbonates.

1.2. Molasse Zone

The Molasse Zone is defined as the trough in front of a prograding nappe system at the late stage of orogenesis. Compilations on stratigraphy and tectonics of the Molasse Zone including Eastern Austria were made by R. JANOSCHEK (1964), F. BRIX & G. GÖTZINGER (1964), R. GRILL (1968), W. FUCHS (1976, 1980a), F. BRIX, A. KRÖLL & G. WESSELY (1977), A. KRÖLL (1980), F. STEININGER, G. WESSELY, F. RÖGL & L. WAGNER (1986), A. TOLLMANN (1986) and E. ANIWANDTER, J. BIMKA & D. ZYCH (1990). In eastern Austria, in the region west of Vienna, the Molasse sediments cover the area between the west–east-extending Alpine mountain range and the Variscan Bohemian Massif to the north (Fig. 1).

North of Vienna the Molasse Zone is bordered to the SE by the Waschberg Zone, the external thrust sheet of the Alpine-Carpathian nappe system. To the NW the Molasse sediments onlap the crystalline rocks of the Bohemian Massif. This is the basement of the western part of the Molasse formations. In the easternmost part the Molasse sediments are underlain by Jurassic and Upper Cretaceous autochthonous formations.

Uplift and regression took place during the Paleocene and Eocene. The prograding Alpine-Carpathian nappe system turned the passive margin of the Bohemian Massif into a foreland Molasse trough during the Oligocene. The Molasse transgression started with the shallow marine "Eger Sandstone" of the Melk Formation (Tab. 1), which prograded more than 35 km onto the foreland. This was followed by the Eggenburgian–Ottnangian sequence (Lower Miocene) which is characterized by shales, shaly marls and silty sandstones.

The *Oncophora* deltaic complex prograded out from the Variscan crystalline mainland towards the SE and covered half of the basin during the Ottnangian. At the end of the Lower Miocene during the Karpatian, a thick, mostly transgressive marine claystone sequence of the Laa Formation was deposited north of the Danube.

The shallow marine Grund formation of Middle Miocene age (Lower Lagenid Zone) represents the final stage of marine sedimentation in the southern part of the remaining Molasse basin.

The beginning of uplift and erosion of the Molasse Zone together with the Alpine Carpathian range is marked by the onset of detrital influx containing blocks derived from the Flysch Zone. Contemporareously subsidence and sedimentation began in the Vienna Basin.

From late Middle Miocene onward the Molasse basin north of the Danube also became a mainland. During the first period of the Upper Miocene, the Zaya river, the so called "Paleo-Danube", transported detrital material from the western Alpine ranges and the Bohemian Massif through the Zaya depression (Hollabrunn talus fan).

In the Vienna Basin autochthonous Molasse has been encountered only in the wells Zistersdorf ÜT 1a and ÜT 2A represented by marls, sandstones and coarse clastics consisting of components of Malmian carbonates and an Upper Cretaceous olistolith.

1.3. Waschberg Zone

The Waschberg Zone (R. GRILL, 1953, 1961, 1962, 1963, 1968; A. TOLLMANN, 1985; F. BRIX, A. KRÖLL & G.WESSELY, 1977; P. SEIFERT,1982; F. STEININGER, 1991) represents an external nappe (leading edge) of the Alpine-Carpathian mountain belt. It is a tectonic unit composed of Molasse sediments (Allochthonous Molasse according to F. STEININGER, G. WESSELY, F. RÖGL & L. WAGNER, 1986) and minor Mesozoic klippen. It is situated between the Danube and the Czechoslovakian border. The nappes of the Waschberg Zone overlie the undis-

Table 1.
Stratigraphy of the Molasse and Waschberg Zone.

				St. Pölten – Tulln	North of the Danube	Waschbergzone
TERTIARY	NEOGENE	Miocene	Pannonian		Hollabrunn Gravel Fan	
			Sarmatian		Rissoa Beds	
			Badenian		Grund Fm.	
			Karpatian		Laa Fm.	Laa Fm.
			Ottnangian	Oncophora Sands*)	Oncophora Sands	
			Eggenburgian	Eggenburg Group Sandstreifen Schlier	Eggenburg Group Sandstreifen Schlier	Auspitz Fm.
	PALEOGENE	Oligocene	Egerian	Melk Fm.	Upper Melk Fm. Eger Sandstone*)	Michelstetten Fm. Thomasl Beds
			Rupelian			Niemtschits Fm. (Menilite Series)
			Lattorfian			
		Eocene Paleocene		Moosbierbaum Conglomerate		Reingrub Fm. Haidhof Fm. Waschberg Fm. Bruderndorf Fm.

*) Gas reservoir rocks.

turbed sequences of the Molasse Zone in the NW and are covered by the Flysch nappes in the SE (Fig. 22).

The nappes of the Waschberg Zone consist mainly of an Upper Oligocene–Lower Miocene sand-shale sequence with a primary thickness of 400–700 m.

Starting in the Oligocene, first laminated, followed by cyclic sediments transgressed onto the SE flank of the Bohemian Massif, which had remained in a passive margin setting from the Dogger to the Eocene.

Upper Jurassic marlstones and calcarenites of the Klentnice Formation and reefal limestones of the Ernstbrunn Formation, Upper Cretaceous glauconitic sandstones, Paleocene limestones and marls and Eocene coral reefs, marls and sandstones represent the different types of shelf sedimentation during the passive margin stage of the Bohemian Massif.

During the last orogenic movement of the Alpine-Carpathian belt, the Molasse sequence in the area NE of Vienna was scraped off and thrusted with parts of the underlying formations to form the Waschberg Zone.

At the end of the Lower Miocene, during the Karpatian stage at 17 MM years, the Waschberg Zone reached its present position. During Middle Miocene it was partially covered by younger sediments (Fig. 22).

Today we find small thrust sheets of Mesozoic to Eocene shelf sediments 20–200 m thick within and at the base of the Waschberg Zone nappes.

Below the Vienna Basin the Waschberg Zone has been encountered only by the deep wells of Zistersdorf and Maustrenk ÜT and two additional wells along the Steinberg fault. Mainly pelitic Eocene to Oligocene sequences were penetrated. Intercalations of Menilite facies and some sandstones and breccias were observed.

1.4. Flysch Zone, "Helvetic Zone", Klippen Zones

The Flysch Zone is exposed as a narrow strip in front of the Northern Calcareous Alps. Northeast of Vienna the Flysch Zone continues below the Neogene basin fill of the Vienna Basin. Further to the northeast it outcrops again in the Western Carpathians. Within the Flysch Zone (Figs. 15,16) a narrow "Ultrahelvetic" unit is squeezed to the surface, known as "Schottenhofzone" (F. Brix, 1961) or as a part of the "Hauptklippenzone" (S. Prey, 1979). The stratigraphic content of this Ultrahelvetic Zone is a strongly deformed sequence of variegated marls (Buntmergelserie, Tab. 5) of uppermost Lower Cretaceous to Middle Eocene age (S. Prey, 1974). Mesozoic klippen (Keuper, Jurassic, Neocomian) are tectonically embedded within variegated marls. Conglomerates of the Eocene contain components of extraalpine Malmian carbonates. In the southern part of the Flysch Zone another Klippen Zone, the St. Veit Klippen zone occurs. After S. Prey (1974), it is assumed, that the klippen, consisting also of Keuper, Jurassic and Neocomian sequences (Tab. 3) are the original base of the Flysch.

The Flysch Zone tectonically overlies sediments of the Molasse Basin and is overthrusted by the Northern Calcareous Alps.

The Flysch sediments were deposited in an oceanic-trench environment that existed north of the Penninic and Austroalpine nappes. This trench was entirely filled with turbidite sediments of Lower Cretaceous to Middle Eocene age (Tabs. 2,3). The Flysch sediments of the Eastern Alps were deposited below the

Table 2.
Stratigraphy of the Flysch Zone.

		Greifenstein Nappe	Kahlenberg Nappe	Laab Nappe
Paleogene	Eocene	Greifenstein Formation (–500 m) Altlengbach Formation (–1000 m)		Agsbach Formation (–500 m)
	Paleocene			Hois Formation (–500 m)
Upper Cretaceous	Maastrichtian		Sievering Formation (–700 m)	Dark shales and glauconite quartzites
	Campanian	"Oberste Bunte Schiefer" (0–100 m)	Kahlenberg Formation (–500 m)	Kaumberg Formation (100–300 m)
	Santonian	Zementmergel Formation (ca. 200–500 m)		
	Coniacian			
	Turonian	"Obere Bunte Schiefer" (ca. 50 m) Reiselsberg Sandstone + "Untere Bunte Schiefer" (10–50 m)	Red and green shales + Reiselsberg Sandstone	
	Cenomanian			
Lower Cretaceous	Albian	Gaultflysch	Gaultflysch	
	Aptian			
	Barremian	Wolfpassing Formation (200–300 m)		
	Hauterivian			
	Valendisian			
	Berrriasian			

calcite compensation depth (CCD), in abyssal trench environments between 3500–5000 m (BUTT, 1976).

Within the Flysch Zone three main tectonic units or nappes can be distinguished from north to south: the Greifenstein-, the Kahlenberg- and the Laab Nappe (K. FRIEDL, 1921, 1930; F. BRIX, 1970, 1972; S. PREY, 1968, 1974).

Recently, new interpretations of the tectonic position of the Kahlenberg nappe and the Laab Nappe have been proposed (PREY, 1979, 1983).

The oldest formation of the Greifenstein Nappe is the Wolfpassing Formation of Lower Cretaceous age, consisting of calcarenites intercalated by marly shales or claystones and interbedded by units of glauconitic quartzarenites and claystones. The thickness of the Wolfpassing Formation reaches up to several hundred meters.

The Cenomanian sediments are represented mainly by variegated red and green shales of unknown thickness. Sediments of the Upper Cenomanian to Santonian age are missing in the Greifenstein Nappe, probably due to tectonic removal.

The Santonian-Campanian is represented by thin-bedded turbiditic sequences of marls, limy marls, fine-grained sandstones and siltstones and thin intercalated claystone intervals (Zementmergel Formation).

In the Upper Campanian red and occasionally greenish marls and claystones intercalated with thin, calcareous sandstone beds were deposited ("Oberste Bunte Schiefer").

The Upper Campanian to Lower Paleocene sediments are represented by the Altlengbach Formation, a 600–1200 m thick succession of alternating sandstones and shales.

The youngest sediments of the Greifenstein Nappe are the Greifenstein Formation of Paleocene to Middle Eocene age, characterized by very coarse-grained sandstones. The thickness is more than 600 m. The Greifenstein Nappe has been encountered by 11 wells in the Höflein field.

The sediments of the Kahlenberg Nappe are dominated by the Kahlenberg Formation of Santonian to Campanian age and the Sievering Beds of Maastrichtian to Lower Paleocene age. The Kahlenberg Formation consists of alternating calcareous sandstones, spiculites, marlstone and shale. The Sievering Formation is similar to the Altlengbach Formation of the Greifenstein Nappe.

The Laab Nappe consists of typical Upper Cretaceous distal turbidites of the Kaumberg Formation with grey, red to violet or greenish pelites and thin bedded sandstones followed by dark shales and glauconite quartzites. The Paleogene is represented by the Laab Formation, devided into the Paleocene Hois Formation, consisting mainly of sandstones and the Eocene Agsbach Formation, an uniform series of thin bedded shales with fiew thin layers of sandstone.

The Flysch Zone below the Vienna Basin (W. HAMILTON, R. JIRICEK & G. WESSELY, 1990) has been encountered mainly in the Steinberg area and in the Matzen field. The tectonostratigraphic subdivision is similar to the surface. In the Steinberg area the Greifenstein Nappe and the Raca nappe below it consist of an Upper Cretaceous tubiditic series of alternating sands and shales (M. RAMMEL, 1989). In the Paleogene three horizons of thick glauconitic sandstone are overlain by an Eocene sequence of shales with several horizons of sandstones ("Steinbergflysch"). In the Pirawarth-Hochleiten fields equivalents of the Kahlenberg Nappe were encountered, in the Matzen field equivalents of the Laab Nappe including picrites and pyroclastic picritic sediments.

1.5. Calcareous Alps

The Calcareous Alps were deposited in the area of the former Tethys in the South of the Central Alps. In this basin carbonates of Mesozoic age predominate and form sections up to several thousand meters thick. Shallow, sometimes continental influenced environments can change vertically or laterally into deeper basinal developments. These changes are particularly noticeable from north to south. Thick sections of Triassic platform carbonates are mainly developed in the intermediate and southern sedimentary units. During the main phase of Alpine orogeny the Calcareous Alps were overthrust over the central Alps and now rest in a rootless position upon the Flysch Zone and the northern part of the Central Alps. Fractured Triassic dolomites play an important role as reservoir rocks.

The stratigraphy and facies are objects of classical work compiled by A. TOLLMANN (1976a,b and 1985). The Calcareous Alps continue from the eastern border zone of the Alps into the Preneogene base of the Vienna Basin, similar to the other tectonic units. Detailed information about this Calcareous Alpine floor of the Vienna Basin is given in the papers of A. KRÖLL & G. WESSELY (1973), G. WESSELY (1975, 1988) and W. HAMILTON, R. JIŘÍČEK & G. WESSELY (1990).

Permian, Lower Triassic

The first beds deposited in the Calcareous Alpine sedimentary sequence (Tab. 3) are gray evaporitic-dolomitic sediments of Permoskythian age. Variegated shales are interbedded. Halite has been encountered in some wells. Sandstones and claystones, mostly micaceous and violet coloured are typical for the Lower Triassic part. This sequence represents the change from inner-shelf to continental environment. These beds are thicker in the middle and highest nappes. As basal detachment members they are often mylonitized. On the surface, a Permian conglomerate (Prebichl Conglomerate) forms the base of the Calcareous Alps along their southern border.

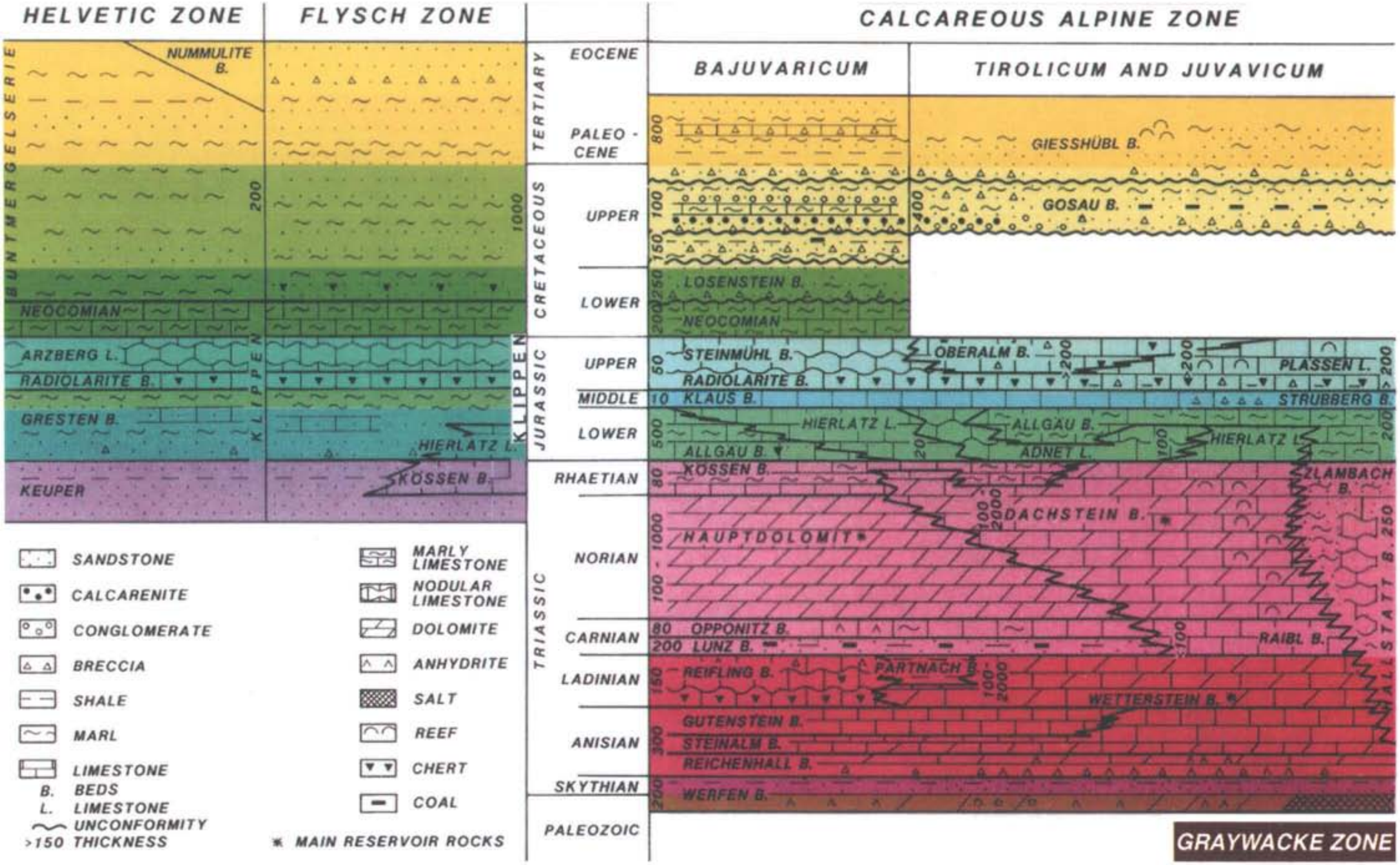
Middle Triassic

The Middle Triassic is divided into an Anisian and a Ladinian section. The lowest beds are grouped under the term “Reichenhall Beds”. In their basal parts they may reach down into the uppermost Lower Triassic. They consist of breccias, dolomites, rauhwacke and dark laminated shallow water limestones. In the following Middle Triassic sequence basinal and platform developments are to be distinguished.

For the basinal facies the Anisian, dark bedded Gutenstein Limestone and the dark, nodular Reifling Limestone of Upper Anisian to Ladinian age are characteristic (H. SUMMESBERGER & L. WAGNER, 1972). The dark Reifling Limestone is followed by light coloured, bedded limestones with gray, milky or reddish chert nodules. It becomes more massive in the upper part. Grey shales similar to Partnach beds and greenish tuffites, derived from a Middle Triassic volcanism, may be intercalated. The pelagic facies of the Juvavic units is represented by the Hallstatt Limestones, partly characterized by a red condensed sequence with low thickness. Ladinian radiolaritic sediments of an oceanic realm, well-known from the Western Carpathian Mountains, have been detected recently in the Northern Calcareous Alps, too (G.W. MANDL, this volume, part II).

The Middle Triassic platform facies of the Anisian section is represented by the Steinalm Limestone, a gray limestone built up mainly by fragments of Chlorophyceans and tubes of Dasycladaceans. In Ladinian to Lower Carnian

Table 3.
Stratigraphy of the Alpine Nappes in Eastern Austria.



time, the Wetterstein Limestone, also rich in algal detritus and in Dasycladaceans, is dominant. Reef buildups, composed of algae and sponges, are found in higher Calcareous Alpine units. Their thickness is up to 2.000 m (Tab. 3). Dolomitisation has created large, irregular cloudy complexes of dolomite.

Upper Triassic

Uniform shallow marine conditions existed basinwide throughout the Carnian (Upper Triassic). In the Bajuvaricum and Tirolicum nappes, the siliciclastic Lower Carnian Lunz Formation separates the Middle to lowermost Upper Triassic from the mainly Upper Triassic carbonate complexes. The Lunz Formation contains dark shales and fine-grained sandstones with high feldspar content and the constant presence of apatite in the heavy mineral association. In some areas coal beds were deposited. The environment is interpreted to be mainly shallow marine. The Lunz Formation is thickest in the areas where Middle Triassic is basinal. Toward the south, the Lunz Formation is replaced by shallow water carbonates.

In the Upper Carnian the carbonate facies continues with the Opponitz Formation. In the frontal part (Frankenfels-Lunz Nappe) an evaporitic facies (anhydrites in boreholes and rauhwackes at surface) is developed in addition to the shallow water limestones and dolomites. Carbonates with some shaly intercalations predominate southwards from the Tirolicum. In the southern and western parts of the Calcareous Alps various carbonates with interbedded dark shales occur. These are predominantly bioclastic shallow water carbonates such as the Raibl Formation. However a transition into deeper carbonates is developed in the southernmost parts.

In the southernmost part of the eastern Calcareous Alpine areas, a basinal facies is significant (Aflenz Beds composed of dark limestone, often cherty and marly). The pelagic Hallstatt facies continues.

In Norian time the following paleographic situation existed (from north to south): shallow water shelf with continental influence, passing into lagoonal conditions to reef complexes and finally to basinal and pelagic environments (Tab. 3).

The dominant formation in the northern units is the Hauptdolomit, a mostly intertidal sediment with alternating layers of algae derived mud and laminated algal stromatolites, sometimes brecciated. In mud-stones abundant worm burrows may occur.

In the Bajuvaricum the Hauptdolomit is more heterogenous in colour, bedding, texture and shale content. Green or gray shale with some detrital quartz is occasionally interbedded and points to continental conditions (Keuper beds). In the Tirolicum, especially in boreholes, a darker basal complex with some intercalations of green shale can be distinguished from a uniform light gray middle part. This is overlain again by a heterogenous shaly section.

Southwards, the Hauptdolomit facies changes into the bedded Dachsteinkalk facies which is characterized by its cyclicity of intra-, sub- and supratidal layers known as Lofer cyclothems (A.G. FISCHER, 1964). The supratidal member is a shaly, breccious, often reddish horizon. The intertidal member is a dolomitic one with laminated algal biostromes and the subtidal one is rich in typical fossils, especially large megalodontides.

In some areas the Dachsteinkalk facies contains hundreds of such cycles forming a thickness of up to 2000 m (Tab. 3). The bedded Dachsteinkalk facies passes laterally into a massive one, formed by reefs of sponges, corals, algae

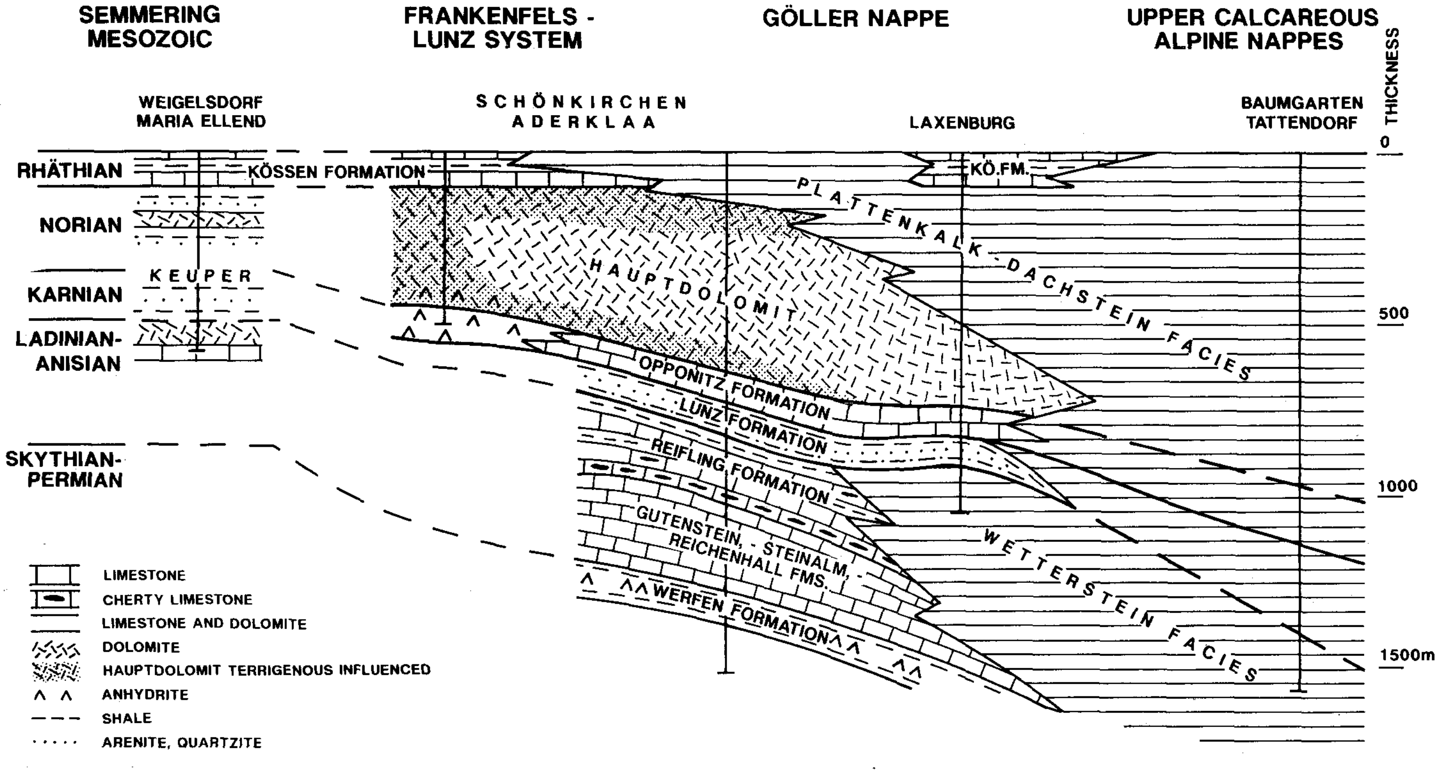
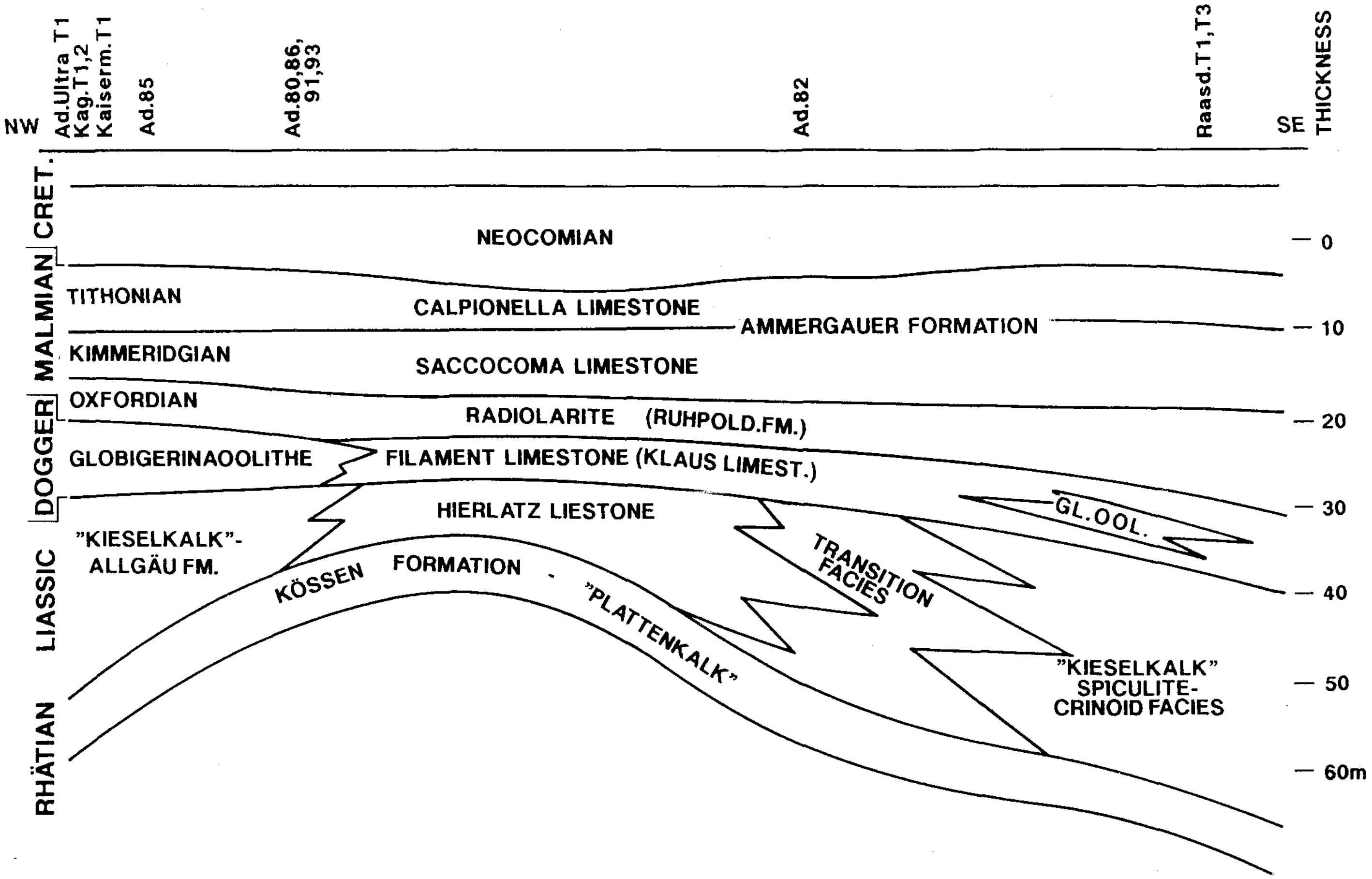


Fig. 8: Calcareous and Central Alpine floor of the Vienna Basin: stratigraphy and facies in the Triassic (G. WESSELY, 1992).

FRANKENFELS - LUNZ SYSTEM, AREA ADERKLAA AND VIENNA



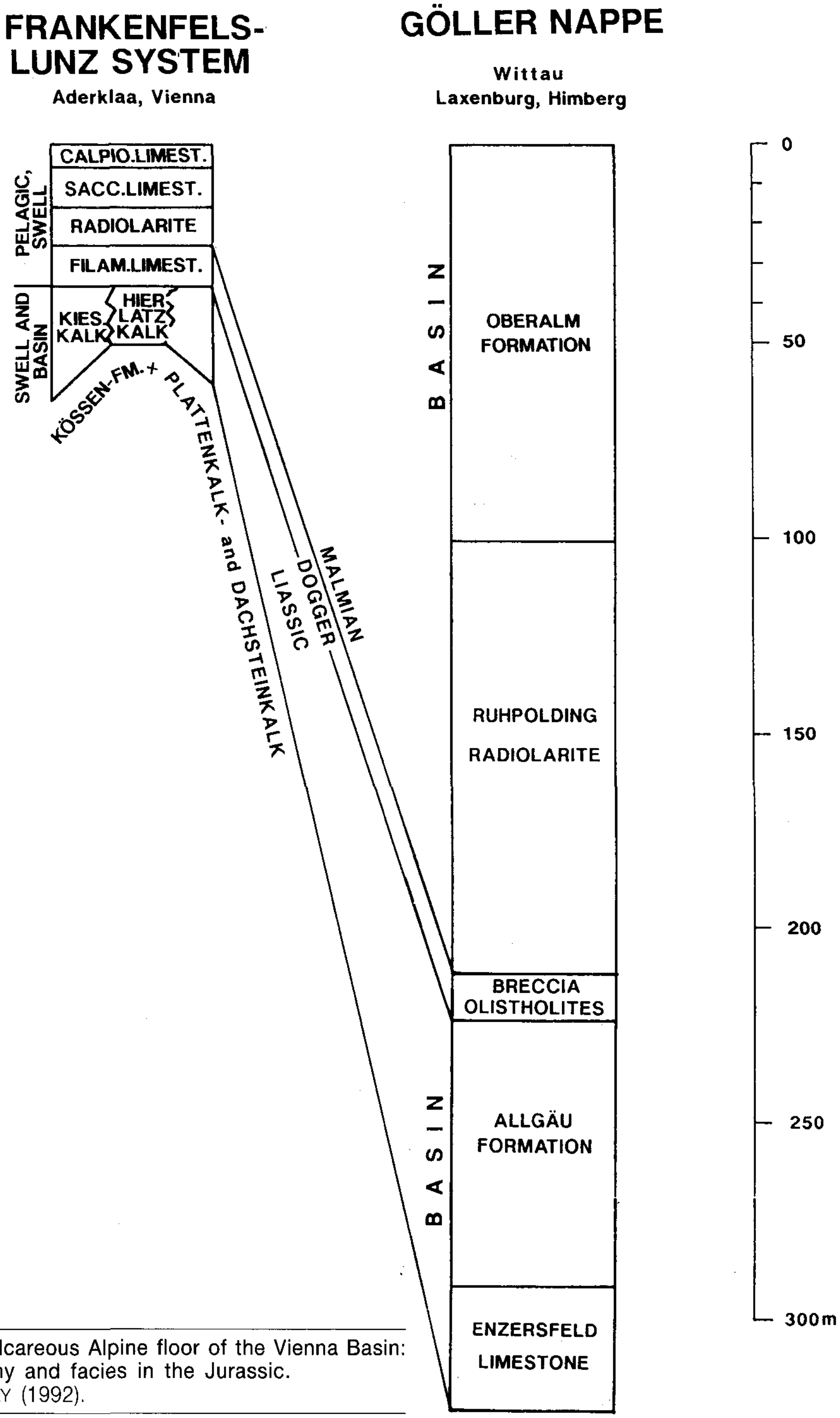


Fig. 9: Calcareous Alpine floor of the Vienna Basin: stratigraphy and facies in the Jurassic.
G. WESSELY (1992).

etc. Both, bedded and massive Dachsteinkalk continues into the Rhaetian. In the southernmost parts the basinal facies is preserved mainly in the dark biodetritic and cherty limestone facies of the Aflenz type and the continuation of the Hallstatt type with its pelagic red and light gray coloured limestone.

In Rhaetian time the predominant member of the northernmost Calcareous units is the Kössen Formation. It is composed of dark bioclastic, oolitic limestones, lumachelles and dark marls, sometimes with coral bioherms. A continental influence in the Uppermost Rhaetian of the northernmost nappes is evident by variegated shales and the content of terrigenous quartz in the Schattwald Formation. The Plattenkalk, dark and gray, often dolomitized (bedded) limestone is considered to be a transitional facies between the Kössen Formation and the Dachstein Limestone.

The southernmost basinal facies is represented by the marly Zlambach beds, with its rich microfauna (E. KRISTAN-TOLLMANN, 1964).

Distribution and thickness of the Triassic members in the Calcareous Alps below the Neogene of the Vienna Basin is shown in Fig. 8.

Lower Jurassic

Remarkably constant north–south facies zonation along the strike of the tectonic units, continued in Jurassic time. The Liassic of the frontal part of the Bajuvaricum is developed as "Kieselkalk", a cherty-sandy development replacing the Allgäu beds. It is a basinal sequence several hundred meters thick composed of gray to dark cherty limestones, rich in spicules with a large amount of terrigenous quartz and of some marls with intercalations of crinoidal detritus. Spotted marls and marly limestones of the Allgäu Formation are another basinal facies. In distinct areas they continue into the Dogger. In another zone, in the southern Bajuvaricum, several meters of shallow water and pink crinoidal limestone (Hierlatz Limestone) were laid down. Variously coloured cherty crinoidal limestones change to a gray basinal facies. In the Tirolicum the pelagic, red, nodular Adnet Limestone was deposited, followed by the Allgäu Formation, in areas of subsidence.

Middle Jurassic

The marly facies of the Liassic continues into the Dogger in many localities. Where it is absent, red or brownish thin pelagic limestones of the Klaus Formation follow. Characteristically it has abundant filaments derived from shells of *Bositra*. In some sections of the southern Bajuvaricum this limestone is accompanied by light gray globigerina oolites. Occasionally the Dogger rests unconformably on Preliassic rocks. Coarse breccias, equivalent to Strubberg beds, with boulders of Lower Jurassic to Triassic rocks (found in wells in the Göller nappe below the Vienna Basin) point to a tectonic event at that time.

Upper Jurassic

The thickness and facies changes of the Malmian reflect the areal variation in subsidence and rate of sedimentation: Mainly pelagic and condensed deposits in the Bajuvaricum and gray, detritic sediments with larger thickness in the Tirolicum. The Jurassic is generally not preserved in the highest tectonic units.

In the lowermost Malmian horizon of radiolarites, with green or red thin bedded cherty limestones is typical and widespread. It is thin in the Bajuvaricum ("Ruhpoldinger Radiolarit") but reaches remarkable thickness in the Tirolicum. Intercalations of shales become frequent. In the middle and uppermost Malmian of the Bajuvaricum the condensed sequence continues with red nodular limestones of the Ammergau Formation. It also typically contains Saccocoma microfacies and red and white Calpionellids limestone. In the Tirolicum the Middle and Upper Malmian is represented by the Oberalm Formation with gray bedded limestones having cherty mudstones with bioclastic layers and intercalated marls. Bioherms equivalent to the Plassenkalk are rare.

Detailed facies distributions within the Jurassic and the relationships of thicknesses in the Bajuvaricum and Tirolicum below the Neogene of the Vienna Basin is shown in Fig. 9.

Cretaceous and Paleocene

Lower Cretaceous sediments are restricted to the Bajuvaricum. Spotted marls and marly limestones of the Neocomian Schrambach Formation were followed by the clastic Roßfeld Formation and reach a thickness of 200–300 m.

Thin spotted marls and black marls represent Aptian to Albian (Tannheim Formation).

A change in the type of sedimentation is demonstrated by the Albian to Cenomanian Losenstein Formation, which transgressed over older sediments and filled longitudinal synclines in the northern zones of the Bajuvaricum. Sandstones, marls, breccias and conglomerates with exotic components are all found in this unit. It is missing towards the south.

The continuation of the Cretaceous sequence is to be seen in Gießhübl syncline (Fig. 16).

The transgressive uppermost Cenomanian is composed of dark marls. This is followed without significant interruption by the mostly brackish-limnic Turonian group (conglomerates, bituminous limestones with itruvians, coaly shales, red marls).

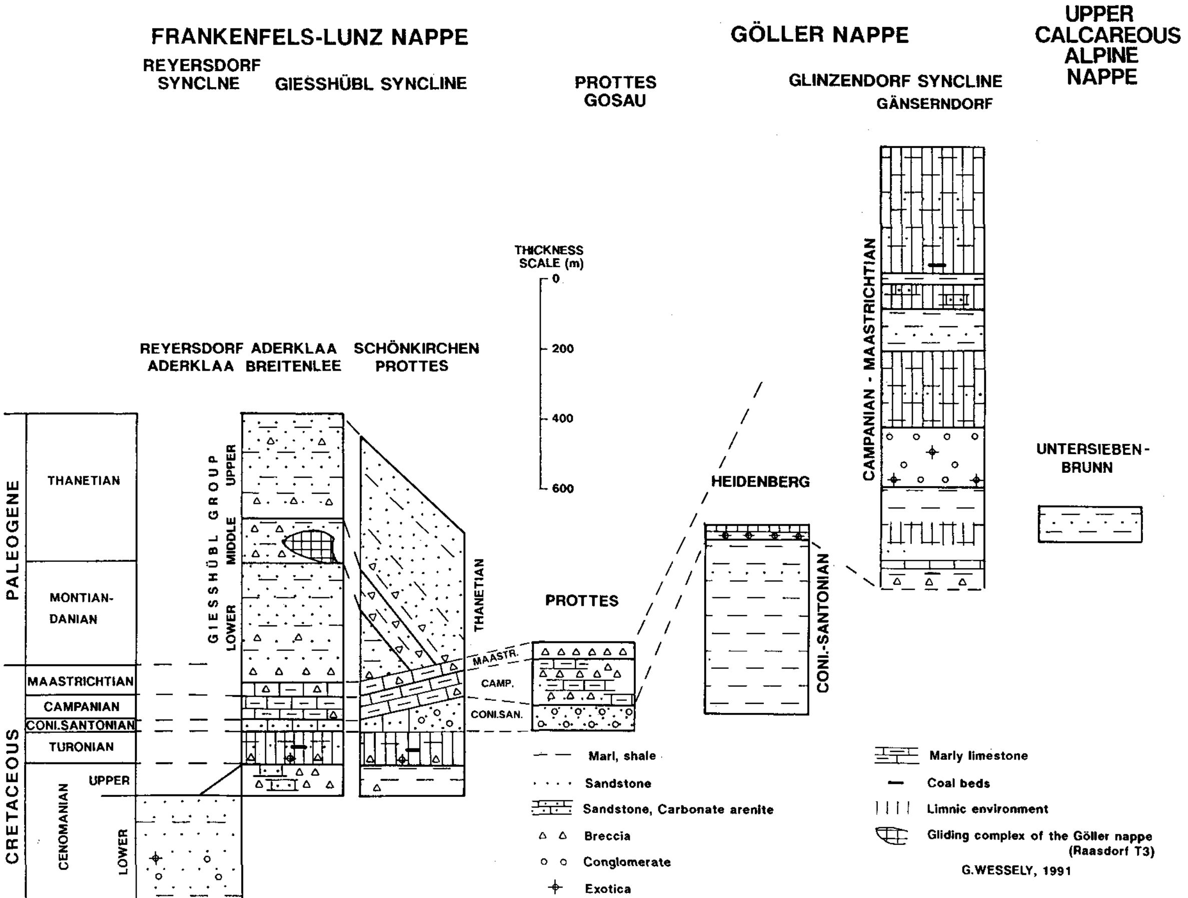
In the Bajuvaricum, no gap is developed between the Turonian and the Gosau sequence. In the Tirolicum, pregosauic Cretaceous sediments are missing, which points to a pregosauic tectonic event there.

The "Gosau" sediments are the first which are developed on all nappes beginning with the Coniacian. A succession in facies and thickness from north to south is evident. A several meters thick sandstone of Coniacian to Santonian age, rich in biodetritus and bioturbation in the Bajuvaricum, changes southward in the Northern Tirolicum into thick coarse clastics. The lithology is typically dominated by dolomite-conglomerates, dolomitic sandstones and gray marls.

The Campanian deposits on the Bajuvaricum consist of thin pelagic marly limestones (red, light gray and greenish). Some slope derived breccias are interbedded. In the Northern Tirolicum these slope sediments become more dominant. This sequence continues into the Lower Maastrichtian. In the southern part of the Tirolicum, a 1000 m thick Upper Cretaceous complex, with limnic development fills the "Glinzendorf" syncline (Fig. 10). It consists of variegated and gray shales and marls, sandstones and layers of conglomerates containing exotic components. The similar "Grünbach" syncline was proven by coal mining (B. PLÖCHINGER, 1961). Basal conglomerates are followed by hippurites reefs, actaeonellid-limestone and a thick series of brackish to limnic sediments with coal beds at its base. Sandstones with orbitoids and marls with inoceramides form the higher part of this 1,200 m thick Upper Cretaceous sequence (Fig. 188).

In the uppermost part of the Maastrichtian a new type of sediments was deposited with flysch like turbiditic characteristics. This was the result of the deepening of the Calcareous Alpine region. These deposits are grouped under the term "Gießhübl Group" (B. PLÖCHINGER, 1964; G. WESSELY, 1975; R. SAUER,

Fig. 10.
Calcareous Alpine floor of the Vienna Basin: stratigraphy and facies in the Cretaceous and Paleogene.
G. WESSELY (1992).



CALCAREOUS ALPINE FLOOR OF THE VIENNA BASIN:
STRATIGRAPHY AND FACIES DISTRIBUTION IN THE CRETACEOUS AND PALEOGENE

1980) and extend into the middle part of the Paleocene. In the Gießhübl Syncline, this is marked by breccias at the base of the "Lower Gießhübl Formation", formed primarily by components of dolomite. A series of turbidites with sandstones and variegated or gray shales followed. In the "Middle Gießhübl Formation" the sandstones contain more carbonate detritus and the marls are no longer variegated. A few horizons of coarse breccias, rich in Lithothamnion algal debris form markers. The "Upper Gießhübl Formation" is again rich in siliciclastics and also contains gray and variegated shales. In the Grünbach Syncline the Paleocene "Zweiersdorf Formation" (B. PLÖCHINGER, 1961) shows similarities to the Gießhübl Group. The distribution of Cretaceous and Paleocene sediments in the Calcareous Alps below the Vienna Basin is shown in Fig. 10.

1.6. Greywacke Zone

In its eastern part the Greywacke Zone ("Grauwackenzone") is divided into two tectonic units, the deeper Veitsch Nappe and the higher Noric Nappe (H.P. CORNELIUS, 1952; A. TOLLMANN, 1977; H. SCHÖNLAUB in R. OBERHAUSER, 1980). The Veitsch Nappe contains only Carboniferous dark graphitic shales and quartz clastics. The Noric Nappe comprises a wide range of Early Paleozoic to Lower Carboniferous rocks: some crystalline slices, Ordovician phyllites (Silbersberg Group), porphyroids (Plasseneck Porphyroid), quartzites and lydites, Silurian greenschists, siliceous slates, interbedded limestones and flaser limestones, Devonian to Lower Carboniferous limestones and dolomites with siderite and magnesite deposits. Unconformably deposited on older rocks of the Greywacke Zone are conglomerates and violet sandstones and slates of the Permian Prebichl Formation. These form the stratigraphic base of the Calcareous Alps.

In the pre-Tertiary floor of the Vienna Basin, dark Paleozoic shales and quartzwackes as well as calcphyllites were encountered (A. KRÖLL & G. WESSELY, 1973).

1.7. Central Alps, Tatrides

Crystalline complexes of the Semmering-Wechsel region cover a large area of the northeastern part of the Central Zone. They belong to several Austroalpine tectonic units of the Lower and Middle Austroalpine.

These crystalline complexes are separated from each other by the sedimentary cover of the Permomesozoic sequences, in a Central Alpine facies (A. TOLLMANN, 1977; A. PAHR in R. OBERHAUSER, 1980; G. FUCHS, 1990). They are strongly deformed and show lowgrade metamorphism. They are best developed in the Semmering Series (Tab. 4), which continues into the Vienna Basin, encountered by several wells. Permian phyllites and porphyroids (Alpine Verrucano) are common at the base. These are followed by Lower Triassic greenish quartzites ("Semmeringquarzit"), with "Rötschiefer" slates on top. In the Middle Triassic rauhwacke, dark to light gray, bedded or banded, in some complexes also massive limestones and dolomites occur. They may be correlated with Calcareous Alpine platform or basin carbonates. Black slates with sandstones (Kapellen slates) may be equivalents of the Lunz Formation (H. BARNICK, 1967). A typical member is the Keuper (H.P. CORNELIUS, 1952; A. TOLLMANN, 1977, K.-H. NEUNER, 1964), a series of variegated slates, interbedded quartzites, thinbedded

Table 4.
Permomesozoic succession of the Mürztal-, Semmering- and Wechsel area.

TRIASSIC	Upper	Slates with limestone and dolomite layers interbedded Variegated slates with quartztite, dolomite, rauhwacke, anhydrock and gyprock (Variegated Keuper) Black slates with sandstones interbedded (Kapellen beds)
	Middle	Pale, hardly bedded dolomite (Wetterstein Dolomite) Thin bedded black dolomite Banded limestone with cherts Variegated streaky limestones and dolomites Series of slates interbedded with limestones, dolomites and breccias Rauhwacke
	Lower	Slate (Alpine Röt Beds) Quartzite with quartz conglomerates interbedded (Semmering Quartzite)
PERMIAN		Phengite phyllites, sericite phyllites, arcosic phyllites, breccias, porphyroids (Alpine Verrucano)
BASE		Crystalline basement

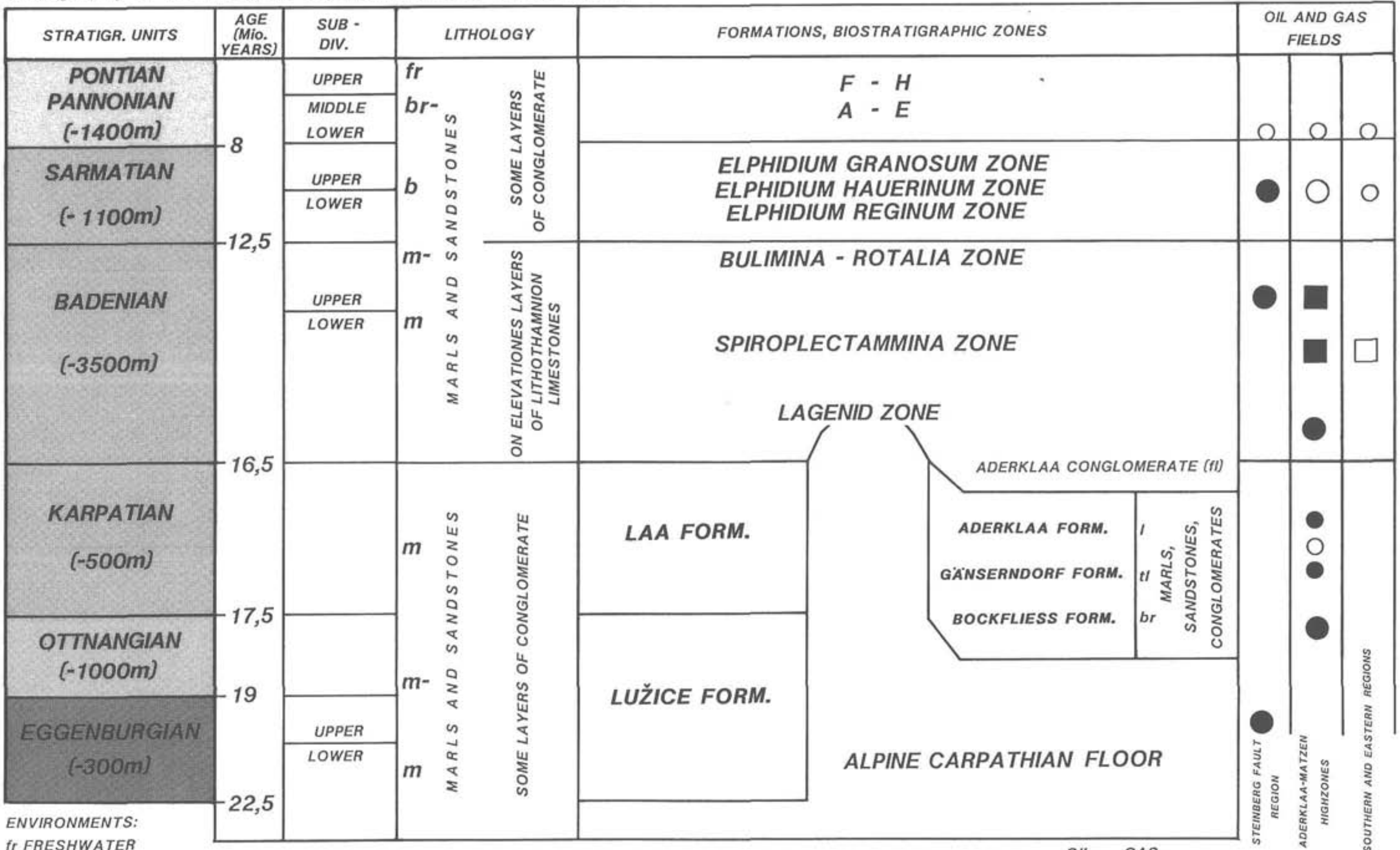
dolomites, gypsum and rauhwacke, representing a continental-related facies. In boreholes, dark Rhaethian fossiliferous limestones and Liassic spiculiferous limestones complete this series (A. KRÖLL & G. WESSELY, 1973). The occurrence of the continental facies in Upper Triassic shows that, in relation to the Calcareous Alps, the Lower Austroalpine unit originally had a more northern position with respect to the Calcareous Alps.

The Tatridic crystalline complex (A. PAHR in R. OBERHAUSER, 1980) in the Hainburg Mountains in Eastern Austria is represented by the Bratislava granitoid body. It is a Variscan intrusion into a paragneiss complex. Towards the west it is covered by Paleozoic slates, Permian porphyroids and violet and green Triassic quartzite. The rather thick Middle Triassic section consists of gray dolomites and limestones and shallow water platform carbonates. Locally, infills of Liassic breccia occur in karst cracks (A. KULLMANOVA, 1990) pointing to an Upper Triassic gap. Continuous sedimentation with Middle Triassic carbonates and Upper Triassic Keuper were found below the Neogene of the adjacent Vienna Basin in boreholes (A. KRÖLL & G. WESSELY, 1973; G. WESSELY, 1975). A complete Jurassic section (up to Tithonian limestones) is exposed in the neighbouring Slovak part of the Little Carpathians (D. PLAŠIENKA, J. MICHALIK, M. KOVÁČ, P. GROSS & M. PUTIŠ, 1991; D. PLAŠIENKA, F. MARKO, A. HACURA & D. ŘEHÁKOVÁ, 1991).

1.8. Vienna Basin

The stratigraphy and paleotology of the Vienna Basin has been a subject of classical studies since the nineteenth century. Paleontological monographies (e.g. M. HÖRNES, 1856, 1870; A. D'ORBIGNY, 1846; F. KARRER, 1867) were followed by stratigraphic and paleogeographic works. R. GRILL (1941, 1943) established the zonations in the Sarmatian, Badenian and lower Miocene by microfauna. A. PAPP (1951, 1953) subdivided the Pannonian and (1954, 1956) the

Table 5.
Stratigraphy of the Neogene sediments of the Vienna Basin.



STRATIGR. UNITS	AGE (Mio. YEARS)	SUB - DIV.	LITHOLOGY		FORMATIONS, BIOSTRATIGRAPHIC ZONES	OIL AND GAS FIELDS: STEINBERG FAULT REGION	ADERKLAA-MATZEN HIGHZONES	SOUTHERN AND EASTERN REGIONS
PONTIAN PANNONIAN (-1400m)	8	UPPER MIDDLE LOWER	fr br-	MARLS AND SANDSTONES SOME LAYERS OF CONGLOMERATE	F - H A - E	○	○	○
SARMATIAN (- 1100m)	12,5	UPPER LOWER	b		ELPHIDIUM GRANOSUM ZONE ELPHIDIUM HAUERINUM ZONE ELPHIDIUM REGINUM ZONE	●	○	○
BADENIAN (-3500m)	16,5	UPPER LOWER	m- m	ON ELEVATIONES LAYERS OF LITHOTHAMNION LIMESTONES	BULIMINA - ROTALIA ZONE SPIROPLECTAMMINA ZONE LAGENID ZONE	●	■ ■ ●	□
KARPATIAN (-500m)	17,5		m	MARLS AND SANDSTONES SOME LAYERS OF CONGLOMERATE	LAA FORM. ADERKLAA CONGLOMERATE (fl) ADERKLAA FORM. l GÄNSERNDORF FORM. tl BOCKFLIESS FORM. br MARLS, SANDSTONES, CONGLOMERATES		● ○ ●	
OTTNANGIAN (-1000m)	19		m-		LUŽICE FORM.		●	
EGGENBURGIAN (-300m)	22,5	UPPER LOWER	m		ALPINE CARPATHIAN FLOOR	●		

ENVIRONMENTS:
fr FRESHWATER
fl FLUVIATILE
tl TERRESTRIC-LIMNIC
br- SEMIBRACKISH
b BRACKISH
br BRACHYHALINE
m- REDUCED MARINE
m MARINE

OIL	GAS	
■	□	IMPORTANT
●	○	LARGE
•	○	SMALL

Sarmatian by macrofossils. J. KAPOUNEK, A. PAPP & K. TURNOVSKY (1960), F. STEININGER, F. RÖGL & E. MARTINI (1976) and F. STEININGER & A. PAPP (1979) replaced older stratigraphic subdivisions of the Neogene of the Vienna Basin by new concepts using biostratigraphic and radiometric correlations within the Central Paratethys. Complete stratigraphic compilations contain the volumes of "Chronostratigraphie und Neostratotypen" with contributions of A. PAPP, J. CICHA, J. SENES & F. STEININGER (1978; Badenian), A. PAPP, F. MARINESCU & J. SENES (1974; Sarmatian) and A. PAPP, A. JAMBOR & F. STEININGER (1985; Pannonian). For a detailed bibliography the recent publication of W. PILLER & N. VAVRA (1991) is recommended.

The Vienna Basin is a Miocene feature superimposed on the outer allochthonous nappes of the Alpine-Carpathian thrustbelt. During the first stage of its evolution (Lower Miocene) it can be classified as a "piggy back" basin. Subsidence and sedimentation took place on top of the northwestward prograding nappe system. Only one large sedimentation area existed which included the Molasse trough (i.e. the Alpine-Carpathian foredeep) and the Vienna Basin as its southeastern part.

In the area of todays Northern Vienna Basin, the Molasse sediments upon the nappes ("Parautochthonous Molasse" according to F. STEININGER, G. WESSELY, F. RÖGL & L. WAGNER, 1986) were deposited in depressions formed already by transtensional movements, as shown by synsedimentary faults (G. WESSELY, 1988; W. LADWEIN, F. SCHMIDT, P. SEIFERT & G. WESSELY, 1991) and thick basinal sediments. Therefore this parautochthonous Molasse is identical with the filling of the Vienna Basin in its first stage.

The W–E-trending extensional basin opened at the beginning of the Eggenburgian (23–19 MMY). Basal conglomerate complexes with components from the uplifting Flysch Zone and Calcareous Alps were deposited. These were then overlain by sediments, transported from the SW and NE by deltaic systems into the eastern part of the basin (Fig. 11). The middle part of the basin with water depths of 200–300 m was dominated by silty-shaly sedimentation. To the south deposition was continental. Variegated clays and breccias were deposited in small depressions. During the Ottnangian (19–17.5 MMY) the basin enlarged southward.

Thrust movement of the Alpine nappes resulted in a partial separation of the Paratethys from the Mediterranean. Salinity conditions became brackish (Bockfließ Formation). A regression marked the transition to the Karpatian (Late Lower Miocene, 17,5–16,5 MMY) and the movement of the Alpine-Carpathian fold belt died out. Inversion of the basement of the Vienna Basin followed and the depocenter shifted south. A new fluvio-deltaic system was established in the southern part of the basin (Fig. 12). It continued into a large limnic-deltaic complex, the Aderklaa Formation in the middle part of the basin. Material from the various rising Alpine units was transported northwards into the northern basin, which was still dominated by shaly sedimentation under marine conditions.

The northeast part of the basin was filled by two deltas coming from the south (Central Carpathians) and NE (Flysch belt). Total regression and local deposition of fluvial sediments, the Aderklaa Conglomerate marked the transition from the Lower to the Middle Miocene. Sedimentation started with a transgressive marine sand-marl sequence of lowermost Badenian along the newly developed NNE–SSW basin axis.

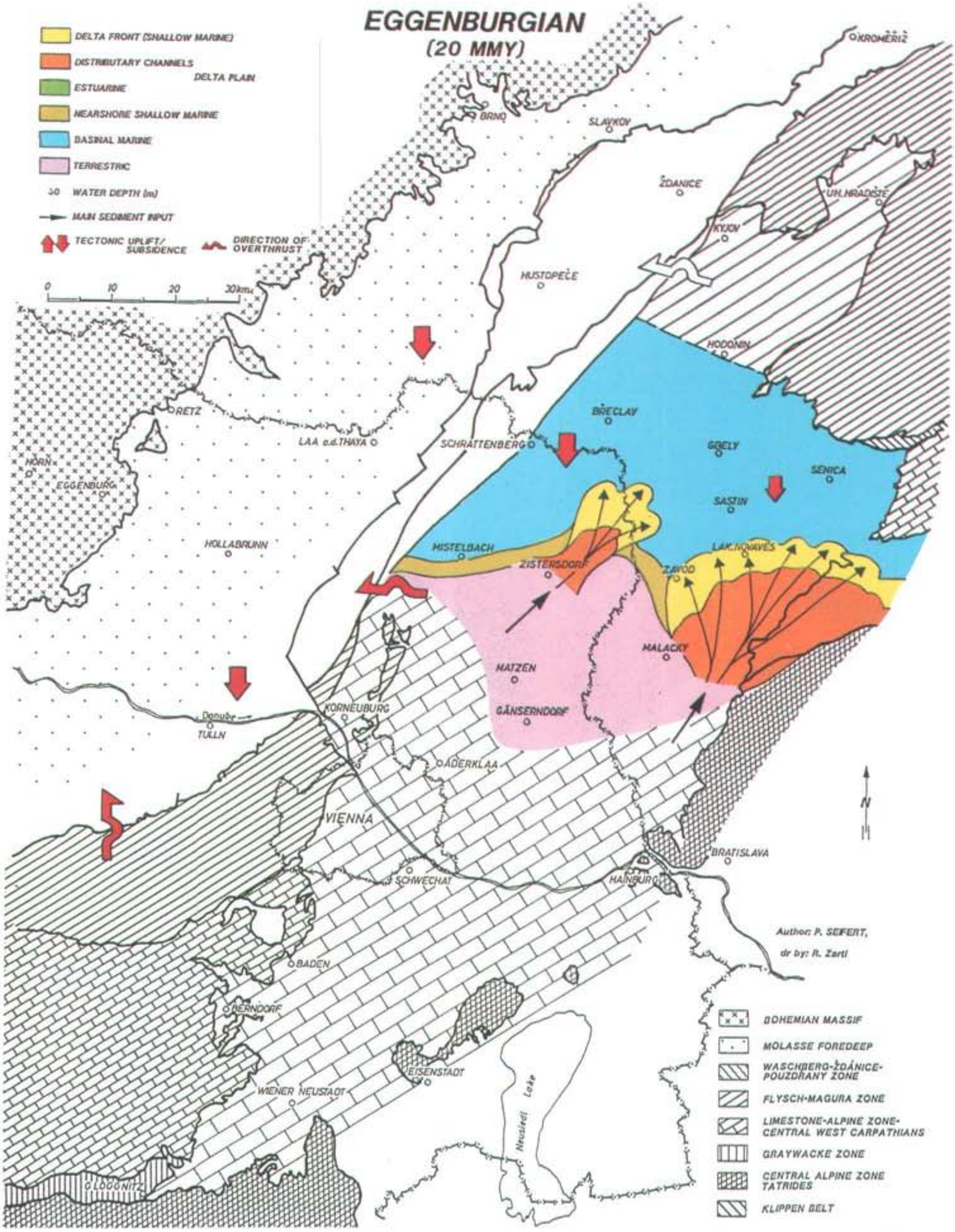


Fig. 11: Vienna Basin. Paleogeography and Facies in the Eggenburgian (20 MMY; P. SEIFERT).

During the Middle Badenian (15 MMY) the basin reached its maximum extent (Fig. 13). Clay sedimentation down to the maximum water depth of 250 m took place basinwide. A new 40 × 50 km broad deltacomplex developed on the westflank of the basin carrying sediments from the Molasse area, through the Zaya depression, into the Vienna Basin. The interaction between basement

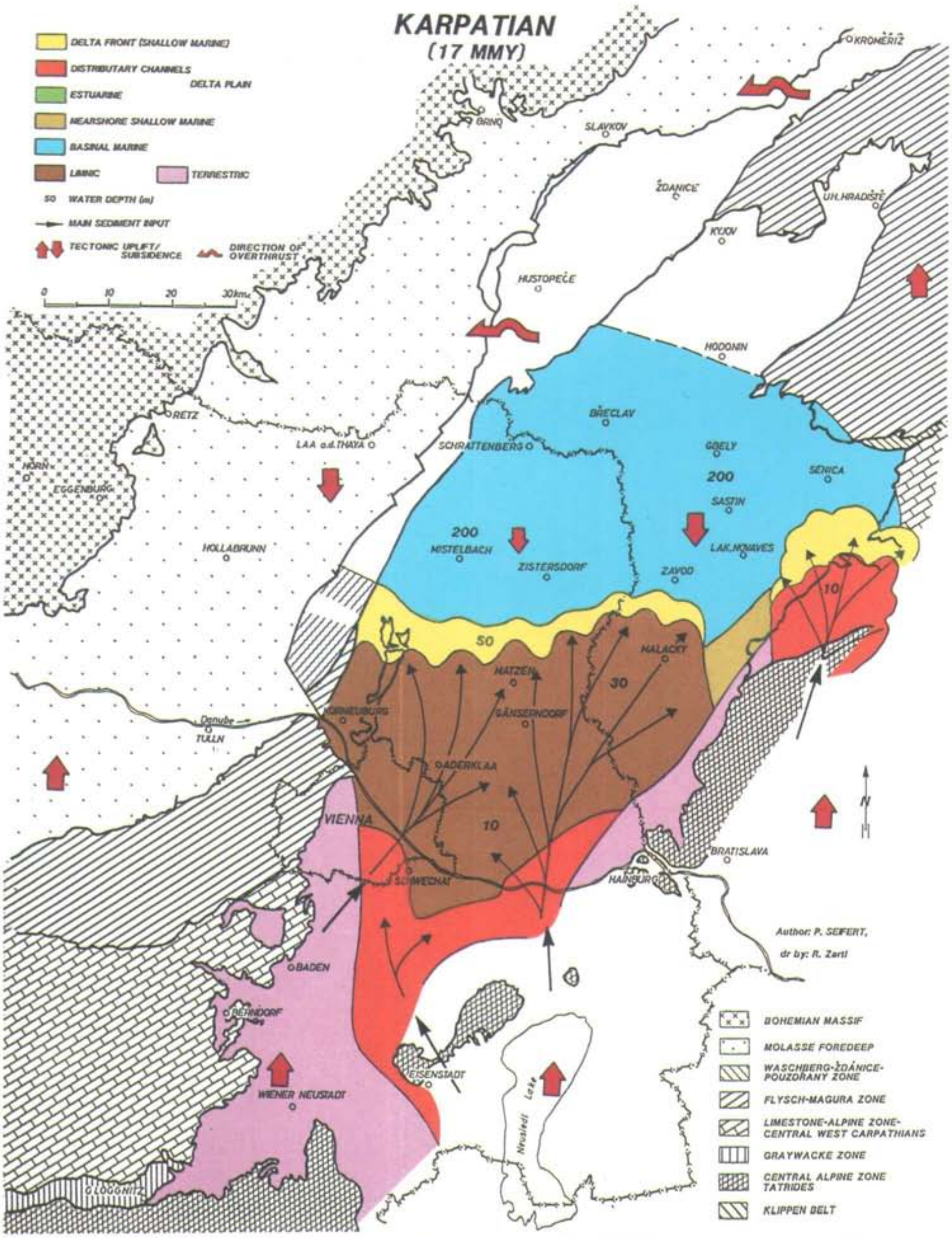


Fig. 12: Vienna Basin. Paleogeography and Facies in the Karpatian (17 MMY; P. SEIFERT).

movement, sediment supply and eustatic sea level changes resulted in a system of transgressive-regressive sedimentation cycles (KREUTZER, 1986, 1990; POGACSAS & SEIFERT, 1991). Most hydrocarbon production in eastern Austria is produced from reservoirs of this sequence. Lithothamnion Limestone covered shallow swellzones like the areas near Zistersdorf, Matzen, Laxenburg, the Leitha

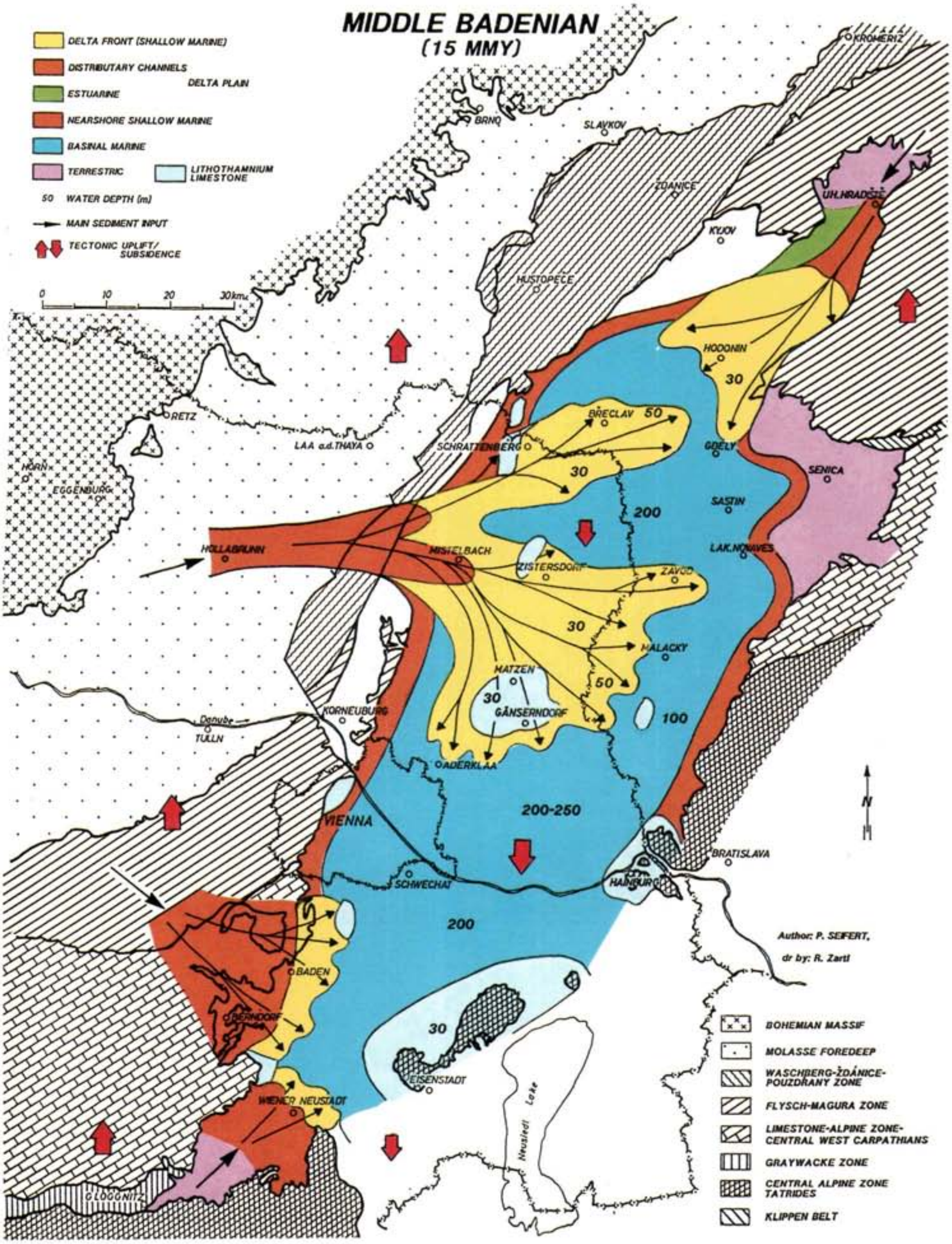


Fig. 13: Vienna Basin. Paleogeography and Facies in the Middle Badenian (15 MMY; P. SEIFERT).

Mountains and the westflank of the basin (N. KREUTZER, 1978). Some smaller local deltas in the SW brought sandy-conglomeratic material into the basin. Another delta developed in the NE corner of the basin. The connection across the SE-flank of the basin with the Paratethys resulted in stable marine conditions at that time. Very similar sedimentary conditions, but decreasing salinity charac-

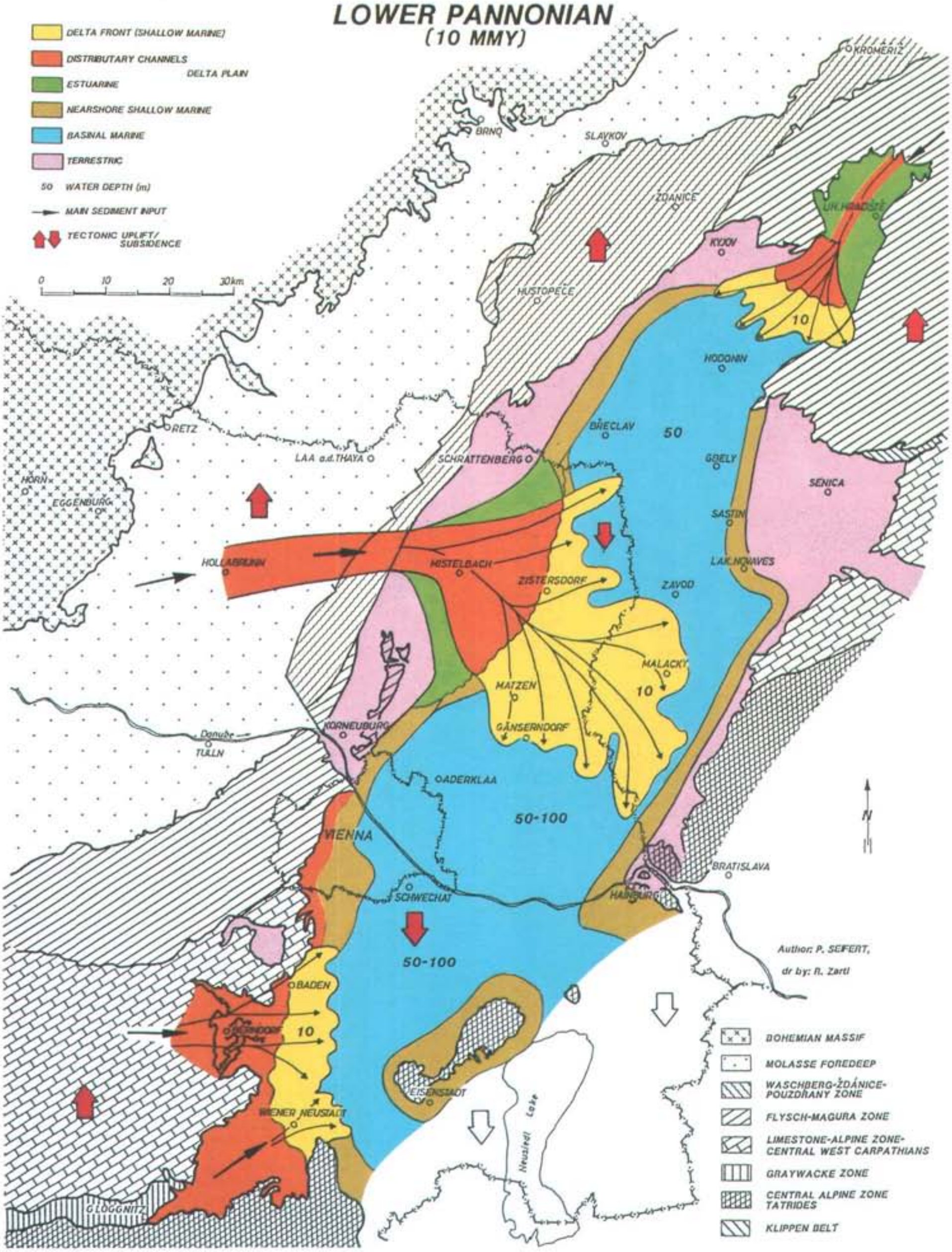


Fig. 14: Vienna Basin. Paleogeography and Facies in the Lower Pannonian (10 MMY; P. SEIFERT).

terized the Sarmatian (13.5–11.5 MMY). Regression and local unconformities characterized the transition to the Pannonian (11.5–8.5 MMY). In the northwest part of the basin, subsidence ceased and the depositional conditions became fluvial (Fig. 14).

The main delta systems continued to transport sediments into the shallowing basin. Salinity decreased continuously from brackish to limnic. The period of sedimentation reached its final stage with the Pontian (Upper Miocene). The Alpine-Carpathian nappe system continued to be uplifted. The Paleo-Danube river altered its course during the late Pliocene southward to todays current position.

A narrow Pliocene graben parallel and adjacent to the SE flank of the basin is filled with 50–100 m of conglomerate. An active line of seismicity runs parallel to that feature and confirms that strike slip and extensional movements are still continuing. Detailed investigations of sedimentation in the Badenian, Sarmatian and Pannonian of the Central Vienna Basin were done by N. KREUTZER (1971, 1974, 1984, 1990) and N. KREUTZER & V. HLAVATY (1990). The stratigraphy and facies of the Alpine-Carparthian substratum of the Neogene is included in chapters 1.3.–1.7. Stratigraphic informations on the autochthonous Mesozoic and Molasse below the Vienna Basin are given in chapters 1.1. and 1.2.

2. Tectonic Setting and Structural Evolution of the Area

The tectonic history of the eastern part of Austria since the Variscan orogeny is mainly connected with the alpidic tectonics and how they interact at the European plate margin. The foreland and the subalpine base before the Alpine orogeny will be considered first, then the Alpine Carpathian foldbelt which developed as a result of this orogeny will be dicussed. Finally, the Vienna Basin, a product of late to postorogenic movements, will be described (Fig. 25).

As there are many tectonic elements assembled in this region, many documents exist and are compiled in general monographics and special papers (L. KOBER, 1911, 1912, 1955; F.X. SCHAFFER, ed., 1951; R. OBERHAUSER, ed., 1980; A. TOLLMANN, 1976, 1985; F. BRIX, A. KRÖLL & G. WESSELY, 1977; A. KRÖLL in F. BACHMAYER, 1980; W. JANOSCHEK & A. MATURA, 1980).

2.1. Foreland and Subalpine Base

The Bohemian Massif (Figs. 2,3) belongs to the Variscan orogenic system. Compilations of it were made by A. TOLLMANN (1977) and G. FUCHS & A. MATURA in R. OBERHAUSER (1980). In Austria it is composed of medium to high grade metamorphic rocks of Precambrian to Paleozoic age and Variscan granite plutons. The Moravian unit is overthrusted by the Moldanubian unit. Postorgenic continental sediments of Upper Carboniferous to Permian age are preserved in a narrow graben structure. A number of wells have reached these crystalline or Upper Paleozoic rocks below the Molasse Zone. Below the Alpine-Carpathian thrustbelt only crystalline rocks were found (F. BRIX, A. KRÖLL & G. WESSELY, 1977).

The southern part of the Bohemian Massif forms a southward directed spur, which plunges under the Alps. This results in the division of the Mesozoic Basin into a Lower Austrian eastern part and an Upper Austrian part to the southwest. Molasse has been deposited in these basins and also covers the Spur.

The Mesozoic cover on the eastern margin of the Bohemian Massif (F. BRIX, A. KRÖLL & G. WESSELY, 1977) rests unconformably on the Hercynian basement. Dogger deltaic complexes are synsedimentary subsided in asymmetric graben

structures formed by rift faults. On the subsided part of the fault blocks sediments are thicker than on the stable part. In the uppermost Dogger the differ-

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The opening of the distant Penninic ocean seems to be the reason for the mentioned rift faults and half grabens.

Limited igneous activity related to rifting produced diabases and tuffites. The former axis of rifting is assumed to be in the present Carpathian-Pannonian region. Rifting ceased in late Dogger, platform conditions were established. In the Malmian, rapid subsidence in the east continued without substantial faulting.

It is not certain whether the Early Cretaceous regression and Upper Cretaceous transgression are the result of tectonic deformation in the Alpine areas. Upthrusting and duplications within the autochthonous Jurassic and Cretaceous reflect Oligo–Miocene Alpine movements.

Molasse sediments of Eocene–Oligocene to Lower Miocene age rest unconformably on the Mesozoic deposits and its crystalline northwestern borderzone. The sediments are mainly flat lying, however, differential compaction has created some structural features (E. Aniwandter, J. Bimka & D. Zych, 1990). Faulting is sometimes related to older lines of movement within the basement. Reactivation of Pretertiary faults took place. A prominent example is the Mailberg normal fault. It was active during the Dogger and reached a vertical displacement of more than 2000 m at that time. Displacements within the Tertiary are considerably less. To the east, the Molasse and its substratum dip under the Alpine-Carpathian thrustbelt.

Deposition of the Tertiary Molasse is dependent on the progression of the Alpine-Carpathian thrustfront. In Upper Austria sedimentation started in Upper Eocene time, and lasted till Lower Miocene (Ottnangian). Toward the east, it began in Upper Oligocene or even Lower Miocene and lasted till the Middle Miocene (F. Brix, A. Kröll & G. Wessely, 1977).

2.2. Alpine-Carpathian Units

The Alpine-Carpathian thrust belt is a heterogenous unit composed of tectonic elements having various paleogeographic provenance and deformational patterns (Fig. 2). The distinction between the Alpine and Carpathian parts of the belt is, by convention, the Danube river.

The different tectonic units are very heterogenous, primarily as a result of their paleogeography. The external units were related to the European plate and the Austroalpine units were related to the African plate. Both regions were separated by the Penninic region many hundreds of kilometers from each other and were undergoing their own tectonic history before they were joined to form a relatively narrow stack of units. In general, the orogenic movements are oldest in the south and become younger towards the northern units.

Structural Description

Before reconstructing the evolution of the Alpine-Carpathian nappe system, a short overview of the current structural position of each unit is given using descriptions, interpretations and compilations from numerous authors as well as drilling results. A. TOLLMANN (1976, 1985 and 1986) covers many of the topics in this chapter and contributes a complete bibliography. Detailed informations for different specific issues are given in papers of F. STEININGER, 1991 (Waschbergzone); S. PREY, 1974, 1980 (Flysch Zone); O. THIELE, 1980 (Penninic Zone); B. PLÖCHINGER, 1974, 1980 (Calcareous Alps); A. TOLLMANN, 1964 (Semmering); A. KRÖLL, K. SCHIMUNEK & G. WESSELY, 1981, G. WACHTEL & G. WESSELY, 1981 (drilling results in the Alps); A. KRÖLL & G. WESSELY, 1973, G. WESSELY , 1975, 1984, 1988, 1992, W. HAMILTON, R. JIRICEK & G. WESSELY, 1990, and G. WESSELY, 1992 (drilling results in the Alpine floor of the Vienna Basin).

The Waschberg Zone is only developed north of the Danube and contains strongly deformed and northwestward transported Molasse and klippen sheared off from Mesozoic substratum of the Molasse. Deformation continues far below the Vienna Basin (Figs. 15,22).

The Helvetic Zone is the southern marginal part of the European platform. It is represented in eastern Austria by Cretaceous to Paleogene variegated marls and some coarse clastics. It was overridden and squeezed into narrow slices by the Flysch Zone. One of these slices is represented by the Schottenhof zone (F. BRIX, 1961), which outcrops at the surface in front of the Laab Nappe.

The Flysch Zone comprises several nappes accumulated in front of the Calcareous Alps and thinned out below them.

West of Vienna (Figs. 15,16) the succession of nappes, from the deepest to the highest units, is: the Greifenstein Nappe, the Kahlenberg Nappe and the Laab Nappe. This also has been confirmed by well data (for example Mauerbach 1, St. Corona 1, Manzing 1). The latest results concerning the sliced internal structure of the Greifenstein Nappe were obtained from the wells of the gas-condensate Höflein field. The St. Veit Klippen Zone contains Mesozoic klippen in an envelope of Flysch. Below the Neogene of the Vienna Basin nappes of the Flysch strech from the western basin margin into Slovakia (Figs. 16,21). The Flysch Zone is subdivided into the Harrersdorf (= Raca) unit, the Greifenstein Nappe (Gösting and Zistersdorf subunit), the Kahlenberg Nappe (Sulz subunit) and the Laab Nappe.

The Calcareous Alps are divided in several main tectonic units (Figs. 15,16). The northernmost group, the Bajuvaricum, with the Frankenfels-Lunz Nappe; an intermediate group, the Tirolicum with the Ötscher Nappe system including the Reisalpen-, Unterberg- and Göller Nappe; and the highest tectonic units the Juvavicum, with Hohe Wand-, Mürzalpen- and Schneeberg Nappe. Within each unit there are synclines, anticlines and thrust faults. The Gießhübl syncline (filled with Upper Cretaceous to Paleogene sediments) rests unconformably on the Bajuvaricum and separates this unit from the Tirolicum. The southernmost part of the Göller nappe is developed as a synclinal zone with Jurassic and Cretaceous sediments.

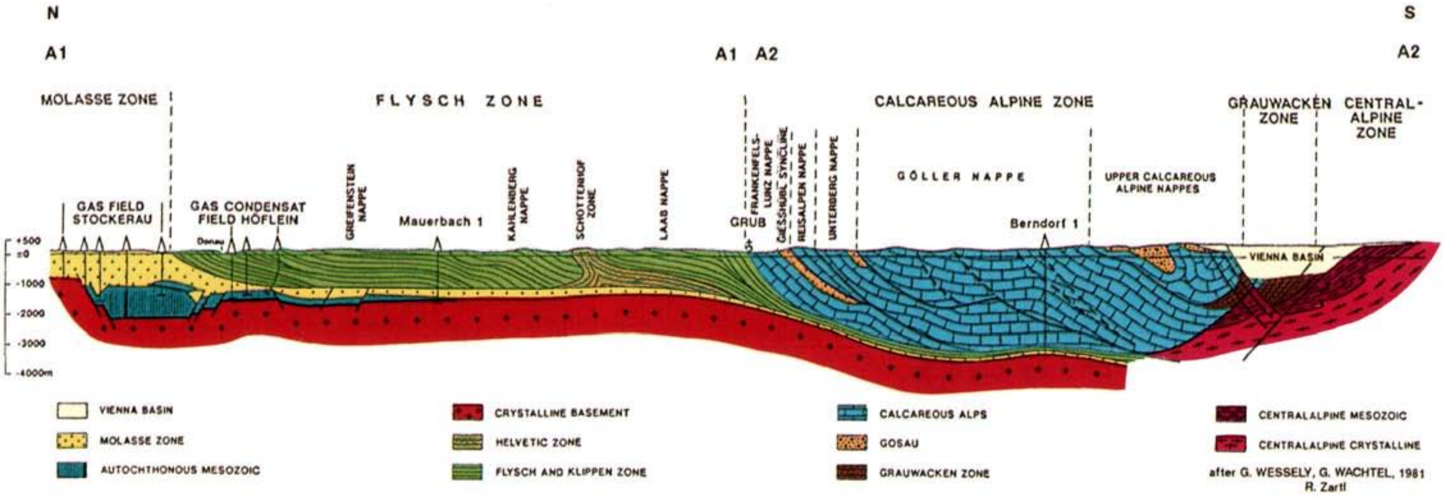


Fig. 15: Cross section through the northeastern Alps showing the subdivision of the Alpine tectonic units.
After G. WESSELY & G. WACHTEL (1981).
Position of cross section see Fig. 16.

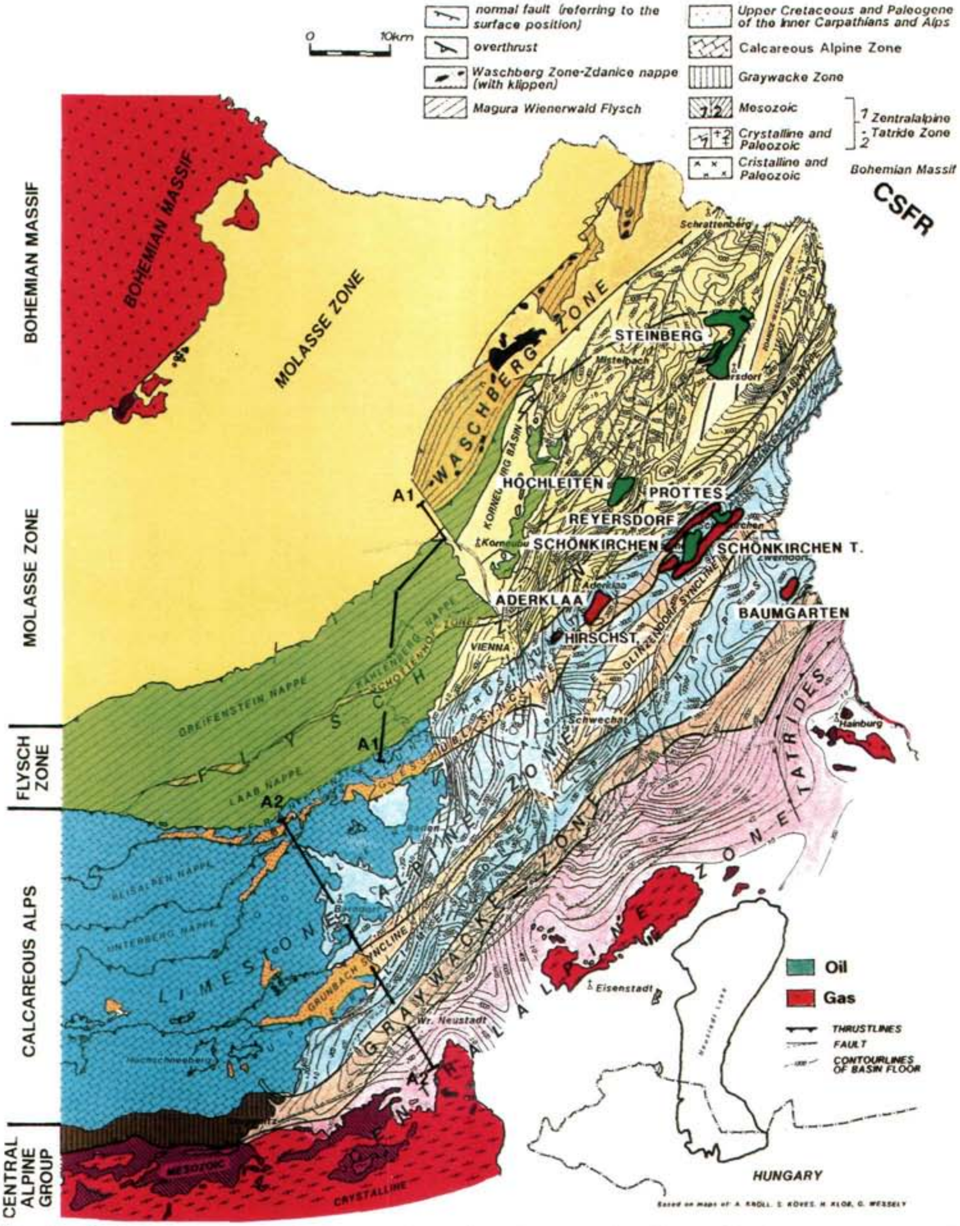
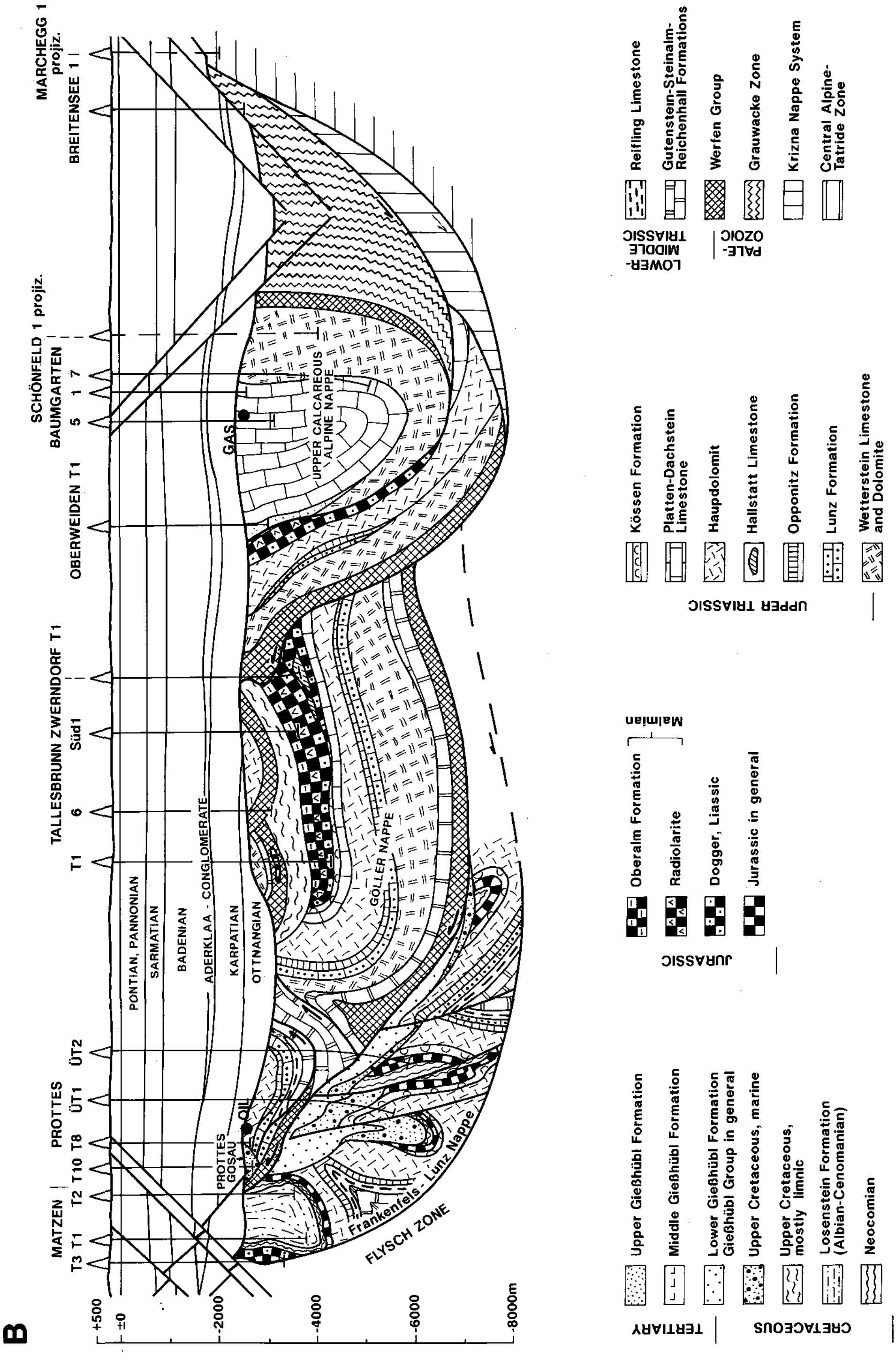


Fig. 16: Alpine-Carpathian units and their continuation into the Vienna Basin. Based on maps of A. KRÖLL, S. KÖVES, H. KLOB and G. WESSELY.

The Hohe Wand nappe, with the mountain range of the Hohe Wand and some outlayers, moved over this zone. A synjurassic gravitational gliding before Alpine thrusting, is considered (preliminary investigations by SUMMESBERGER and MANDL).


B
MATZEN
T3 T1 T2
PROTTES
T10 T8 ÜT1 ÜT2
TALLESBRUNN
T1 6
ZWERNDORF
Süd1 T1
OBERWEIDEN T1
BAUMGARTEN
5 1 7
SCHÖNFELD 1 projiz.
BREITENSEE 1
MARCHEGG 1
projiz.
+500
±0
-2000
-4000
-6000
-8000m
PONTIAN, PANNONIAN
SARMATIAN
BADENIAN
ADERKLAA - CONGLOMERATE
KARPATIAN
OTTNANGIAN
PROTTES GOSAU
OIL
GAS
UPPER CALCAREOUS ALPINE NAPPE
GÖLLER NAPPE
Frankenfels - Lunz Nappe
FLYSCH ZONE
TERTIARY
Upper Gießhübl Formation
Middle Gießhübl Formation
Lower Gießhübl Formation Gießhübl Group in general
CRETACEOUS
Upper Cretaceous, marine
Upper Cretaceous, mostly limnic
Losenstein Formation (Albian-Cenomanian)
Neocomian
JURASSIC
Oberalm Formation
Radiolarite
Malmian
Dogger, Liassic
Jurassic in general
UPPER TRIASSIC
Kössen Formation
Platten-Dachstein Limestone
Haupdolomit
Hallstatt Limestone
Opponitz Formation
Lunz Formation
Wetterstein Limestone and Dolomite
LOWER-MIDDLE TRIASSIC
Reifling Limestone
Gutenstein-Steinalm-Reichenhall Formations
Werfen Group
PALEOZOIC
Grauwacke Zone
Krizna Nappe System
Central Alpine-Tatride Zone

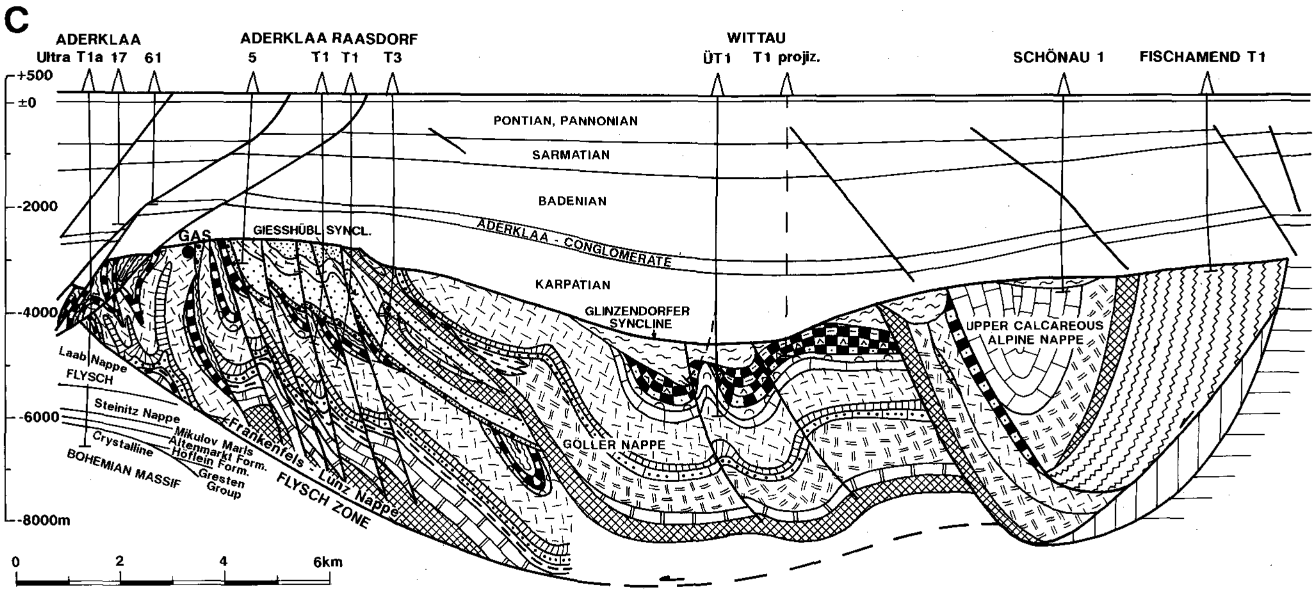


Fig. 17: Cross sections through the Calcareous Alpine floor of the Vienna Basin (G. WESSELY, 1992). Location of sections see Fig. 4 (B: Matzen – Zwerndorf – Marchegg; C: Aderklaa – Wittau – Fischamend).

The deep syncline of Grünbach is between the Hohe Wand Nappe and the Schneeberg Nappe. It has been filled with the Upper Cretaceous to Paleocene "Grünbacher Gosau". The Gosau Group also overlies the overthrust of the Schneeberg Nappe composed mainly of middle Triassic Wetterstein Limestone. The flat position of the above mentioned complex exposes the Tirolicum and Hohe Wand Nappe in windows (e.g. the Ödenhof-, Hengst- and Höflein Window). At the southern margin of Schneeberg Nappe the overthrust contact between Middle Triassic carbonates and underlying Permotriassic siliciclastics is documented by inserted tectonized slices of Upper Anisian to Lower Norian pelagic fazies. The siliciclastic Prebichl Formation of the lowermost unit is in transgressive contact to the Greywacke Zone (G. MANDL, this guide book, part II).

The Greywacke Zone, is split up into two units:

○ The deeper Veitsch Nappe formed by Carboniferous sediments and
○ the higher Noric Nappe consisting of metamorphosed Paleozoic sediments and of igneous rocks.

The Greywacke Zone is thrusted over the Middle and Lower Austroalpine units.

The structural style of the Calcareous Alps and the Greywacke Zone below the Neogene of the Vienna Basin is similar to the construction in the outcropping Alps (Figs. 17,28). The folded Frankenfels-Lunz Nappe representing the Bajuvaricum is overlain unconformably by the Upper Cretaceous–Paleogene series of the Gießhübl syncline, which has been overthrusted by the Tirolicum, represented only by the Göller Nappe.

The frontal part of the Göller nappe in the Schönkirchen – Prottes area (Fig. 28) shows folding and backthrusting, whereas the main part of the Göller nappe (Fig. 17) flattens or even rises toward south and contains a complete Triassic–Jurassic series there, discordantly overlain by the Glinzendorf Gosau. The Prottes Gosau on top of the frontal Göller nappe may be connected with the southern part of the Gießhübl syncline. The highest Calcareous Alpine nappe contains a deep syncline which was encountered in Baumgarten. Indirectly, a frontal thrustslice can be established. In the Tallesbrunn area, it extends as an outlier over the Glinzendorf syncline. The Greywacke Zone seems to be connected with the highest Calcareous Alpine nappes. It disappears in the Slovakian part of the basin. The Krizna nappe system may be thought of as a part of the Bajuvaricum (perhaps its former northern part). This is assumed because of the terrestrical Keuper facies in the Upper Triassic in contrast to the Frankenfels Lunz system, where the lagoonal Hauptdolomit dominates. The Calcareous Alps rest rootless upon Flysch Zone and Central Alps – Tatrides respectively.

The Lower Austroalpine zone of the Semmering-Wechsel area consists of several tectonic units. The deepest appears in the Wechsel Window and is composed primarily of Wechsel Gneisses and Wechsel Schists. This unit is covered by the Grobgneis Series. Large areas show an inverted position of this unit (G. FUCHS, 1990). This series is also exposed in the Leitha Mountains. A higher crystalline complex is the Troiseck crystalline to the west, which belongs to the Middle Austroalpine (TOLLMANN, 1959).

TOLLMANN (1959) identified a Middle Austroalpine unit distinct from an Lower Austroalpine one, having its own crystalline and Permomesozoic parts. In the Semmering area only the latter are preserved.

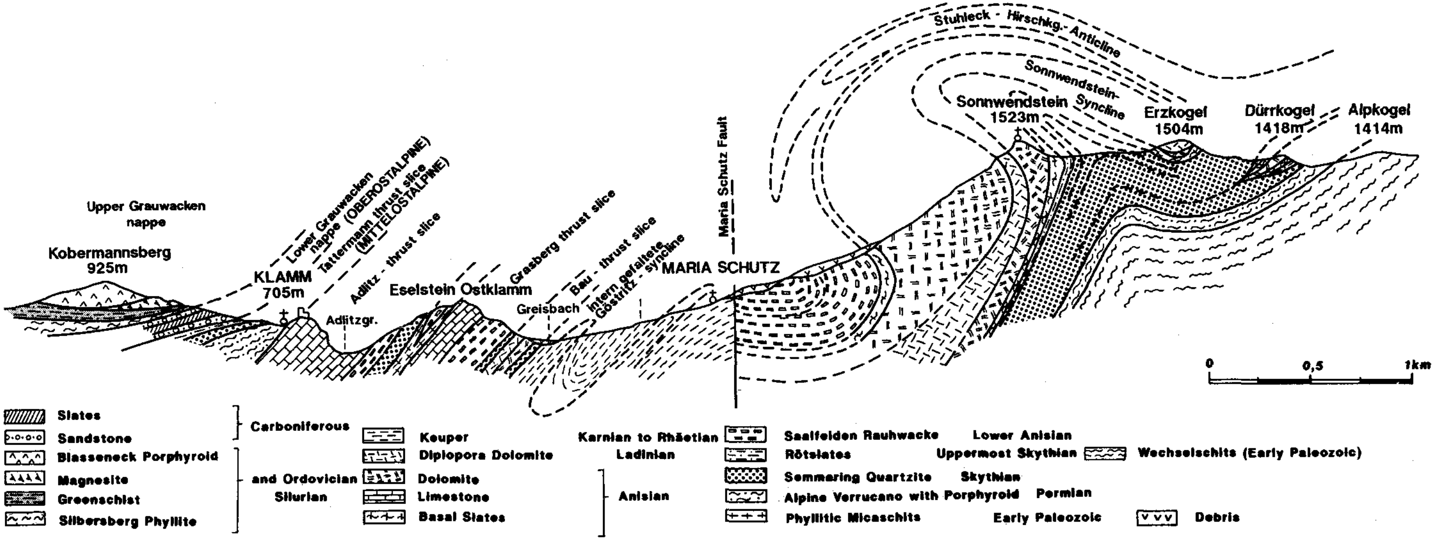


Fig. 18: Geological section through the Semmering structural system and the Middle and Lower Austroalpine Units in the Sonnwendstein region. After A. TOLLMANN (1968).

Within the Vienna Basin the Permomesozoic sequence of the Lower Austroalpine unit forms a broad belt below the south-eastern part of the basin. Its internal construction is not evident because of low density of wells.

Tectonic Evolution

To explain the evolution of the Alpine-Carpathian thrust belt in the eastern part of Austria it is necessary to simplifiy these complex proceedings and to concentrate on the main events.

In the Penninic region both sea floor spreading and subduction occured from Middle to Upper Cretaceous. Turbidite sequences of the Flysch indicate a trench development in the northern part of the area from uppermost Lower Cretaceous to Middle Eocene. The tectonic movements during and after that time formed the Penninic nappes with crystalline cores, Mesozoic sedimentary cover and ophiolites thought to be derived from oceanic crust (V. HÖCK & Ch. MILLER, 1980). Further motion of the European and African plates led to a collision in the Upper Cretaceous to early Tertiary time. This resulted in the Austroalpine units being moved over the Penninic Zone. The Calcareous Alps were emplaced with their southern part over the Lower Austroalpine and with their northern part over the Flysch Zone (Fig. 15).

Observed gravity movements in the Calcareous Alps observed, outside and within the Vienna Basin had already taken place in the Jurassic. Coarse breccias and olistholites deriving from erosion or gliding from elevated areas were transported into areas of subsidence. Thus Triassic platform carbonates and late Triassic to Early Jurassic rocks can be found in Jurassic basinal sediments. This was previously documented in Upper Austria and Salzburg, where whole sections of higher nappes were identified as "glidder complexes" transported into a Malmian basin of the Tirolicum, possibly in connection with halokinetic movements caused by Permoskythian evaporites (PLÖCHINGER, 1976).

The first compressional movements started in the northern parts of the Bajuvaricum. Here, Albian to Lower Cenomanian synorogenic clastic sediments filled troughs of tectonic origin and were later unconformably covered by Upper Cenomanian. In the Tirolicum and Juvavicum, Early Cretaceous rocks are missing; Coniacian covers folded Jurassic and Triassic rocks, and thrust planes of higher nappes. Later, the thrusting was reactivated.

A general subsidence led to deposition of the turbiditic Upper Maastrichtian to Paleocene Gießhübl Group. At that time, the overthrust of the Göller Nappe over the Gießhübl nappe began. Remnants of the Lower Gießhübl Formation (Danian–Montian), on the front of the Göller Nappe, overthrusted the Middle Gießhübl Formation (Thanetian) and indicate continuous thrusting. Frontal parts of the nappe advanced and were covered by sediments, before the main unit followed (well Raasdorf T3, Fig. 17).

The earliest thrusting of the Calcareous Alps over the Flysch Zone, occurred in the late Eocene. During thrusting, the Calcareous Alps and the Greywacke Zone were separated from their crystalline basement and advanced far to the north, pushing the main part of the Flysch Zone ahead of it. Attenuation of the Flysch beneath the overlying thrust complex is demonstrated in the well Berndorf 1 and in other wells west of this area.

The overthrust of the Flysch and Helvetic zones over the Molasse took place in Late Oligocene and Early Miocene. The Berndorf 1 well, situated 35 km south from the northern edge of the Alps, has Oligocene resting on the crystalline basement. In wells within the Flysch Zone, Early Miocene (Eggenburgian) is over-

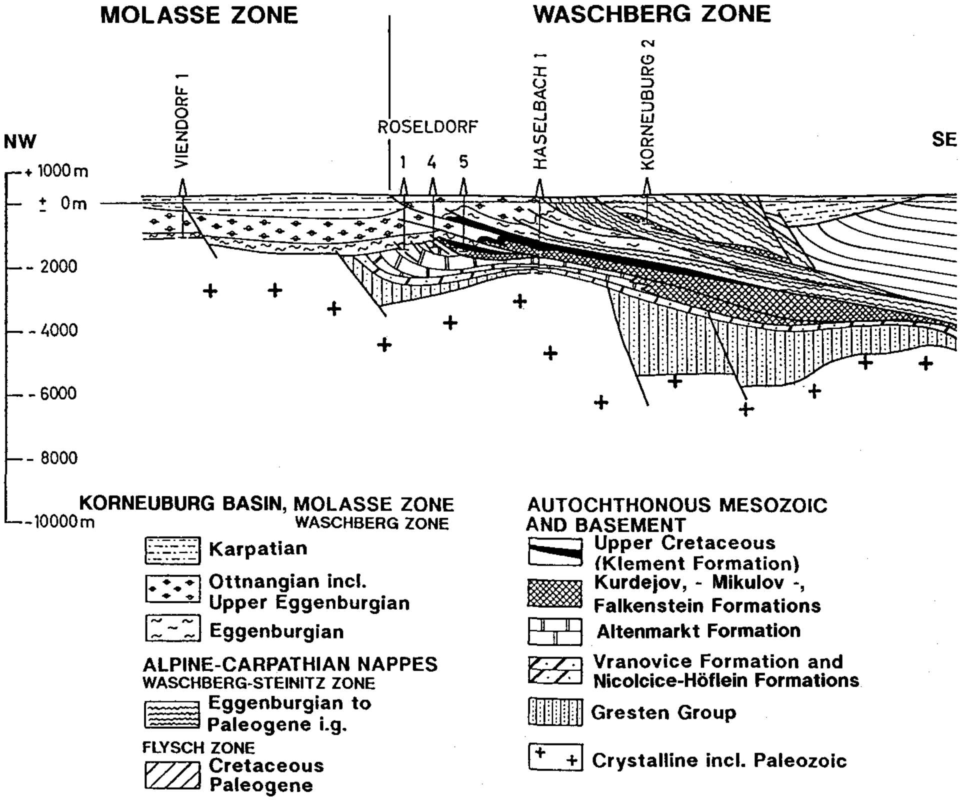


Fig. 19: Lower Miocene synsedimentary thrusting along the Waschberg Zone north of the Danube.
After F. BRIX, A. KRÖLL & G. WESSELY (1977, modified).

thrusted. South of the Danube, the frontal thrusting causes upthrusting of Oligocene shear bodies and folding of the Miocene Molasse.

In the Höflein area, tectonic wedges of Lower Miocene Molasse are accumulated beneath the front of the Flysch.

North of the Danube, the Waschberg Zone, consisting of strongly deformed Molasse, appeared as a new tectonic unit in front of the Flysch.

Successively younger Molasse beds of Egerian to Karpatian age were involved in the Oligo-Miocene deformation process. Older, internal thrust planes were successively covered and sealed by synchronous sedimentation (Fig. 19).

2.3. Vienna Basin

The knowledge of the tectonic setting and geodynamics of the Vienna Basin is mainly based on wells in various parts of the basin. The first important compilations of the basin construction were made by K. FRIEDL (1929, 1936) and R. JANOSCHEK (1939, 1951). Modern aspects of the basin and fault development were discussed by H. STOWASSER (1966). L. ROYDEN (1982, 1988) first introduced at first the idea of a pull apart mechanism of the basin, modified by G. WESSELY (1988) and W. LADWEIN, F. SCHMIDT, P. SEIFERT & G. WESSELY (1991). The paleogeographic and paleobiogeographic position of the Vienna Basin within the frame of the Paratethys and the circum-Mediterranean Neogene was described by RÖGL & STEININGER (1983).

Structural Description

The Vienna Basin is an intermontane basin that subsided on Alpine-Carpathian nappes. It is 200 km long and 60 km wide and extends over the territories of Austria and ČSFR. It was filled by Neogene clastic sediments during a period of intense tectonic activity. Shallow marginal blocks around the flanks of the basin are separated from the depocenters by large normal faults (W. HAMILTON, R. JÍŘÍČEK, G. WESSELY, 1990; V. CEKAN, C. TOMEK & D. ZYCH, 1990). An elevated zone with a sigmoidal shape runs along the central axis of the basin. Several generations of synsedimentary faults created deposits up to 3,000 m thick and in depocenters more than 5,000 m thick. The most important faults were of Middle and Late Miocene and Pliocene age.

It is necessary to define the reference surfaces for delineating structural elements. According to the tectonic development, deeper parts of the basin show more intensive deformations than younger stratigraphic sections.

In Austria the most extensive marginal blocks along the western border of the basin are the Poysbrunn, Mistelbach and Mödling Blocks (Fig. 20). The Schrattenberg – Steinberg – Bisamberg – Leopoldsdorf Fault systems separated these marginal blocks from a system of depressions – the Zistersdorf-, Groß-Engersdorf- and Schwechat Depressions.

A median highzone extends from the Hodonin Spur in CSFR along the Rabensburg – Eichhorn Ridge to the Matzen – Aderklaa elevations. The Wienerherberg – Enzersdorf High is an isolated high situated in the Southern Vienna Basin. The median high zone is separated from the Marchfeld Depression by the Markgrafneusiedl Fault, followed eastward by the Zwerndorf – Tallesbrunn High.

Along the Eastern flank of the Vienna Basin is a system of grabens: the Wiener Neustadt Basin, the Mitterndorf Graben, the Lassee Graben and the Zahor – Plavecky – Mikulas Graben in the CSFR. Extension of these grabens, is continuing to present day. They are separated by large faults (Pottendorf Fault, Kopfstetten – Engelhartstetten Fault system) from eastern marginal blocks such as the Leitha Mountains Block, Deutsch Altenburg Spur and the Male Karpaty Block. Based on seismic data (flower structures; Fig. 20) and surface observations, vertical displacements as well as lateral motions occurred. A trend of seismicity (R. GUTDEUTSCH & K. ARIC, 1988) indicates that present day movement is still occurring.

The faults mentioned above are synsedimentary, often with large displacements (Steinberg Fault 5,000–6,000 m (Fig. 19, cross section 1), Leopoldsdorf Faults up to 4,000 m, Fig. 24). Most activity has occurred since Badenian time. However there are also structural elements and faults, which indicate tectonic movements in the pre-Badenian age. These elements are known in the northern part of the Vienna Basin. The structural features of the basin are also reflected in gravity measurements (ZYCH, 1988).

Because of the external position of the Vienna Basin within the thrustbelt, the sub Alpine-Carpathian basement is relatively shallow and has controlled the basin forming mechanism to a certain extent.

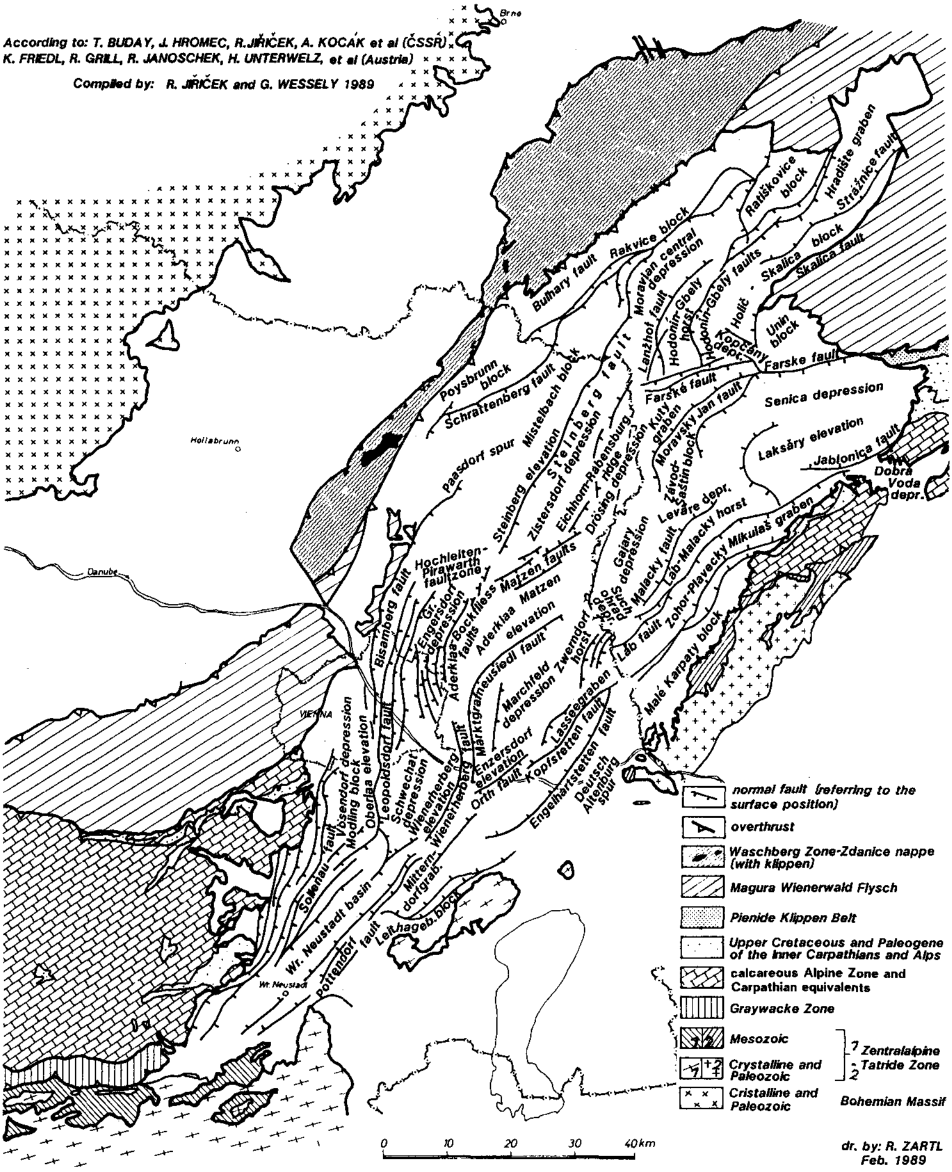
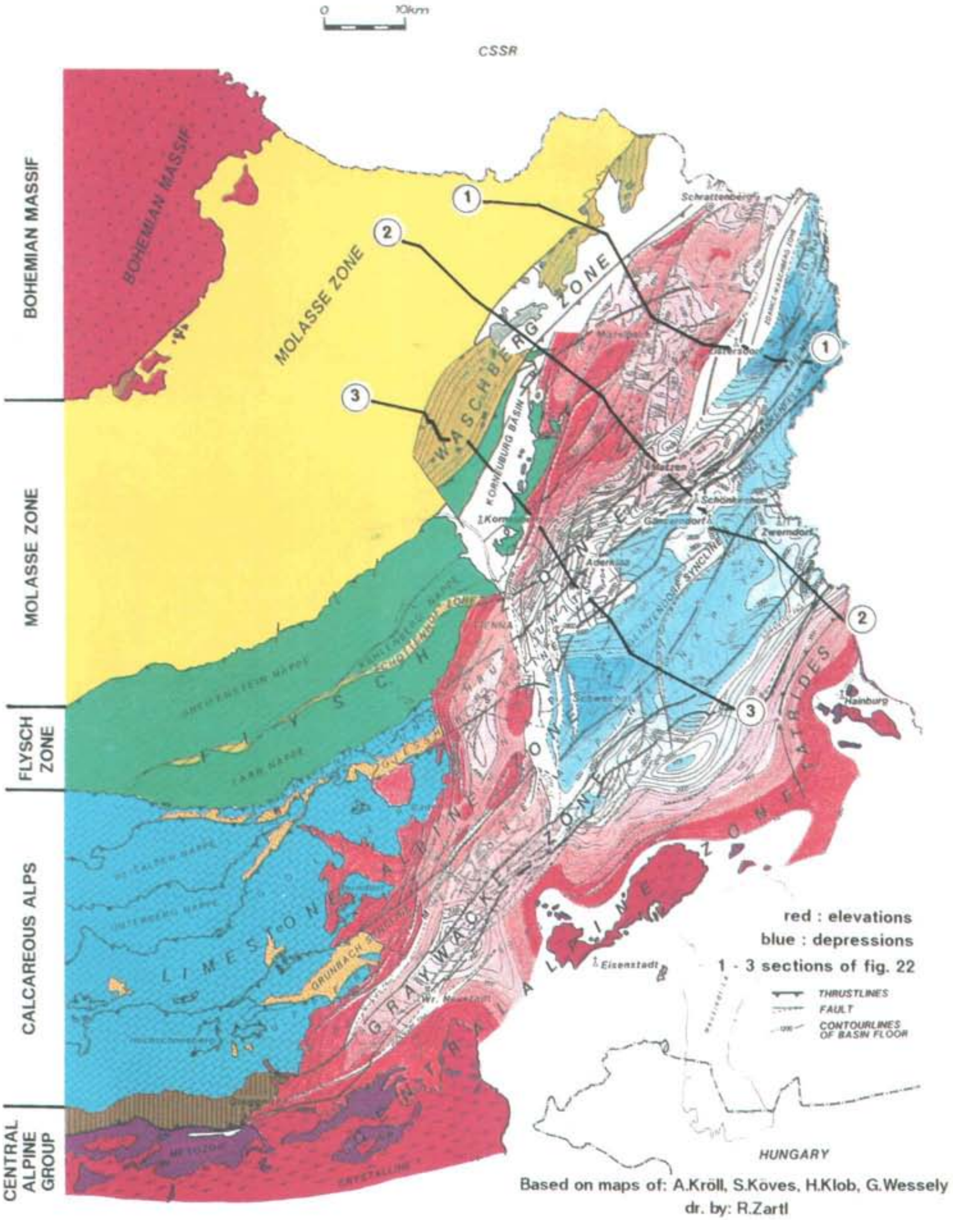


Fig. 20: Vienna Basin – main structural elements.
According to T. BUDAY, J. HROMEC, R. JÍŘÍČEK, A. KOCÁK et al. (ČSFR); K. FRIEDL, R. GRILL, R. JANOSCHEK and H. UNTERWELZ et al. (Austria) – compiled by R. JÍŘÍČEK and G. WESSELY (1989).
In: W. HAMILTON, R. JIRÍCEK & G. WESSELY (1990).

The Eisenstadt Basin is a subbasin of the Vienna Basin and has the same subsidence history.

The Pannonian Basin, began to dip towards the east during Pannonian time. This was the result of downwarping rather than major faulting (Fig. 51).

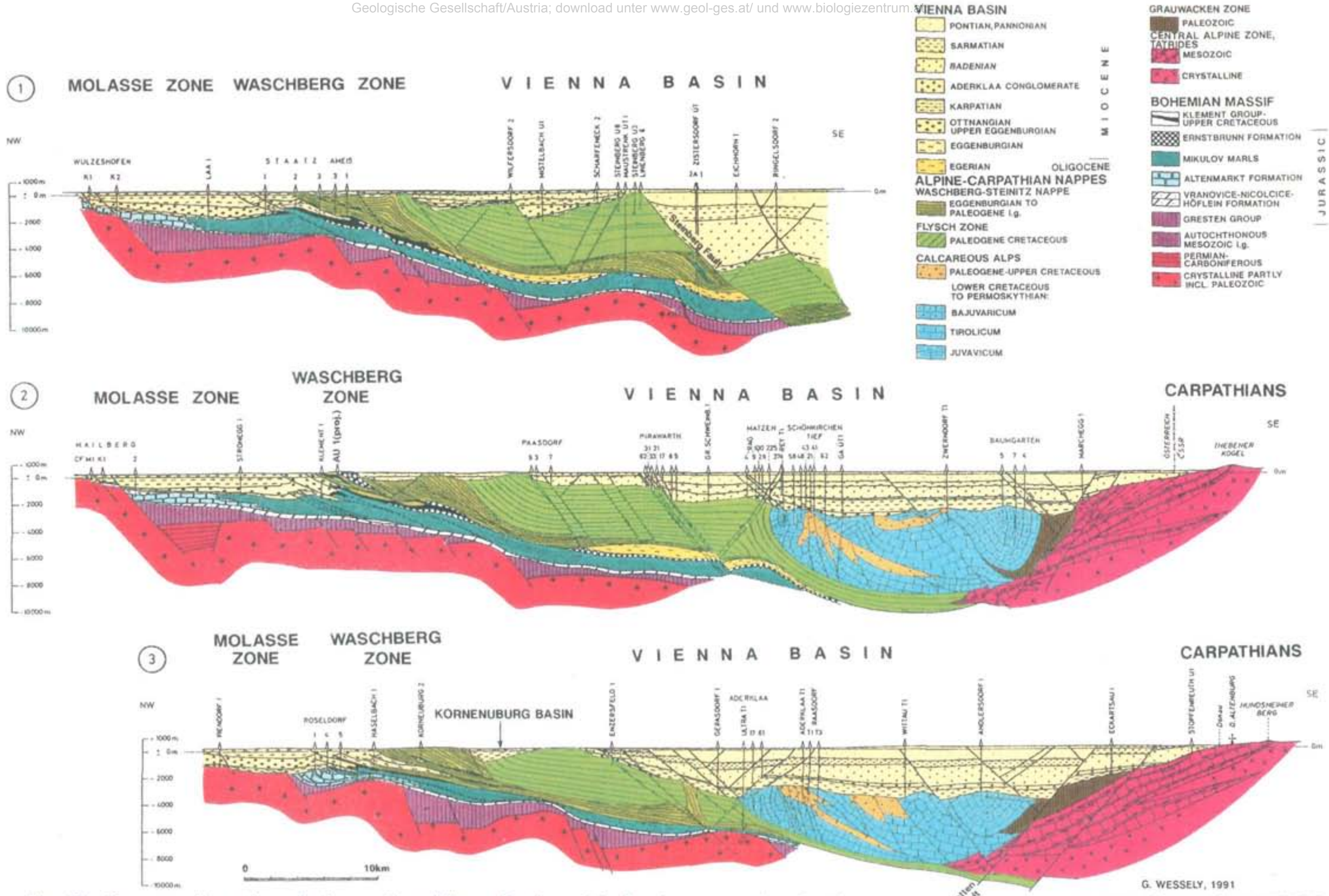


Based on maps of: A.Kröll, S.Köves, H.Klob, G.Wessely
dr. by: R.Zartl

Fig. 21: Vienna Basin. Base Neogene and subcrop of Alpine-Carpathian Units. Based on maps of A. KRÖLL, S. KÖVES, H. KLOB and G. WESSELY.

Tectonic Evolution

The development of the Vienna Basin is closely connected with late Alpine tectonic events. Along the front of the Alpine-Carpathian belt in general, the age of thrusting gets progressively younger from west to east, as it has been proven



G. WESSELY, 1991
after U. HERZOG, S. KÖVES, A. KRÖLL, H. UNTERWELZ
R. Zartl

Fig. 22: Cross sections through the northern Vienna Basin and its border zones showing the Alpine-Carpathian nappe system, its foreland and the intramontaneous Vienna Basin, with its 3 floors: the Neogene (first), the Alpine-Carpathian (second) and the Autochthonous (third) floor. G. WESSELY (1988), modified after U. HERZOG, S. KÖVES, A. KRÖLL, H. UNTERWELZ and G. WESSELY.

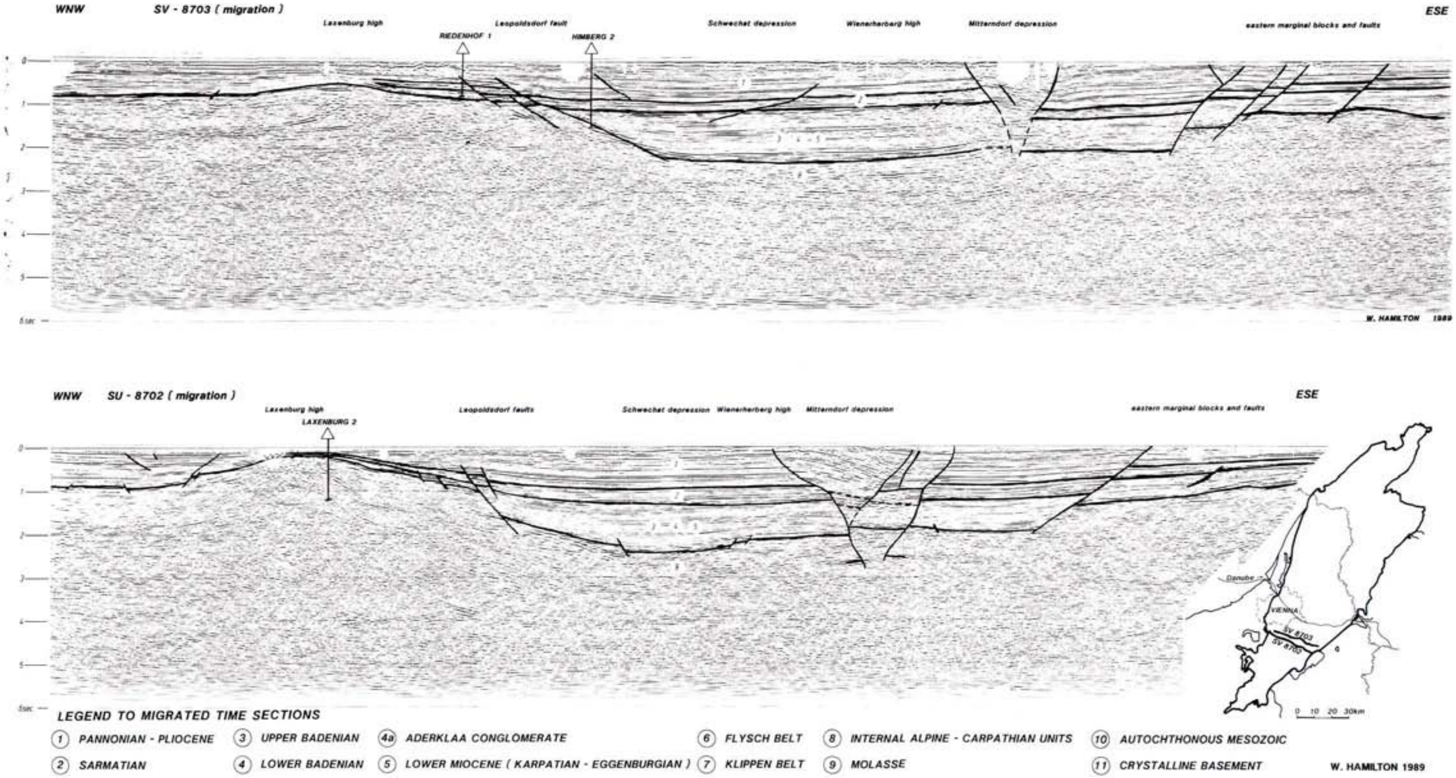


Fig. 23: Seismic sections through the southern Vienna Basin showing the Laxenburg elevation in the WNW, bordered by the Leopoldsdorf fault system; flower structures in the eastern part point to a young strike slip movement along NE striking faults (W. HAMILTON, 1989). In: W. LADWEIN, F. SCHMIDT, P. SEIFERT & G. WESSELY (1990).

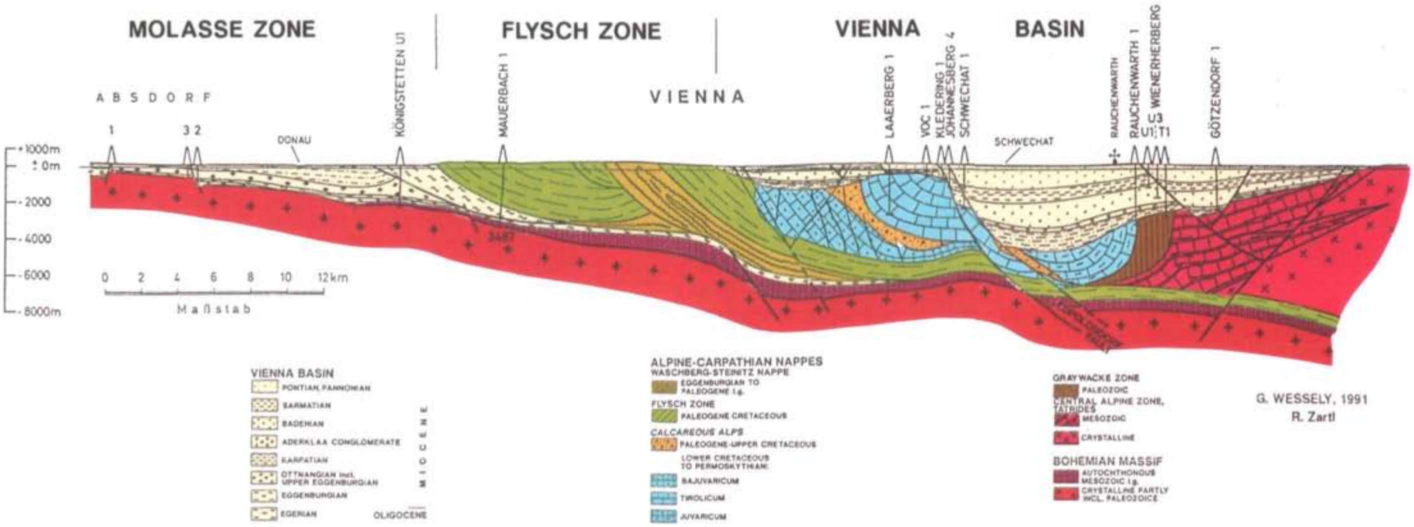


Fig. 24: Geologic cross section through the Southern Vienna Basin with a marginal shallow depression, the Oberlaa-Laxenburg high, the Leopoldsdorf fault and the Schwechat depression (G. WESSELY).

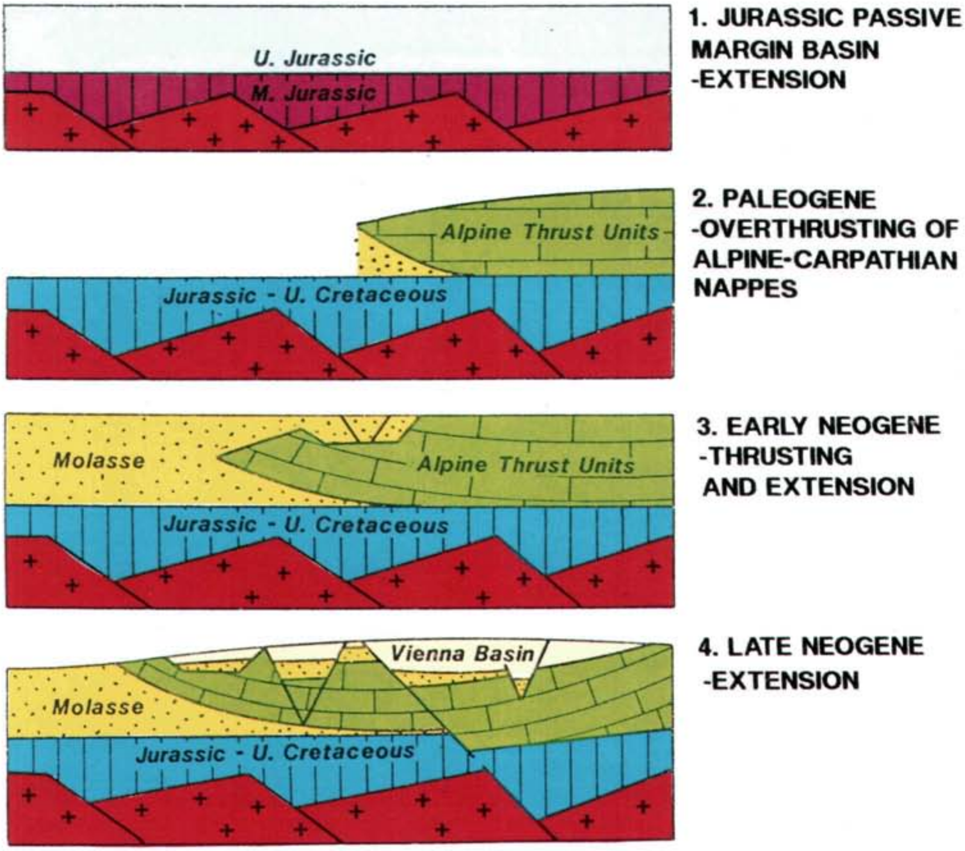


Fig. 25: Tectogenis of the Vienna Basin.
After W. Ladwein, F. Schmidt, P. Seifert & G. Wessely (1990).
1) Jurassic rift basin and passive margin basin – extension.
2) Paleogene – overthrusting of Alpine-Carpathian nappes.
3) Early Neogene – thrusting and extension.
4) Late Neogene – extension.

in the Carpathian part (Jiříček, 1979; Jiříček & Tomek, 1981). The movement of nappes was also influenced by the Bohemian Massif. Thrusting stopped in the area of the southern Bohemian Spur, however, thrusts continued to advance east of it. This caused tension between areas already fixed and the still advancing parts of the thrust complex. During the Late Oligocene, the strike of the Alpine-Carpathian thrust front in the area south of Vienna was E–W. The Early Miocene propagation of the nappes was combined with a continuous rotation of strike, into a final NE–SW direction.

Thrusting was accompanied by sedimentation and synsedimentary faulting in an already existing Paleo-Vienna Basin, which was created by extension. At the end of the Karpatian, thrust movements ceased west of the basin. In the basin itself inversion and erosion took place. The Middle Miocene Badenian transgressive sequence rests unconformably on different stratigraphic units of the Lower Miocene basin fill and the Flysch. This can be seen in the Matzen area.

Tension and subsidence reached their maximum in Middle Miocene to Pliocene time. The supply of sediments was very high, so that depressions were filled immediately during subsidence.

The rhomboidal shape of the basin is obvious (Fig. 20). In addition to the predominant normal displacement of faults left lateral movement is demonstrated by the bending of structures and faults and the right stepping en echelon arrangement of faults.

In the case of the Leopoldsdorf Fault system, sufficient control shows that there is no large lateral displacement in the strike of Preneogene units (Fig. 16). Along the Steinberg Fault this conclusion is not possible because of a lack of well control on the downthrown block. A well documented example of westdipping, rightstepping, synsedimentary, en-echelon faults are the Bockfließ faults which are limited to the western border of the median high zone (WESSELY, 1988).

The current view is that the explanations concerning a pull apart mechanism have to take into consideration the summation of the lateral components of movement along the main Alpine-Carpathian thrust planes. A large number of normal faults (or conjugate fault pairs) seem to be restricted to the allochthonous thrust complex. The autochthonous basement must have controlled the strike of the Alpine Carpathian thrust front and Late Miocene faulting, because of the coincidence with the strike of Mesozoic tectonostratigraphic units. The direction of the NE-striking Dogger faults shows a slight deviation from the NNE-striking Miocene faults.

All these phenomena are common in pull apart basins. The assumption of a pull-apart mechanism forming the Vienna Basin was documented by ROYDEN (1988). Two transform faults are thought to cause extension due to their listric character "soling out" into the detachment planes of Alpine tectonic units. The resultant tension is interpreted to be restricted to the allochthonous thrust complex.

The listric nature of the largest Late Miocene faults indicate that their continuation into the crystalline basement is questionable, and they perhaps only extend into Autochthonous Mesozoic cover.

A zone of a very recent extension, connected with strike slip movement, exists along the whole eastern flank of the basin.

The tectogenesis of the Vienna Basin area is illustrated by Fig. 25.

3. Occurrence of Hydrocarbons

3.1. Oil- and Gas Fields in the Vienna Basin

The oil- and gas provinces of the Vienna Basin (K. FRIEDL, 1957; A. KRÖLL, 1980; W. LADWEIN, F. SCHMIDT, P. SEIFERT & G. WESSELY, 1991) coincide with distinct structural features. A concentration occurs along 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.

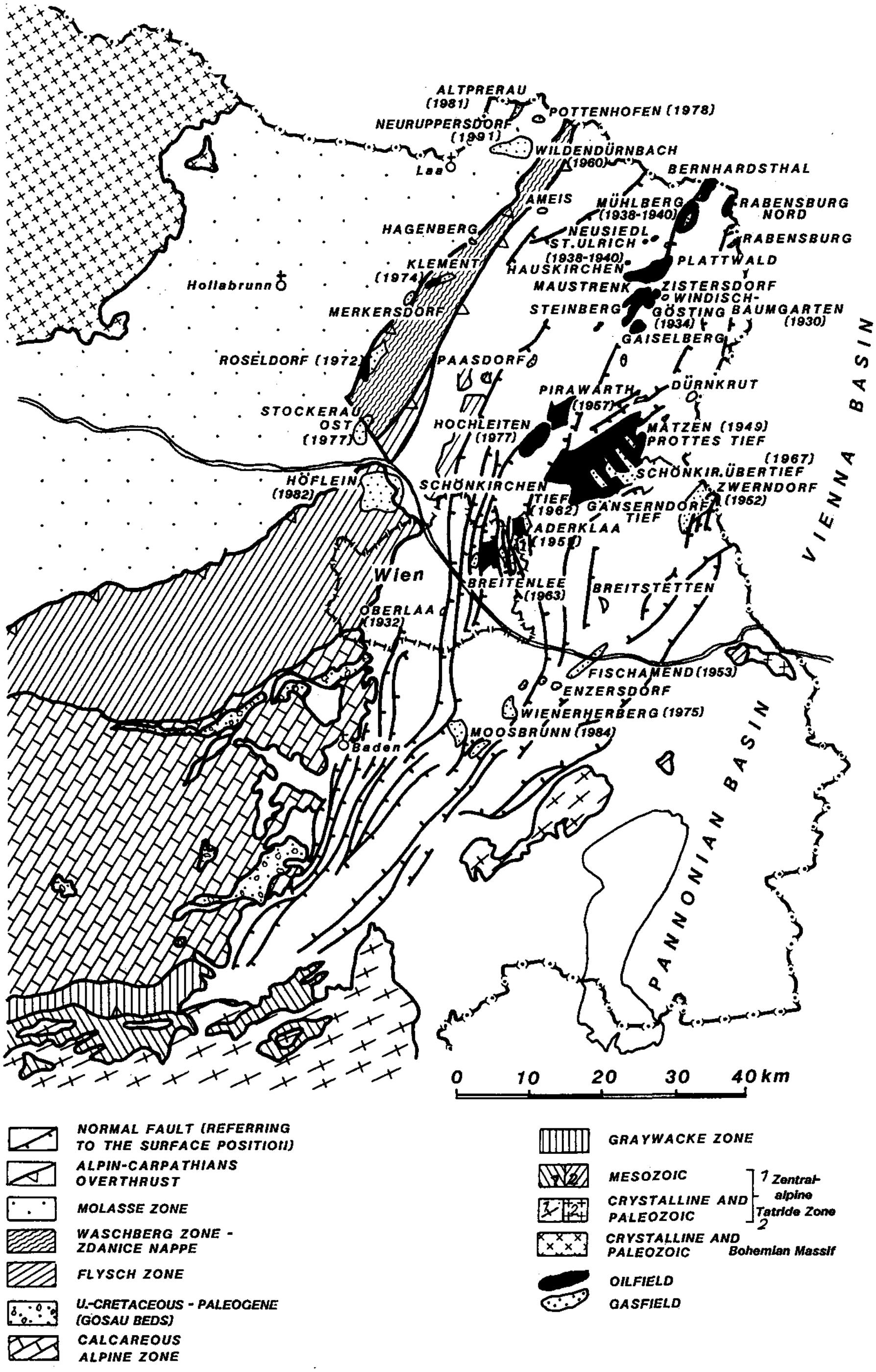


Fig. 26: Oil and Gasfield in Lower Austria (Vienna Basin, Molasse, Alps).

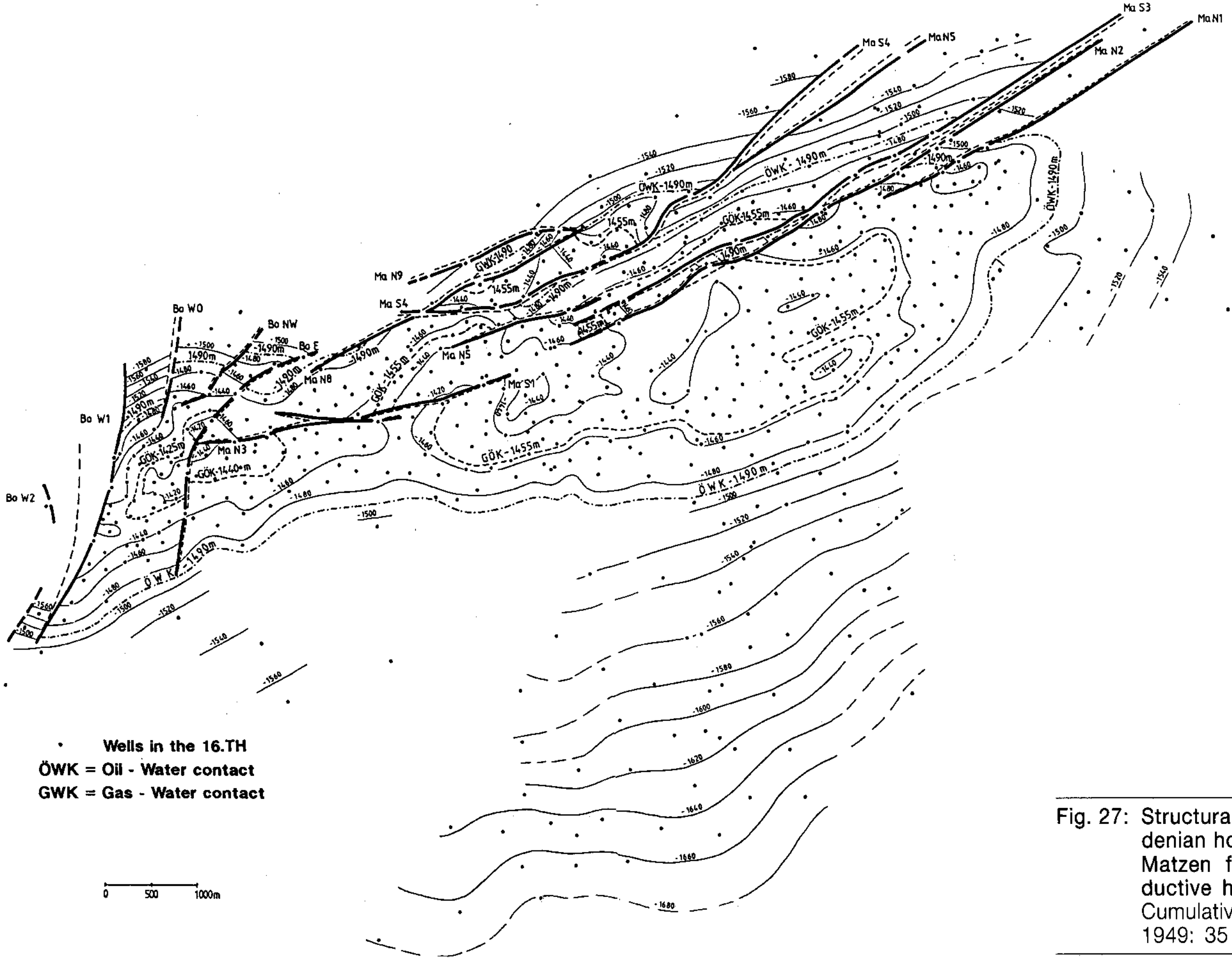


Fig. 27: Structural map of the 16. Badenian horizon (16. TH) in the Matzen field, the most productive horizon in Austria. Cumulative production since 1949: 35 Mio t (N. KREUTZER).

The northern and central provinces contain oil and gas of thermocatalytic origin. Gas of biogenic and mixed origin was found in the south and southeastern regions.

Lower and Middle Miocene transgressive and regressive sandstone cycles resulted in a stack of multiple productive zones (N. KREUTZER, 1986). As a result nearly every field in the Neogene floor produces from several horizons. The number of Miocene sandstone horizons changes from province to province, as does their thickness and internal structure. At Matzen field, for example, at least 9 Lower Miocene, 16 Badenian, 9 Sarmatian and 4 Lower Pannonian horizons contain hydrocarbons.

In the central provinces of Matzen and Aderklaa, oil production comes from Lower Miocene and Badenian horizons, whereas the Sarmatian and Pannonian horizons contain only gas. In the northern fault provinces, the oil production comes mostly from Sarmatian horizons. In the southern and southeastern fault provinces only gas occurs in Badenian (Zwerndorf) and Sarmatian horizons (Fischamend, Orth, Moosbrunn).

The best productive zone is the transgressive 16th Badenian horizon in the Matzen field (Fig. 27).

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. Faults in these areas influence the shape of the structures, but are not a trapping mechanism.

The Flysch Zone below the Neogene is only productive in the area of the Steinberg High and neighbouring structures (Fig. 16). 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 (Fig. 16).The reservoirs are Upper Triassic dolomites (Hauptdolomit) and, in one case, dolomitic limestones (Dachstein Limestone). The dolomites reach thicknesses of up to 500 meters, with the hydrocarbons 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 (Fig. 28).

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 Calcareous 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 gas fields 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.

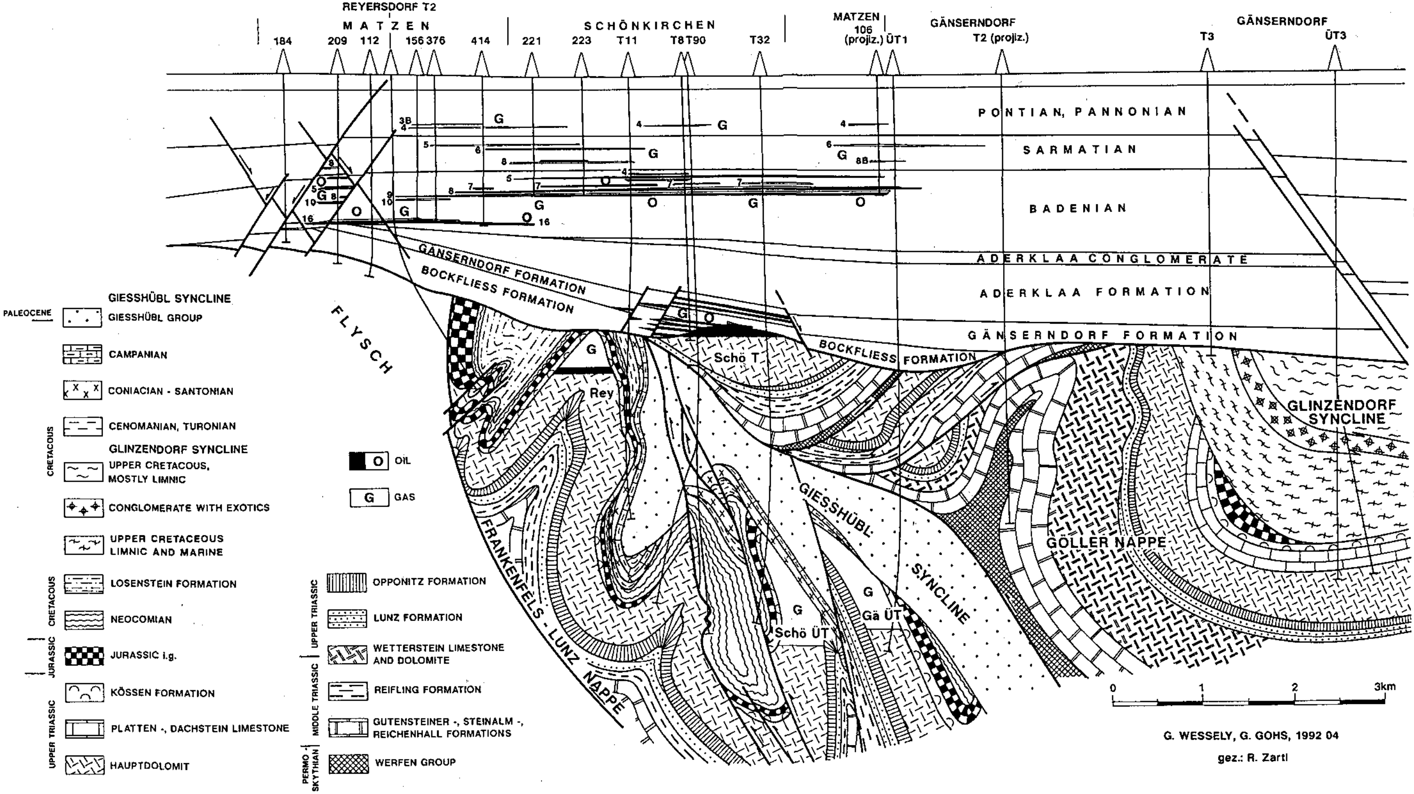


Fig. 28: Cross section through the Matzen-Schönkirchen oil and gas fields.
Accumulations of gas were found in Sarmatian and Pannonian, oil and gas in the Badenian and Ottnangian, oil in the Hauptdolomit of the Göller Nappe of Schönkirchen Tief (Schö T). In the Frankenfels-Lunz Nappe gas and some oil were found in the Reyersdorf Hauptdolomit (Rey) and gas in the Hauptdolomit of Schönkirchen Übertief (Schö ÜT) and Gänserndorf Übertief (Gä ÜT).

In the Austrian part of the Vienna Basin, at least 46 fields have been found. The largest cumulative oil production (till 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).

3.2. Oil- and Gas Fields in the Molasse Zone

The oil- and gas fields of the Molasse Zone (A. KRÖLL, 1980) are not as large as these of the Vienna Basin (Fig. 26). They are mostly connected with a structural type of trapping, but stratigraphic traps also occur in the northernmost group of gas fields. Biogenic gas generation took place within the Tertiary sediments, upper Jurassic marls and Middle Jurassic shales of the pre-Tertiary base. Both of them may be responsible for migrated additional thermocatalytic hydrocarbons.

The hydrocarbons occur in the Tertiary Molasse and its Mesozoic base below (A. ANIWANDTER, J. BIMKA & D. ZYCH, 1990). Small oil fields have been found in Malmian carbonates. The productive interval is usually detritic limestones as the Altenmarkt Formation (e.g. Roseldorf) sealed by Molasse. Deltaic sandstones in the Dogger produced in Klement. Gas was recently discovered in dolomitized Upper Malmian calcarenites near the Czechoslovakian border (Pottenhofen).

In the Tertiary Molasse there are two productive gas plays: basal marine sandstones of Upper Oligocene (Egerian) and marine to brackish sandstones of the Lower Miocene (Ottnangian, Karpatian).

Both play types occur in areas of upthrusting in frontal positions of the Alpine-Carpathian thrustbelt [e.g. the Egerian sandstone in the Stockerau field, GRÜN, 1984; the Lower Miocene sandstones in the Roseldorf field).

In the northern part of the Austrian Molasse Zone, Ottnangian to Karpatian sandstones form low relief anticlines partly caused by differential compaction. The largest field is Wildendürnbach. Smaller accumulations are the Alt Prerau-, Pottenhofen- and Neuruppersdorf fields (A. ANIWANDTER & J. BIMKA & D. ZYCH, 1991).

3.3. Gas Condensate Field Höflein below the Alps

The Höflein Field is located about 10 km NNW of Vienna (Fig. 23). The reservoir is developed within rocks of the Autochthonous Mesozoic on a basement structural high (Fig. 29). It is directly overlain by sediments of the Molasse and then overthrusted by the Flysch (Greifenstein Nappe) (Fig. 30). The pay horizons occur at depths between 2700–3000 m, within sediments of the uppermost Autochthonous Dogger (Tab. 6).

The most important reservoir horizons are the Höflein Formation (Dolomitische Quarzarenitserie) of Callovian age and the Gresten group (Untere und Obere Quarzarenitserie) of Toarcian to Bathonian age (GRÜN, 1984).

Fig. 29: Structural map of the gas condensate field Höflein, top Dogger (W. GRÜN, A. KRÖLL, H. UNTERWELZ & D. ZYCH).

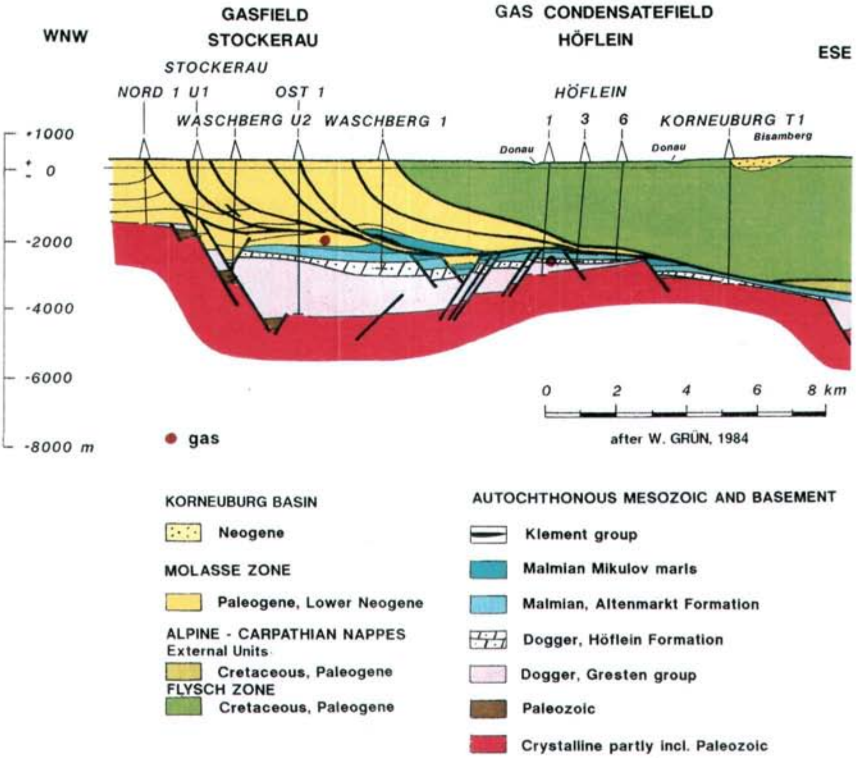


Fig. 30: Cross section through the gas condensate field Höflein (Dogger) and the gasfield Stockerau (Egerian).
After W. GRÜN (1984).

3.3.1. Höflein Formation

The Höflein Formation (R. SAUER, Internal Report, ÖMV 1992, in preparation) can be divided into two units by differences in lithology and reservoir properties. The thickness of the Höflein Formation ranges from 28–55 m.

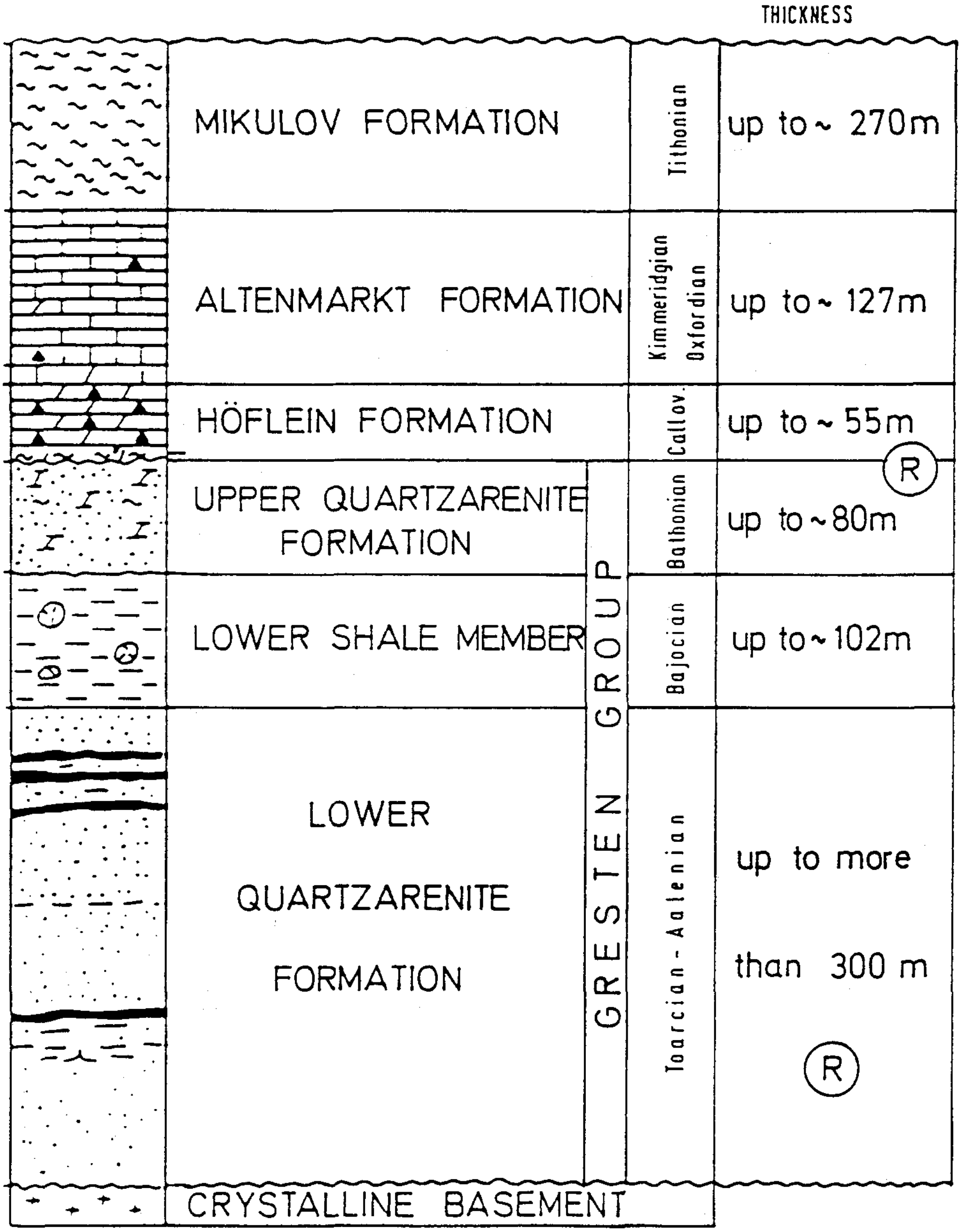
Shallow marine deposition with terrigeneous and tidal influence has been postulated.

Höflein Formation (upper member)

Lithology

Light to dark gray slightly sandy dolomites. Whitish to brownish, porous or tight chert beds and nodules (Fig. 31). Sometimes also sandy, greenish-gray, glauconite rich beds can be observed. Frequently small, sometimes solution-enlarged fractures appear.

Table 6.
Autochthonous Mesozoic of the Höflein field.



Formation	Group	Stage	THICKNESS
MIKULOV FORMATION		Tithonian	up to ~ 270m
ALTENMARKT FORMATION		Kimmeridgian Oxfordian	up to ~ 127m
HÖFLEIN FORMATION		Callov.	up to ~ 55m
			Ⓡ
UPPER QUARTZARENITE FORMATION	GRESTEN GROUP	Bathonian	up to ~ 80m
LOWER SHALE MEMBER		Bajocian	up to ~ 102m
LOWER QUARTZARENITE FORMATION		Toarcian - Aalenian	up to more than 300 m Ⓡ
CRYSTALLINE BASEMENT			

R = RESERVOIR HORIZON

Fig. 31: Core slab of the Höflein Formation (Upper Member).
Höflein 3 – 2769.65–2770.0 m.
Characteristic is the irregular distribution of porous chert nodules (whitish to brownish) within slightly sandy dolomites (grayish to greenish). Essential are the numerous fractures and microfractures (partially solution enlarged), because they connect the porous zones and enhance permeability considerably.
Core length is ≈ 35 cm.

Mineralogical composition

Dolomite: 87–95 % dolosparite
4–13 % detrital quartz grains,
traces of glauconite, pyrite and feldspar

Sandy dolomite: 50 % dolosparite
40 % quartz
6 % glauconite
3 % feldspar
traces of pyrite, mica, etc.

Chert: mainly microcrystalline quartz, inclusions of detrital quartz grains, glauconite, feldspar and dolomite rhombohedrons. Often very porous (Fig. 34 and 36). The pores are barren of clay minerals!

Porosity types

Macroscopically visible: porous cherts; secondary solution porosity; fracture porosity.

Effective porosity	Permeability
min–max: 1,3–24,3 %	0,1–1119 md
mean: 10,6 %	30,2 md
Best porosities are developed within cherts (Fig. 32)	Values larger than 100 md are influenced by microfractures.

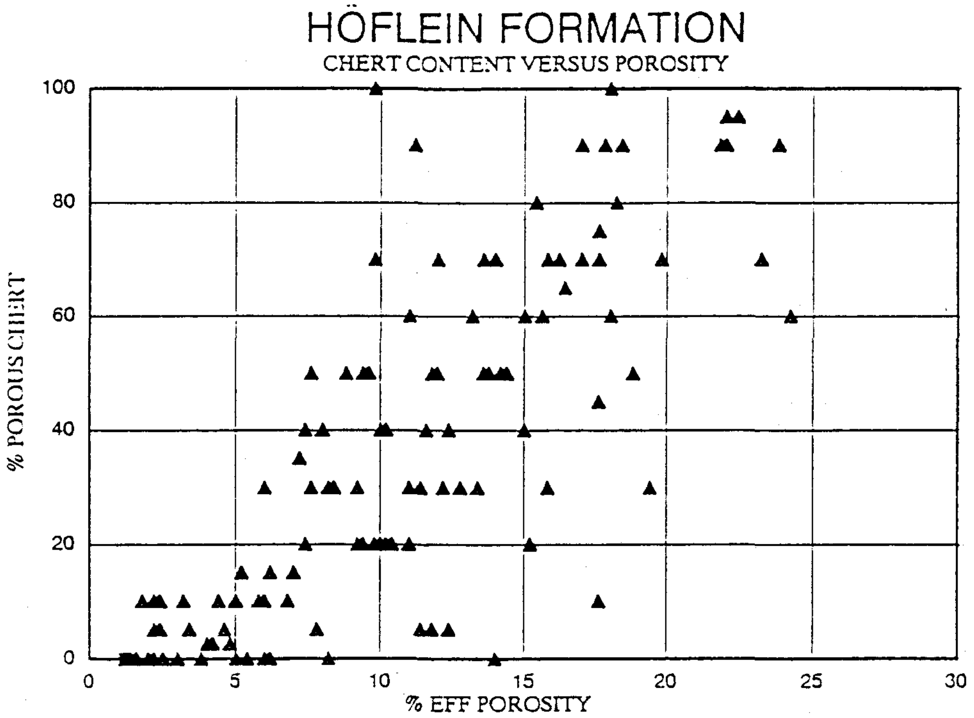


Fig. 32: Höflein Formation – chert content versus porosity (R. Sauer).

Höflein Formation (lower member)

Lithology

Silicified sandy dolomites with thin chert bands and nodules. The silicification of the dolomite increases towards the base and the lowermost parts are nearly entirely silicified. Flaser structures are common (probably diagenetic).

Open fractures and irregularly distributed vugs up to 2 cm diameter occur occasionally.

Mineralogical composition

Dolomite to completely silicified dolomite:

tr –94 %	dolosparite
2–74 %	microcrystalline quartz cement
0–46 %	detrital quartz grains
0– 8 %	feldspar
1 %	mica + glauconite
0–12 %	opaque matter (mostly pyrite)

Chert: similar to the upper part of the Höflein formation, porespace is also generally clean.

	Effective porosity	Permeability
min–max:	1.4–25.4 %	0.1–131 md
mean:	9.8 %	4.3 md

3.3.2. Gresten Group

Within the Gresten Group two different pay zones can be distinguished, the Upper Quartzarenite Formation (Obere Quarzarenitserie) and the Lower Quartzarenite Formation (Untere Quarzarenitserie), both are separated by a shale horizon of variable thickness.

Upper Quartzarenite Formation

Lithology

Sandstone, light to dark gray, coarse to fine grained, partially dolomite cemented. Sporadically thin, dark gray dolomitic shale or claystone beds occur.

Irregularly distributed quartz grains (up to 1 cm diameter) and coal fragments (up to 5 cm diameter) as well as pyrite within the sandstone beds are common.

The uppermost sandstone beds are frequently parallel laminated.

The lower parts are irregularly bedded and mostly bioturbated.

From top to the bottom of the section the reservoir quality decreases due to increasing dolomite cementation and clay mineral content.

The thickness ranges from 30 – 80 m.

Mineralogical composition

The sandstone can be classified as subarkosic to arkosic sandstones (Fig. 27).

20–70 %	quartz
2–24 %	feldspar (mainly potassium feldspar)
0– 9 %	crystalline rock fragments
0– 4 %	mica
0– 2 %	opaques

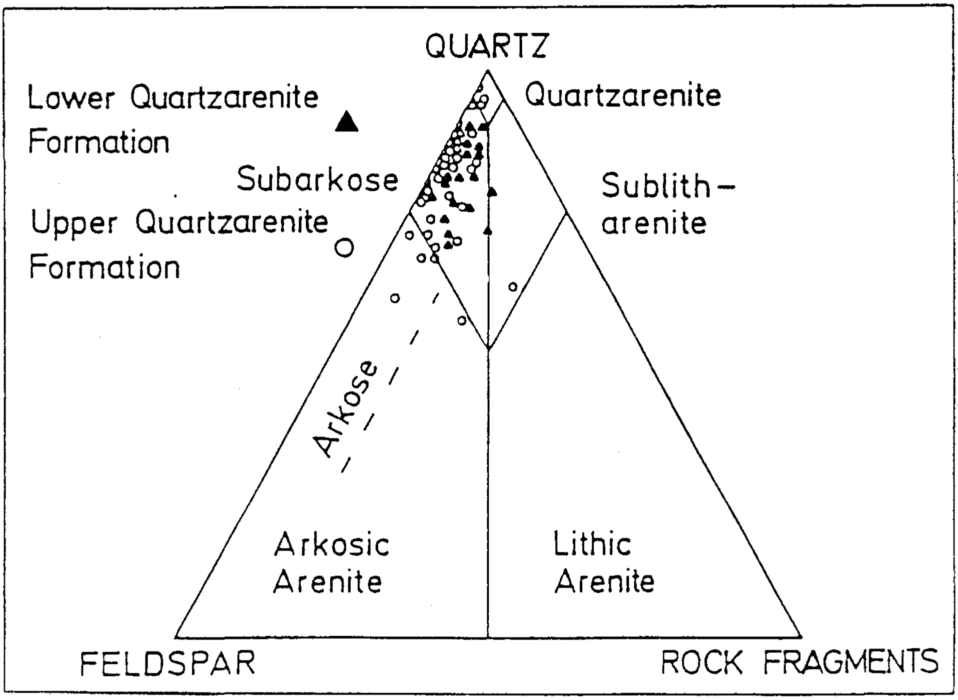


Fig. 33: Rock types of the Gresten Group (R. SAUER).

0–20 % clay minerals
tr –72 % dolomite cement
0– 8 % quartz cement

Porosity types

Mainly intergranular porosity, reduced by overgrowths of quartz cement or by dolomite cementation. Some solution porosity (dissolved feldspar). The pores occasionally contain kaolinite (Fig. 37). Some shaly sandstones also have illite-mixed layer mineral components.

	Effective porosity	Permeability
min–max:	0.1–21.2 %	0.1–3236 md
mean:	8.5 %	56.2 md

The best reservoir properties occur in the uppermost parallel laminated sandstone beds.

Lower Quartzarenite Formation

Lithology

Gray, coarse to fine grained sandstones interbedded with dark gray claystone and coal seams. The thickness of the sandstone beds reaches up to several meters. The coarse grained sandstone beds generally exhibit no sedimentary structures but often have irregularly dispersed coal fragments. The finer grained sandstone beds are often parallel laminated and cross bedded. Within coaly

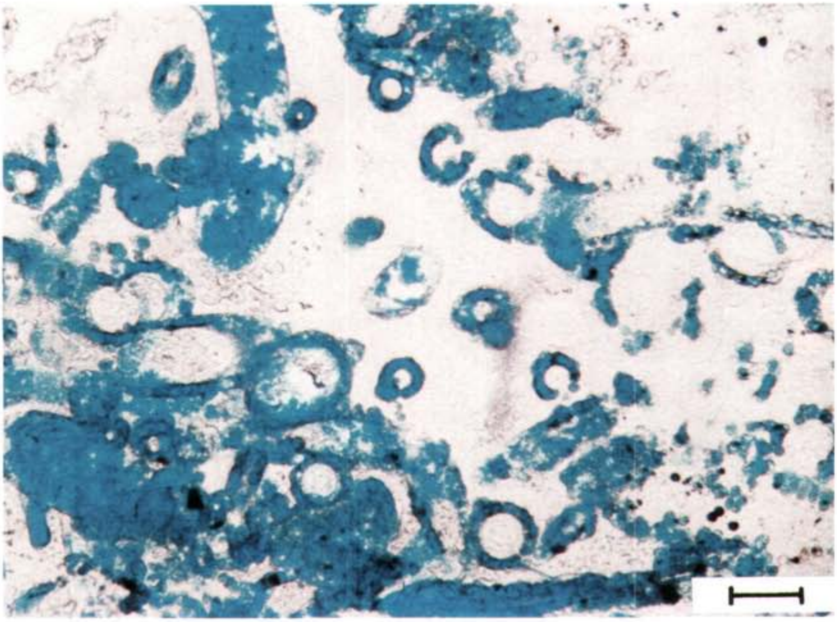


Fig. 34: Porous chert, with abundant molds of sponge spicules; Höflein Formation.
Höflein 8, 2843.2 m; length of scale = 0.1 mm.

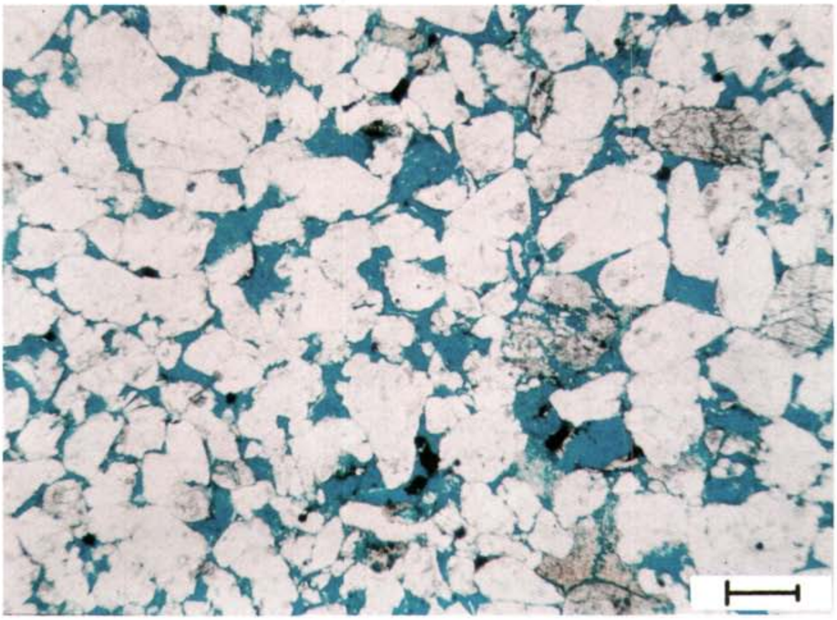


Fig. 35: Porous sandstone with interparticle porosity and partially solution pores (dissolved feldspars); Lower Quarzarenite Formation.
Höflein 1, 2959.9 m; length of scale = 0.4 mm.

Fig. 36.
SEM-Photograph of porous chert; Höflein Formation.
Höflein 8, 2843.2 m.
Length of scale = 36μ.

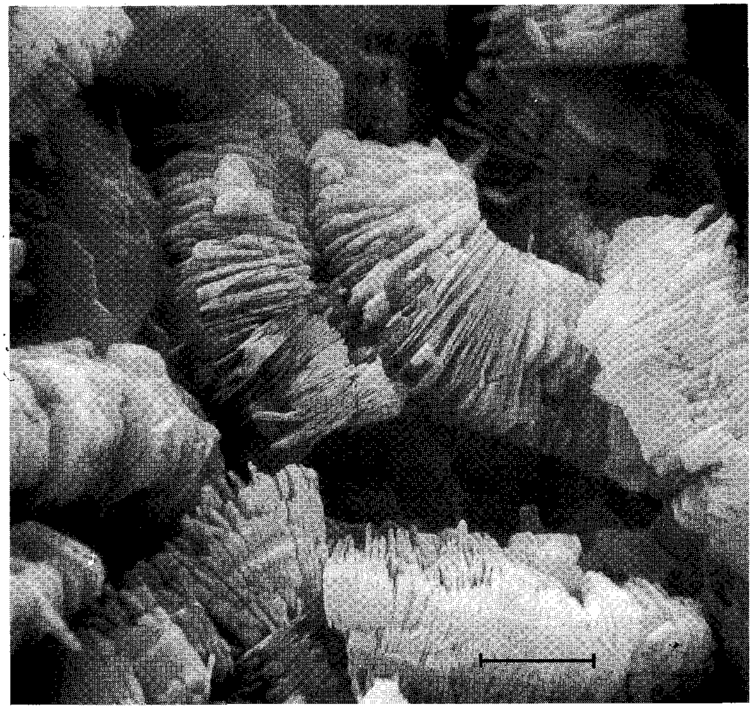


Fig. 37.
SEM-Photograph of the porespace filled with kaolinite booklets; Upper Quartzarenite Formation.
Höflein 8, 2863.3 m.
Length of scale = 4μ.

claystones rootlet horizons can often be observed. Pyrite nodules are also very common. The thickness of the entire interval can be more than 300 m.

Mineralogical composition

Most of the sandstones are to be classified as subarkoses (Fig. 33).

55–92 %	quartz
6–21 %	feldspar (mainly potassium feldspar)
0– 4 %	crystalline rock fragments
0– 7 %	mica
0– 9 %	opaques
0–20 %	clay minerals
0–22 %	calcite cement
0– 5 %	dolomite cement
0– 3 %	quartz cement

Feldspars are often altered to kaolinite.

Porosity types

Mainly interparticle porosity (Fig. 32) which can be reduced by quartz cement and clay minerals. Secondary solution porosity can be observed (feldspars). The most important clay minerals occuring in the pores are kaolinite with some minor amounts of illite-smectite-mixed layer minerals.

Effective porosity		Permeability
min–max:	0.4–16.6 %	0.1–516 md
mean:	8.9 %	39.9 md

3.4. Types of Reservoir Rocks and Reservoir Properties

3.4.1. Neogene reservoir rocks

Key for the symbols used in the mineralogical descriptions

Monocrystalline quartz (MQ), polycrystalline quartz (PQ), chert (CH), feldspar (FSP), limestone and bioclasts (L+B), dolomite (DOL), rock fragments (RF), mica (MI), glauconite (GL), opaques (OP), clay, calcite cement (CC),quartz cement (QC), dolomite cement (DC), tr = traces (chapters 3.4.1., 3.4.4.; stops 3/1, 3/5).

Vienna Basin

The Neogene reservoir rocks of the Vienna Basin and the Molasse Basin are mainly siliciclastic rocks.

The most famous and important reservoir rock of the Vienna Basin is the Matzen sand of Badenian age (Middle Miocene). It is a typical basal, transgressive sand. The Matzen Sand unconformably overlies various older Miocene formations and onlaps, from south to north, with progressively increasing angularity. The thickness of the sand reaches 80 m within the Matzen field.

It has a gross oil pay of 35 m in the main block and 65 m in the western Bockfließ block. The productive area covers about 22 km^2. The basal part of the Matzen Sand is composed of a coarse grained sand (partially a pebbly sandstone). The grain size decreases toward the top of the unit, which is often calcite cemented.

The sandstone can be classified as a medium-grained sandstone with grain supported fabric having prevailing point and concav-convex contacts. The mineralogical composition of the Matzen Sand is distinctly different from all other

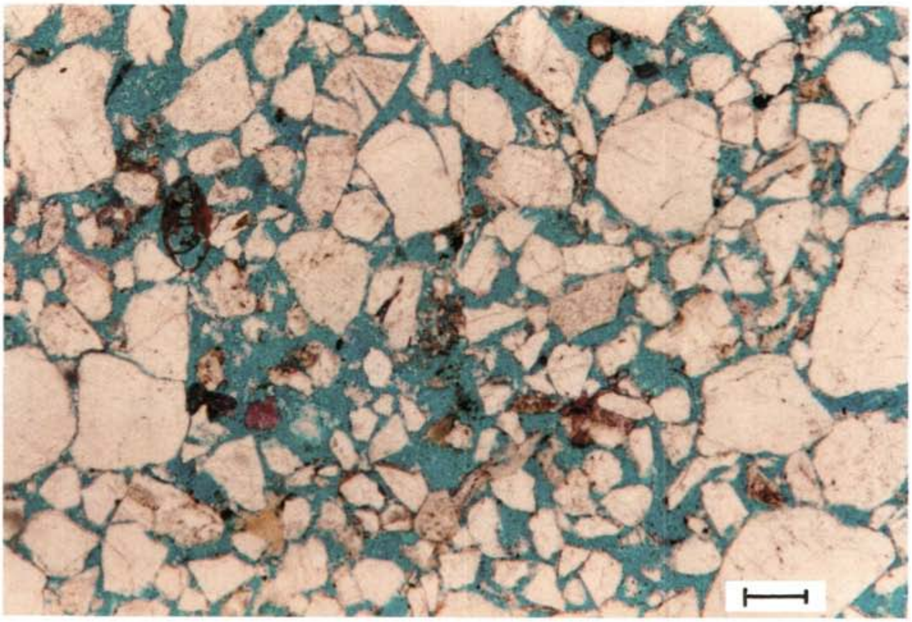


Fig. 38: Typical thin section photomicrograph of Matzen Sandstone (Por:27.9 %; K = 3017 md) Matzen 398, 1650.3 m; length of scale = 0.14 mm.

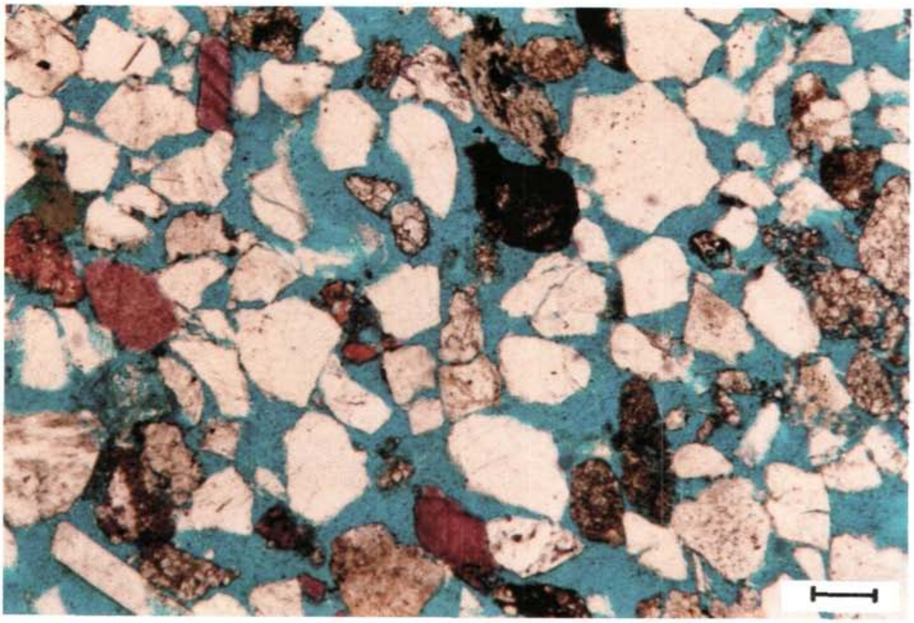


Fig. 39: Calcilithic sandstone with interparticle porosity (Por: 32.8 %; K = 6064 md). Typical are the abundance of dolomite grains and coaly remains. 11th TH horizon; Prottes 201, 1368.05 m; length of scale = 0.32 mm.

Later Neogene reservoir sandstones. Typical is the low content of detrital carbonate particles (Fig. 35).

A typical analysis is given below.

MQ	PQ	CH	FSP	RF	L+B	DOL	MI	GL	OP	CLAY	CC	QC
66	15	1	4	3	6	1	1	tr	tr	tr	1	1

The sand represents a high quality reservoir, average porosity is 26 % (porosities up to 32 %), average permeability is 1000 md (maximum up to several thousand md). The porosity types are primary interparticle porosity and subordinate secondary solution porosity (dissolved feldspars and carbonates). The permeability is influenced by the degree of bioturbation and occasionally by calcite-cemented sandstone- and shale beds causing permeability barriers. The cumulative oil production out of this sand has been about 35 million tons of oil (1949 – end 1991).

Above the Matzen Sand numerous sand-tongues alternating with shale interbeds occur. The thickness of these sands varies from several meters down to several centimeters. These sands can be characterized as medium- to fine-grained calcilithites. Typical is the general high content of detrital carbonates esp. dolomite grains (Fig. 38).

An example for the mineralogical composition of a typical sand horizon (9. TH) is given below (mean of 12 analyses):

	MQ	PQ	CH	FSP	RF	L+B	DOL	OP	CLAY	CC	DC	QC
mean	39	9	1	3	3	5	22	1	11	0	6	0
max	48	13	3	5	5	11	36	2	36	3	21	1
min	29	1	0	2	1	2	9	0	0	0	0	0

These sands also form good reservoirs.

The reservoir quality is strongly controlled by the degree of bioturbation (Fig. 40), the interlayering of thin shale laminae or thin shale beds and locally calcite-cemented sandstone beds ("hard layers"). These Upper Badenian horizons are primarily marine, or regressive marine parts of deltas (delta front and prodelta, KREUTZER, 1986).

Younger Sarmatian to Pannonian sediments also contain several reservoir horizons. The depositional environment is mostly deltaic or marine to brackish (esp. the Pannonian).

Other reservoir rocks in the Neogene Vienna Basin fill, for example the Karpatian to Ottnangian formations (Lower Miocene), are only of minor importance.

Molasse Basin

The most important reservoir rocks of the Molasse Basin in Eastern Austria are the *Oncophora* Formation and the Eger Sandstone.

Oncophora Formation

The *Oncophora* Formation is a succession of alternating sands and shales of Ottnangian age. The thickness of single sandstone beds can attain 5 m but is usually much less (dm–cm). The Sandstone beds can be classified as fine-grained lithic arenites or lithic graywackes. Significant is the large amount of detrital mica and the occasionally high clay content (Fig. 41). The clay minerals in the pore space consist mainly of smectite and smectite mixed-layer phases and illite.

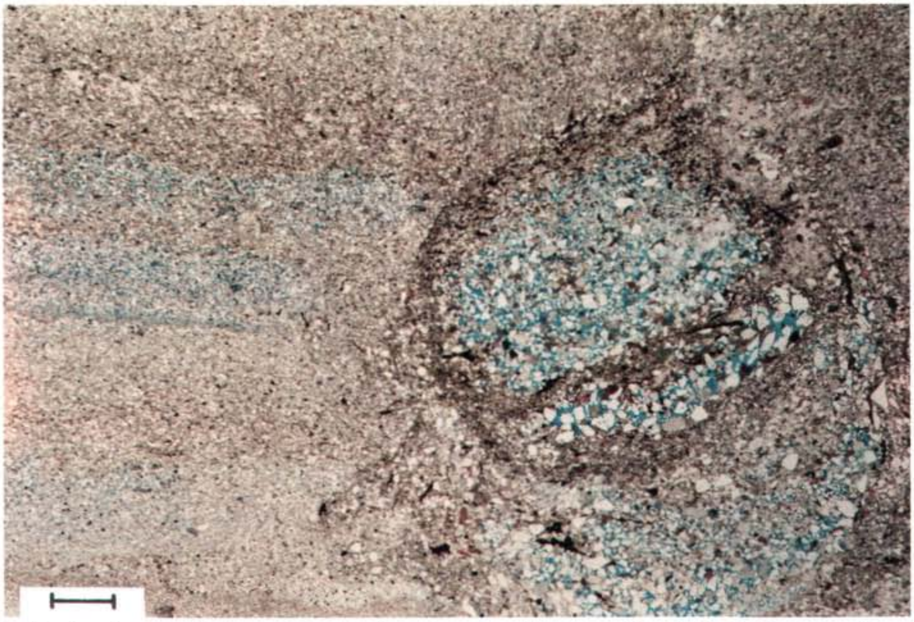


Fig. 40: Sandstone with irregularly distributed permeable zones (Por: 15.6 %; K = 1.3 md) caused by bioturbation.
11th TH horizon; Prottes 201, 1355.9 m; length of scale = 1 mm.

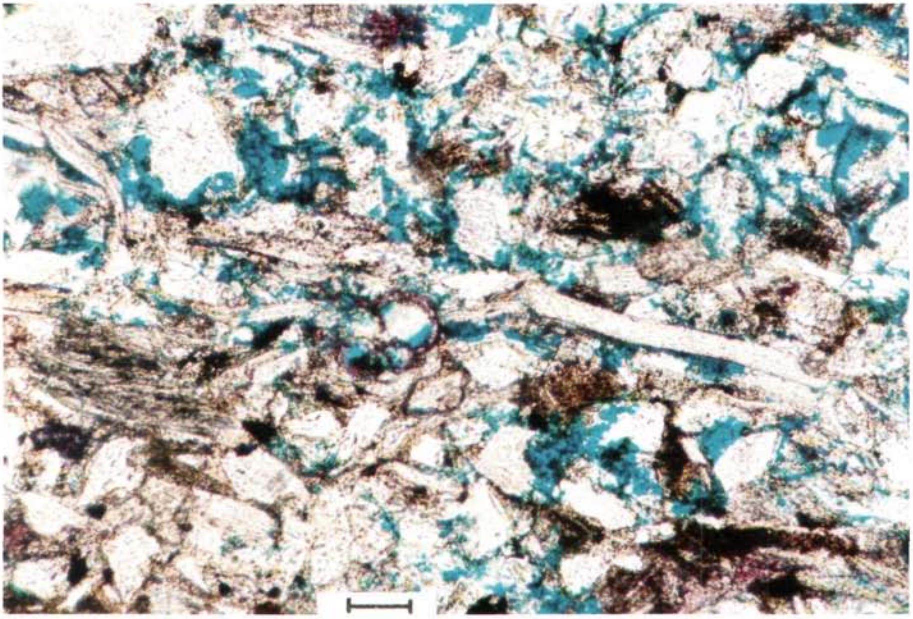


Fig. 41: Typical thin section photomicrograph of an Oncophora Sandstone bed.
Characteristic is the high amount of detrital mica (Por: 29.5 %; K = n.m.)
Neuruppersdorf 5, 886.15 m; length of scale = 0.07 mm.

A typical sandstone composition is given below (average of 22 samples):

	MQ	PQ	FSP	RF	L+B	DOL	MI	GL	OP	CLAY	CC	DC
mean	35	11	8	7	2	4	12	tr	2	13	4	2
max	49	24	20	14	7	9	24	1	6	53	29	9
min	24	2	2	1	1	tr	2	0	1	tr	0	0

The clay mineral content makes log interpretation and reservoir quality prediction difficult.

The average porosity is around 22 %. The permeabilities are strongly dependent on the content and type of clay minerals present in the pore space and vary considerably. The permeabilities vary from some tens to some hundreds of millidarcies. The prevailing porosity type is a primary interparticle porosity which is reduced by variable amounts of clay minerals.

Eger Sandstone

The Eger Sandstone horizon is the basal, transgressive sandstone in the Molasse Basin in Eastern Austria. It is the first depositional unit of Molasse sedimentation in the Upper Oligocene. The thickness of the Eger Sandstone horizons can reach up to 70–80 m.

The sandstones can be described as partially calcite-cemented coarse to medium grained sublitharenites to subarkoses.

The mineralogical composition, based on an average of 40 samples, is given below:

	MQ	PQ	FSP	RF	L+B	DOL	MI	GL	OP	CLAY	CC	DC	QC
mean	63	6	8	3	3	0	1	1	1	3	10	0	1
max	89	21	36	62	21	1	10	2	10	46	50	1	6
min	28	0	0	0	0	0	0	0	0	0	0	0	0

The main porosity types are secondary solution porosity and reduced interparticle porosity. Most of the secondary porosity was created by dissolution of carbonate particles and feldspar (Fig. 42).

The interparticle porosity is reduced by calcite and quartz cement. The pores contain variable amounts of kaolinite and sericite.

The porosity values vary from 3 to 18 % (average around 11 %). The permeability is up to 70 md, (average around 13 md). The porosity and permeability values are very dependent on the degree of calcite cementation.

Both the *Oncophora* Sandstone and the Eger Sandstone form gas reservoirs.

3.4.2. Flysch Zone

Reservoir rocks in the Flysch Unit are primarily in the Eocene to Paleocene section.

The most important reservoir horizon is the Glauconite Sandstone Formation.

Glauconite-Sandstone Formation

The Glauconite Sandstone Formation consists of several, coarse grained glauconitic sandstones, rhythmically intercalated with olive gray to dark gray shale beds. The gross thickness reach more than 50 m. The sandstones are mainly sublithic arenites with a typical mineralogical composition of 75–85 % quartz, 5–10 % glauconite, traces of feldspar, mica, heavy minerals, etc.

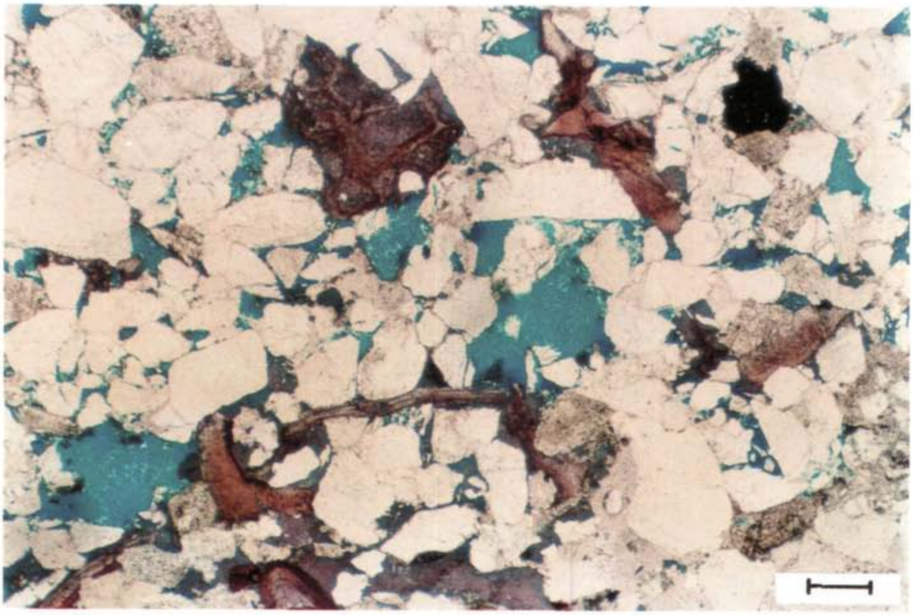


Fig. 42: Thin section photomicrograph of an Egersandstone with secondary solution porosity and reduced interparticle porosity (Por: 15.3 %; K = 22.9 md).
Stockerau Ost 1, 2225.1 m; length of scale = 0.32 mm.

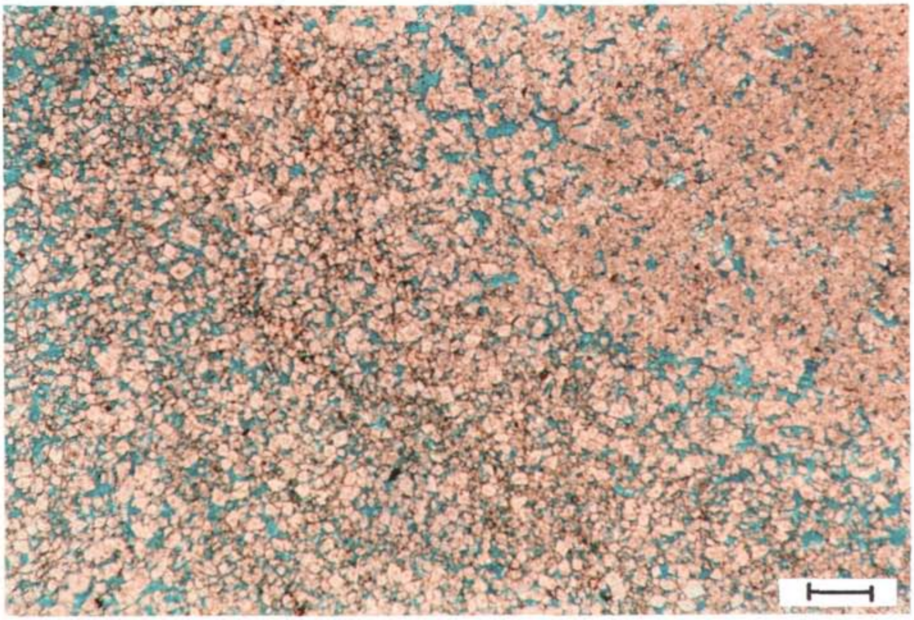


Fig. 43: Dolosparite of Ernstbrunn Formation with intercrystalline porosity (Por: 20.9 %; K = 53 md).
Ameis 1, 2638.9 m; length of scale = 0.35 mm.

The sandstone is mainly quartz-cemented, occasionally also clay or calcite-cemented. The matrix porosities of the sandstones are moderate (between 6–11 %) and the matrix permeabilities are low (0.1–2 md). The permeability is considerably reduced due to the influence of quartz cement and glauconitic clay mineral content.

The reservoir quality depends largely on the frequency of open fractures and mylonitized fracture zones within the sandstone intervals.

3.4.3. Calcareous Alps

The most important reservoir rocks of the Calcareous Alpine unit in the Vienna Basin are the Upper Triassic Hauptdolomit and to a lesser extent the Dachstein Limestone. All other Mesozoic to Paleogene rocks of the Calcareous Alps are of subordinate importance.

Hauptdolomit

The Hauptdolomit consists of dolomicrite to dolosparites with small contents of siliciclastic (mainly illite and quartz) and organic matter.

The siliciclastic content in the Hauptdolomit decreases from the deepest nappes (Lunz/Frankenfels Nappe) to the higher nappes (e.g. Ötscher Nappe).

The reservoir properties of the Hauptdolomit are very heterogeneous. Unfortunately the most productive zones of these high quality reservoir rocks have not been measured in the laboratory. These intervals are always so intensely fractured that cores have never been successfully recovered.

The main porosity type is a micro- and macrofracture porosity. Core analysis usually only measures the matrix porosity of the dolomite, which is always very low, between 0.1 % and about 2 %. The permeabilities range from 0.01 to several hundred millidarcies (dependent on the presence of microfractures).

Intercrystalline and solution porosity are essentially of no importance in the Hauptdolomit.

The most productive intervals are concentrated in highly fractured or mylonitic zones. Porosities in these zones are 10 % or more and permeabilities several hundred up to 2000 millidarcies.

The Hauptdolomit produces from two types of traps in the Vienna Basin. The first are relief or buried hill pools at depths of about 2600–3000 m, entrapped by Neogene marls. The second type are the Calcareous Alps internal pools, sealed by Cretaceous to Paleocene sediments at depths of 5000–6000 m.

3.4.4. Autochthonous Mesozoic

Ernstbrunn Formation (Upper Tihonian)

In Ernstbrunn limestones carstification occurred in Zistersdorf ÜT2A, but the cavities are filled by tight material of Cretaceous age. Dolomitization caused porosity in Ameis 1 (Fig. 43).

Kurdejov Formation (Upper Tithonian)

Gas has recently been discovered in the Kurdejov Formation.

The Kurdejov Arenite Formation is a succession of medium- to coarse-grained, partially dolomitized, sandy calcarenites (pack- to grainstones). Dolomitized intervals are irregularly distributed. Pockets of intense bioturbation occur.

A typical petrographical composition is given below (average of 7 samples; legend see chapter 3.4.1.):

	MQ	FSP	L+B	GL	OP	CC	DC	QC
mean	8	tr	49	1	tr	22	18	1
max	12	tr	61	4	tr	37	41	2
min	4	0	31	0	0	11	1	0

The most important porosity types are intercrystalline porosity (esp. in the dolomitized parts) and secondary solution porosity, caused by dissolution of calcite cement and carbonate particles (Figs. 44,45).

The porosities vary from 5 % to 17 %, the permeabilities range between 0.2 md and 88 md.

Best reservoir properties occur near the top of the formation, in proximity to the erosional unconformity to the overlying Neogene Molasse sediments.

Mikulov Marls (Kimmeridgian to Upper Tithonian)

The Mikulov Marls can form reservoirs if they are fractured. At great depths (7500–8500 m) intense fracturing was observed (Zistersdorf UT 2a), probably caused by effects associated with hydrocarbon generation, producing high pressure. The matrix porosity is up to 7 %.

Carbonates of the platform facies (Altenmarkt Formation, Oxfordian to Tithonian)

Within the platform facies four sedimentologically different carbonate types can be differentiated.

From top to bottom these are:

1) The coral-sponge (patch) reef facies (coral-sponge boundstones, framestones, partially dolomitized);
2) the algal-sponge-mud mound reef facies (partially dolomitized bindstones);
3) the chert-spiculite facies (strongly silicified, partially dolomitized biomicrites and biosparites) and
4) the spiculite facies, mainly spiculitic biomicrites and biointrasparites. Laterally, reef complexes may be replaced by oolitic-bioclastic limestones.

The reservoir quality depends on the degree of dolomitisation (Fig. 45), secondary solution porosity (vugs, partially molds) and on the presence of micro- and macrofractures. If there is a combination of these properties, good reservoir properties can be expected.

The porosities vary from 0.2 % to 25 % (depending strongly on the degree of dolomitisation and on the occurrence of secondary solution porosity). The permeabilities range from 0.1 up to 1000 md (average around 10 md), and are strongly influenced by the presence of fractures.

Höflein Formation (Callovian)

The Höflein Formation is a succession of sandy dolomites, with intercalations of nodular chert layers. The thickness of the Höflein Formation, in the Höflein Field is 55 m.

The main porosity types are secondary solution porosity and fracture porosity. The best porosities are developed within cherts.

The porosities vary from 1.3 % to 25 %. The permeabilities from 0.1 md to 1119 md. They are strongly influenced by microfractures.

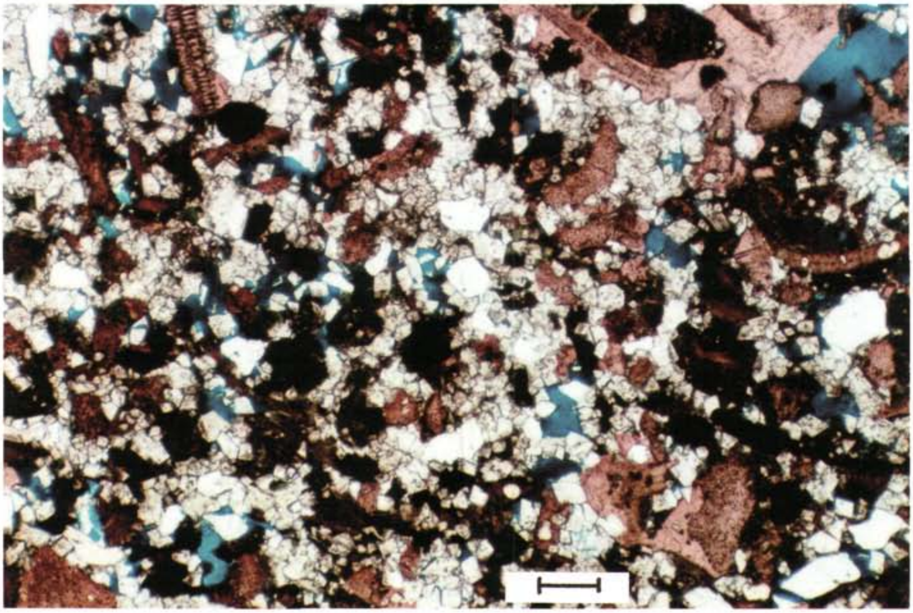


Fig. 44: Kurdejov Arenite Formation; partially dolomitized sandy packstone with secondary solution and intercrystal porosity (blue stained; Por: 14 %; K = 89 md).
Neuruppersdorf 2, 1219.5 m; length of scale = 0.32 mm, .

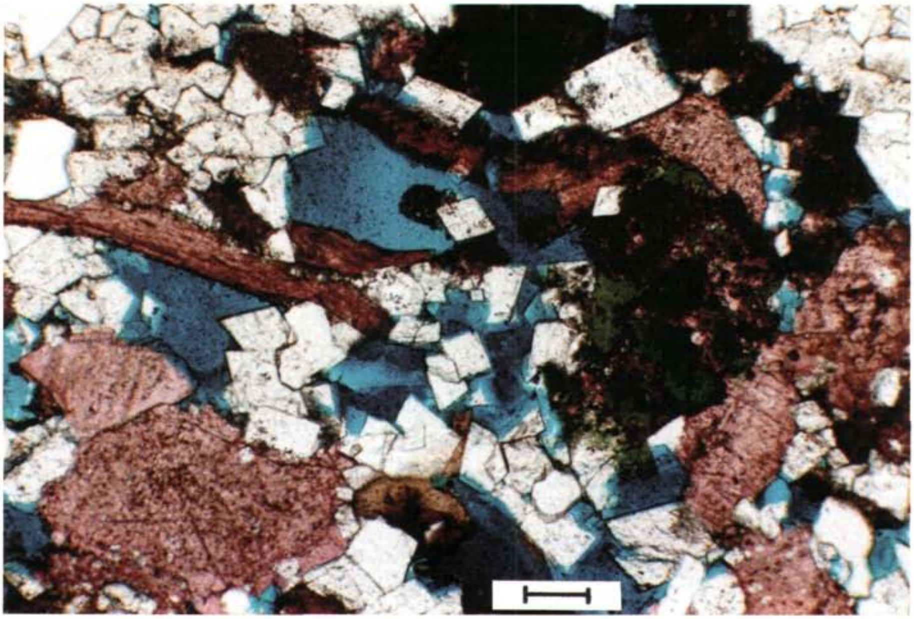


Fig. 45: Detail of Fig. 44.
Length of scale = 0.13 mm.

The Höflein Formation is described in more detail in the description of the gas condensate field Höflein (chapter 3.3.).

Gresten Group (Aalenian to Bathonian)

The Gresten Group comprises siliciclastic sediments deposited in various deltaic environments. Reservoirs are developed in the sandstone units of the Lower Quartzarenite Formation which is more or less continental and within the shallow marine Upper Quartzarenite Formation.

The thickness of the Gresten Group varies, depending on the tectonic position, from 100 m to more than 1000 m. The thickness of single sandstone beds vary from dm to several meters.

The most important porosity types are interparticle and secondary solution porosity. The pore space is partially reduced by quartz cement, kaolinite and especially in the Upper Quartzarenite member by dolomite cement.

The porosities vary from 1–21 % (mean 9 %), the permeabilities from 0.1 to several hundred millidarcies. A more detailed description of the reservoir properties of the Gresten Group is given in the description of the gas condensate field Höflein (chapter 3.3.).

3.5. Source Potential

The generation of hydrocarbons in the Vienna Basin, the Molasse and below the northeastern part of the Alps is connected with the existence of autochthonous Malmian marls, which exceed a thickness of 1 km. A minor component is contributed by shales interbedded in the autochthonous Dogger deltaic sequence (LADWEIN, 1988; LADWEIN, SCHMIDT, SEIFERT und WESSELY, 1991). Systematic investigations of all units of the Vienna Basin and Molasse area led to this conclusion (more than 2,600 rock samples analyzed).

The Neogene clastic material of the Vienna Basin contains a total organic carboncontent (TOC) of slightly more than 1 %, of kerogentype III. The maturity is usually too low for the generation of hydrocarbons.

The shales of the Flysch Zone have very low organic carbon content.

The Calcareous Alpine rocks, although large in thickness contain on average less than 0.5 % TOC. Some horizons (Lunz Formation, Middle Triassic basinal sediments, Kössen Formation, Early Upper Cretaceous sediments) are expected to contain further source potential, but the thermal history is difficult to reconstruct.

The TOC of the autochthonous Upper Jurassic marls and Middle Jurassic shales range from 0,2 % to more than 10 %, with the average being about 2 %. The kerogen is of type II to III.

Numerous oil correlation studies using gas chromatography and gas mass spectrometer data, indicate that all Vienna Basin oils belong to one major family of highly mature oils. The oil-source rock correlations show, that the oils of this major oil family correlate well with the extracts from basinal autochthonous Malmian marls. The oils show different degrees of biodegradation.

An important contribution to the understanding of hydrocarbon generation in the Vienna Basin was the exploration down to the "deepest floor" of the basin. The data obtained from these wells in the Zistersdorf-Maustrenk area enabled the reconstruction of the burial history. Relative low subsidence rates occurred throughout Mesozoic time and Molasse deposition. The overthrusting by the Alpine-Carpathian nappes caused rapid and strong donwarping, followed by subsidence with a large amount of Neogene basin fill. This rapid burial resulted in temperatures high enough for the main phase of hydrocarbon generation at the depths between 4500–6000 m.

A large percentage of the source rocks have already passed through the oil window. The oil- and gas fields in the Vienna Basin are located on central highzones and near main faults. The fact that they are very close to the generative depocenter, points to a mainly subvertical migration pathway. The multiple stacking of reservoir rocks – especially Miocene sandstones and Triassic dolomites – has had a very positive impact on the oil and gas prospectivity of this relatively small basin.

4. Austrian Exploration History

6.1. General Review

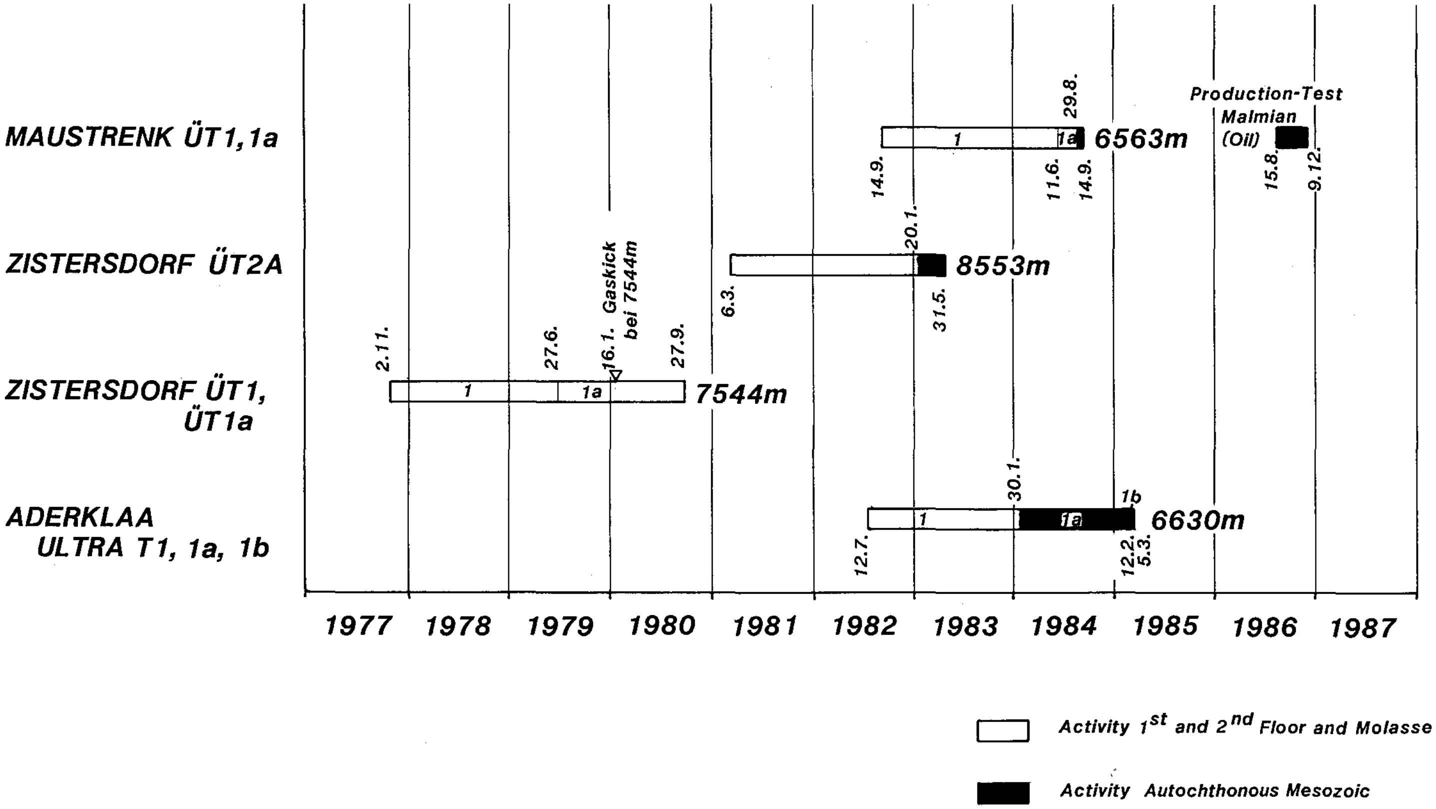
The search for hydrocarbons in Austria has focused primarily in the Vienna and Molasse Basin and, to a minor degree, the Pannonian-Styrian basins. Recently, the Eastern Alps have become prospective.

A review of the development of hydrocarbon exploration in Austria (A. KRÖLL, 1980; G. WESSELY, 1991) shows that the exploration targets have changed from shallow to progressively deeper objectives. Exploration of the shallow Vienna basin (Neogene or first floor) is in an advanced stage. Important discoveries have been made since the thirties, along the main fault systems (especially the Steinberg Fault system) and in the central highzone (Matzen and Aderklaa Highs) (Fig. 26). In the fifties, extensive seismic exploration of the Molasse Zone began and resulted in many oil and gas discoveries. In the late fifties, exploration of the allochthonous (Calcareous Alpine) "second floor" of the Vienna Basin was successful. Oil and gas was found in very structurally complicated dolomitic reservoirs (Fig. 28). Up to date only 4 wells have reached the lowermost Autochthonous Mesozoic (third floor) below the Vienna Basin (Tab. 7, Fig. 22). The 8553 m deep Zistersdorf ÜT2A well was a great technological challenge and has established a remarkable depth record. None of these deep wells have encountered economic hydrocarbons, however they have contributed significantly to our knowledge of the basin's construction and history. Abundant hydrocarbon shows and the existence of a favourable source rock provide encouragement for future exploration projects.

4.2. Exploration in the Vienna basin

The history of hydrocarbon exploration in the Vienna Basin began in the present day ČSFR at Gbely (former Egbell) in 1914. Gas-seeps, used for heating a farmhouse caused an explosion and led to the first drilling activity. Oil was produced from a depth of 164 m from a Neogene sandstone (15 t/d). In the Austrian part of the Vienna Basin (Fig. 26), the first economic oil production began with the Gösting II well in the Steinberg area near Zistersdorf in 1934. This field was discovered by surface mapping, carried out by the Austrian oil pioneer K. FRIEDL. Other fields at shallow depths were found between 1938 and 1940,

Table 7.
Deep drilling activity in the 3rd floor of the Vienna Basin.



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mostly along the Steinberg Fault. Later the Neogene of the median high zone in the center of the basin was explored; in 1949, the extremely important Matzen, the largest oil field in Central Europe, was discovered at a depth of about 1,700 m. Between 1950 and 1977, the Aderklaa, Pirawarth and Hochleiten oil fields and the Zwerndorf and Fischamend gas fields were discovered. The maximum depths of these fields was 3,000 m.

The Flysch Zone of the second floor (Fig. 16) was explored simultaneously with the first floor. Turbiditic sandstones in the Steinberg area have been the most productive.

In 1959 the Aderklaa discovery led to a new phase of exploration. Gas was found within fractured Triassic dolomites of the Calcareous Alpine Zone below the Neogene. Similar structural discoveries in Triassic dolomites followed (Baumgarten gas field 1960, Schönkirchen Tief oil field 1962, Reyersdorf oil and gas field 1971 and the Hirschstetten gas field 1973). Depths ranged from 2,600 to more than 6,000 m. The exploration and development of these fields was difficult for many reasons: the complex structures in that floor; drilling difficulties due to varying lithology, steep structures and deep position of the targets; and for the production technology because of sourgas.

In the late seventies, the search for new reserves led to the exploration of the deepest (third) floor of the Vienna Basin (6300–8500 m depth).

This activity was based on

1) The assumption of an autochthonous sedimentary cover of the Bohemian Crystalline Massif with reservoir and source rocks continuing below the Vienna Basin.
2) The hypothesis that deep seated structure was causing the known shallow updoming.
3) The belief, that shallow oil and gas production has migrated from deeper sources.

Four deep wells were drilled between 1977 and 1987 – Zistersdorf ÜT1a, ÜT2A, Maustrenk ÜT1a and Aderklaa ÜT1a (Tab. 7). The Zistersdorf ÜT2A well, became the deepest hydrocarbon exploration well outside the USA with a final depth of 8,553 m. It required 2 years for completion. A great deal of information about the autochthonous Mesozoic cover and of the Molasse, as well as of the allochthonous Waschberg- and Flysch Zone below the Vienna Basin was acquired. The overthrust of the Flysch by Calcareous Alps was proven by the well Aderklaa UT 1. It was also the first well to reach the crystalline basement in the Vienna Basin (Fig. 22, cross section 3).

The Zistersdorf ÜT2A well encountered nearly 1000 m of autochthonous Malmian marls, overlain by platform carbonates. In the Maustrenk ÜT1 well, this carbonate member has been sheared off as klippen and out of the shear zone a limited amount of oil was produced. In the Aderklaa UT1a well Malmian carbonates rest directly on crystalline rocks. Molasse has been totally removed by the Alpine-Carpathian thrust complex consisting Helvetic and a southernmost Flysch nappe and the Calcareous Alps (Fig. 22, cross section 3).

At Zistersdorf (Fig. 22, cross section 1), autochthonous Molasse with basal conglomerates rests on Mesozoic. In contrast, at Maustrenk only allochthonous Molasse exists, which forms a substantial part of external Carpathian nappes. Finally, four Flysch thrust sheets overrode these sediments. This whole complex was subsequently affected by the Miocene synsedimentary Steinberg Fault with a displacement of 5,000–6,000 m.

The oil and gas shows in the third floor encourages further exploration. All these hydrocarbon bearing systems are highly overpressured. The Malmian carbonates have only produced shows till now, however, autochthonous reservoirs with better porosity, such as in the foreland, are also expected beneath the Vienna Basin. A large source potential is present in the thick Malmian marls.

4.3. Exploration in the Molasse Zone

In the late fifties and the sixties, another new area of exploration became important. Oil and gas was discovered in Eocene and Upper Cretaceous sandstones in the Molasse Zone of Upper Austria (KOLLMANN & MALZER, 1980). This exploration involved the first intensive use of seismic investigations. Gas was also found in the Miocene Molasse of Lower Austria (1960 Wildendürnbach) and later in Malmian carbonates (1972, Roseldorf field), dolomitised calcarenites (1988 Pottenhofen, 1991 Neuruppersdorf) and in Dogger sandstones (1974 Klement) (Fig. 26).

4.4. Exploration in the Alps

An increase in exploration activity in the Alps has occurred in the last decade. The rational for alpine exploration is based on experience and discoveries related to the exploration in Eastern Austria: Autochthonous Mesozoic; the Tertiary of the Molasse Zone; the Upper Triassic of the Calcareous Alps in the Vienna Basin.

Two main targets are considered to be prospective:

1) A subthrust target, which is the autochthonous sedimentary cover below the Calcareous Alps. Reservoirs to be expected are Dogger sandstones, Malmian carbonates and Cretaceous to Eocene sandstones. The source rock is thought to be Malmian marls in the east and Oligocene marls and shales in the west. Prospective traps will be basement highs, faultblocks and onlapping of sediments onto the basement.
2) An intrathrust target, which is the Calcareous Alpine dolomites entrapped by tight internal sediments within Alpine folds and thrust slices.

Exploration activity has resulted in the discovery of the gascondensate Höflein field, below the Flysch Zone near Vienna (depth 2,700–3,000 m). In Upper Austria a noncommercial amount of oil was found in a Lower Cretaceous sandstone in the GRÜNau 1 well below the Calcareous Alps (depth about 4,900 m). Gas in the Molln 1 well from a Middle Triassic limestone within the Calcareous Alpine nappes (depth 3,300 m) is shut in. The wide extent of the Calcareous Alpine thrustbelt with its different style provide promising opportunities for further exploratory drilling.

20 wells in the Flysch Zone (depth 1,300–4,600 m) and 4 wells in the Calcareous Alps (depth 3,030–6,030 m) have been drilled to the crystalline basement. Another 3 wells remained within the Calcareous Alpine thrust complex. They are shown in Fig. 46.

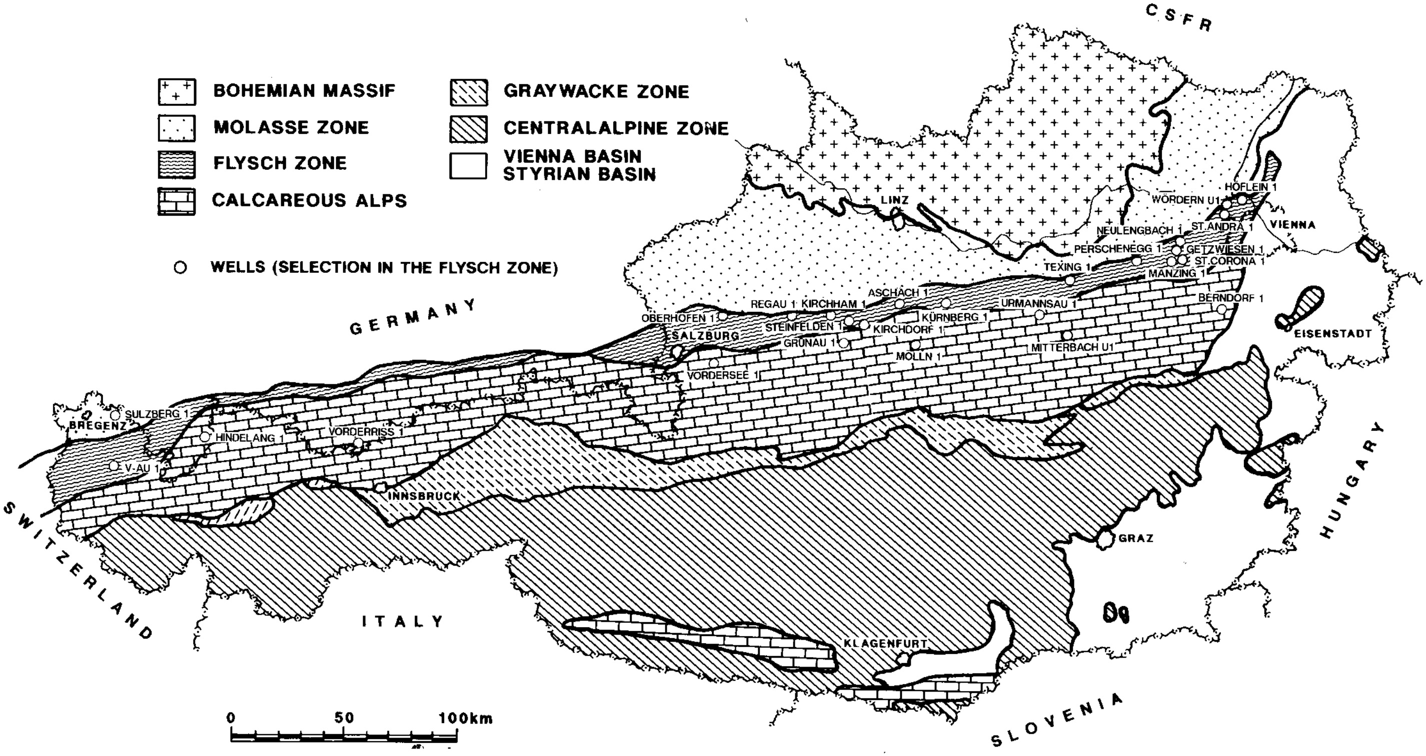

Fig. 46: Location of wells in the Flysch Zone and in the Calcareous Alps in Austria and Germany near the Austrian border.

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