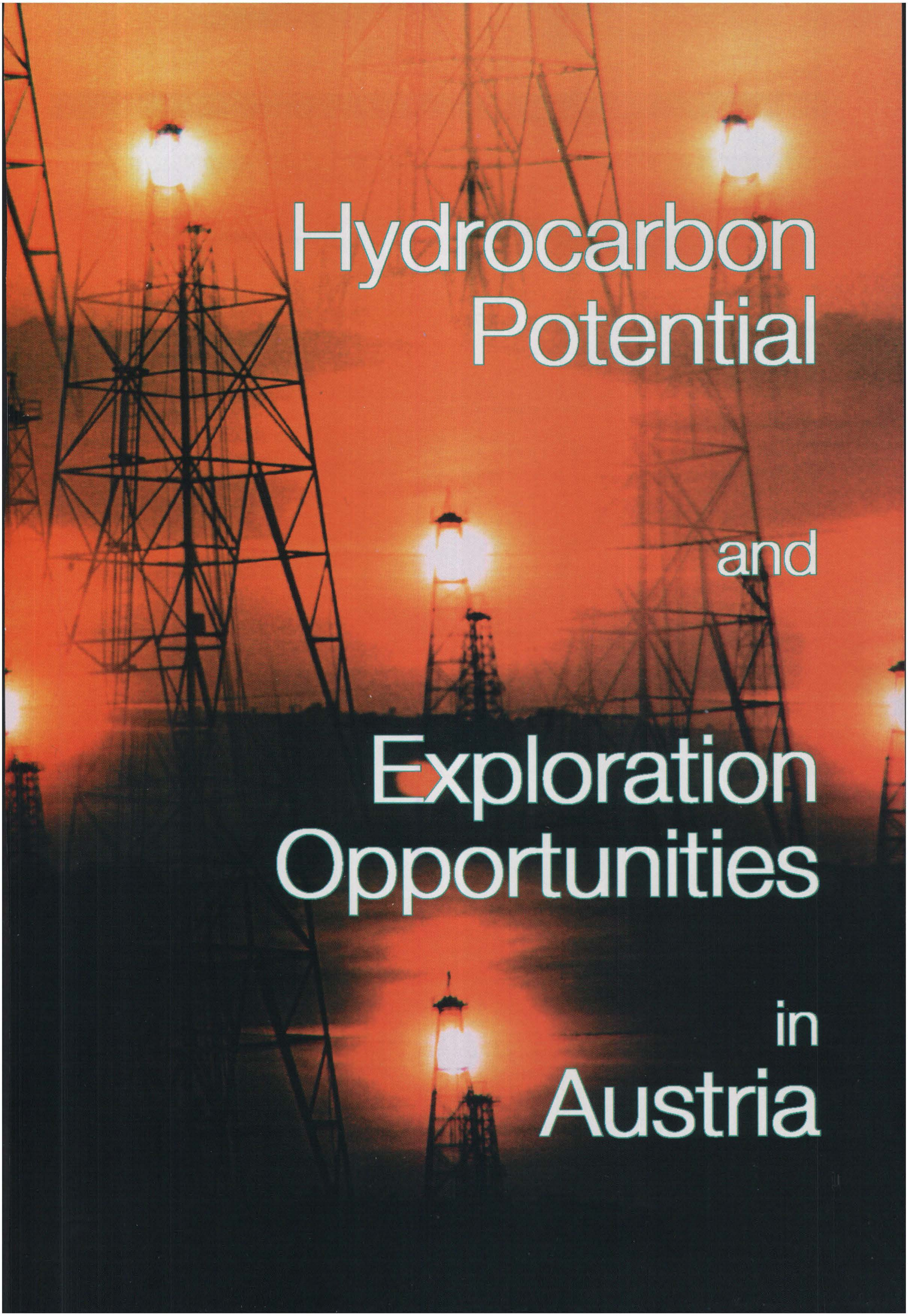
Hydrocarbon Potential and Exploration Opportunities in Austria



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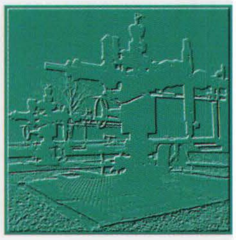
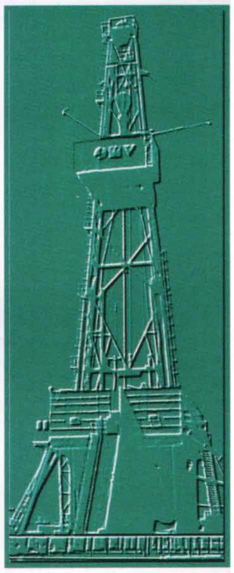


Introduction



The purpose of this brochure is to review briefly the current knowledge of the geology and the oil- and gas-bearing strata in Austria, and to inform the foreign visitor about any possibilities and opportunities for exploration and exploitation of hydrocarbons in Austria.

The legal background and the geological framework were compiled by the authorities involved: the Supreme Mining Authority and the Geological Survey of Austria. Brief outlines concerning Austria's oil and gas fields were prepared by regional experts and thus provide first-hand information.

The editors kindly wish to invite those who are interested in additional information to contact one of the authorities or organizations listed in this brochure.

The editors and authors gratefully acknowledge the assistance of the American Association of Petroleum Geologists for making this publication possible, in particular staff members Anne H. THOMAS, Special Projects, and Dr. Ken WOLGEMUTH, Publications Manager.

Mining Authorities and Legislation in Austria

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Organization and Duties

In Austria, public duties and responsibilities are divided between the Republic of Austria – the Federal State – and Austria's nine provinces (Vienna, Lower Austria, Burgenland, Styria, Upper Austria, Carinthia, Salzburg, Tyrol, Vorarlberg). Mining is among the federal duties in legislation and execution, as mandated by Austria's constitution. It is based on the 1975 Mining Law Federal Gazette No. 259 in the version of art. II of the Salt Monopoly Law, Federal Gazette No. 124/1978, the 1982 amendment to the Mining Law, Federal Gazette No. 520, art. II of the 1988 amendment to the Industrial Law, Federal Gazette No. 399, the 1990 amendment to the Mining Law, Federal Gazette No. 355, art. V of the Federal Law in Federal Gazette No. 450/1994, the 1994 amendment to the Mining Law, Federal Gazette No. 633, art. XXI of the Federal Law, Federal Gazette No. 518 and the amendment to the Mining Law, Federal Gazette No. 219/1996, and the announcement in Federal Gazette No. 193/1993. According to the 1975 Mining Law, mining in Austria is controlled by special federal authorities („Mining Authorities"; "Bergbehörden").

Mining authorities of the first stage are the Regional Mining Authorities ("Berghauptmannschaften"), special and professional federal authorities, and the Federal Minister for Economic Affairs (second and appeal stage). Mining authorities report directly to the Federal Minister. There are six Regional Mining Authorities in Austria. They are located in Vienna (Vienna, Lower Austria, Burgenland); Graz (East, South and West Styria); Leoben (Upper Styria); Klagenfurt (Carinthia); Innsbruck (Tyrol, Vorarlberg); and Salzburg (Salzburg, Upper Austria). The Federal Ministry for Economic Affairs in Vienna is divided into several departments. Mining is subject to Department VII "Oberste Bergbehörde" ("Supreme Mining Authority").

The duties of the mining authorities are extensive, covering among others mining licenses, hazard prevention, legislation, optimal use of deposits, and education of miners and foremen.

Legal Base for the Mining Industry

The legal base for the Austrian mining industry is the 1975 Mining Law, Fed. Gaz. 259, with several amendments. This law applies to the prospecting, exploration, exploitation, storage, and processing of mineral raw materials "free for mining" (§ 3 "Bergfreie mineralische Rohstoffe"), "state-owned mineral raw materials" (§ 4 "Bundeseigene mineralische Rohstoffe"), and "landowners' mineral raw materials" (§ 5 "Grundeigene mineralische Rohstoffe"), as well as the processing of those minerals in as far as it is carried out in the course of prospection, exploration and exploitation, the processing of other mineral commodities, and the exploration and investigation of geological structures suitable for storing liquid and gaseous hydrocarbons, storing hydrocarbons, etc.

These provisions also refer to mining aspects of exploration, and the supervision of activities relating to geothermal energy and the use of geothermal heat, where tunnels, shafts and wells of more than 100 m are used, the exploration of the earth's crust for its suitability for storing any substances, and the use of workings in closed-down mine sites and purposes other than the production of mineral commodities.

Exploration is considered to be divided into two phases: the initial search (Prospecting; "Suche"), followed by investigation (Exploration; "Untersuchung"). The permits required vary slightly depending on the classification of minerals:

"Mineral Raw Materials Free for Mining"
(§ 3 "Bergfreie mineralische Rohstoffe")

1. All mineral raw materials from which iron, manganese, chromium, molybdenum, tungsten, vanadium, titanium, zirconium, cobalt, nickel, copper, silver, gold, platinum and PG-elements: zinc, mercury, lead, tin, bismuth, antimony, arsenic, sulfur, aluminum, beryllium, lithium, rare earths, or compounds of these elements can be produced, if they are not listed below and do not represent state-owned or landowner's or other mineral raw materials.
2. Gypsum, anhydrite, barite, fluorite, graphite, talc, china clay (kaolin), and leucophyllite.
3. All types of coal and oil shale.

Prospecting for "free for mining" mineral raw materials needs a prospecting permit ("Suchbewilligung"), entitling the holder to search for such minerals within the jurisdiction of the Regional Mining Authority ("Berghauptmannschaft"). It does not confer an exclusive right.

An exploration license ("Schurfberechtigung") confers an exclusive right for "free for mining" mineral raw materials within a specified area located in the area of jurisdiction of the respective Regional Mining Authority.

Mining of those mineral raw materials requires a mining-permit ("Bergwerksberechtigung").

"State-owned Mineral Raw Materials"
(§ 4 "Bundeseigene mineralische Rohstoffe")

belong to the federal state.

1. Rock salt and all salts occurring together with rock salt,
2. Hydrocarbons, and
3. Minerals containing uranium and thorium.

Persons meeting certain criteria can acquire exploration rights through a civil-right contract granted by the Federal Minister of Economic Affairs in consent with the Federal Minister of Finance on behalf of the state.

The right to explore for salt has been ceded by law to the Österreichische Salinen Aktiengesellschaft.

The right to explore, exploit and store hydrocarbons is granted to OMV Aktiengesellschaft and Rohöl Aufsuchungs Aktiengesellschaft by a civil-right contract. By that contract companies must pay royalties. This contract also fixes the rights and duties concerning prospection, exploration, exploitation and storage as well as rights and duties for searching for and investigating hydrocarbon-bearing geological structures suitable for storing. The royalties have been fixed by law (Fed. Gaz. 287/1985 amended by 134/1988 and 291/1989).

In all cases a working program ("Arbeitsprogramm") must be drawn up and approved by the Regional Mining Authority.

The Regional Mining Authority is obliged to approve this working program if the activities are not outside the license area and not in the license areas of others, except where there is an agreement. Furthermore, safety measures and measures concerning reclamations subsequent to the mining activities have to be fixed by the Regional Mining Authority. Opinions of other authorities in charge must be considered. The approval of the working program needs no agreement of the owner of the property, but the utilization of the property requires agreement by the land owner.

Whenever a hydrocarbon-bearing deposit has been detected, an exploitation-field ("Gewinnungsfeld") must be lined out and must be approved by the Regional Mining Authority. As long as exploitation is economical, the owner of the mining rights is obliged to operate the deposit.

Initiating of production or storing hydrocarbons in an exploitation field ("Gewinnungsfeld"), as well as any interruption longer than 2 months, or resumption, must be reported to the Regional Mining Authority immediately. The duration of an interruption must always be reported.

Ceasing exploitation or storing also requires a permit ("Abschlußbetriebsplan") approved by the Regional Mining Authority.

The exploration for and investigation of non hydrocarbon-bearing geological structures suitable for storing hydrocarbons are subject to a permit by the Regional Mining Authority. The storage of hydrocarbons in suitable structures requires a storage permit ("Speicherbewilligung"), issued by the Regional Mining Authority.

"Landowner's Mineral Raw Materials"
(§ 5 "Grundeigene mineralische Rohstoffe")

Magnesite; mica; illite clay and other expandable clays; quartz, quartzite, and quartz sand that is suitable for the manufacturing of glass or fireproof products or as starting material for the manufacture of cement; clays suitable for the manufacture of fireproof or acid-proof products, cements, brick work and other ceramic products; dolomite suitable for the manufacture of fireproof products; limestone suitable for the manufacture of quick lime or as starting material for the manufacture of cement or as aggregate for metallurgical processes; marl suitable for the manufacture of cements; basaltic rock suitable for the manufacture of fireproof products or of rock wool; bentonite; kieselgur; asbestos; feldspar; trass; andalusite; sillimanite and cyanithe.

A prospecting permit to search, followed by an exploration permit to investigate, are needed for the above-mentioned minerals. Both permits will be issued by the Regional Mining Authority.

* * *

All minerals not listed above are subject to the category of

"Other Mineral Raw Materials"
(§ 6 "Sonstige mineralische Rohstoffe")

Prospecting on the surface for "other mineral raw materials", and their production, require a license according to the Trade Law ("Gewerbeordnung 1994"). In underground activities, the commencement of mining must be reported to the Regional Mining Authority.

The holder of mining rights ("Bergbauberechtigter") enjoys certain rights. Under certain conditions he may, in the course of exploration and production, utilize other minerals not listed in his mining right title as well. The Mining Law furthermore allows to use mine waters whenever required for mining operations, as long as it does not merge with permanent surface waters.

The holder of the mining rights may also engage in processing minerals and in their beneficiation (pelletizing, bricketing, drying, roasting, carbonizing, coking, gasifying, liquefying and dissolution of minerals or making a suspension) during processing in accordance with operational and local conditions and further processing to a saleable product. He is also entitled to use mines for purposes other than exploitation of minerals, to bring in or to store goods in geological structures if these operations do not interfere with the production and storage of minerals.

The holder of the mining rights is faced with special obligations as well. Opening and closing mines have to be announced in advance. During mining operations, the holder of the mining rights must protect life and health of persons, the property of others and properties not transferred to him for use, to protect the environment, deposit and surface, to provide reclaimation of surface after ending mining activities. Concerning the protection of the environment, he is obliged to do everything to prevent any permanent damage to soil, vegetation and livestock.

If a person not belonging to the mining company is killed or injured or becomes ill, or property is damaged by a mining operation, this is referred to as a mining damage ("Bergschaden").

Mining activities must be carried out in such a way to prevent emissions using the latest technology. It's the duty of the holder of the mining rights to follow mine maps under the supervision of a mine surveyor ("Markscheider"). In the case of any accident occurring in other mining operations, the holder of the mining rights is obliged to send rescue men and equipment upon request.

Mineral production and the storage of hydrocarbons in geological structures has to be done in accordance with the operating plan ("Hauptbetriebsplan"), which must be approved by the Regional Mining Authority in respect of the operations envisaged and the measures planned. This does not apply to small enterprises. Small enterprises are defined as mining enterprises or independent operational units of a mining enterprise employing fewer than 40 persons on regular basis. In case of landowners minerals, production may be resumed after an interruption of more than five years on the basis of an exploration and production plan ("Aufschluß- und Abbauplan") approved by the Regional Mining Authority.

The holder of mining rights must appoint a manager, a deputy manager, and technical supervisors for every mining enterprise. In small enterprises, where operational hazards can be expected to remain at a low level, a responsible manager may hold multiple appointments for other small enterprises. The holder of the mining rights also has to appoint a responsible mine-surveyor ("Verantwortlicher Markscheider") for each unit. Any appointment is subject to approval by the Mining Authority.

Holders of mining rights jointly owning a mining right title or jointly entrusted with the use of a mining right title, single holders of mining rights or commercial law firms residing abroad permanently must appoint a person living in Austria ("Bergbaubevollmächtigter"), who is authorized to receive legally valid orders and written communications by the Mining Authorities.

Mining areas must be clearly entered in the land use plan ("Flächenwidmungsplan"). Buildings and other installations not serving the purpose of mining operations may be constructed in mining areas only upon obtaining a special permit from the Mining Authority.

*

For any questions feel free to contact one of the Regional Mining Authorities or the Supreme Mining Authority.

Outline of the Geology of Austria

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Introduction

Austria is part of central Europe and covers an area of 83,849 km². It is populated by almost eight million citizens. It extends from east to west more than 550 km and from north to south more than 300 km. Its most characteristic features are the mountainous Eastern Alps with the highest peak at Großglockner (3,789 m); the Danube Valley with its main tributaries of Inn, Salzach, Enns, and March; and the eastern lowlands.

The Eastern Alps extend about 500 km from the Rhine Valley in the west to Vienna in the east, where they pass into the Carpathians. This latter continuation, however, is buried under the Miocene and Pliocene Vienna Basin.

The pioneering phase of geological research in the Alps started in the early 19th century and has progressed especially since the foundation of the Geological Survey in the year 1849. At that time systematic mapping of the Austrian-Hungarian monarchy began, at a scale of 1 : 75,000. Among those whose contributions are of invaluable importance to the knowledge of Austrian geology during this classical era belong the names W. HAIDINGER, F. v. HAUER, D. STUR, E. and F.E. SUESS, E. v. MOJSISOVICS, G. GEYER, A. WEGENER, O. AMPFERER, B. SANDER, and L. KOBER.

At present, geologic research is being carried out by the Geological Survey of Austria and by several departments at the universities of Vienna, Graz, Salzburg, Innsbruck, and Leoben. In addition, research institutions such as museums and the Austrian Academy of Science provide comprehensive data needed for modern understanding of all earth-science-related phenomena.

The Geological Landscapes of Austria

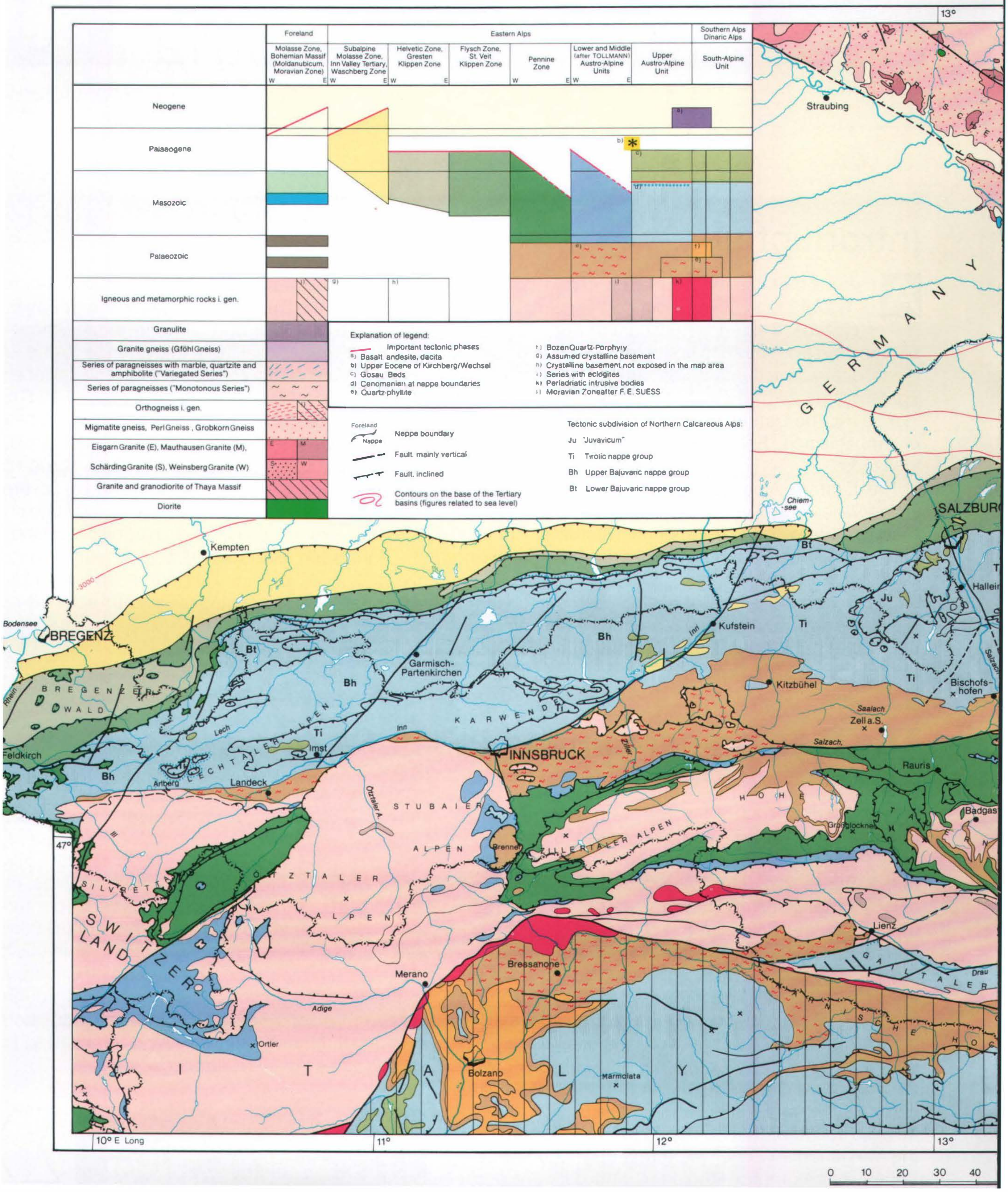
The area north of the Danube River belongs to the Bohemian Massif and represents a former fragment of Northern Gondwana that split off during early Paleozoic time to collide with Avalonia and Baltica during middle Paleozoic time. This block is essentially composed of medium-grade metamorphic rocks of early to late Proterozoic and early Paleozoic age and extensive granites of early Hercynian age. Structurally, the Bohemian Massif of Austria consists of two units, the Moldanubian Zone in the west and the Moravian Zone in the east. The former consists of paragneisses overlain by a complex of variegated crystalline rocks, granulites, and orthogneisses while the latter exhibits low- to medium-grade micaschists, metasedimentary rocks, orthogneisses and the 550 m.y. old Thaya Batholith. During the Variscan Orogeny the Moldanubian Zone was thrust upon the Moravian Zone. Their complex lithologies and different evolutionary histories suggest that originally the two zones may have represented two separate microplates.

The Bohemian Massif, with its locally preserved late Paleozoic and Middle Jurassic to Cretaceous age cover, continues to the south under the Alps. In fact, crystalline basement rocks have been encountered by a series of drill holes as far south as the Calcareous Alps. During Paleogene and Neogene time this basement subsided considerably and was transformed into the Molasse Basin. The newly formed trough was filled with clastic sediments supplied from both the Bohemian Massif and the Alps, the latter having started to rise in late Oligocene time.

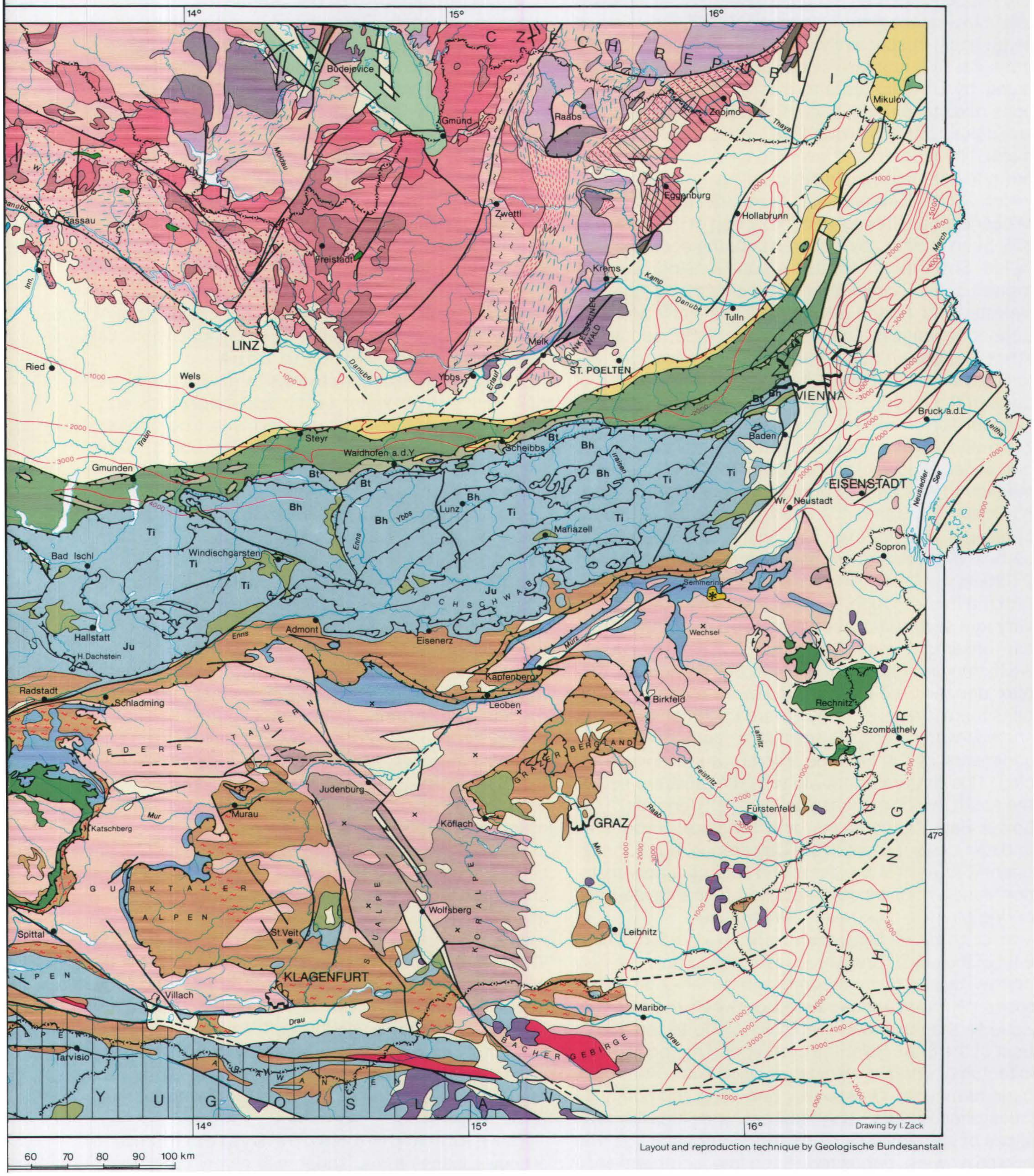
For Fig. 1
(Geological Map of Austria; 1980)
see the following pages 10 and 11.

GEOLOGICAL MAP OF AUSTRIA 1:1,500.000

(WITHOUT QUATERNARY)



Compiled by P. BECK-MANNAGETTA (Eastern Alps) and A. MATURA (Bohemian Massif)



60 70 80 90 100 km

Layout and reproduction technique by Geologische Bundesanstalt

The **Molasse Zone** comprises up to 5,000 m of predominantly marine to brackish sediments of late Eocene (developed only in the Provinces of Upper Austria and Salzburg but not in the Vienna Basin) to late Miocene age that unconformably overlie the crystalline basement of the Bohemian Massif and its cover sequences, respectively. The overall lithologies are transgressive-regressive clastic sequences dominated by sandstones and siltstones with intercalations of distal turbidites, contourites, conglomerates, and deltaic and fluvial deposits, and to a lesser degree marls, limestones, and even some economically important coal-bearing horizons. The latter occurred mainly in the Badenian and Sarmatian stages of late Miocene time. Although the major part of this zone has only been affected by local faulting, the southern, so-called Sub-Alpine, Molasse was considerably deformed due to northward movements of the adjacent Helvetic and Flysch Zones until the early Miocene Eggenburgian–Ottnangian stages. Subsequently, these faults were overprinted by transpressional tectonics that resulted in a lateral eastward extrusion of parts of the basin.

According to recent drilling activities, the Molasse Zone extends far to the south underneath the Alps. As mentioned elsewhere, the Molasse Zone hosts the majority of Austria's oil and gas reserves. At present, however, only some 1.2 Mio t of oil and 1.2 Mio m^3 of gas per year are exploited. In the Vienna Basin the oil-bearing horizons are at depths between 900 and 2,000 m.

In the Eastern Alps, the late Paleozoic to early Tertiary age sedimentary sequences on top of the Variscan basement were deposited in a series of east–west-trending facies belts. Each belt reflects a complex depositional history. However, in the northern belts there is a general southward transition from thin, shallow-water deposits to thicker, fairly deep-water sediments of the Helvetic, Flysch, and Penninic facies. This pattern contrasts with the adjacent belt to the south, which exhibits shallow shelf deposits of the Lower East Alpine facies, and the thick carbonates and reef development of the Calcareous Alps. Consequently, rates of subsidence and sediment accumulation varied considerably between these facies belts during Mesozoic and early Tertiary time.

In contrast to Switzerland, the **Helvetic Zone** east of the city of Bregenz is restricted to an extremely narrow belt of dismembered and sheared off thrust slices ("Klippen") intercalated between the Molasse Zone to the north and the Flysch Zone to the south. East of the Enns River the corresponding rocks occur in tectonic windows within the Flysch Zone. They have been termed the Gresten Klippen Zone and comprise limestones, marls, sandstones, and locally, even slices of serpentinites of Jurassic to Eocene age that originally were deposited along the southern shelf margin atop the Variscan basement of the Bohemian Massif.

The tectonostratigraphic unit of the **Flysch Zone**, following to the south, extends along the northern margin of the Calcareous Alps from the Western Alps to the Carpathians. It is one of the major south-dipping thrust sheets that has overridden the Helvetic Zone to the north but also was overthrust by the Calcareous Alps to the south. Its internal structure is very complex. Dominating lithologies are siliciclastic sediments such as sandstones, siltstones, claystones, and marls ranging in age from the Cretaceous to the Paleogene. In terms of its original paleogeographic position, the Flysch Zone is regarded as the southern continuation of the Helvetic Zone, representing thus the depocenter northward and somewhat younger than the neighbouring main trough to the south, which resulted from the opening of the Penninic Ocean. After closure of this ocean during the Alpine Orogeny, the associated rock succession was transformed to the **Penninic Zone**.

This southern trough was filled by a thick pile of predominantly deep-water pelitic and calcareous sediments that are locally associated with true ophiolite sequences (including serpentinites, gabbros, pillow lavas, tuffs, quartzites) indicating an oceanic crust in parts of the basin during the Jurassic Period. Although in the Penninic trough sedimentation lasted without major breaks from late Carboniferous to late Cretaceous time, the climax occurred during deposition of the Bündnerschiefer Formation during Jurassic time. This formation comprises different lithologies, ranging from quartzites to phyllites, calcareous mica schists, greenschists, breccias, marbles, calcareous phyllites, garnet-bearing schists, and other metasediments that were strongly deformed and metamorphosed to medium-grade during the Alpine Orogeny. In another part of the Penninic Zone, however, the original Variscan basement was still preserved and is represented by various pre-Variscan crystalline rocks and huge volumes of Variscan granites that intruded the surrounding Paleozoic parasequences.

In Austria, the equivalents of the Penninic Zone are generally buried underneath the huge, flat lying thrust sheet of the so-called East-Alpine Nappe System. A few exceptions, however, do occur in which the corresponding rocks are exposed, e.g., in the Engadin Window of western Austria, the Tauern Window in the central and most impressive part of Austria, and some smaller outcrops near the eastern spur of the Eastern Alps. These tectonic windows offer a remarkable view into otherwise buried rocks of continental and oceanic crustal origin. In the tectonic framework of the Alps the Penninic Zone is regarded as the lowermost tectonic unit.

The **East-Alpine Nappe System** represents a huge rootless thrust sheet with a very complex internal structure. In the nappe pile of the Eastern Alps of Austria, it occupies the uppermost position. Depending on different models it may be divided into two or three subunits, named the Lower, Middle, and Upper East-Alpine Nappes. Each is composed of a pre-Variscan and Variscan basement of crystalline rocks or an unmetamorphosed Paleozoic rock succession, covered by highly varying sedimentary sequences of Mesozoic age, displayed for example in the Radstädter Tauern of the Province of Salzburg or in the Calcareous Alps.

In the Eastern Alps the **Calcareous Alps** form the most impressive landscape, resulting from different types of limestones, dolomitic rocks, and shales, and their tectonic juxta- and superposition. Generally, the Upper Permian clastic sequence passes into platform and deep-water carbonates in the Lower Triassic strata; higher in the succession several shaly and arenaceous sediments of varying thicknesses were deposited during Jurassic and the Early Cretaceous time. In addition, repeated deepening and shallowing events caused strongly varying and partly diachronous environmental conditions that are documented in a wide range of depositional features, like lagoonal, reef, reef-slope, and deep-water limestones. East–west, the Calcareous Alps extend in an up to 50 km wide, 500 km long belt, from the outskirts of Vienna to the Rhätikon range in the Province of Vorarlberg. Clear evidence for extensive horizontal movements of the Calcareous Alps is provided by a series of small tectonic windows showing the underlying rocks of the Flysch Zone up to 20 km south of the northern margin of the Calcareous Alps.

Stratigraphically, the Calcareous Alps are linked to the underlying **Graywacke Zone**, displaying a fossiliferous sequence of Early Ordovician to Middle Carboniferous and locally also Late Carboniferous ages. In parts of Styria and Lower Austria, this zone can be further subdivided into two nappes named the Noric and Veitsch Nappe, respectively.

In the western and eastern part of Austria south of the Graywacke Zone, a large area is occupied by different igneous and metasedimentary rocks, most of which were metamorphosed during the Variscan Orogeny. Recent research, however, indicates a major Alpine overprint in certain areas. Locally, these complexes grade into weakly metamorphosed fossil-bearing lower Paleozoic series, e.g., the famous fossiliferous sequences in the vicinity of Graz, the area around Murau in western Styria, and in Middle Carinthia. In this region the Paleozoic sequence is unconformably overlain by Upper Carboniferous meta-sandstones, Permian red beds, and Triassic dolomites and limestones known, for example, from south of Innsbruck, the Krappfeld area, St. Paul, the surroundings of Griffen, and from other parts of the Gurktal Nappe of Carinthia and Styria. Moreover, a considerably thicker and slightly varying Triassic to Cretaceous succession is recorded in the Northern Karawanken Alps and the so-called Drauzug of Carinthia and Eastern Tyrol. Elsewhere, however, within crystalline complexes unfossiliferous metasedimentary intercalations occur. This suggests caution regarding whether the basement-cover relationship is of stratigraphic or of tectonic nature.

The southern boundary of the East-Alpine Nappe System is formed by a very prominent fault system that dissects the whole Alpine mountain chain, from the Thyrrenian Sea to the Carpathians. In Austria the local names **Pustertal Fault and Gailtal Fault**, respectively, are applied. Associated with this vertical or steeply south-dipping fault are several minor granitic to tonalitic intrusive bodies of apparently Alpine age. Concerning lateral movements, in recent years convincing evidence has been presented in favour of significant dextral displacements along this fault system.

The area to the south of the Gailtal Fault, i.e., the Carnic and Karawanken Alps, belongs to the **Southern Alps**. Bounded by Italy and Slovenia on one side and Austria on the other, an up to 10 km wide belt consists of Paleozoic strata that have long been famous for their rich content of fossils and the diversity of rocks ranging without major unconformities from Ordovician to Late Permian in age. In short, they represent the sedimentary basement of the Mesozoic development of the Southern Alps of Northern Italy and the Dinarides.

The Geodynamic Evolution of Austria

In recent years a set of new data has been provided from different Earth-science-related sources that sheds new light on the geologic history of the Alps in general and the Eastern Alps and the Bohemian Massif in particular. Application of plate tectonics, including the terrane concept, additional and revised biostratigraphic, geochronologic, and paleomagnetic data, as well as paleoenvironmental studies of rocks and fossils, not only confirmed the already existing mobilistic models about the geodynamic development of the Alps but greatly expanded these ideas. In fact, these new approaches suggest an odyssey by Austria nearly halfway around the globe during the past two billion years.

The oldest unambiguous biostratigraphic data available indicate an Early Ordovician age for pelitic sequences of the Graywacke Zone. Older age assignments based on acritarchs suggest deposition of black shales which were metamorphosed into the schists of the Habach Formation of the Hohe Tauern at approximately 600 m.y., but these findings are not unanimously accepted. Nevertheless, there is further evidence of crust-forming events in the late Proterozoic: for example, Ar-Ar age spectra of detrital muscovites collected from Late Ordovician age clastics indicate a formation age as old as 600 m.y. These data are constrained by Rb-Sr and U-Pb isotope ages in high-grade metamorphic rocks of different places in the Eastern Alps, including the Hohe Tauern region. The metamorphic rocks are explained as deriving from thermal events and volcanic activity in an island-arc setting between 500 and 670 m. y., and by magmatic events recorded in multiply zoned detrital zircons of metasedimentary rocks of central Europe that reveal a complex geological history. The chronology of these events suggests contemporaneity with thermodynamic events of northern Africa, and more precisely, with Pan-African orogenetic events. Hence, during the Proterozoic Eon, parts of Africa can be considered as the provenance for sediments of the "primitive" Alps, and also a connection with the supercontinent Rodinia may have existed that formed around 750 m.y. Subsequently, Rodinia split into several asymmetrically rifting plates with intervening new oceans, in particular the Proto-Pacific Ocean between Laurentia on one side and East Antarctica and Australia on the other. Finally, in latest Precambrian time at approx. 550 m.y. several disrupted plates collided to form the supercontinent Gondwana, which was separated from Siberia, Baltica, and Laurentia by the lapetus Ocean and the Tornquist Sea. In this new plate organisation the precursors of the Alps were part of the European shelf and located at approx. 15° to 20° southern latitude. Although for this period a near-equatorial setting is implied for the Alps, no direct evidence of related warm-water sediments has yet been found in Austria, in contrast to the surrounding areas of Sardinia, Southern France, and Germany.

The breakup of Gondwana during early Paleozoic time resulted in a poleward shifting of Africa. At the same time, its northern portion was affected by fragmentation processes, creating several microplates that split off from Africa, e.g., Avalonia, Perunica (the Bohemian Massif), the Armorican-Iberian Massifs, and also those that later formed the Alps. For the following period, from Ordovician to Carboniferous time, paleomagnetic, lithic, and faunal data from Paleozoic strata of the Alps indicate a gradual drift towards lower latitudes. Collision of individual microplates started in Late Devonian time and caused deformation and metamorphism in a central axial zone. The final closure of intervening ocean basins, however, occurred during Middle and Late Carboniferous time when the Variscan orogeny reached its paroxysm. In this newly assembled supercontinent Pangea the major part of Austria was located in an equatorial position.

According to F. NEUBAUER (1994), V. HÖCK et al. (1994), and others, the post-Variscan history can be briefly summarized in terms of a two-stage collisional model. Recently new radiometric data indicate that rifting processes had begun in the Permian and affected the crystallline Variscan basement upon which the major part of the sediments of the Calcareous Alps were deposited during Mesozoic time. Associated with these events were basaltic dykes that were metamorphosed to eclogites during the Alpine overthrusting. In the Middle Triassic Period continuous rifting led to the opening of the "Hallstatt-Meliata Ocean". This narrow ocean was bordered to the north by the passive southern margin of the East-Alpine Realm to the north and by the South-Alpine block (Fig. 2).

During the Early to Middle Jurassic Period, north of this area and adjacent to stable Europe, the Penninic Ocean opened and established another passive margin. As a consequence, the neighbouring East-Alpine microplate drifted southward and the Hallstatt-Meliata Ocean began to close between 160 and 150 m.y., i.e., in Late Jurassic time.

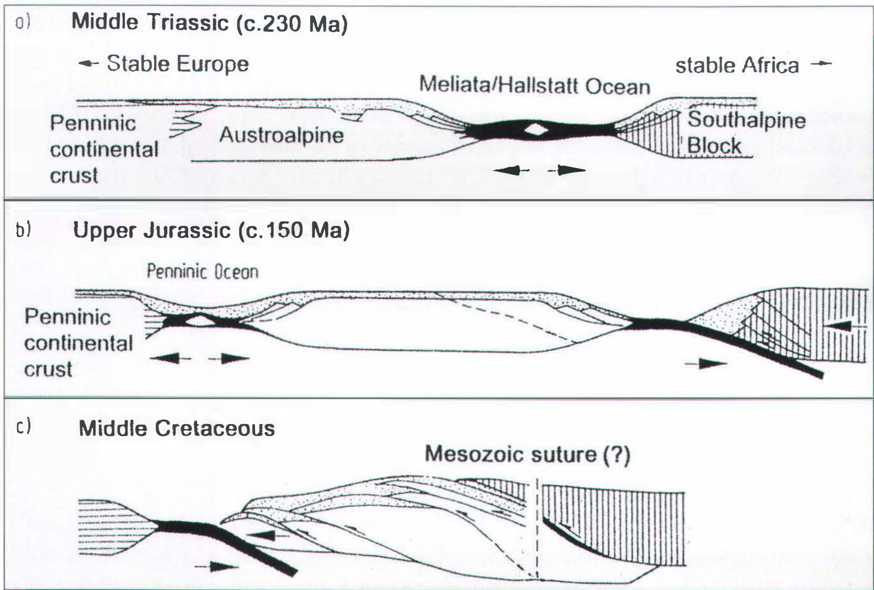
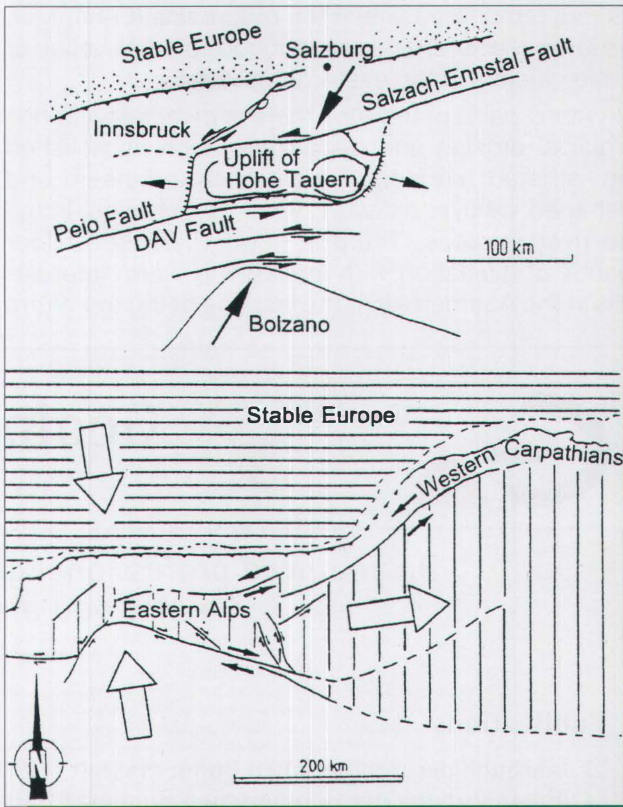


Fig. 2.
Model of the early Alpine tectonic evolution in the Eastern Alps and Western Carpathians.
Modified after NEUBAUER (1994).

Fig. 3.
Post-collisional evolution of the Eastern Alps.
Modified after NEUBAUER (1994).



Next, from the Late Jurassic to the middle Cretaceous Period, i.e. between 140 and 90 m.y., the South-Alpine and the East-Alpine microplates collided and produced the so-called "Early Alpine" or "pre-Gosauan" overriding tectonics and imbrication of thin crustal wedges. This pile of nappes consisted of pre-Variscan and Variscan basement rocks and their post-Variscan Permian and Mesozoic sedimentary cover. However, the associated oceanic crust of the former Hallstatt-Meliata Ocean was almost completely subducted. The resulting accretionary wedge started to shift northward and closure of the Penninic domain began. During this final phase, between 80 and 60 m.y., the Penninic oceanic crust was continuously subducted below the continental crust of the East-Alpine block, causing high-pressure paragenesis and formation of eclogites followed by blueschists in a later stage. At the same time, the northern trough was characterized by flysch-type sedimentation.

At the end of Eocene time, the Penninic Ocean was completely closed and subducted. The whole Penninic realm was covered by the East-Alpine nappe, causing a younger thermal event well-known as "Tertiary Tauern metamorphism". Finally, the East-Alpine block docked to stable Europe.

Post-collisional processes included a considerable north-south shortening by contraction between the Adriatic "intender" and the northern Alpine foreland. There was also uplift of metamorphic core complexes followed by exhumation of the Tauern Window, and simultaneous differential eastward escape of different tectonic units along a sinistral wrench corridor and along the dextral Gailtal Fault and its continuation, respectively (Fig. 3). This lateral displacement may be up to 450 km. According to paleomagnetic data, the escape was a very fast process, since all significant movements ended at 16 m.y. in mid-Miocene time.

As the result of crustal extension during the Neogene Period, several sedimentary basins, such as the Vienna, the Styrian, and intra-Alpine basins, were formed. These eastern basins are characterized by Neogene volcanism and are genetically related to the extensive volcanic region of the Carpathian arc and the Pannonian Basin of Hungary. This volcanic activity is associated with subduction and back-arc extension originating from collision between the Alps and the European plate. In eastern Austria, three types of volcanics can be recognized.

1. In the Karpatian to lower Badenian Stages of the Miocene, the oldest volcanic rocks occur and are represented by calc-alkaline volcanics of trachyandesitic-latitic composition such as at Gleichenberg, Weitendorf or Kollnitz.
2. The second volcanic phase occurred between 11.5 and 10.5 m.y. during the early Pannonian stage of late Miocene time, and is represented by the "diabase" of Pauliberg and the alkali basalts of Oberpullendorf.
3. After a period of inactivity, a long-lasting, very active effusive and pyroclastic phase occurred during late Pliocene time at Klöch, Wilhelmsdorf, Mühlbach, and Unterweissenbach. In these rocks the total alkali content is continuously increasing. Radiometric ages of these youngest volcanics range from 3.7 to 1.7 m.y. thus representing the youngest volcanic episode of Austria, during the earliest Pleistocene. This late volcanism is related to extensional conditions of continental rifting associated with thermic subsidence of the Pannonian Basin.

Austria's landscape today is mainly the result of the last glacial epoch (D. VAN HUSEN, 1987). During its climax, the Alpine valleys were filled with extensive, over 1000 m thick glaciers. Even the highest peaks were ice-covered nunataks. Barrier effects at valley junctions allowed individual ice streams to move over smaller watersheds to join other less-developed glaciers and together spread as piedmont glaciers far into the foreland (e.g., Inn and Salzach glaciers). Further east, due to decreased precipitation and elevation, glaciers terminated within the mountains (Enns, Mur, and Drau glaciers) or were reduced to small valley or cirque glaciers in the easternmost part.

In many parts of the Alps there is plentiful evidence of glacial erosion and deposition, such as polished and striated surfaces, roches moutonnées and U-shaped valleys, different types of moraines, kame and river terraces. There is good evidence of four phases of glaciation with intervening warm interglacials in the Austrian Alps, the last one being the Würm glacial period, which lasted from approx. 110,000 to 10,000 years before the present.

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Exploration History

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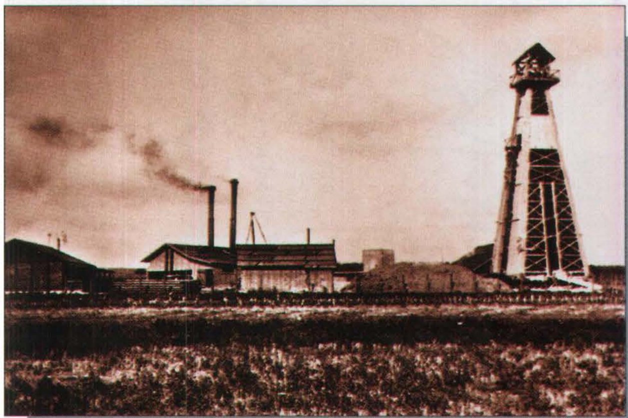


Fig. 4.
"Gösting 2"; 1934.

At the end of the last century, Austria-Hungary was the third largest oil producer in the world, behind the USA and Russia.

Oil production started in 1860 from the Flysch zone in Galicia (now Poland) with a few thousand liters of crude oil per year. This production reached 1.1 million tons per year by 1913.

In the Vienna Basin the first economic oil production was achieved in the area of Egbell (Gbely, now Slovak Republic) in 1914. In 1934 the well "Gösting 2" (Fig. 4) was drilled by the Erdölproduktions-Ges.m.b.H. (EPG), and it became the first economic oil well in the Austrian part of the Vienna Basin.

After World War II the oil industry of Eastern Austria was put under Soviet administration. This began increased exploration activity in the Vienna Basin and resulted in the discovery of the Matzen Field in 1949. Matzen remains the largest oil field in Middle Europe (1,300 MMSTBBL oil in Place; 480 MMSTBBL produced). In 1955 the Sowjetische Mineralölverwaltung (SMV – the predecessor of the ÖMV AG and now OMV AG) achieved a peak production of 3.7 million tons (26 MMSTBBL) oil per year.

Exploration in the western parts of Austria, mainly in Upper Austria, started in 1947. The Rohöl Gewinnungs AG. (RAG), which was founded in 1935 as a subsidiary of the Socony Mobil and Royal Dutch/Shell, in 1956 discovered the field Puchkirchen in the Molasse Zone of Upper Austria. Until the end of the '50s, Austria was one of the few countries in the world able to meet its oil demand by domestic production.

Despite great exploration efforts like the extension of exploration areas within Austria and the drilling of ultra-deep wells (Fig. 5: Zistersdorf Übertief 1a: 8,553 m; 28,061 ft), Austria's oil industry was not able to maintain these high production rates.

Consequently Austria's oil industry entered the international oil business. Since 1979 OMV AG has been successfully active in numerous countries (e.g. UK, Canada, Pakistan, Vietnam, Libya, Albania, Bulgaria, Yakutia, Tunisia, Indonesia, Malaysia, Egypt). This activity produces enough oil to cover about 30% of Austria's oil and gas demand (15% foreign production, 15% domestic). Austria's gas production demand is covered at 22%, predominantly from domestic production.

Fig. 5.
"Zistersdorf UT 1a"; 1980.

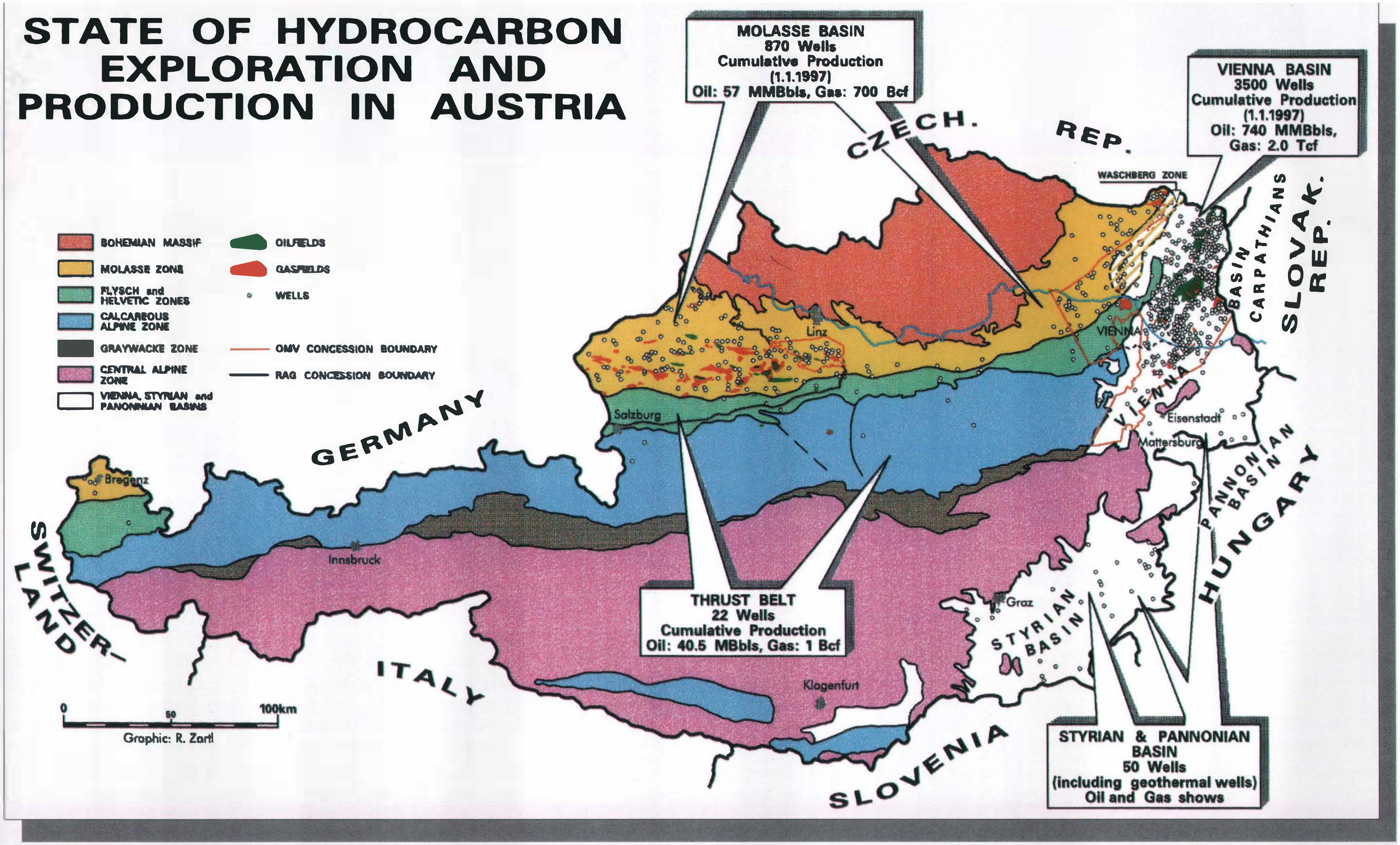
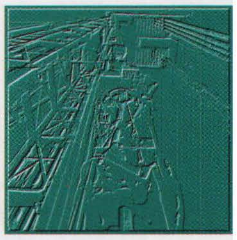


Fig. 6.
State of hydrocarbon exploration and production in Austria.

Exploration Opportunities



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Molasse Basin

Geology

Mesozoic Basement

Upper Austria and Salzburg are covered by autochthonous and allochthonous sediments from the Mesozoic basement, the Alpine thrust sheets, and the foreland. The autochthonous Mesozoic sediments overly the crystalline basement of the Bohemian Massif and locally preserved Paleozoic siliciclastic deposits. The fluvial to shallow-marine, Middle Jurassic sandstones and shallow-marine Middle and Upper Jurassic to Lower Cretaceous carbonates belong to the European shelf (Fig. 12a). The karst-developed surface of the Jurassic carries a sequence of up to 1000 m thick, glauconitic sandstones and shales from Early or middle Cretaceous to Late Cretaceous age.

Tertiary Molasse

The sedimentation in the Tertiary Molasse of the Alpine Foreland began in late Eocene time with deposition of fluvial and shallow-marine sandstones, shales and carbonates. The transgressive sequence migrated further up on the Crystalline basement with time in Oligocene and Miocene. The Early Oligocene fishshale is the source rock for the oil in Upper Austria. The several hundred meters thick Oligocene and Miocene deep marine turbiditic and contouritic deposits are derived from the Central Alps.

The Cenozoic sediments of the Molasse are subdivided into three tectonic units (Fig. 9).

The autochthonous Molasse, from Eocene to Miocene age, rests relatively undisturbed upon Mesozoic and crystalline basement strata of the Middle European shelf.

The parautochthonous Molasse are Molasse sediments riding piggyback upon Helveticum, Flysch or East Alpine nappes (Fig. 8), e.g., in the Vienna Basin.

The allochthonous Molasse is composed of southern Molasse sediments, which are included in the Alpine-Carpathian thrusts and which are moved tectonically into and across the southern autochthonous Molasse. The allochthonous Molasse includes the Molasse imbrications, the disturbed Molasse, and the Waschberg Zone.

Tectonic History

Fault Systems

North–west- and north–east-trending fault systems already existed in Paleozoic times. The faults became reactivated in Early Jurassic, Early Cretaceous, and early Tertiary times. Through these periods of tectonic activity, the crystalline basement and its cover were pulled apart along the old fault planes.

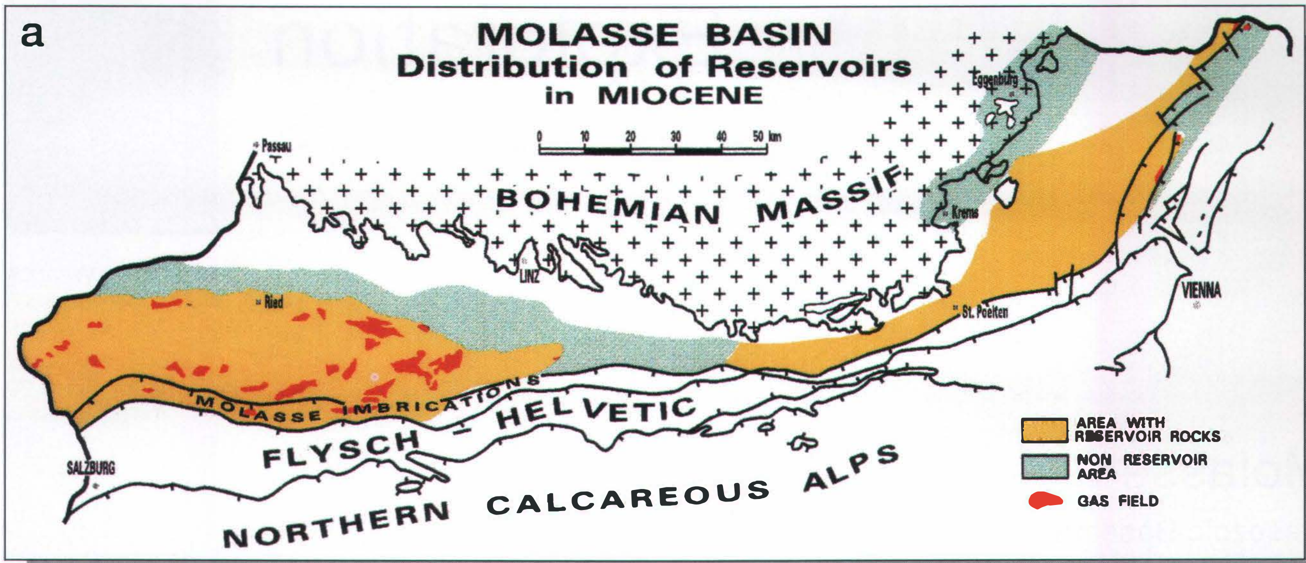
During latest Eocene and earliest Oligocene time a dense network of W–E-trending, antithetic and synthetic extensional faults developed. In Tertiary and Quaternary time the pre-Tertiary and early Tertiary extensional fault systems became reactivated by a dextral and sinistral transpression with shear, strike-slip, and overthrust compression structures.

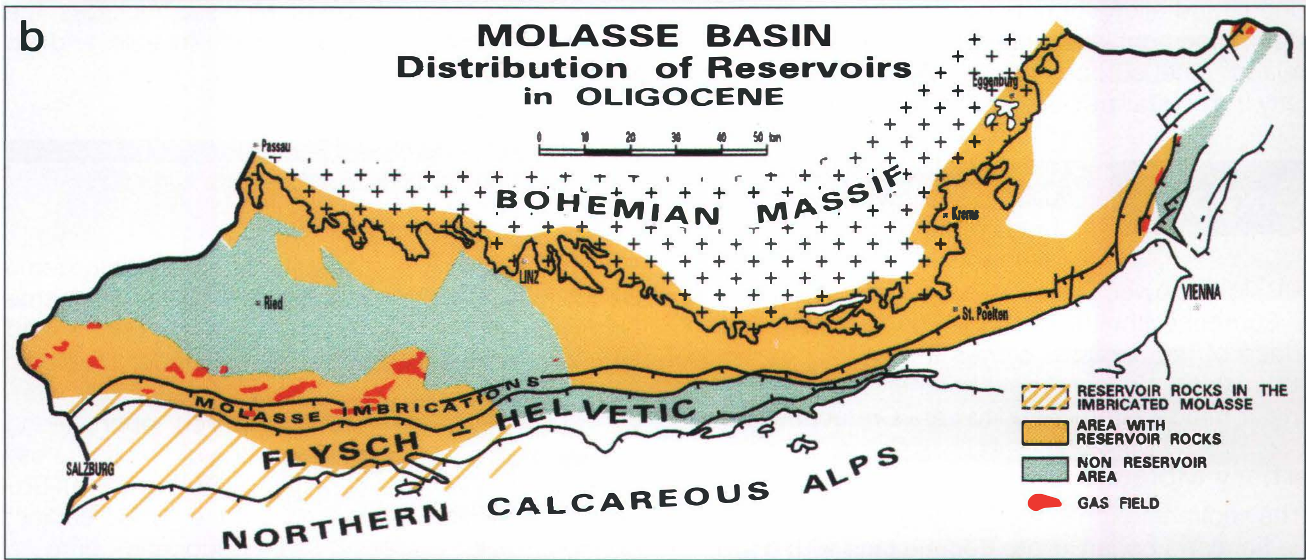
Helveticum

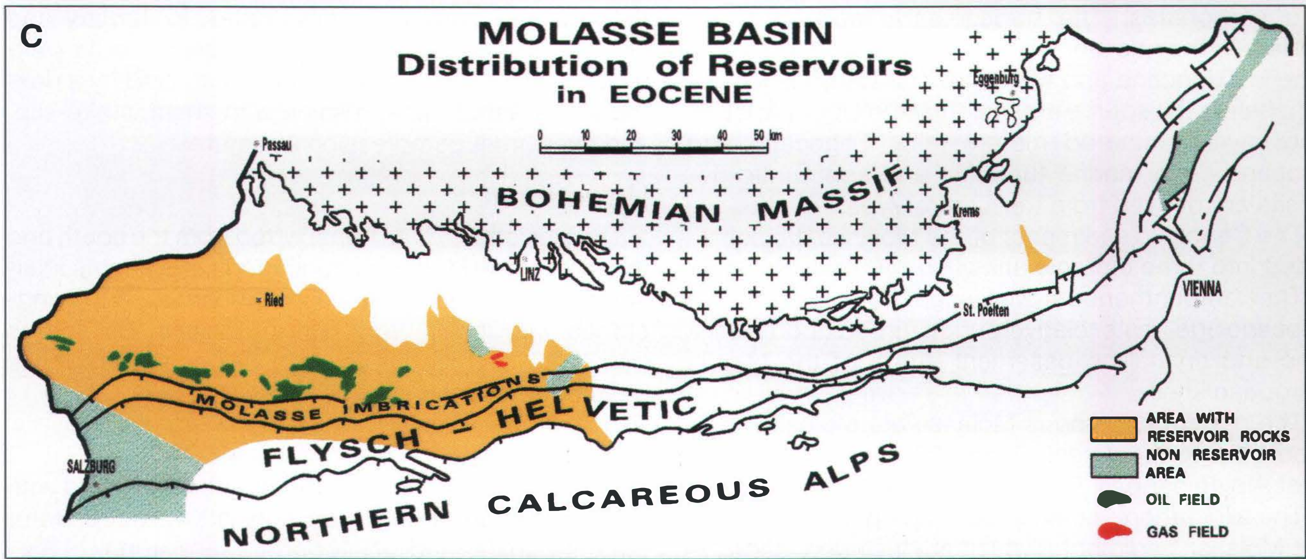
The Helveticum was transported from the south and thrust over the Molasse imbrications. It contains shallow and deep-marine shales, carbonates, and sandstones with locally very high porosities. Sediments from Late Cretaceous to early Oligocene age have been determined (Fig. 9).

Flysch

The Flysch nappes were thrust and imbricated with the Helveticum. The Flysch consists of deep-water turbiditic shales and locally porous sandstones of Early Cretaceous to early Tertiary age.


a
MOLASSE BASIN
Distribution of Reservoirs
in MIOCENE
0 10 20 30 40 50 km
Passau
BOHEMIAN MASSIF
Eggenburg
Krems
LINZ
Ried
St. Poelten
VIENNA
MOLASSE IMBRICATIONS
HELVETIC
FLYSCH
SALZBURG
NORTHERN CALCAREOUS ALPS
AREA WITH RESERVOIR ROCKS
NON RESERVOIR AREA
GAS FIELD


b
MOLASSE BASIN
Distribution of Reservoirs
in OLIGOCENE
0 10 20 30 40 50 km
Passau
BOHEMIAN MASSIF
Eggenburg
Krems
LINZ
Ried
St. Poelten
VIENNA
MOLASSE IMBRICATIONS
HELVETIC
FLYSCH
SALZBURG
NORTHERN CALCAREOUS ALPS
RESERVOIR ROCKS IN THE IMBRICATED MOLASSE
AREA WITH RESERVOIR ROCKS
NON RESERVOIR AREA
GAS FIELD


c
MOLASSE BASIN
Distribution of Reservoirs
in EOCENE
0 10 20 30 40 50 km
Passau
BOHEMIAN MASSIF
Eggenburg
Krems
LINZ
Ried
St. Poelten
VIENNA
MOLASSE IMBRICATIONS
HELVETIC
FLYSCH
SALZBURG
NORTHERN CALCAREOUS ALPS
AREA WITH RESERVOIR ROCKS
NON RESERVOIR AREA
OIL FIELD
GAS FIELD

Oil and Thermal Gas

The "Schöneck fish shale" (early Oligocene age) is the correlated source rock for the oil in Upper Austria. The kitchen is mainly below the Alpine thrusts. Generation started in Miocene time and may still be continuing.

Hydrocarbon Occurrences

Reservoirs of oil and thermal gas are fluvial and shallow-marine sandstones and carbonates of Dogger, Cretaceous (Cenomanian, Turonian, and Campanian), late Eocene and Oligocene (Kiscellian and Egerian) age (Fig. 7a). The oil is trapped in fault, stratigraphic, combined-stratigraphic, and fault structures, anticlinal, and imbrication structures.

Biogenic Gas

Reservoirs of biogenic gas are Oligocene (Fig. 7b) and Miocene (Fig. 7c) turbiditic sandstones and sandy conglomerates and shallow-marine to brackish sands. The gas is trapped mainly in stratigraphic and compaction structures or in a combination of both types and imbrication structures. Strike-slip faulting influenced and delineated the distribution of the reservoirs. In the Helveticum and Flysch nappes, water-bearing sandstones were tested.

Exploration Outlook

The relatively maturely explored Molasse basin with the Molasse imbricated zone is still under exploration by RAG. With the aid of new geophysical, geological, sedimentological, and tectonic methods and interpretations, there is a chance to find additional hydrocarbons.

Over recent years the oil exploration stagnated. There are subtle or complex structures unexplored in the deep overthrust area as well as in the shallow northern Molasse basin.

Fig. 7.
Geological maps of the Molasse Zone of Austria.

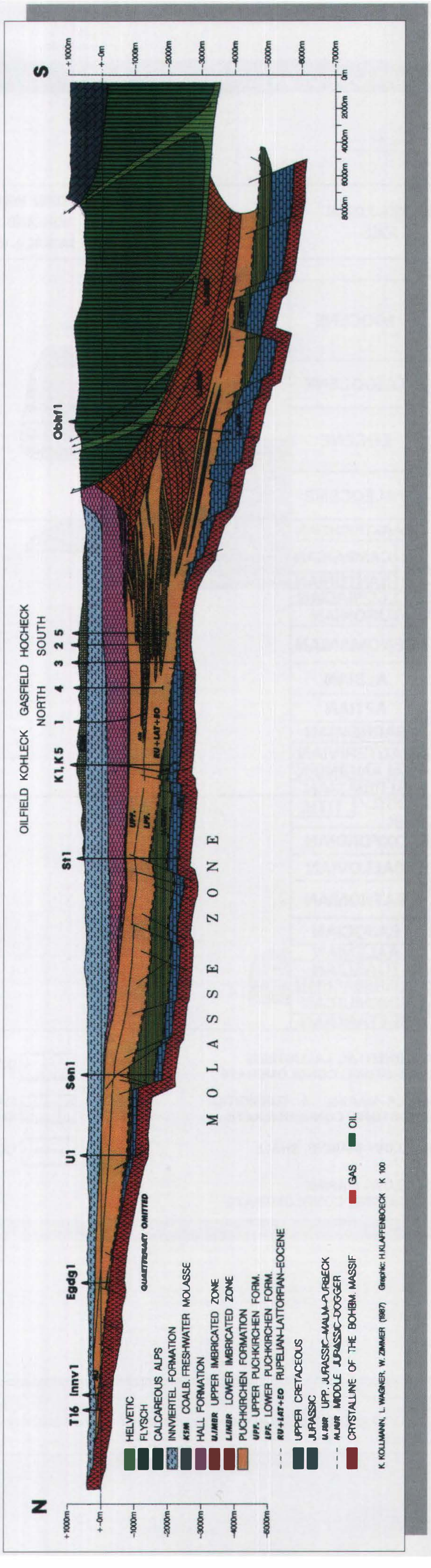


Fig. 8.
Geological cross section through the western part of the Molasse Zone of Austria.

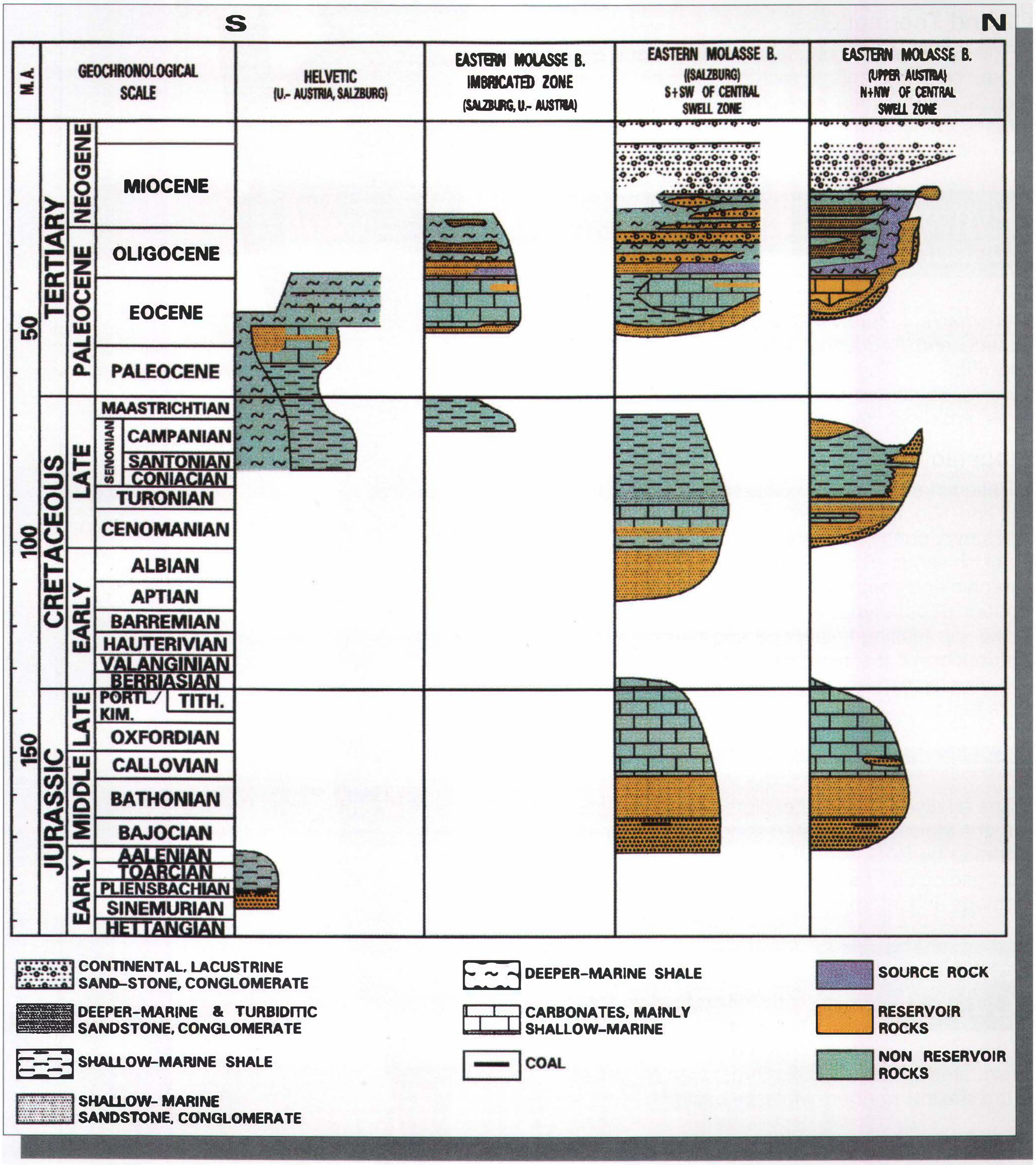


Fig. 9.
Chronology and lithostratigraphic columns of the Molasse Basin and its Mesozoic subcrop in Upper Austria and Salzburg.

The Northern Alpine Thrust Belt
(Calcareous Alps, Flysch Zone, Helvetic Zone)

General Remarks

Within the Austrian Calcareous Alps and the Flysch Zone, 32 wildcats have been drilled in a 740-km-long, 55-km-broad area.

Twenty-four wells were located in the Flysch Zone and eight in the Calcareous Alps. One well investigated Helvetic Jurassic sequences. One economic gas-condensate field was found in Höflein in a Middle Jurassic sequence below the Flysch Zone. An oil discovery was made in an autochthonous Cretaceous sandstone below the Calcareous Alps, a gas discovery within Calcareous Alpine nappes. Both remain uncommercial up to now. The depth of the Alpine wells ranges from 1,300 m to 6,028 m.

A grid of seismic 2-D profiles, two 3-D surveys, a complete set of gravity and magnetic maps, and extensive geological surface mapping give a sufficient overview of the tectonics and depth ranges of many regions.

Wells and seismic sections show a gentle southward-dipping of the basement below the northern Alps and a long-distance thrusting, especially evident in the Berndorf 1 and Molln 1 wells.

The source rocks for Alpine plays are lower Oligocene "Schöneck fish shale" and shales of Rupelian age (Molasse) in the west, and Malmian marls (Autochthonous Mesozoic) in the east. Some Calcareous Alpine formations could contribute hydrocarbons if they have a suitable thermal history.

The targets of Alpine exploration are the intra-thrust Alpine nappe system and the sub-thrust autochthonous Mesozoic and basal Tertiary Molasse (Fig. 10).

Intra-Thrust Targets

Calcareous Alps

In the Calcareous Alps, fractured Hauptdolomit analogous to the hydrocarbon-rich sub-Neogene floor in the Vienna Basin and the Wettersteindolomit are expected to be abundant reservoir rocks.

Cap rocks may be pelites and tight sandstones of the Cretaceous–Paleocene Gosau Group, shales of the Lunz Formation, or shales and evaporites of the Werfen Formation (Fig. 11). Potential traps are folds, imbricates, and unconformities below the transgressive Gosau beds.

The Molln 1 well tested gas from a 300 m thick column below 3,000 m in a fractured Middle Triassic limestone. In the Urmannsau 1 well, oil shows within the Triassic to Neocomian Calcareous Alpine sequences point to a possible accumulation of hydrocarbons in structures nearby.

Flysch Zone

In the Flysch nappes no oil or gas has been found to date, because of lack of traps or suitable porosities.

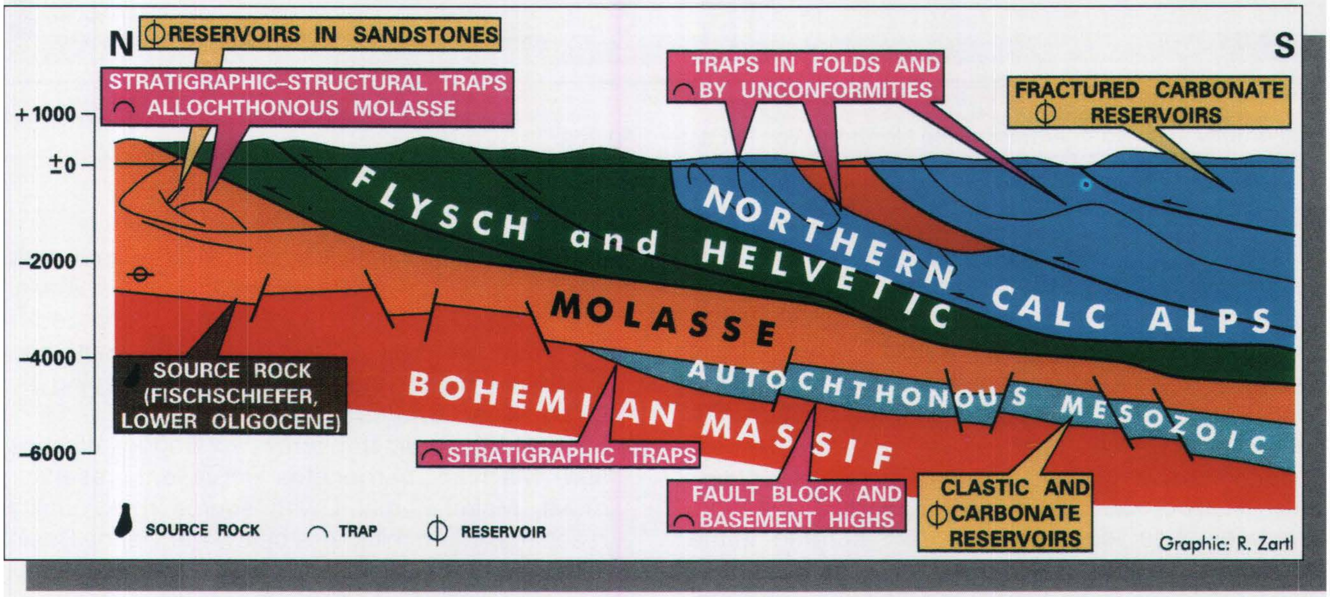


Fig. 10.
Schematic play concept of the Northern Alpine Thrust Belt.

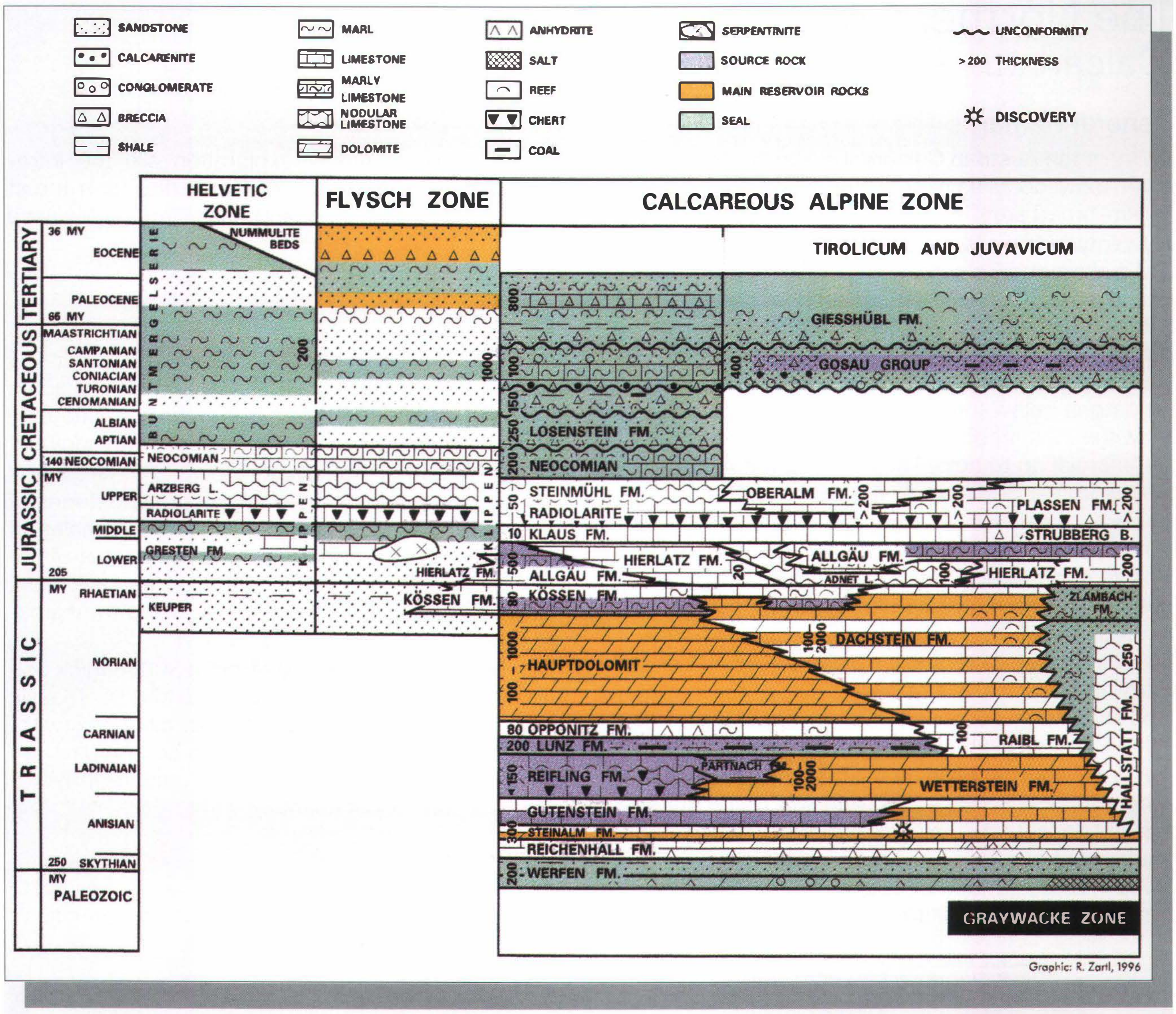


Fig. 11.
Stratigraphy and hydrocarbons of the Northern Alps in Eastern Austria.

Helvetic Zone

Reservoir conditions could exist in the Helvetic Middle Jurassic clastics and Malmian to Cretaceous carbonates in western Austria. In the Hindelang 1 well in Germany (TD. 5,653 m) near the Austrian border, gas was tested within Lower Cretaceous limestones of the Helvetic nappe system ("Säntis" nappe s.l.) below the Calcareous Alps and Flysch, but no production was possible because of low permeabilities. In other German wells porosities in Helvetic Jurassic members have been observed, but only water saturated. In the well Vorarlberg-Au 1 (TD. 4,297 m), Jurassic formations were found to be tight. The Helvetic units reach remarkable thicknesses and large distribution in Vorarlberg. Many surface shows of hydrocarbons have been observed in the Vorarlberg area.

Sub-Thrust Targets Below the Alps

- A spur of the Bohemian Massif extends far under the Alps and is covered only by Molasse with basal clastics of Oligocene or Eocene age. Source rocks are probably Molasse marls. Toward the south and southeast on the basement spur, onlapping by Mesozoic sediments is expected.
- East of this spur, transgressive Dogger clastics and Malmian carbonates represent reservoir rocks. Malmian marls with source rock quality reach maximum thickness below the Vienna Basin (1,000 m in the northern Vienna Basin). The Höflein gas-condensate field (depth about 3,000 m) lies within this area. The main reservoir is an uppermost Dogger dolomitic cemented sandstone with abundant chert.

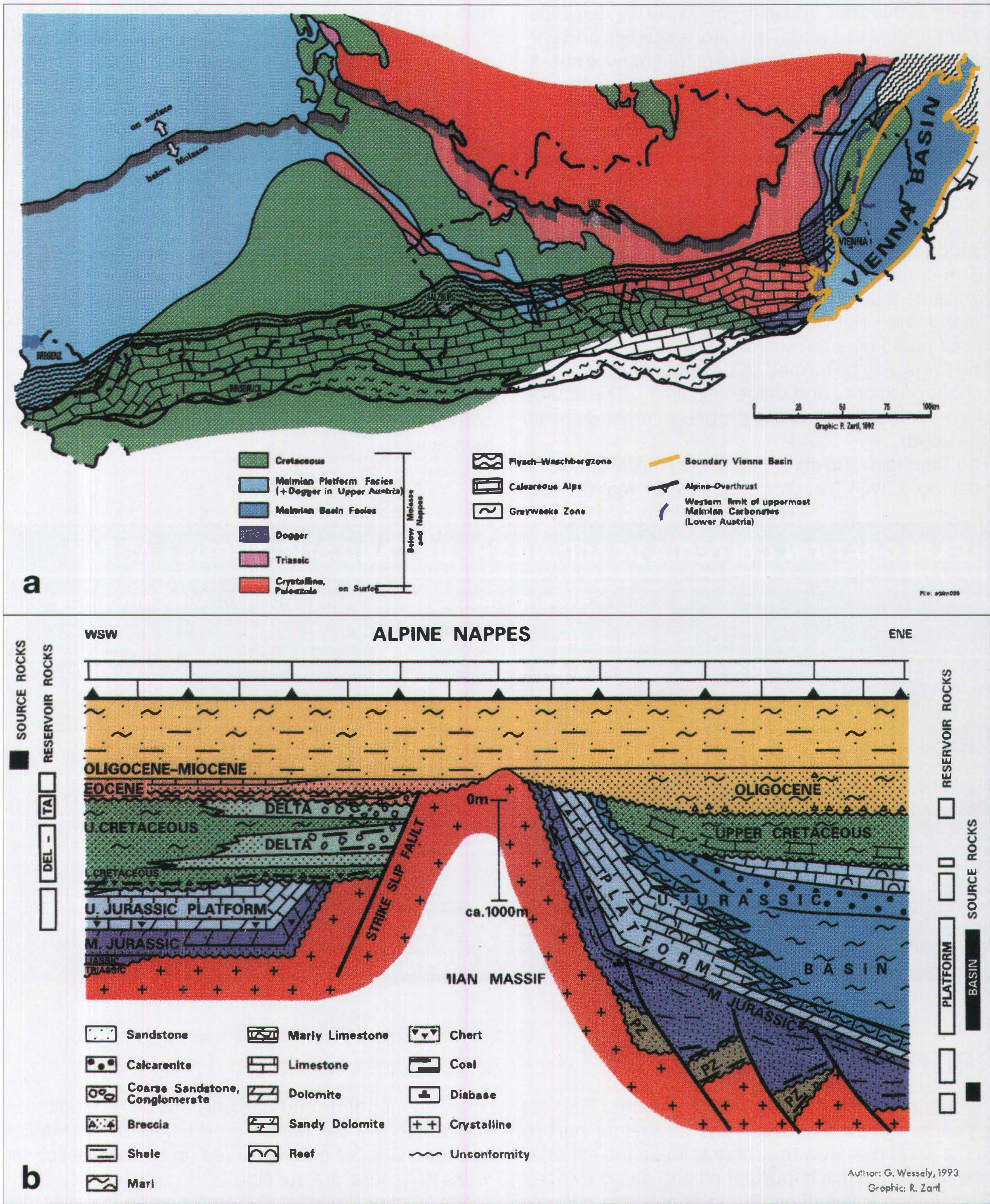


Fig. 12.
The Autochthonous Mesozoic.
a) Sub-crop map of the Autochthonous Mesozoic below Molasse and nappes.
b) Stratigraphic scheme of the Autochthonous Mesozoic and Molasse covering the southern Bohemian Massif.

- West of this spur, Triassic (only in the westernmost part) to Jurassic and Cretaceous clastics and carbonates lie on a stable platform that may be subdivided into zones of preserved sediments and zones of inversion and erosion along swells. The autochthonous cover can be followed by seismic till to the southern border of the Calcareous Alps. Within an uppermost Lower Cretaceous sandstone overpressured oil was discovered in the well Grünau 1 at a depth of about 4,900 m. The initial production was 117 t/d but soon it decreased. The cumulative production was 3,466 t of oil. A zone of thick Upper Cretaceous deltaic clastics along the southwestern flank of the Bohemian spur could be a further target.

The traps may be formed by basement highs, faults, pinchout positions, and diagenetic limits. The source rocks are Molasse marls and probably Jurassic shales to the south.

The Tannheim sub-thrust lead, the final target of the Hindelang 1 well (which could not be realized because of pressure problems), represents an extended basement high at a depth of about 6,500 m. According to seismic investigations the top of autochthonous Mesozoic is shallower in the eastern part of the Calcareous Alps (4,600–6,000 m) and deeper in the western parts, as in Salzburg and the Tyrol (6,000–7,000 m). In the west, in Vorarlberg, the basement rises in general toward the Rhein valley.

Exploration Criteria

Summarizing, we can conclude that the exploration density within the Northern Alps is very low.

Expected hydrocarbons are gas/condensate and oil; toward the south a generation limit may occur in source rocks of the autochthonous sub-Alpine sediments. Exploration has been in progress, in some cases to a rather mature stage (for example targets around Tannheim/Hindelang, Grünau, Molln, or Urmannsau).

EXPLORATION CRITERIA IN ALPINE THRUST AND SUB-THRUST AREAS

	Allochthonous		Autochthonous
	Calcareous Alps	Helveticum, Molasse	
Reservoir	fair	poor	poor to fair
Seal	poor	fair	fair
Trap	poor	fair	fair
Pressure	normal	high to normal	mostly high
Seismic quality	mostly poor	fair to poor	fair to poor
Drilling frequency	very low	low	very low
Drilling depths	2000 -5000 m	3000 -5000 m	4600 - 7000 m
Drilling costs	moderate to high	moderate to high	very high

Vienna Basin

Although all parts of the Austrian Vienna Basin are under contract by OMV and to a minor part by RAG, a short overview may characterize the situation of exploration in this important oil and gas province.

The Vienna Basin (Figs. 3 and 6) is a maturely explored area. Although in shallow depths exploration has reached an advanced stage, there is a further remarkable potential in and around even older fields. Deep and ultra-deep targets are prospective for the future, but today are not viable economically. From the view of source and generated hydrocarbon potential a large amount of oil and gas may still be producible in addition to the cumulative production of 740 MMBls of oil and 2 Tcf of gas produced up to now. Reservoir rocks in general are suitable.

The Vienna Basin is an intramontane basin at the boundary area between the Alps and the Carpathians. It opened by a pull-apart effect in early Miocene time. The main subsidence occurred in middle Miocene time. The cause of extension is a retarding of the Alpine nappes in the region of the spur of the Bohemian Massif west of Vienna and an unhindered advancing of the Alpine-Carpathian nappes NE of Vienna, in an area of repeated subsidence since Middle Jurassic time. Whereas the nappes stopped west of Vienna in Karpatian time (early Miocene), toward the NE along the Carpathian bend, movement continued. Large faults and deep depocenters of sediments were the result of the pull-apart effect. Large amounts of pelites, sandstones, and some gravel filled the basin, in some cases by deltaic sedimentation (Fig. 13).

In the Vienna Basin three floors have to be considered (Fig. 14). The first floor is the Neogene basin fill, the second floor consists of the allochthonous Alpine-Carpathian nappe system below the Neogene sediments, the third floor is the autochthonous basement and its Mesozoic cover and the Tertiary Molasse below the nappes.

First Floor

There is a good chance for reactivating areas of older fields in the first floor (Matzen, Aderklaa, southern Vienna Basin, Mistelbach block and its eastern and southern borders in the northern Vienna basin) by:

- Advanced seismic resolution of fields and pools and their surroundings especially by 3-D seismic surveys. The results of a 3-D survey in the Matzen area are excellent and an example, of how to proceed.
- Reinterpretation of logs and application of complex interpretation, including sequence stratigraphy and new developments in structural geology.
- Horizontal drilling in cases of oil-bearing strata with heterogeneous porosity distribution (for example lower Miocene sandstones along the crest of the Matzen – Spannberg ridge).

All these steps are already in progress and promise profitable results.

Second Floor

Several tectonic belts cross the Vienna Basin from the Alpine to the Carpathian border below the Neogene basin fill: The Waschberg Zone, the Flysch Zone, the Calcareous Alpine Zone, and the Central Alpine Zone. The stratigraphic range of these zones is depicted in Fig 15.

Only restricted parts of the Waschberg Zone are covered by Neogene sediments of the Vienna Basin, and the structures are difficult to reveal.

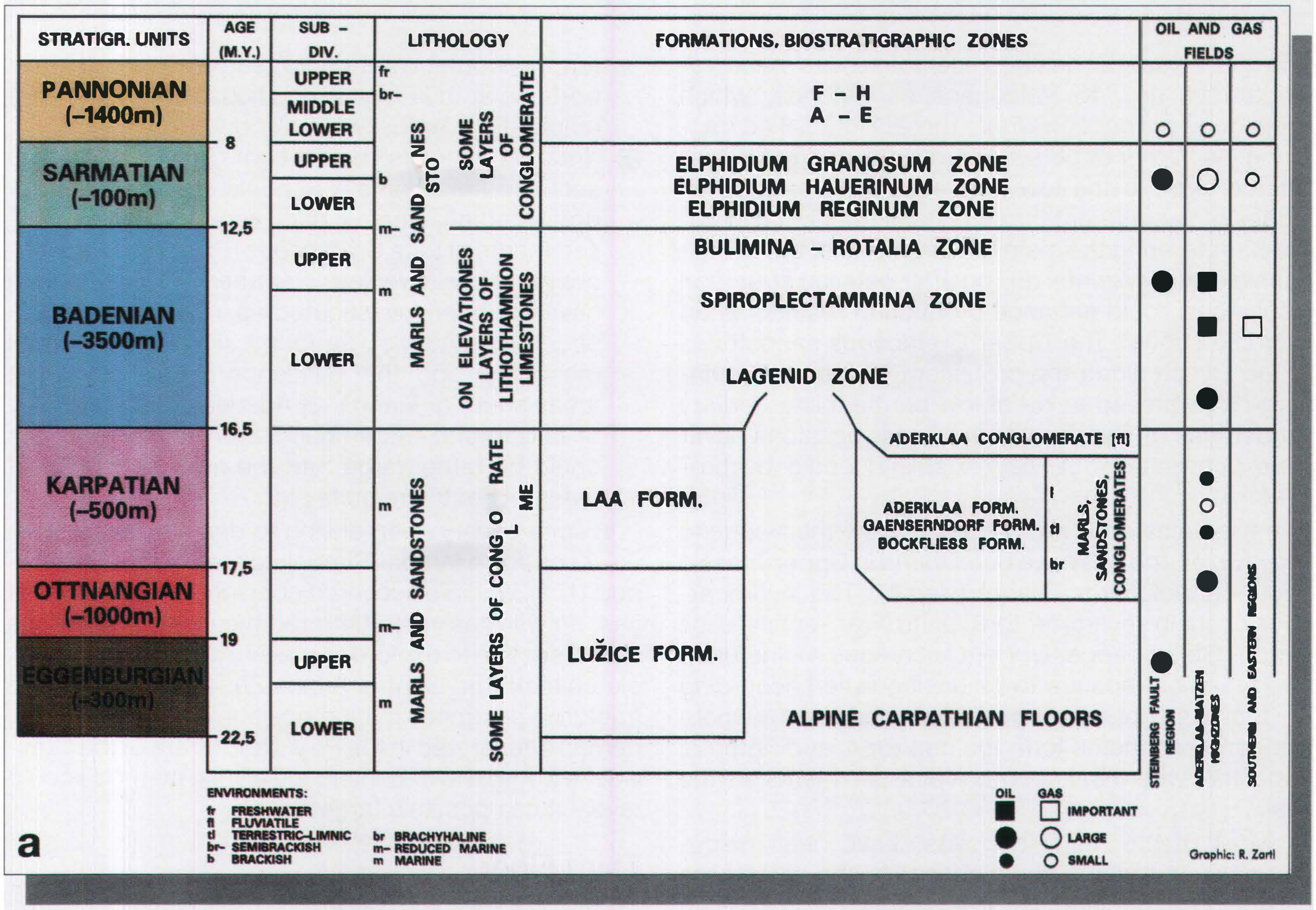


Fig. 13.
Stratigraphy of the Vienna Basin: Neogene.

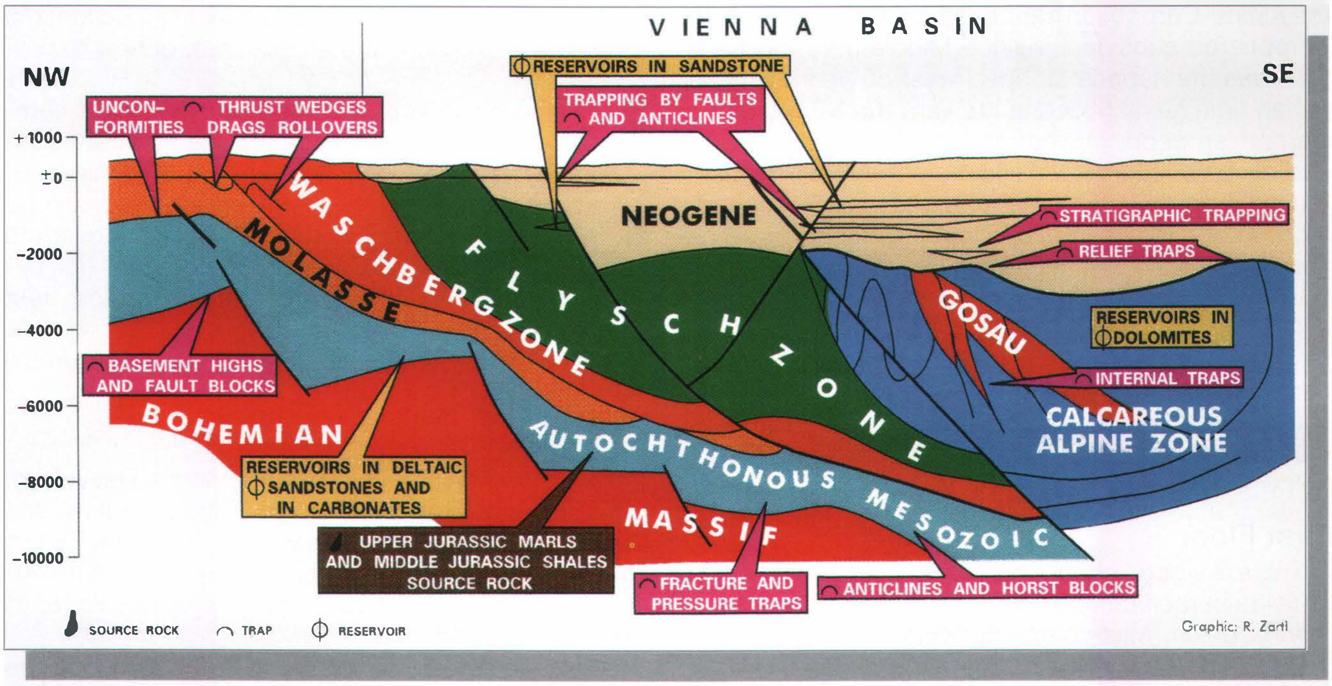


Fig. 14.
Schematic play concept: Molasse – Waschberg Zone – Vienna Basin.

In the Flysch Zone the reservoirs have been restricted till now to Paleogene sandstones, which show good production where there is intensified fracturing. As further targets, fracture zones are to be considered even in the low-permeability Tertiary sandstones of the different thrust units of the Flysch in uplifted areas along the main fault systems of the Mistelbach block. Horizontal drilling after detailed structural resolutions could enhance production results, as an example shows. The Upper Cretaceous sandstones of the Flysch along the prominent Matzen – Spannberg ridge proved to be of low permeability. Tertiary sandstones of Flysch units in deeper positions never were penetrated but may exist and could be prospective.

In the Calcareous Alpine Zone below the Neogene (Fig. 15), oil and gas have been found in Upper Triassic fractured dolomites (Hauptdolomit). The hydrocarbons occur in several tectonic units (Frankenfels/Lunz nappe, Göller nappe, Upper Calcareous Alpine unit). Two types of traps are to be distinguished according to the kind of sealing: "relief deposits", where Neogene sediments form the cap rock; and "internal deposits", where Calcareous Alpine sediments are the seal.

- Most of the "relief deposits" have been discovered, but new highs adjacent to the older ones could be identified by new seismic or processing and interpretation methods, as recent examples show. In high zones where steep dolomite laminae cross the structure, as in Aderklaa or in Baumgarten, horizontal wells could "sample" the reservoir portions at their higher positions, which were not reached by vertical wells till now.
- "Internal deposits" below tight Calcareous Alpine sections (for example Schönkirchen – Gänserndorf Übertief), where a thick sequence of "Gosau" sediments of Late Cretaceous–Paleogene age unconformably overlies fractured Hauptdolomit) have not been investigated as intensively as high structures and may be found along the Gießhübl monocline and the Glinzendorf syncline in the areas south of Vienna, of Aderklaa – Raasdorf, or of Tallesbrunn – Ebenthal. Reserves mainly of gas could be rather large, but the risks and costs of these projects are quite high.

In spite of very deep drilling to depths greater than 6,000 m (for example Schönkirchen T 32, Gänserndorf ÜT1), which discovered considerable amounts of gas, no well has yet penetrated the entire Calcareous Alpine section to explore all possibilities within the single units. In the Central Alpine Zone, Middle Triassic fractured dolomites in high positions could yield gas, perhaps generated in the Paleozoic strata of the Graywacke Zone below. Enhanced seismic methods could reveal these possible targets.

Third Floor

This floor has been drilled by only four wells in three positions: Aderklaa U T1, 6,630 m; Zistersdorf ÜT1 a, 7,544 m; ÜT2a, 8,533 m; and Maustrenk ÜT1, 6,563 m. The geologic preconditions for these pro-

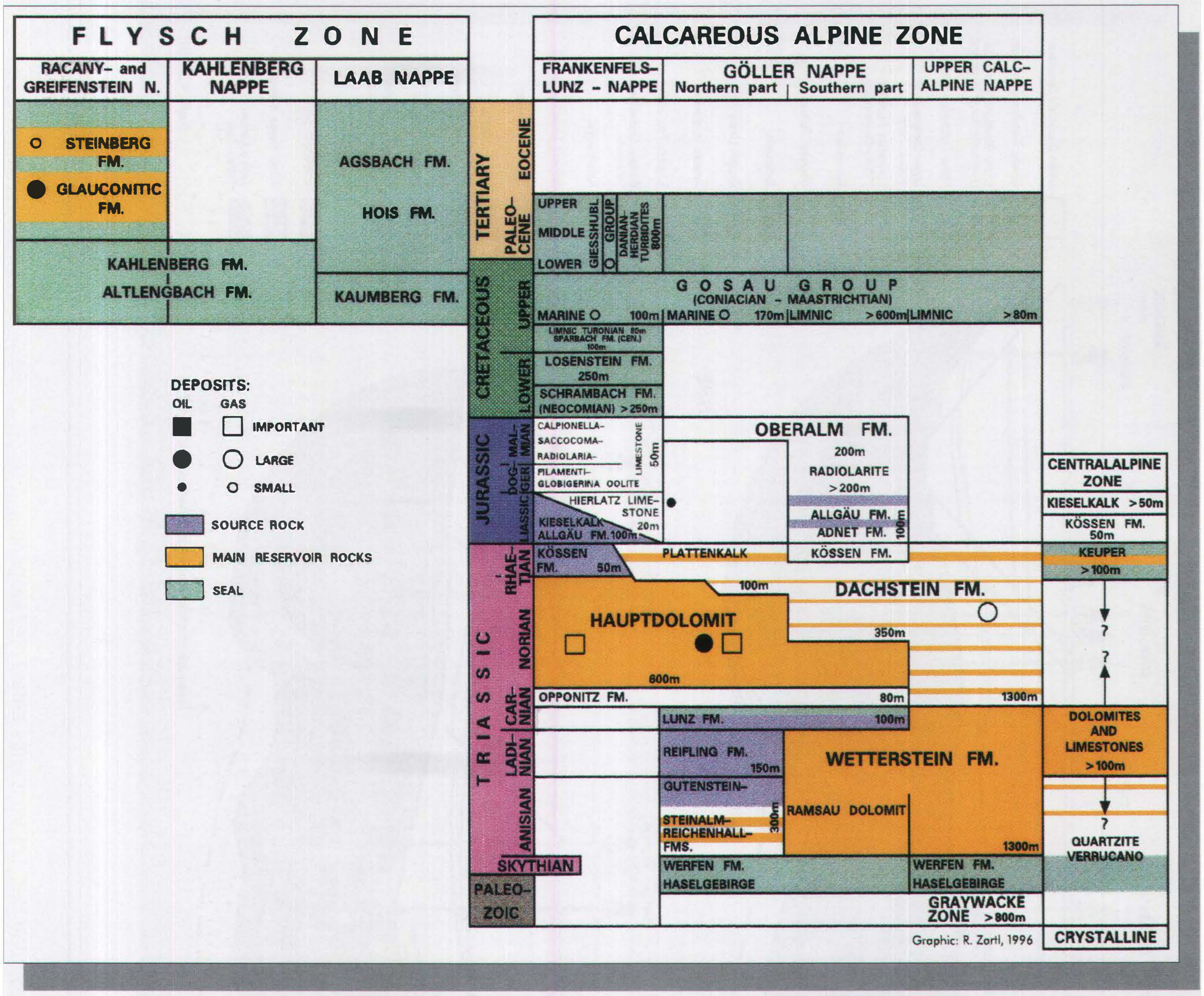


Fig. 15.
Stratigraphy of the Vienna Basin: Thrust units below the Neogene.

jects were their structural aspects, the fact that the positions were close to the source rock mainly responsible for the Vienna Basin hydrocarbons, and the expectation of reservoirs like those in the equivalent drilling profiles in the foreland.

None of these wells encountered conventional reservoir conditions. The well Zistersdorf ÜT1 seemed to have made a gas discovery in a Malmian limestone as indicated by a gas kick at 7,544 m (about 46 MMcfd were calculated). The well collapsed and the nearby projected replacement well Zistersdorf ÜT2A did not penetrate the gas occurrence again.

A new prospectivity arises by porosity investigations of the matrix: porosity of Malmian marls of up to 7% obviously was caused by overpressure due to gas generation. Fracture porosity may also exist. Maustrenk ÜT1 produced some overpressured oil from a thrust zone.

The extended outlook is to find the expected conventional reservoirs, but also unconventional reservoirs, which have low permeability but are very thick. High gas saturation and overpressure is characteristic. At the present time, no economic condition exists to justify continuing this ultra-deep exploration.

Mattersburg Basin

The Mattersburg Basin is a small subbasin of the Vienna Basin, opening at its south-eastern border (Fig. 6). The basement is mainly composed of metamorphic crystalline rocks of the Lower Austro-Alpine Unit.

As it did in the Vienna Basin, deposition started here in early Miocene time (Ottnangian, Karpatian) with terrestrial sandstones, gravel, coal, and shales (Brennberg group). These sediments are only developed in the southern and eastern part, pinching out downdip

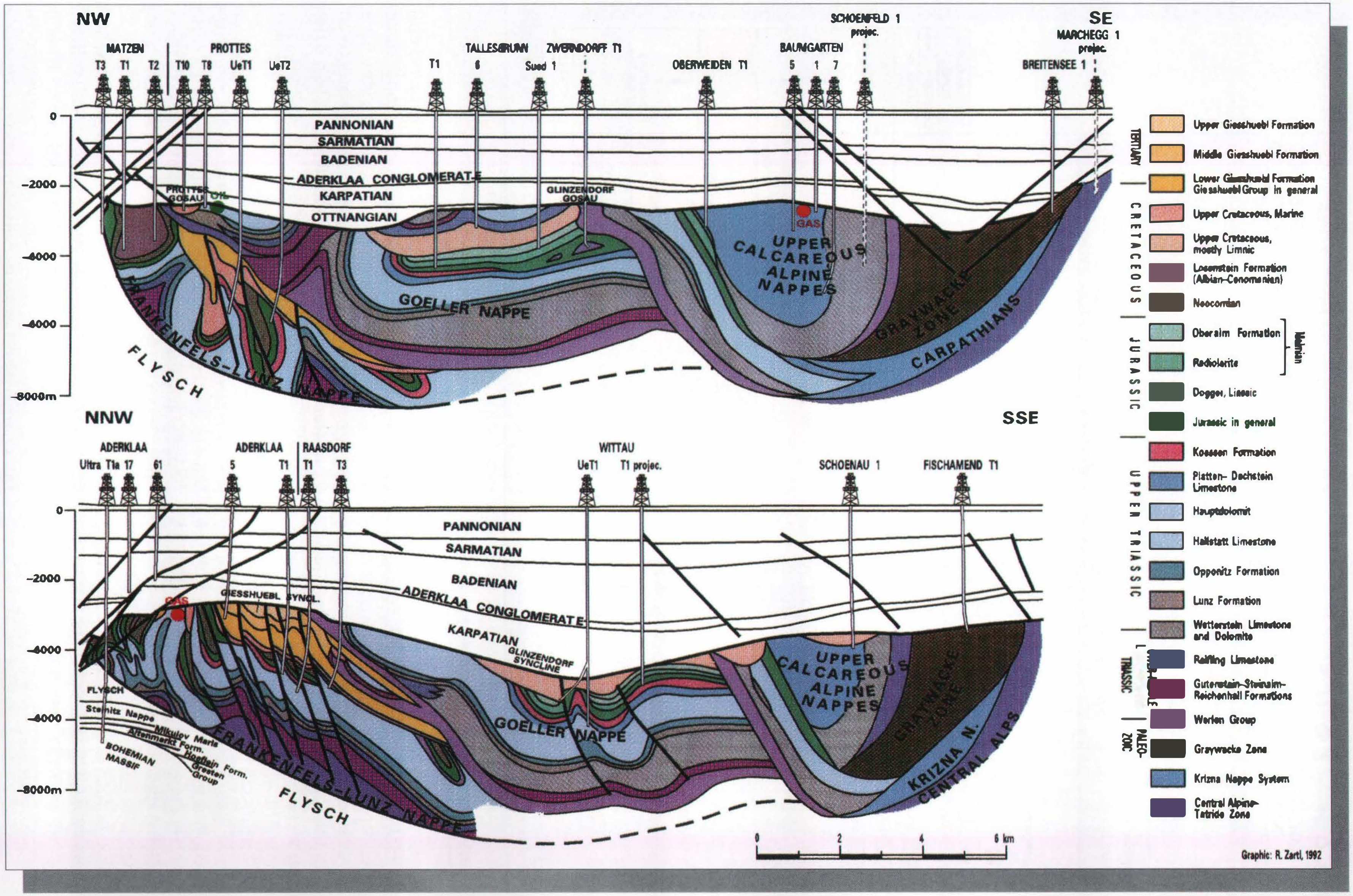


Fig. 16.
Geological sections through the Calcareous Alpine floor of theVienna Basin: Thrust units below the Neogene.

toward the center of the basin. The main part of the basin fill is middle Miocene (Badenian, Sarmatian, Pannonian) with marls, sandstones and – at the borders – carbonates.

The basin is bounded to the southwest by large faults, causing a subsidence of the basin down to 2500 m north of Mattersburg. Toward the east, the basin is separated from the Pannonian Basin by the north–south-striking Rust Ridge, with its parallel-striking marginal faults.

A grid of seismic lines and one exploration well did not reveal structures suitable for hydrocarbon accumulation. Perhaps onlapping positions exist. Coals of the Brennberg group in the southern part could provide biogenic gas. The Mattersburg Basin has been relinquished by OMV in 1983.

Pannonian Basin System

Western Pannonian Basin

The westernmost part of the Pannonian Basin extends into the area of Northern Burgenland and separately into the area of Southern Burgenland and Styria, interrupted by the basement elevations of the highly metamorphosed Penninic Mesozoic series of Rechnitz (Fig. 6).

In Northern Burgenland the western border of the Pannonian Basin is the swell of Bruck and the Rust Ridge, in southern Burgenland and Styria the South-Burgenland swell.

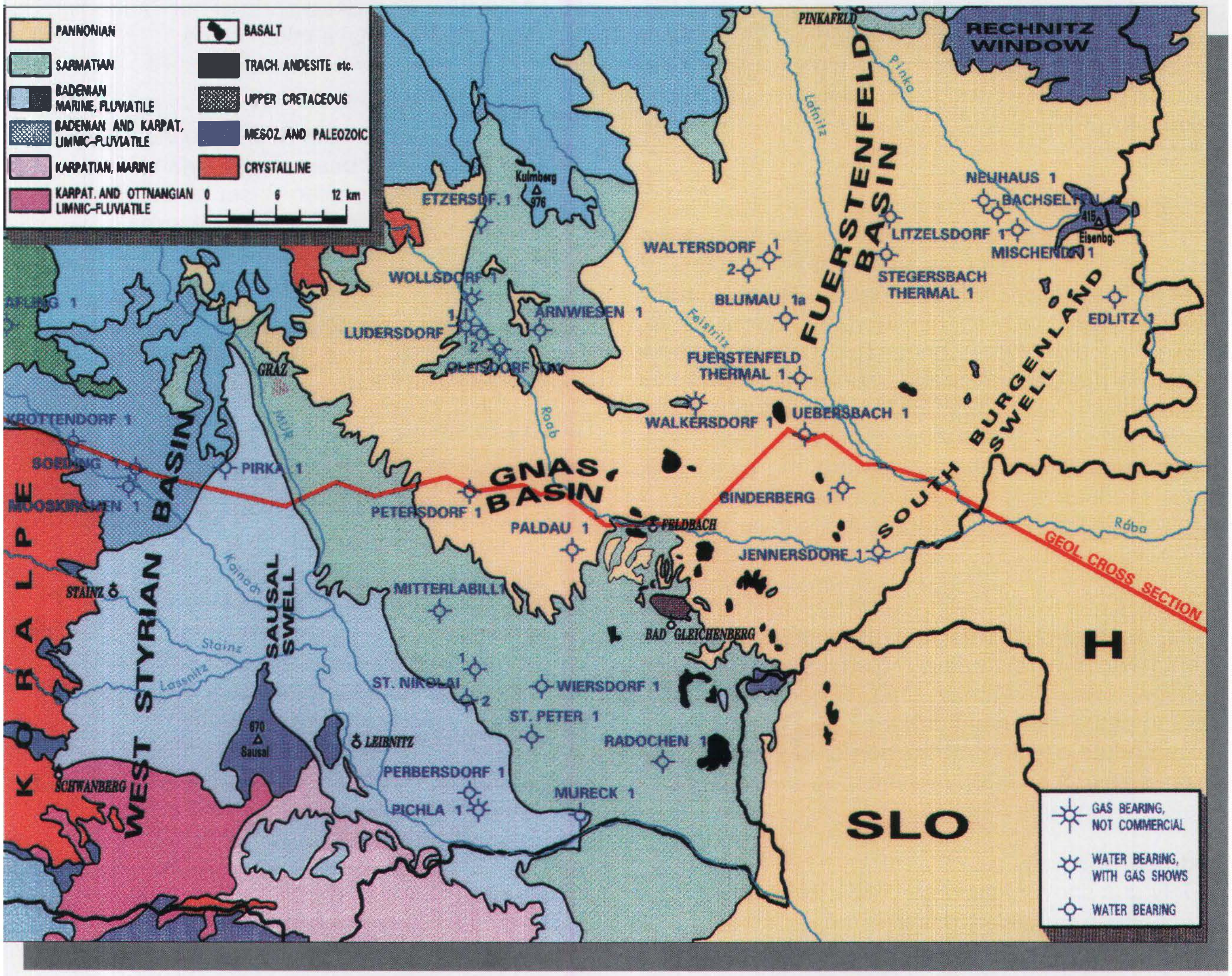


Fig. 17.
Geological Map of the Styrian Basin.

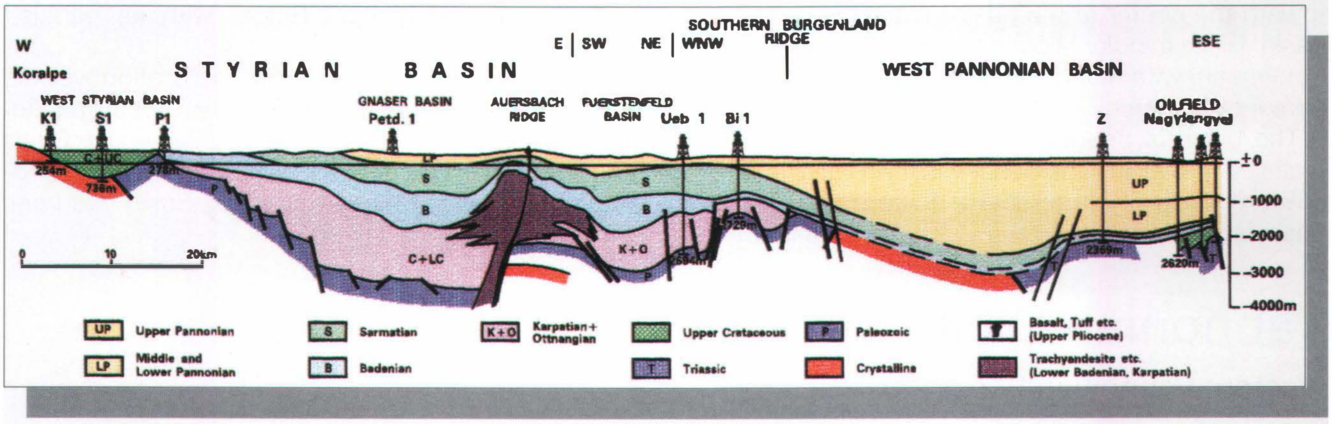


Fig. 18.
Geological section through the Styrian Basin and Western Pannonian Basin.

Basement

In northern Burgenland (mainly "Seewinkel") the basement is composed of the crystalline rocks of the Lower Austro-Alpine Units. In Southern Burgenland and Styria, beside metamorphic Central Alpine Mesozoic and crystalline complexes, slightly metamorphic Paleozoic phyllites and carbonates form the basement.

Tertiary Basin Fill

In the area of the Pannonian Basin, lower and lower middle Miocene sediments are not as thick and complete as in the Styrian and the Vienna Basin. In many areas they exist only as thin littoral remnants, for example the Leitha Limestones. The main subsidence started in the Pannonian (late middle Miocene) time and brackish, later limnic or fluvial marls and sandstones and some gravel were deposited. These sediments considerably thicken toward the east, while some sandstones pinch out updip toward west. In many cases Pannonian strata rest directly upon crystalline basement.

Tectonics

The westernmost part of the Pannonian Basin was characterized by extended regional subsidence, especially during Pannonian time. A gently downward dipping of the basement and the basin fill exists without remarkable faulting at the border of the basin. The basin is more than 2000 m deep in some cases at the Austrian/Hungarian border.

Hydrocarbons

Only gas shows have been reported in wells up to now. Sixteen wells were drilled in the Pannonian Basin and its border zones without hydrocarbon discoveries, not even within a basement structure in the southern part of Northern Burgenland. Along the Southern Burgenland swell, Devonian carbonates contain fresh water at shallow depths. Some prospects could occur in pinchout traps of Pannonian sandstones. The sources of hydrocarbons are not clear. Migration from deep parts of the Pannonian Basin in Hungary may have taken place.

Styrian Basin

The Styrian Basin (Fig. 17), like the Vienna Basin, is a Miocene pull-apart basin. The Styrian Basin is separated from the Pannonian Basin by the Burgenland Swell. Twenty-eight deep oil or geothermal wells have been drilled in Styria.

Basement

The basement is composed of high-grade metamorphic crystalline and low metamorphic Paleozoic phyllites and carbonates.

Tertiary Basin Fill

The Styrian Basin started to form in early Miocene (Ottnangian) time. In flood plains and swamps, shale, sands, and breccias with widespread coal rich in bituminous layers were deposited. In Karpatian time the sea ingressed from the Pannonian Basin. The center of the basin was filled with turbiditic and mass flow conglomerates, shales, and sandstones. Synchronously with the subsidence and extension, andesitic volcanics arose in the southern and central basin. An unconformity separates the Karpatian and Badenian deposits. In early Badenian time the sea reached its largest extent. The central basin's deep marine turbiditic conglomerates, shales, and sandstones were deposited. Along the margins of the basin and on local highs on the slopes of volcanic islands, coral and red algae reefs evolved. The volcanism continued in early Badenian time, but the activity shifted to the north.

The late Badenian and the Sarmatian ages were characterized by regression of the Pannonian Sea. In Sarmatian and Pannonian time the Styrian Basin was separated from the Pannonian Basin. Basaltic volcanics erupted at the end of the Pliocene Epoch.

Tectonics

The Styrian Basin is subdivided by swells into several separate sub basins (Fig. 18). The fault pattern consists of a conjugate southwest–northeast- and southeast–northwest-trending system. The main extensional activity occurred in Karpatian time. The faults became integrated in left lateral transpression in Late Miocene time.

Hydrocarbon Occurrences

No economic hydrocarbons have been found in Styria. Minor amounts of gas have been produced from a shallow reservoir in the Badenian limestones. Traces of oil have occurred in hot water geothermal wells from Paleozoic carbonates. Potential source rocks appear in Ottnangian and Karpatian strata in outcrops and wells. Basin modelling studies predict that oil and gas has been generated.

Maturation of Tertiary Basins in Austria

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Introduction

The formation of petroleum from kerogen in source rocks is a function of temperature and time. Therefore, the knowledge of the thermal evolution of sedimentary basins is of great importance for petroleum exploration. With respect to petroleum generation, organic matter may be immature, mature, or overmature. Mean random vitrinite reflectance (Ro) is a widely used maturation parameter. Although there is no unequivocal correlation between vitrinite reflectance and hydrocarbon generation, it is generally accepted as a rule of thumb that oil is generated from kerogen in a reflectance range of about 0.6 to 1.3 %Ro ("oil window").

Because thermal (and maturation) histories of Tertiary basins in Austria are intimately related to the geodynamics of the Eastern Alps, the late Alpidic (Eocene to Miocene) evolution ofthe Eastern Alps is briefly outlined as follows.

The Eastern Alps are composed of the Austroalpine nappe system, representing the northern margin of the Adriatic plate, and the underlying, generally oceanic Penninic units. The largest outcrop of Penninic rocks, which were overridden by Austroalpine units during Cretaceous to early Tertiary subduction, is in the Tauern Window.

Late Eocene continental collision of the Adriatic and European plates caused crustal shortening within the Eastern Alps and the formation of the Eastern Alpine foredeep along their northern margin. In Oligocene and early Miocene times, Alpine units were thrust over sediments of the southern margin of the foredeep (the Molasse Basin), which is a typical cold foreland basin.

Final compression across the Eastern Alps was accommodated by lateral movement of crustal blocks to the east along sinistral northeast (e.g., Noric Depression) and dextral southeast trending (e.g., Periadriatic Lineament) strike-slip faults and led to the exhumation of the Penninic windows. Transtension, accompanied in some instances by fault steps, caused the formation of pull-apart basins (the Vienna Basin, Fohnsdorf Basin, and Lavanttal Basin).

However, extension also occurred within the eastward-moving crustal blocks. This resulted in the formation of the Styrian Basin. Miocene subalkaline-alkaline volcanic activity in the Lavanttal and Styrian Basins is contemporaneous with major Miocene extension. A second Pliocene-Pleistocene volcanic event produced nephelinitic/basanitic lava flows in the Styrian Basin.

The thermal histories of the above-mentioned basins are very different. The Vienna Basin formed on top of the Alpine overthrust. Consequently the thermal conditions before middle Miocene extension were characterized by low heat flows. Probably basin extension was restricted to shallow crustal levels ("thin-skinned") and did not change the thermal structure of the mantle lithosphere. This may explain the lack of a thermal anomaly in the Vienna Basin area.

Basins in "back-arc position" are located on thin crust (e.g., Styrian Basin) and are characterized by high heat flows. Magmatism in Oligocene (along the Periadriatic Lineament) and Miocene times accentuated this situation. Rapid uplift of the Penninic sequence of the Tauern Window in Miocene times modified the thermal pattern and caused heating of Tertiary basins in the central part of the Eastern Alps.

By late Miocene and Pliocene times local compression along the Periadriatic Lineament was followed by northwestward thrusting of the northern Karawanken over sediments of the Klagenfurt Basin, which was formed in Sarmatian to Pliocene times, probably by a combination of local pull-apart and the load of the overthrust units.

Thermal and Maturation Histories of Tertiary Basins

Eastern Alpine Foredeep

Sediments of the Eastern Alpine Foredeep occur north and underneath the Alpine nappe system. Oil and gas fields are located in Upper Austria north of the thrust front in Eocene and upper Oligocene sediments and in underlying, autochthonous sediments of Mesozoic age.

Coal seams and coaly layers occur in different stratigraphic levels within and beneath the Molasse sediments (Fig. 19). Carboniferous anthracites were drilled only in Hollabrunn 1. In Lower Austria, deltaic sequences of Doggerian age host intermittently thick coal seams in the Klement (4,000 m depth), Mauerbach (2,400 m), and Hollabrunn (1,650 m) area. Coals of a similar age also occur in Upper Austria. Eocene coals were penetrated by many wells at the base of the Molasse in Upper Austria (e.g., Hocheck 3, Grünau 1). The rank of Doggerian and Eocene coals depends on the depth of burial. A vitrinite reflectance of 0.6 %Ro (defining the boundary between Braun- and Steinkohlen, according to the German classification) is reached at a 3,500 to 4,500 m depth. Shallow Neogene lignites represent a final coal-forming phase.

Because of low paleo-heat flows, coalification gradients are generally low in both the autochthonous and the allochthonous Molasse. Coalification of the allochthonous Molasse (e.g., Oberhofen 1) probably ended during the early stages of Oligocene to early Miocene overthrusting.

Potential sources for oil (Lattorfian Fischschiefer and Rupelian Bändermergel formations) reached the hydrocarbon-generation stage beneath the Alpine nappes, but are generally immature north of the Alpine front. Therefore, the presence of oil fields north of the Alpine front indicates a long-distance migration from the south.

Beneath the northern part of the Alpine nappes, hydrocarbon generation started during early Miocene times as a result of deep burial due to the emplacement of the Alpine nappes (Fig. 19). Today, the oil window is located between 4,000 m and 6,000 m deep, and its depth increases towards the south. Locally, northward migration of hot deep fluids along faults may have triggered early Miocene hydrocarbon generation in front of the nappes. Gas generation occurs in areas with even deeper burial of the source rocks. This thermocatalytic gas fills Cenomanian and Eocene reservoirs.

It is important to note that a second, bacterial group of gases is of great economic importance and fills mainly upper Oligocene (Puchkirchen Beds) and lower Miocene (Hall Beds) reservoirs. Mixing of thermocatalytic and bacterial gases is well known.

Oligocene sediments, including Rupelian coals and alginite-rich bituminous marls with a vitrinite reflectance of 0.4–0.55 %Ro, occur in the Lower Inn Valley. They are interpreted as being parautochthonous Molasse. Basin models suggest that Oligocene/early Miocene heat flows in the fault-bounded basin were significantly higher (70 mW/m²) than in Upper Austria. This, and deep Egerian burial, resulted in the early generation of hydrocarbons.

Vienna Basin

The Vienna Basin is a post-Alpine pull-apart basin. The Neogene basin fill was deposited on an allochthonous stack of nappes during and after their thrusting over the autochthonous basement (Bohemian Massif), which is covered by Jurassic, Upper Cretaceous, and Tertiary Molasse sediments.

Autochthonous Malmian marls beneath the Vienna Basin are considered the main sources for hydrocarbons in the Austrian part of the Vienna Basin (Fig. 19). Additional Triassic and Paleogene rocks are discussed as a source for hydrocarbons in the Czech part of the basin. The (final) maturation of these sediments occurred during overthrusting of the Alpine-Carpathian nappes and was enhanced by the Tertiary subsidence of the Vienna Basin.

Heat flow in the central Vienna Basin ranges from 40 to 60 mW/m² and results in present-day geothermal gradients of 29±3°C/km. Basin modelling suggests that Tertiary heat flows were similar to or even lower than present-day values (Fig. 19).

Elevated geothermal gradients along the marginal faults of the southern Vienna Basin are due to hydrodynamic systems. Because of the relatively high heat conductivity of carbonates, the geothermal gradients within the Calcareous Alps in the basement of the Vienna Basin are distinctly lower than in the Tertiary basin fill.

Although Neogene heat flows are slightly higher in the Vienna Basin area compared with those in the Alpine overthrust in Upper Austria, the position of the oil window is similar (4,000 m to 6,000 m). This is due to the interplay of

1. higher coalification gradients in the Vienna Basin,
2. major uplift of the Calcareous Alps in Upper Austria, and
3. the fact that hydrocarbon generation from Malmian sources in the Vienna Basin area is associated with relatively high vitrinite reflectance values (0.7–1.5 %Ro).

Styrian Basin

No commercial hydrocarbon deposits have been detected up to now in the Styrian Basin, which forms part of the Pannonian realm, although sediments with some source potential occur in the lower Miocene section (Fig. 19).

The heat flow history of the Eastern Styrian Basin is governed primarily by Miocene magmatic activity. Heat flow during Karpatian and early Badenian times was up to 300 mW/m² near volcanic centers. The small-scale but extremely high heat flow maxima probably are a result of shallow magma chambers. After the end of magmatic activity, the heat flow decreased. This occurred first near volcanoes in the southern part of the Eastern Styrian Basin (e.g., Nikolai) and later in the central and northeastern part (Ilz – Walkersdorf).

Heat flow changes were due to the northward shifting of magmatic activity. In addition, heat flow decreased immediately after the end of magmatic activity in the Nikolai area, whereas it decreased only 1 m.y. after the end of magmatic activity near the Ilz-Walkersdorf volcano. Perhaps this indicates that the magma chamber beneath the northeastern volcano was larger and needed longer to cool. The influence of increased heat flow in the vicinity of the volcanoes disappeared at a distance of about 10 km and heat flow there approached background values (Fig. 19; about 120 mW/m²).

Since late Sarmatian times, heat flow has gene-

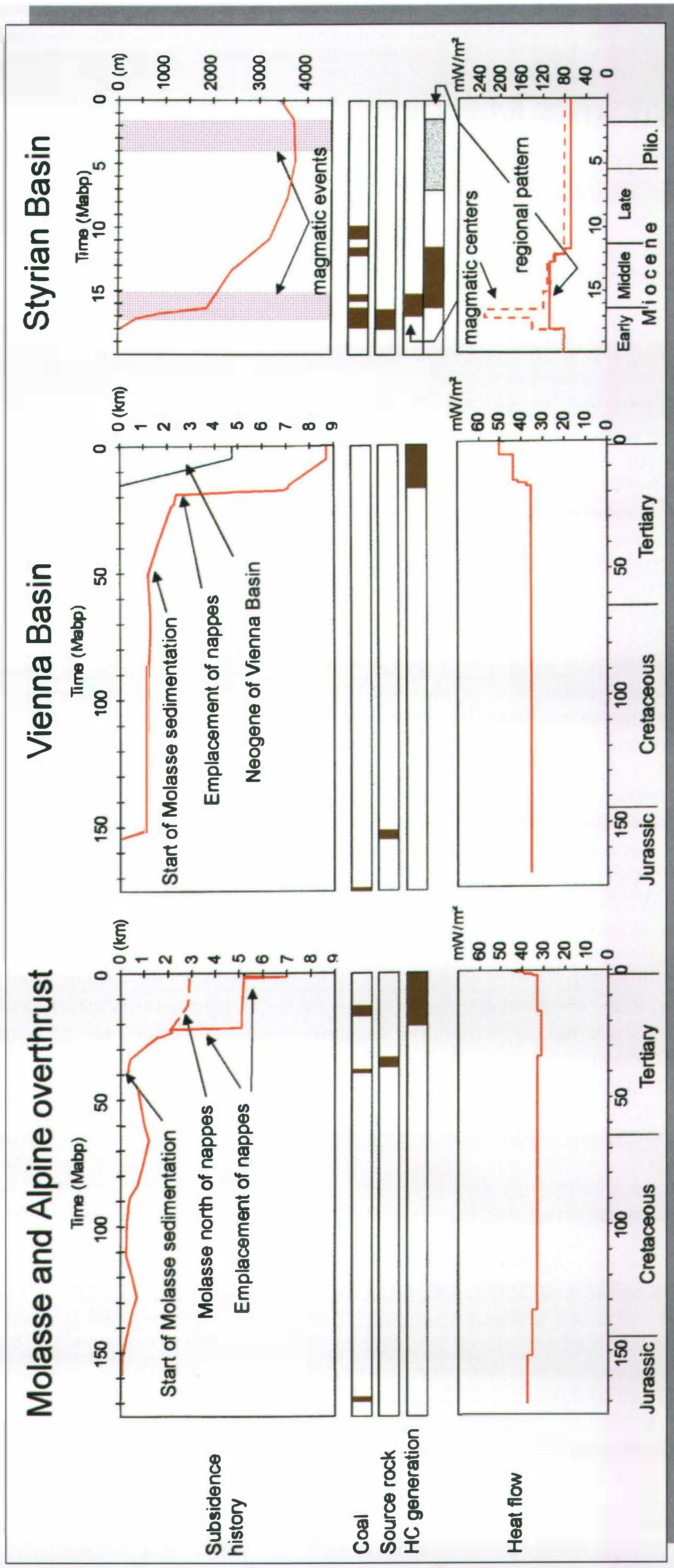

Fig. 19.
Burial history charts and heat flow models for the Molasse Basin, including the Alpine overthrust, for the Vienna Basin, and for the Styrian Basin.
The timing of coal and source rock deposition and of hydrocarbon generation is indicated. Note the early generation phase near magmatic centers in the Styrian Basin.

rally been in the range of 55 to 85 mW/m². This relatively high heat flow is due to the thin crust beneath the Styrian Basin. Present crustal thickness is about 25 to 30 km.

Present day formation temperatures in some wells indicate a slight increase in heat flow (5–10 mW/m²) during Pliocene or Quaternary times. Whether this is due to hydrodynamics (flow of hot waters from the depocenters to basement highs) or due to Pliocene–Pleistocene volcanism is not yet known. In any case, as a result of the great depth of the magma chambers (50–80 km), this latter volcanic phase had little influence on the regional heat flow pattern (Fig. 19). Elevated geothermal gradients above basement highs (e.g., 5.5°C/100 m in the Binderberg 1 well, which is now Spa Loipersdorf) are used for geothermal purposes.

As a consequence of extremely elevated heat flow and temperatures, hydrocarbon generation near the Miocene volcanoes occurred as early as Karpatian and early Badenian times (Fig. 19). These early generated hydrocarbons probably migrated to the surface and were lost. At some distance from the volcanoes, hydrocarbon formation may have continued into the early Sarmatian age. Depending on the depth of the potential source rocks and the kerogen type, oil or oil and gas were formed. Only hydrocarbons generated from late-middle Badenian time onwards had the chance to be trapped in lower and middle Badenian carrier rocks. Only small amounts of oil formed during late Miocene deep burial, because the peak Badenian and Sarmatian temperatures no longer existed.

Noric Depression and Occurrences of Tertiary Sediments along the River Enns

A series of small pull-apart basins formed during Karpatian and early Badenian times between the Tauern Window and the eastern margin of the Alps. The Fohnsdorf Basin, situated at the intersection of the Noric Depression with the major Lavanttal fault system, occupies an exceptional position amongst these basins. Here the thickness of the basin fill exceeds 3,000 m, whereas in most other basins it is only a few hundred meters.

Many of these basins host coal deposits. Their rank increases from the eastern part of the Noric Depression (lignites: 0.3 %Ro) to the Bruck – Leoben – Fohnsdorf area (subbituminous coals: 0.4 to 0.55 %Ro) and the Tamsweg Basin (coaly shales: 0.65 %Ro). Coals in the Fohnsdorf Basin contain an anomalously high methane content, in spite of their low maturity. Average methane production during coal exploitation was up to 50 m³ CH_4 /t mined coal. This makes the Fohnsdorf Basin interesting for coal bed methane exploration.

Vitrinite reflectance gradients decrease from west to east (Tamsweg: about 0.6 %Ro/km; Fohnsdorf: 0.15–0.2 %Ro/km; Upper Mürztal: 0.05 %Ro/km) and were probably locally elevated in the Leoben-Bruck area. A similar west–east trend can be observed in outcropping Miocene sediments in the Enns Valley. Their vitrinite reflectance values decrease from west to east from 0.65 to 0.3 %Ro respectively.

The advanced coalification of sediments located in the vicinity of the Penninic Tauern Window is a result of the rapid Miocene uplift of the latter, causing significantly raised heat flows (150 mW/m²).

Lavanttal Basin

Karpatian to Sarmatian coals in the Lavanttal Basin are lignites to subbituminous coals. The deep Schilting well encountered lower Sarmatian coals with 0.35 %Ro at 1,000 m depth. Because of the small depth interval it is not possible to make detailed comments on thermal history. No influence of Miocene volcanism on maturation can be observed (possibly because of poor outcrops).

Klagenfurt Basin

The 800-m-deep Klagenfurt Basin stretches over approximately 100 km in an east–west direction. Along the southern margin, the coal-bearing Sarmatian to Pliocene basin fill is deformed and overridden by pre-Tertiary rocks of the Northern Karawanken Mountains. Small erosional relics of Sarmatian age also rest on the Karawanken. Vitrinite reflectance of outcrop samples is 0.2 to 0.3 %Ro. The same values characterize coals, which have been sampled directly below the Karawanken overthrust and along the Periadriatic Lineament. Therefore, a thermal influence at the overthrust or at the Periadriatic Lineament in post-Sarmatian times cannot be observed. However, investigations in neighbouring Tertiary basins in Slovenia prove Oligocene and early Miocene thermal events along the Periadriatic Lineament.

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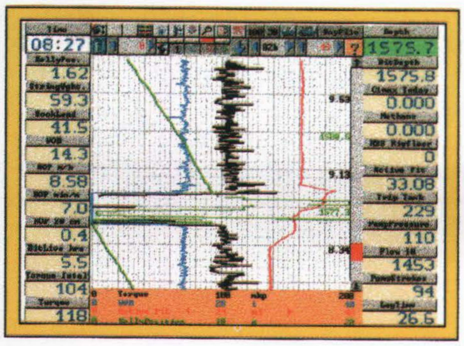
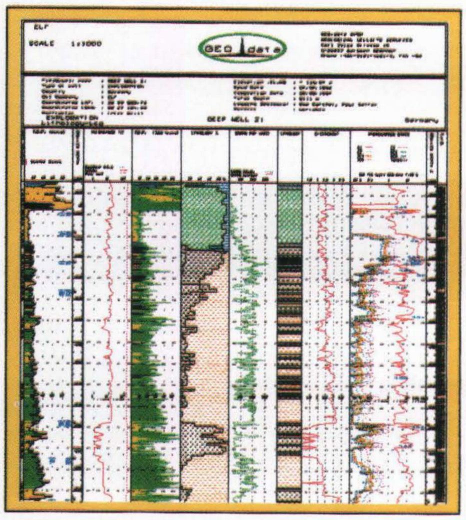
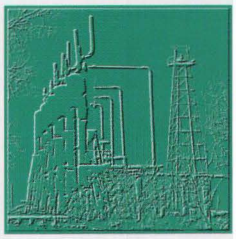




Geothermal Exploitation in Austria



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Exploitation of geothermal energy has been an object of consideration in Austria for a long time. However, it has only been applied to the Styrian Basin and the Molasse Zone of Upper Austria (WESSELY, 1996)

The idea for general applications originated from Felix RONNER, the former Director of the Geological Survey of Austria, who realized in 1974 that the hydrocarbon exploration well "Aspern 1" near Vienna had a rich influx of hot salt water from the underlying dolomite reservoir at a depth of about 3100 m. The first use for heating purposes was established in 1976 at the unproductive oil well "Waltersdorf 1" in eastern Styria, which generated weakly mineralized 61°C hot water from a Paleozoic dolomite at depths between 1094 and 1239 m. In addition, in the Styrian and Pannonian Basins Neogene sandstones have been proven to be important source rocks for thermal waters (Fig. 20).

Based on long-term drilling activities and geophysical research the subsurface of the Vienna Basin is by far best known. In this region sandstones of Neogene age and carbonate rocks of the Calcareous Alps represent the most important reservoirs for hot water.

In the Molasse Zone of Upper Austria, sandstones of Eocene age, Cretaceous deltaic sandstones and gravel deposits, as well as Upper Jurassic (Malm) carbonates are the most promising strata. In the province of Lower Austria the upper Oligocene part of the Molasse Zone consists of sandstones, but also Upper

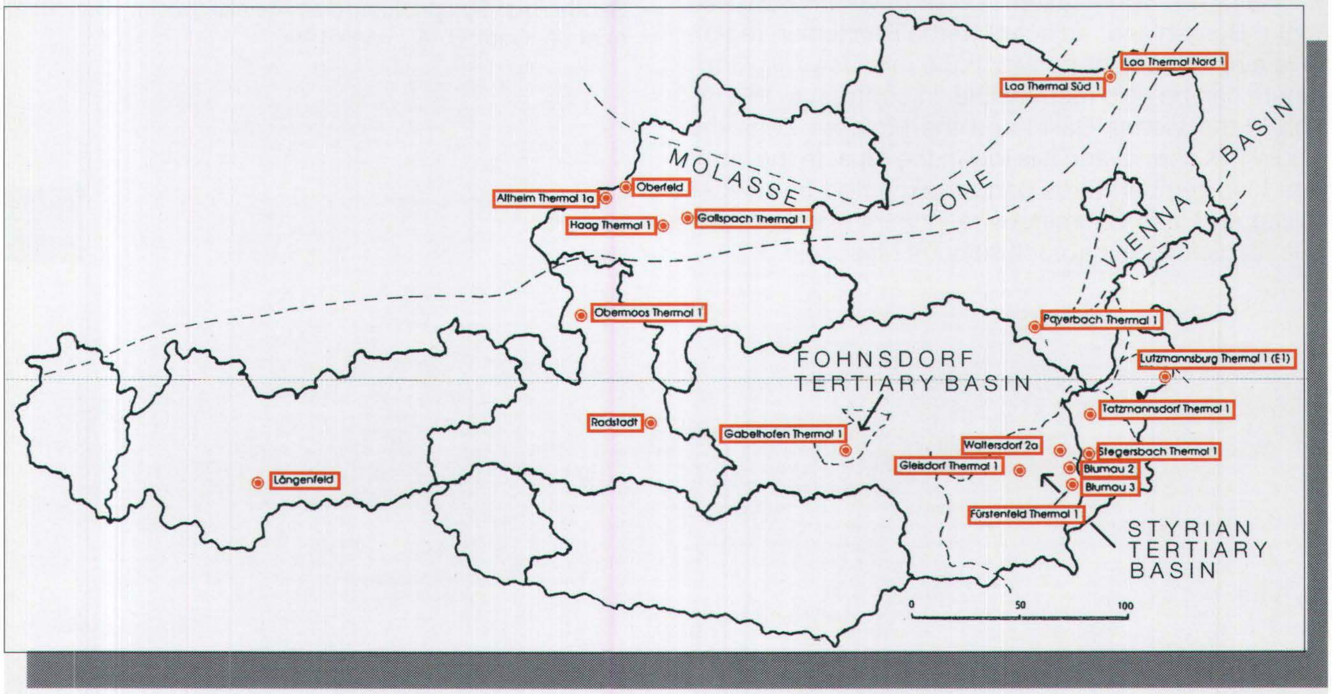


Fig. 20.
Geothermal exploitation in Austria.
After BÖCHZELT & GOLDBRUNNER (1996).

Jurassic carbonate rocks have been proven to contain extended aquifers. In some cases thick deltaic sandstones of Dogger age are regarded as targets for the supply of hot water.

The Calcareous Alps with their thick platform carbonates and joint porosity, represent another large area containing a considerable reservoir of hot water.

Between the years 1985 and 1996, nineteen geothermal wells were drilled in Austria with a cumulative length of 35,180 m (BÖCHZELT & GOLDBRUNNER, 1996). Only two of them were unsuccessful, and most of the wells are or will be producing water for balneology and/or geothermal energy. The majority of these wells were drilled after re-interpretation of existing reflection seismic data or additional on-site research complementing geological, hydrogeological, and financial considerations.

The wells produce up to 80 liters per second of thermal water with temperatures up to 105°C. The water is derived from Tertiary sediments as well as from pre-Neogene carbonate rocks and even the crystalline basement.

Within the framework of the DANREG program carried out in the Danube River region since 1990 between the cities of Vienna and Budapest, a new thematic map has been compiled showing the geothermal potential in the border regions between Austria, Slovakia, and northern Hungary.

In Austria areas with a relatively high geothermal gradient can be distinguished from those with a lower gradient. The southeastern parts of Austria (Styrian Basin, Burgenland) adjacent to the Pannonian region have a high gradient for which the relatively thin lithosphere can be held responsible. In contrast to this region in the Vienna Basin and the Molasse Zone the gradient is normal and it is low in the Alps. In the latter area high temperatures can be expected by deeper drilling and also voluminous reservoirs may be available, exploiting the autochthonous Mesozoic.

A major problem for producing thermal water in economically reasonable amounts is the restricted porosity of most rocks. These limiting factors can eventually be solved by the use of acid or gases. In general, acid well stimulation is applied in carbonate rocks, but it has also been successful in crystalline aquifers. Locally casings are cemented or perforated to increase the production of thermal water.

In addition, heat-mining techniques developed and improved in Switzerland, could be applied by hot-wet or hot-dry rock creation of artificial joint-permeability almost everywhere except in those areas where the groundwater is protected.

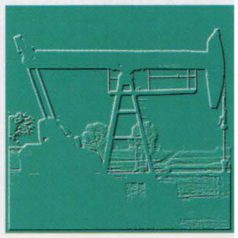
With regard to thermal water resources and cost-management, there are considerable risks for thermal water exploration and exploitation. Potential resources must be checked and evaluated in the early stage of project planning and one must consider geomechanical, geohydraulical, geochemical, and mineralogical effects caused, for instance by alterations of azimuth, pore pressure, salinity, and expanding clay minerals

References

BÖCHZELT, B. & GOLDBRUNNER, J.: Geothermal drilling projects in Austria. – Proceedings-Preprint, 1st International Geothermal Symposium, Bad Kleinkirchheim (Carinthia, Austria), Geol. B.-A., Wien 1996.

WESSELY, G.: Possibilities of energetic geothermal exploitation in Austria. – Proceedings-Preprint, 1st International Geothermal Symposium, Bad Kleinkirchheim (Carinthia, Austria), Geol. B.-A., Wien 1996.

Oil Industry in Austria



OMV Aktiengesellschaft

The Austrian Oil and Gas Group with Integrated Plastics and Chemical Enterprises

The OMV Aktiengesellschaft was founded in 1955 in Vienna, Austria. Today it has sales of ATS 78.3 billions (for 1996, excluding petroleum tax) and some 8,500 employees (end of 1996).

It is the largest industrial enterprise listed on the Vienna Stock Exchange and one of the leading energy groups in Central Europe.

OMV's shareholder structure today is:

- 45.4 % free float
- 35.0 % ÖIAG (Austrian Republic)
- 19.6 % IPIC (International Petroleum Investment Company, Abu Dhabi)

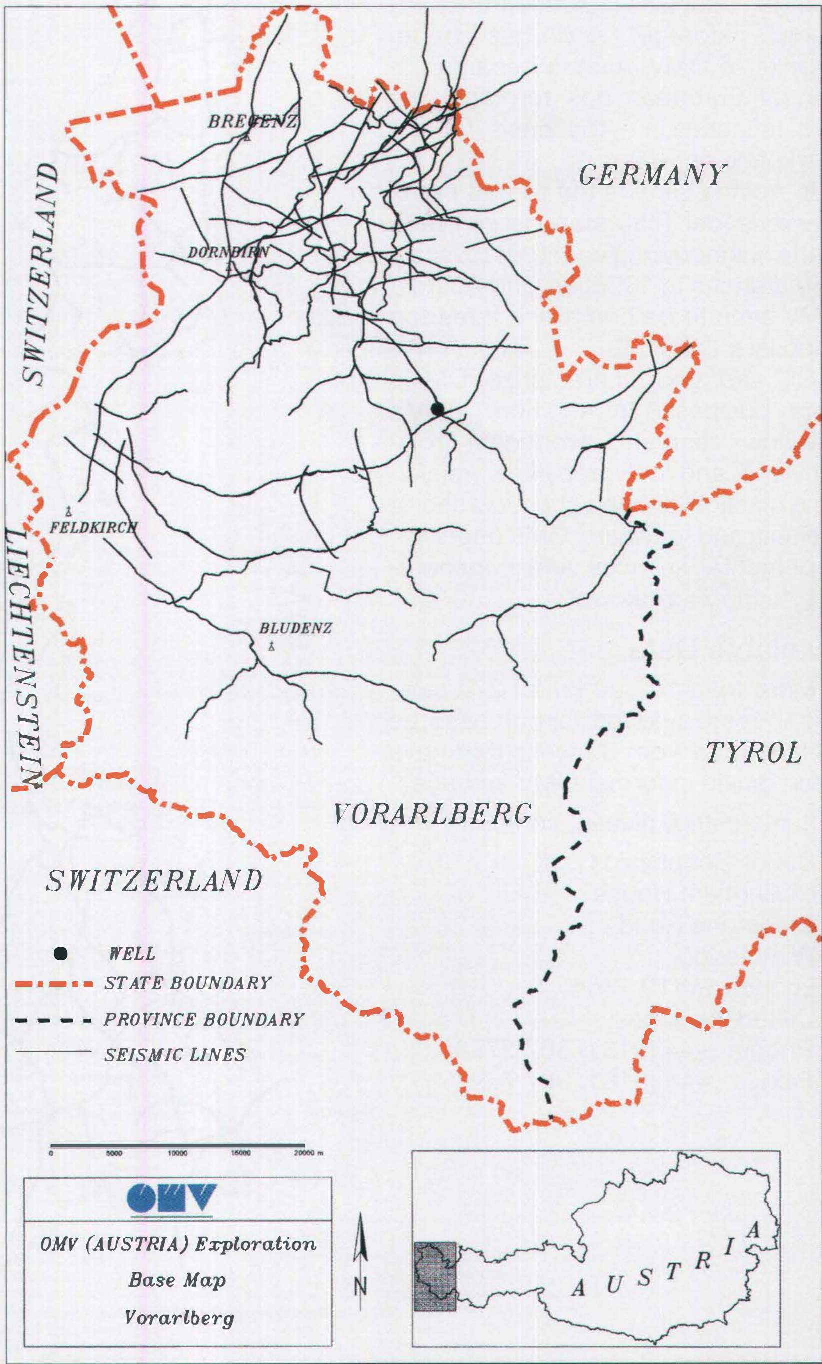


Fig. 21.
Vorarlberg.
Available data: 920 km of 2-D seismic lines.

The main business sectors are:

- Exploration & Production
- Gas
- Refining
- Marketing
- Plastics
- Chemicals
- Environmental Services
- Cogeneration Activities

The exploration and production activities are concentrated on Austria, Great Britain, Libya, and Pakistan. The gas business includes transport, transit, storage, and gas trade. Thanks to OMV, Austria became the central European gas turntable. Its two refineries are the basis for the marketing activities.

In Austria OMV is the oil and petrol marketleader (750 stations in 1996). In the neighbouring countries (over all, 350 stations in 1996) around Austria, OMV aims to be one of the three top suppliers.

Oil and gas characterize OMV's core business. In addition, OMV's plastics segment produces polyethylene and polypropylene (recyclable plastics) and the chemical sector melanin and fertilizers. OMV offers environmental services and cogeneration technology as well.

Available Data

More than 10,000 km of 2-D seismic lines are available for purchase, as well as data from 80 wells that have been drilled in former OMV acreage.

If interested, please, contact:

Count Geophysics Ltd.
Collingham House
Gladstone Road
Wimbledon
London SW19 1WH
United Kingdom
Phone: +44 (0181) 307 7788
Fax: +44 (0181) 307 7697

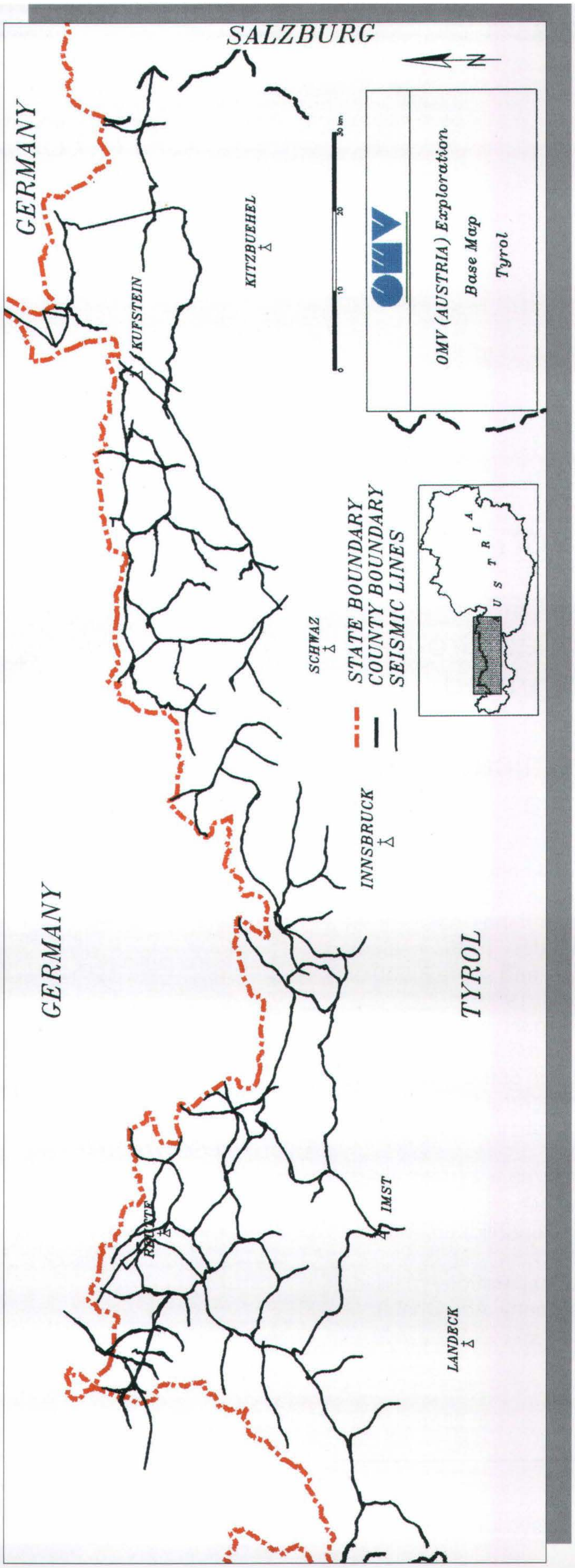


Fig. 22.
Tyrol.
Available data: 1,230 km of 2 D seismic lines.

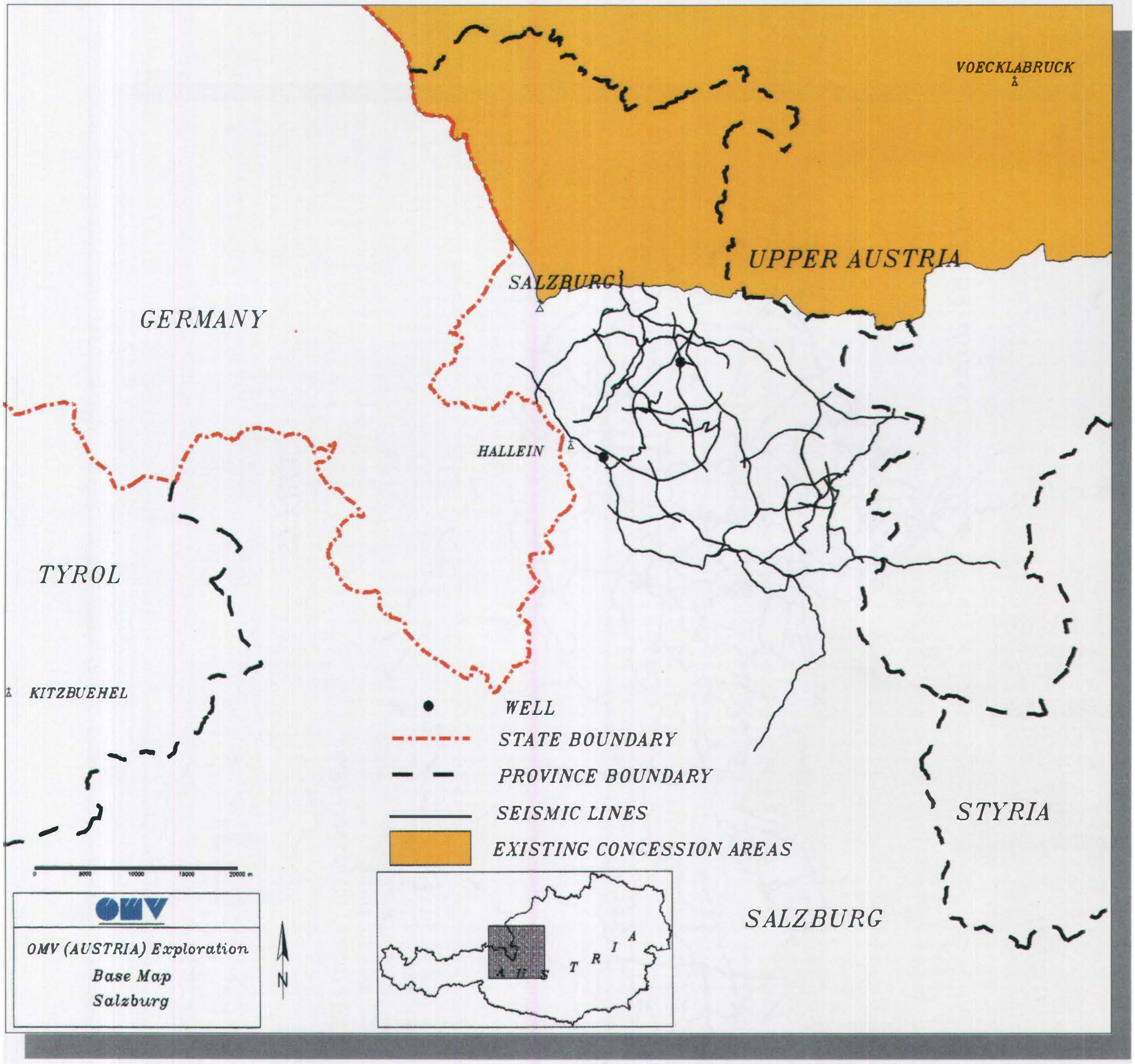


Fig. 23.
Salzburg.
Available data: 530 km of 2-D seismic lines.

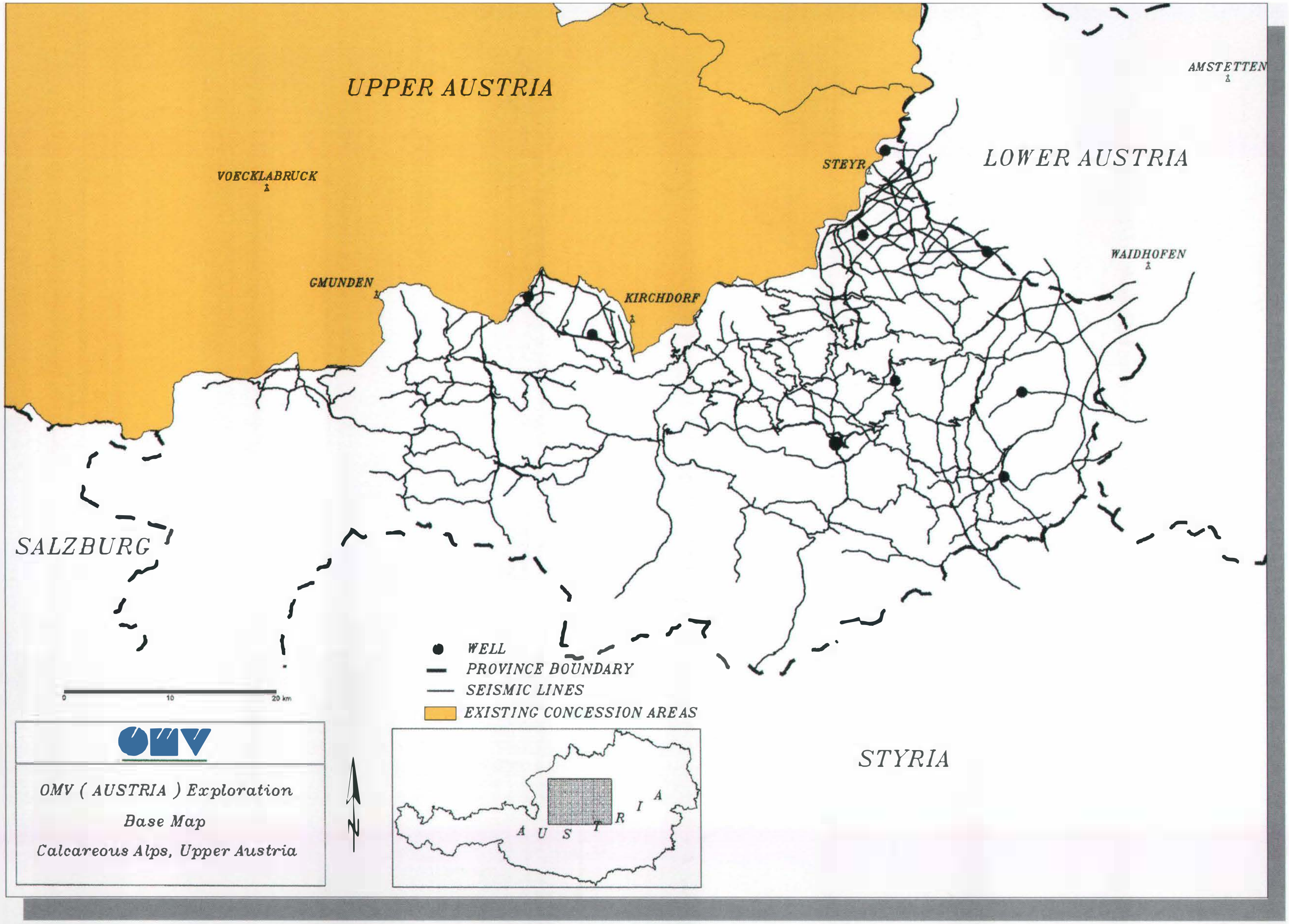


Fig. 24.
Upper Austria.
Available data: 2,000 km of 2-D seismic lines.

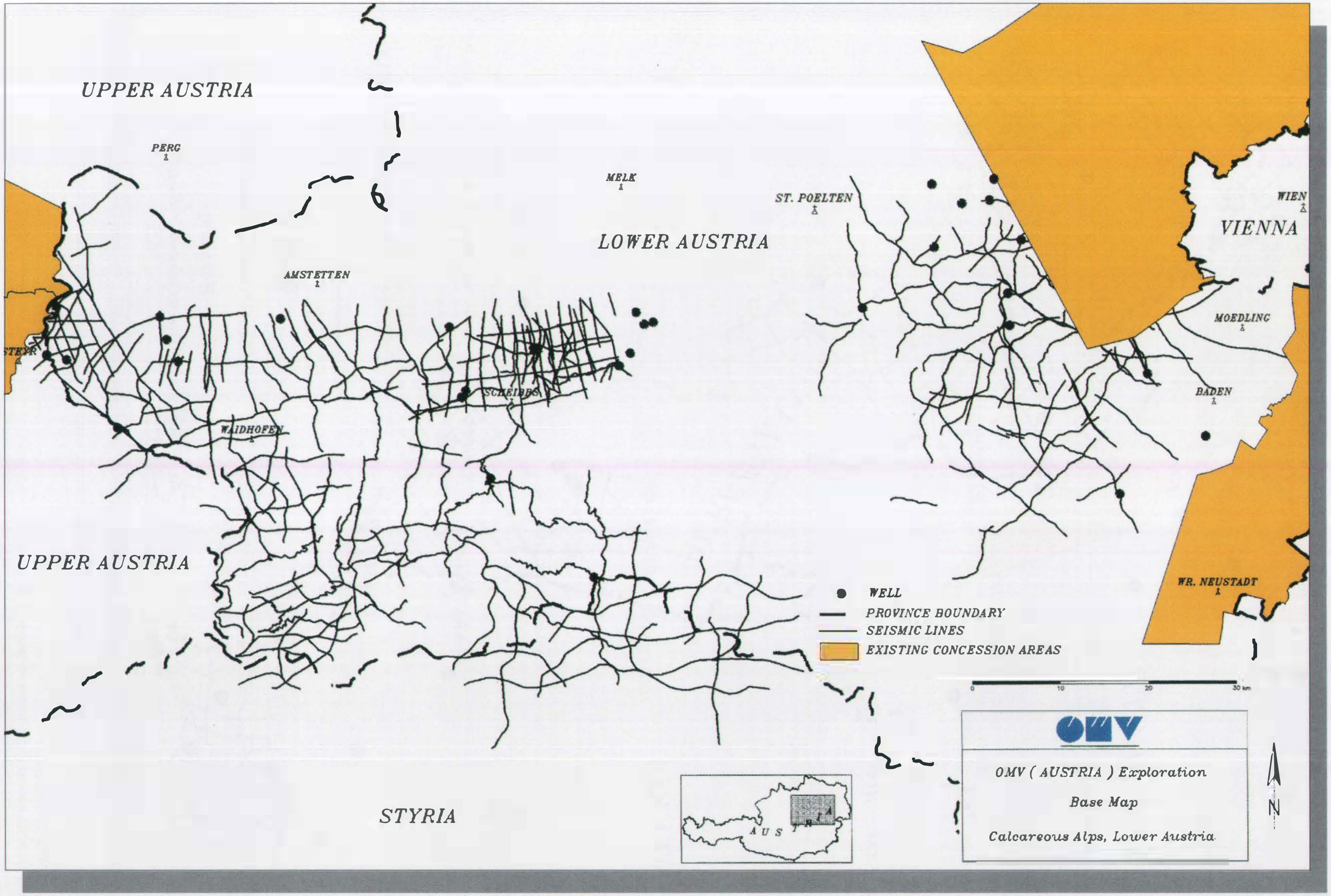


Fig. 25.
Lower Austria and Northern Styria.
Available data: 3,500 km of 2-D seismic lines.

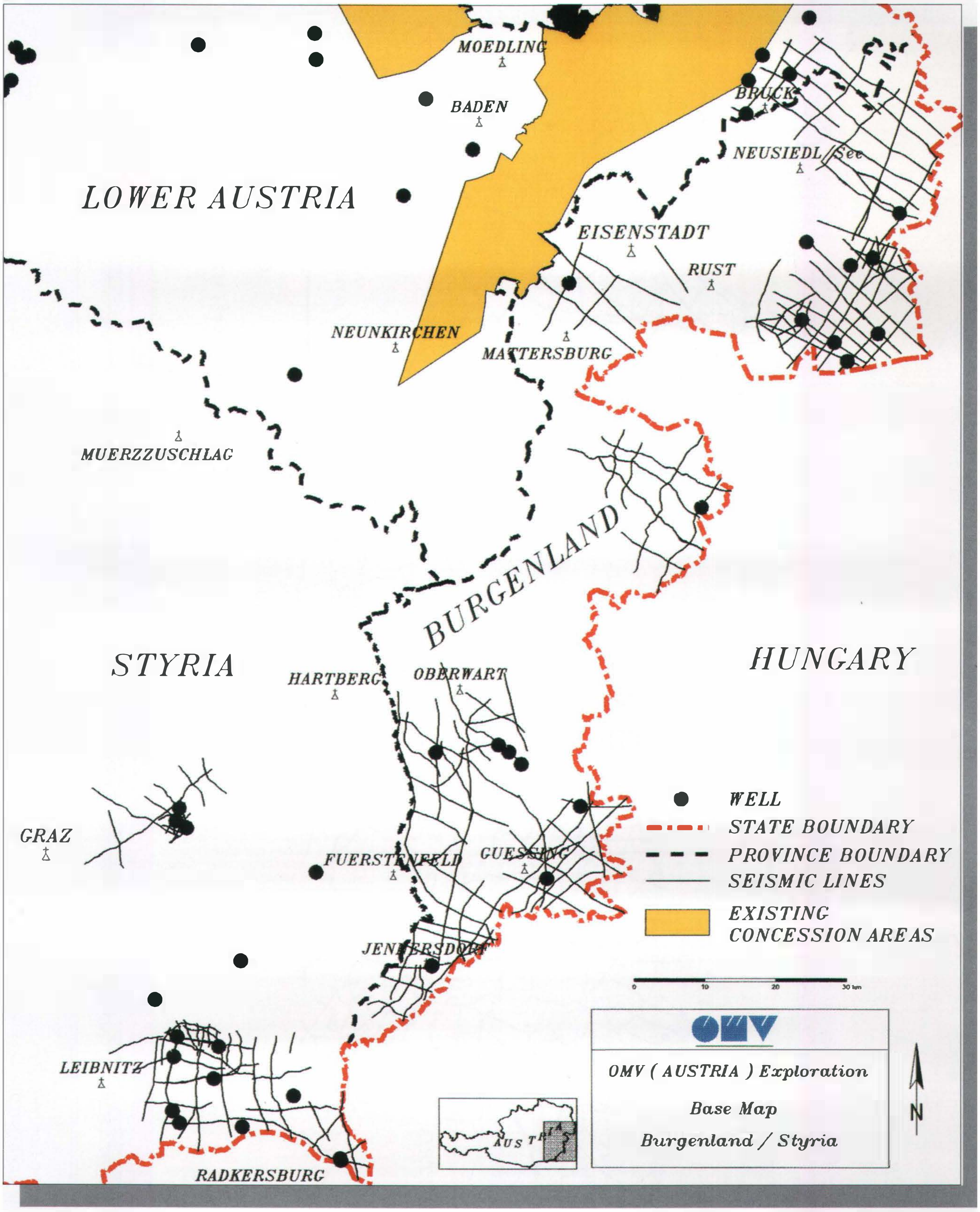


Fig. 26.
Styrian and Pannonian Basin.
Available data: 1,850 km of 2-D seismic lines.

Rohöl Aufsuchungs AG (RAG)

Austria's Oldest Oil Company

In 1935, Rohöl Gewinnungs AG (RAG) was founded by N.V.Be Bataafsche Petroleum Maatschappij (today Royal Dutch Shell) and Socony-Vacuum Oil Company Inc. (today Mobil Oil Corporation) with the objective to explore and produce oil in the Vienna Basin in Lower Austria.

Currently, RAG (now Rohöl Aufsuchungs AG) has six shareholders:

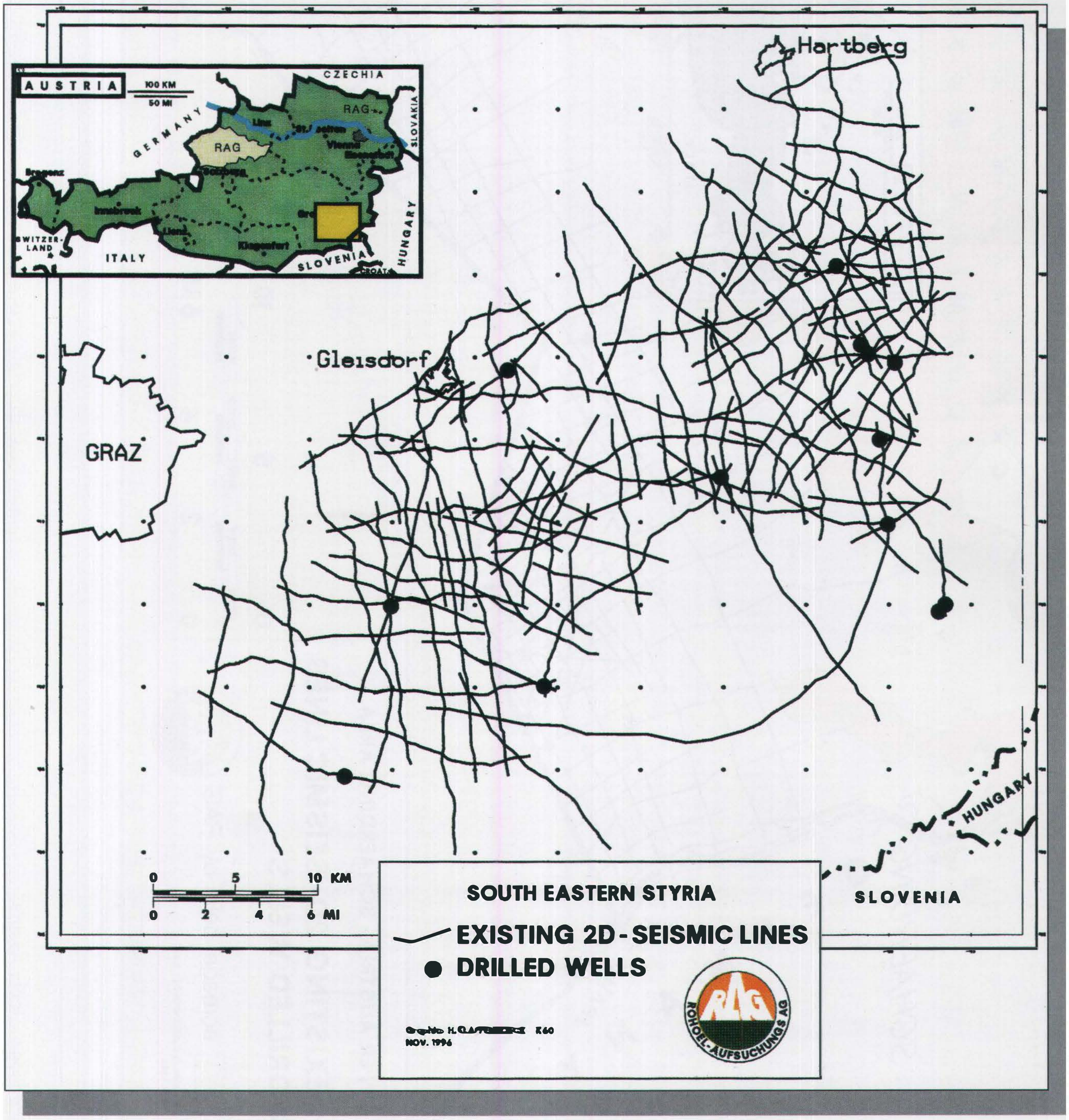


Fig. 27.
RAG exploration in Southeastern Styria.

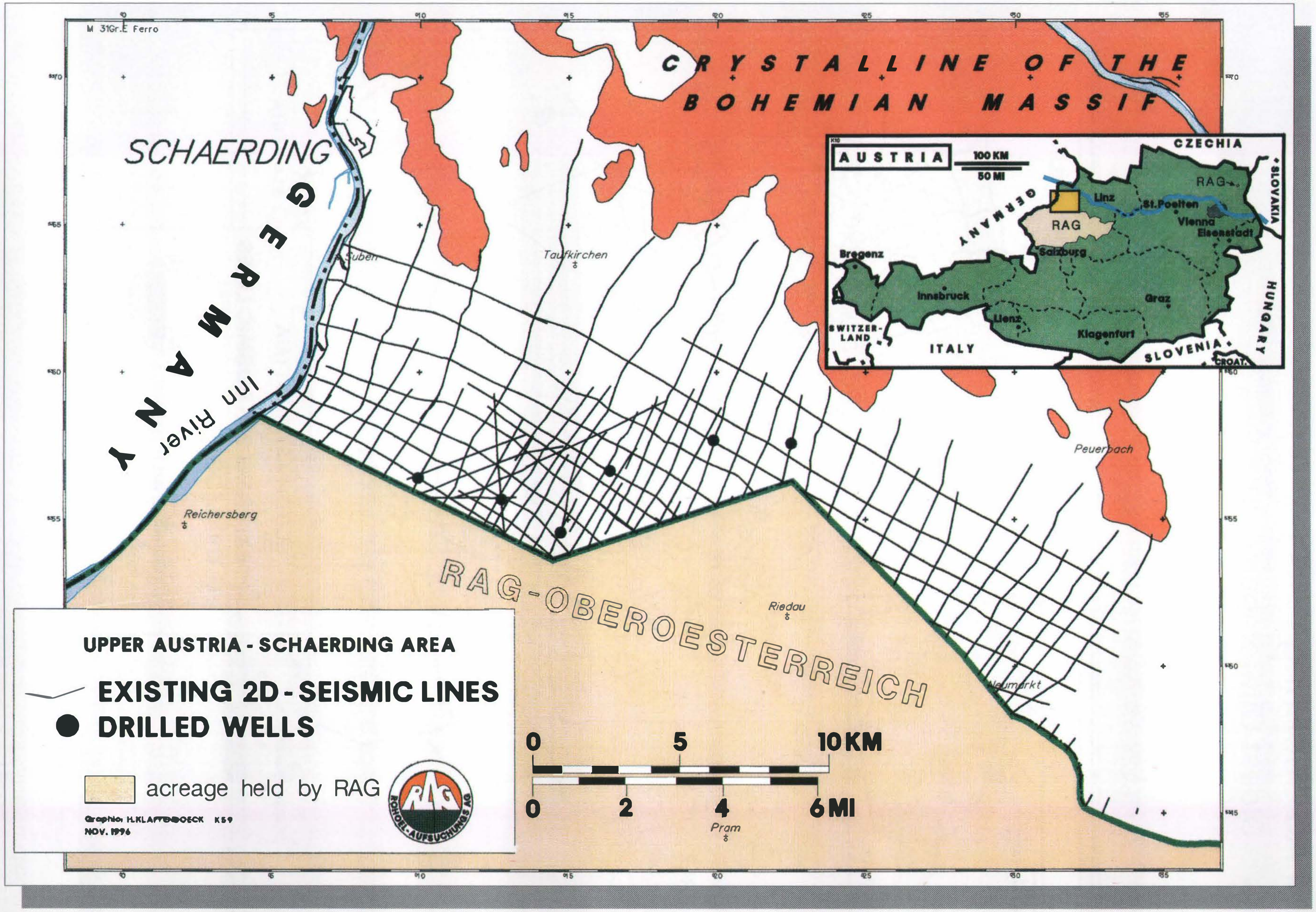


Fig. 28.
RAG exploration in Upper Austria.

- 25 % Shell
- 25% Mobil
- 50% RAG Beteiligungs AG (partnership of EVN, Bayernwerk AG, SAFE, and Steirische Ferngas AG)

RAG is still actively exploring and exploiting domestic oil and gas resources.

Exploration and Production

The acreages held are three small production licenses in the Vienna Basin and some 4,800 km² in the Molasse Basin in Upper Austria and Salzburg. Today's emphasis is on drilling gas prospects in foreland and imbricated Molasse plays.

RAG's total production from 1936 to 1996 was 99.3 MMBO (= 13.7 MM tons of oil) and 607 BCF (=16.3 billion m³) of gas.

The 1996 annual production was some 788 MBO (= 109,000 tons of oil) and 19.3 BCF (= 519 million m³) of gas, which equals 11 and 42 % of Austria's total production.

Additional Business Segments

- Compulsory Storage: RAG stores some 200,000 m³ of oil for third parties under the Compulsory Storage Act.
- Underground Gas Storage: In Puchkirchen, Upper Austria, RAG operates a gas storage facility with a turnover volume of 500 million m³.

Available Data

By the end of 1989, RAG relinquished some acreage in the shallow Molasse Basin near Schärding in Upper Austria. All acreage in the Styrian Basin was given up by the end of 1996. For both areas 2-D seismic lines and well data are available (see enclosed maps).

Other Oil Companies in Austria

- AGIP Austria AG, A-1040 Vienna
- ARAL Austria GesmbH, A-1040 Vienna
- AVANTI AG, A-1010 Vienna
- BP Austria AG, A-1040 Vienna
- ESSO Austria AG, A-1040 Vienna
- Mobil Oil Austria AG, A-1015 Vienna
- Shell Austria AG, A-1030 Vienna

Pipelines in Central Europe

OIL PIPELINES IN CENTRAL EUROPE				
	Length [km]	Diameter [inch]	Capacity [Mt/a]	Remarks
TAL Transalpine-Ölleitung	464	40	36(45)	
CEL Central European Line	700	32/26/22	10,0	closed since 01/97
AWP Adria-Wien-Pipeline	416	18	10,0	
RDO	266	26	17,0	
MERO Mitteleuropäische Rohölleitung	350	28	10,0	since 1996 on stream
DRUSCHBA 1/MVL	1190	25/32	37,0	length to Schwedt
DRUSCHBA 2	1690	24	27,5	length to Prague
JANAF/Adria-Pipeline	800	36	20,0	since 1996 again on stream

M. ZEDLACHER
OMV AG/MR-P
Lassallestrasse 3
A-1020 Vienna

GAS PIPELINES IN CENTRAL EUROPE			
	Length [km]	Diameter [inch]	Capacity [bcm/a]
TRANSGAS & SLOVTRANSGAS	4000	56/32	75
TAG	380	42/38	17,5
WAG	250	32	5
MEGAL	450 + 170	48/36/32	22
MIDAL	640	40–32	7
STEGAL	320	32	6
TENP	830	38/34	6 to 5

M. MAZZUCATO
OMV AG/E-GAS
Gerasdorfer Strasse 151
A-1210 Vienna

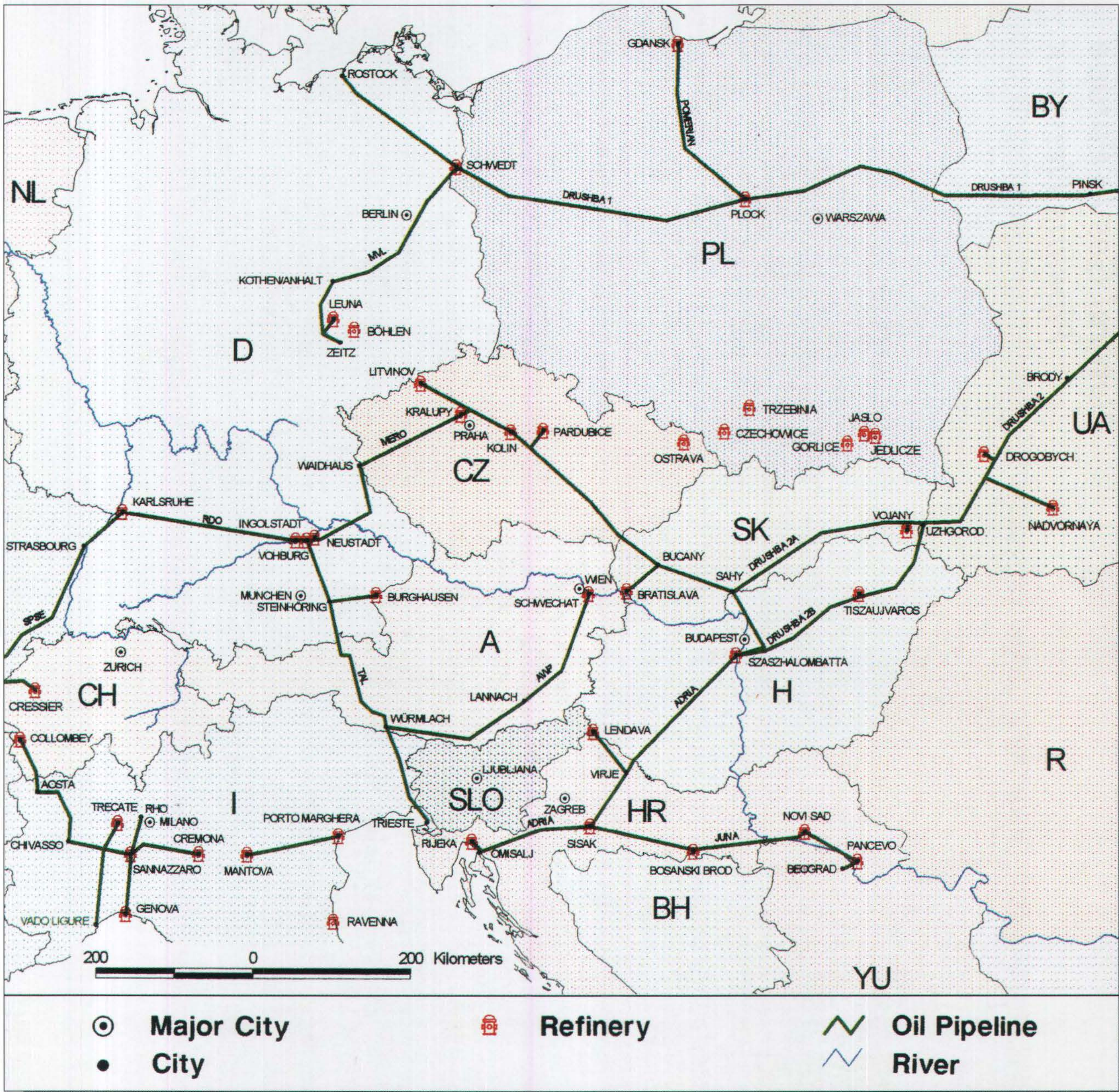
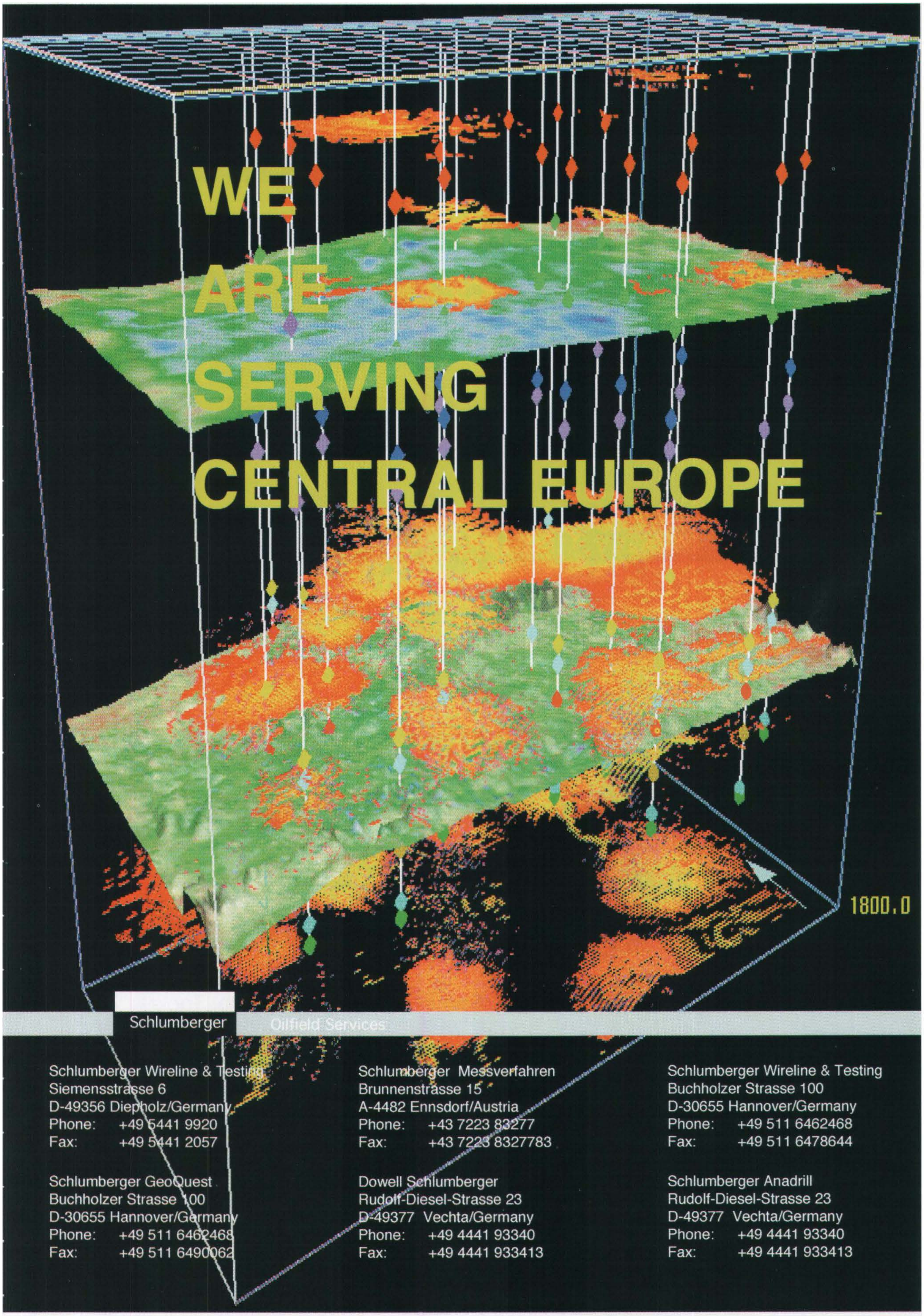


Fig. 29.
Refineries and oil pipelines in Central Europe.

OMV Erdgas

Natural Gas in Europe
Pipeline Network

Fig. 30.
European natural gas pipeline network.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Fax: +49 5441 2057
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Brunnenstrasse 15
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Fax: +49 4441 933413

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Schlumberger Meßverfahren

Brunnerstrasse 15
A-4482 Ennsdorf
See advertisement on page 53

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Fax: (437223) 832-7783

Schlumberger Geco-Prakla

Buchholzer Strasse 100
D-30655 Hannover
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Fax: (49511) 649-7478

Prakla-Seismos GmbH

Krottenbachstrasse 82–88
P.O. Box 9
A-1190 Vienna

☎ (431) 368 9189
Fax: (431) 362 314

Halliburton Company Austria GmbH

Helmaweg 2
A-2201 Seyring

☎ (432246) 4333
Fax: (432246) 4333-15

Schoeller-Bleckmann Oilfield Equipment AG

General Oilfield Equipment, Alloy Steel Drillstring Components
Hauptstrasse 2
P.O. Box 31
A-2630 Ternitz

☎ (432630) 315-211
Fax: (432630) 315-203
e-mail: r.ernst@sbo.co.at

Schoeller-Bleckmann Oilfield Technology GmbH & Co.KG

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P.O. Box 31
A-2630 Ternitz

☎ (432630) 315-240
Fax: (432630) 315-201
e-mail: s.morang@sbo.co.at

SBS Drilling-and Production Systems GmbH & Co.KG

P.O. Box 31
A- 2630 Ternitz

☎ (432630) 318-220
Fax: (432630) 318-555
e-mail: m.hollek@sbo.co.at

M-I Drilling Fluids Co. GesmbH

Trostgasse 16
A-2500 Baden
See advertisement on page 33

☎ (432252) 89711
Fax: (432252) 4279

Mannesmann Handel GesmbH

Schwarzenbergplatz 7
1037 Vienna

☎(431)71149-0
Fax: (431) 71149-323

Mannesmann Anlagenbau Austria AG

Flare Gas Recovery Unit, Tank Truck Filling Station, (Cogeneration) Power Plant
Oberlaaer Strasse 331
A-1230 Vienna

☎ (431) 61036-202
Fax: (431) 61036-375
e-mail: Lafleur@maba.co.at

GEOdata GesmbH

Matzner Strasse 28
A-2242 Prottes
See advertisement on page 38

☎ (432282) 2568
Fax: (432282) 3353

GEOdata, Service Company for Geology

Hydrogeology and Environmental Chemical Analysis
Carl-Zeiss-Str. 15
D-30827 Garbsen
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☎ (495131) 4681-0
Fax: (495131) 4681-60

Weatherford Oil Tool GesmbH

Staudgasse 83/13
A-1180 Vienna

☎ (431) 479 3225

GUR Armaturenerzeugung & Handel GesmbH.

Richard-Strauss-Strasse 6
A-1230 Vienna

☎ (431) 616 1541
Fax: (431) 616 2191

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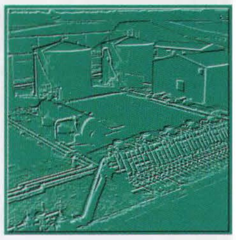

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Department VII (Mineral Resources)
Landstrasser Hauptstrasse 55–57
A-1031 Vienna
☎ (431)1711 02-270
Fax: (431)714 35 81

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A-1030 Vienna
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Fax: (431)718 09 97-104

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Freiheitsplatz 1
A-8011 Graz
☎ (0043)316/830 427-0
Fax: (0043)316/830 427-15

Leoben
Straussgasse 1
A-8700 Leoben
☎ (0043)3842/433 15
Fax: (0043)3842/433 15-21

Salzburg
Weiserstrasse 22
A-5021 Salzburg
☎ (0043)662/881 088
Fax: (0043)662/881 088-22

Klagenfurt
Herrengasse 9
A-9010 Klagenfurt
☎ (0043)463/511 114
Fax: (0043)463/511 114-73

Innsbruck
Herzog-Friedrich-Strasse 3
A-6028 Innsbruck
☎ Tel.: (0043)512/581 939
Fax: (0043)512/570 763

Geological Survey

Geological Survey of Austria

Rasumofskygasse 23
A-1031 Vienna
☎ (431)712 56 74-0
Fax: (431)712 56 74-56

Economic Associations

Federal Chamber of Commerce

Industrial Section – Federation of Austrian Petroleum Industries
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A-1031 Vienna
☎ (431)713 23 48
Fax: (431)713 05 10

Trade Section – Federal Board of Fuel Dealers
Wiedner Hauptstrasse 63
A-1040 Vienna
☎ (431)501 05-33 31
Fax: (431)501 05-3043

Scientific Associations

Austrian Association for Petroleum Sciences (ÖGEW)

Erdbergstrasse 72
A-1031 Vienna

☎ (431)713 23 48
Fax: (431)713 05 10

Austrian Geological Society (ÖGG)

c/o Geological Survey
Rasumofskygasse 23
A-1031 Vienna

☎ (431)712 56 74-0
Fax: (431)712 56 74-56

Austrian Mineralogical Society (ÖMG)

c/o Naturhistorisches Museum
Burgring 7
A-1010 Vienna

☎ (431)521 77-0
Fax: (431)523 52 54

Austrian Paleontological Society (ÖPG)

c/o University of Vienna
Althanstrasse 14
A-1090 Vienna

☎ (431)313 36-97 21
Fax: (431)313 36-784

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