Mitt. Österr. Geol. Ges.	ISSN 0251-7493	**92** (1999)	7-14	Wien, Juli 2000

Aspects of Geology in Austria and Adjoining Areas: Introduction

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Abstract

Geology has a long tradition in Austria, and many contributions to both basic geological research and applied Earth Sciences have been made by Austrian geologists. As major portions of Austria are part of the Alpine mountain belt, these contributions have mainly concerned the research of orogeny, stratigraphy and the paleontology of ancient oceans like the Tethys ocean, as well as the evolution and modeling of orogens. Many techniques have been developed in applied geology, and some fields like economic geology have a very long tradition in the Austrian territory, as mining dates back ca. 2,700 years ago and has flourished here since the Middle Ages. Furthermore, there have been innovations, such as the karst-water based water supply for Vienna proposed by Eduard Suess ca. 140 years ago, the development of specific tunneling methods (New Austrian Tunneling Method) and working models in environmental geology.

Introduction

Austria is a relatively small country in the center of Europe, comprising major portions of the Eastern Alps, their northern Molasse-zone foreland, and the southern sectors of the Variscan Bohemian Massif (Figs. 1, 2). In its eastern sectors, Austria covers a part of the westernmost Pannonian Basin, a major basin that is surrounded by young mountain belts including the Alps, Carpathians and Dinarides. Throughout its history as a state, which has existed as political entity for a millenium, Austria has had an influential political location between eastern countries and Central-Western Europe. In a sense, Austria has assumed a political and cultural transfer role over a millenium, a function which continues even today.

Austria has a long tradition in geological research. The geographic location has governed particular types of geological research activity, for instance: the search for ores and later for coal, research in orogenic belts starting with the Alps and later including the Carpathians and part of the Dinarides within the Austrian-Hungarian Empire around 1900, and large mountain belts in Eurasia. State-supported geological research started as early as the first half of the last century, when a mining school was founded at Vordernberg; it was later moved to its present site Leoben. The Austrian Geological Survey, now the Geologische Bundesanstalt, has been in operation since 1849 (as k. & k. Geologische Reichsanstalt; BACHL-HOFMANN et al., 1999). Three campaigns of geological mapping have been performed since that time, resulting in an overall excellent geological knowledge of the Austrian territory. Some of these maps, which originally covered the whole Austrian-Hungarian monarchy, are still being used in some eastern countries.

Several founders of some subdisciplines of the Earth Sciences worked at Austrian universities. Among these, Eduard SUESS is a monument, whose "Anlitz der Erde" *(Face of Earth)* became famous worldwide and influenced generations of geologists (SUESS, 1885, 1888). Many important stratigraphers and paleontologists, e.g., M. NEUMAYR, A. BITTNER and E. von MOJSISOVICS, developed the biostratigraphy of the Tethys shelf and ocean successions, among others. Engineering geology became an important field as a railway net was created and water supplies for cities (e.g. for Vienna) were built. The mountainous area required special efforts to maintain natural conditions as the infrastructure was continuously developed.

The state of Austria received its present form in 1918, after the First World War. Since that time, geological research activity has focussed on the Alps and their northern foreland, and on paleogeography, structure and orogenic processes. The activity of Otto Ampferer (A[mpferer]-subduction!) is well-known. An increase in activity in applied geology started as new water supplies, roads, highways and hydro-power plants were constructed. Hydrocarbons were found in the Vienna Basin in that period (see BRIX and SCHULTZ, 1993, and references therein).

Geological research was heavily hampered and interrupted by the Second World War, and Austrian geological research lost some of its international renown simply because of the missing international literature. Since the late Fifties and Sixties, Austrian geologists have developed many new

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concepts in applied geology such as the NATM (New Austrian Tunneling Method) or various tracer methods in hydrogeology. In the last decades, many Austrian earth scientists have taken advantage of international careers and have consequently taken the knowledge they gained in their home country to enhance progress in the realm of geology all over the world. It appears that more Austrian geologists working abroad than at home!

Among the most important achievements of Austrian geology over the past twenty years are:

1) The foundation of the Vienna Laboratory of Geochronology led by Wolfgang FRANK, Susanne SCHARBERT and Martin THÖNI, which resulted in many reliable data that changed existing tectonic models.

2) Work by various groups on paleogeographic relationships, specifically in Paleozoic successions, led by Helmut W. FLÜGEL and Hans-Peter SCHÖNLAUB, gave a more detailed understanding of the Paleozoic microplate puzzle.

3) Combined geodynamic, petrological and structural work, which resulted in a modern geodynamic understanding of the evolution of the Eastern Alps and Alps as an entity. This work resulted in a quantitative understanding of the tectonic evolution that is now used in geodynamic modelling.

In addition to these mentioned highlights, Austria currently has a lively geological scientific community covering a wide range of fields and disciplines. Earth scientists from academia/universities, research institutions such as museums and the Austrian Geological Survey pursue research in the network of national and international working groups. Geologists work on many projects outside of Austria, mainly in orogenic belts such as in the Eastern Mediterranean, the Andes, the Caribbeans, the Himalayas, China, Mongolia, northeastern Africa and northeastern Siberia, as well as in remote places like Franz-Josefs-Land.

The contributions of this volume intend to show some basic achievements and present a variety of research results of Austrian geology, although this selection is far from complete. Several strong subdisciplines, such as geophysics, mineralogy, petrology and cosmochemistry are not represented.

To date, nearly all major compilations on major aspects of Austrian geology have been written in German. We would like to mention a number of them here, as well as some written in English, since these represent basic reviews (e.g., OBERHAUSER, 1980; TOLLMANN, 1978, 1985, 1986; JANOSCHECK and MATURA, 1980; BRIX and SCHULTZ, 1993; ZÖTL and GOLDBRUNNER, 1993; WEBER, 1997; FLÜGEL and FAUPL, 1987).

European geological framework

Europe is part of the Eurasian continent, which received its initial shape during the late Paleozoic orogenies and from Mesozoic-Tertiary continental accretion along southern Eurasia (e.g., ŞENGÖR and NATAL'IN, 1996). Europe can be divided into an old, Precambrian area comprising Eastern and Northern Europe and separated by the complex Tornquist-Tesseyre zone (now often also called Trans-European Suture Zone) from Central/Western/Southern Europe, which was formed by superposed Phanerozoic orogenies (Fig. 1).

Eastern and Northern Europe comprise a Precambrian basement that is mainly of Late Archean to Early Proterozoic age (e.g. WINDLEY, 1992) with some subordinate, Late Proterozoic (Sveko-Norvegian) portions. The present exposure of the Precambrian basement is in two shields, the Baltic and the Podolian/Ukrainian shields. Large portions of the Precambrian basement are covered by thin platform sediments forming the Russian platform (e.g., ZONENSHAIN et al., 1990; BOGDANOVA, 1996). This region also includes a number of late Precambrian (Eocambrian/Vendian) to Paleozoic rifts and aulacogens, such as the Devonian Donetzk-Djnpr aulacogen heralding tectonic processes in the adjacent mobile belts.

The Precambrian basement of Eastern and Northern Europe is involved along its northwestern and southwestern margins in Phanerozoic orogens, specifically in the Caledonides. The continuous NE-striking Caledonides belt extends from Ireland to the northernmost tip of Europe in Laponia. It resulted from the Late Precambrian/Cambrian opening of the lapetus ocean and from subsequent accretion processes and final continent-continent collision between northern Europa and North America during the Late Ordvician to Late Silurian (BERTHELSEN, 1992). The collision involved North America-derived Precambrian crust exposed in northwestern Scotland. The resulting continent is called the Old Red continent and it started to rift again along its southern margins during the Early Devonian forming a number of new oceanic basins (DALLMEYER et al., 1995, and references therein).

Long-lasting, Devonian-Carboniferous accretion processes of various microcontinents formed the Variscides extending from Central to Western and Southwestern Europe. The Variscides are exposed in a number of basement massifs, from which the Bohemian Massif is in part on Austrian territory. The Variscan orogeny also created the basement now exposed within Alpine-Mediterranean mountain belts. The Variscan continent-continent collision orogeny was caused by the indentation of Africa (part of Gondwana) into to the Laurussian continent, thereby forming syntaxes as represented both in the Ibero-Armorican and Moravian-Rhenohercynian arcs (e.g., MATTE, 1986; NEUBAUER and HANDLER, this volume). A number of terranes accreted and collided during the Devonian and Early Carboniferous. Details of these processes are still not fully understood, although many aspects were investigated during the last decade (e.g., DALLMEYER and MARTÍNEZ GARCIA, 1990; VON RAUMER and NEUBAUER, 1993; KEPPIE, 1994; DALLMEYER et al., 1995; HÖCK and STUMPFL, 1997). As a whole, the Variscides appears to represent a wide and high mountain belt similar to the present-day Himalayas. The Variscan belt and the formation of the Ural mountains led to the amalgamation of Gondwana and Laurasia forming the Permian Pangea.

Due to the Late Carboniferous and Permian dextral shear between Gondwana and Eurasia, the Tethyan ocean widened as a large bay extending from the proto-Pacific ocean towards west and rifting started again. Late Paleozoic transgression of the Tethyan shelf reached the area of the future Austrian Alps, where corresponding deposits postdate formation of the Variscan basement.

The extra-Alpine Variscan basement was covered by Permian-Mesozoic sedimentary basins along which the German and Paris basin are the most prominent ones. These basins were apparently initiated by Permian rifts which re-

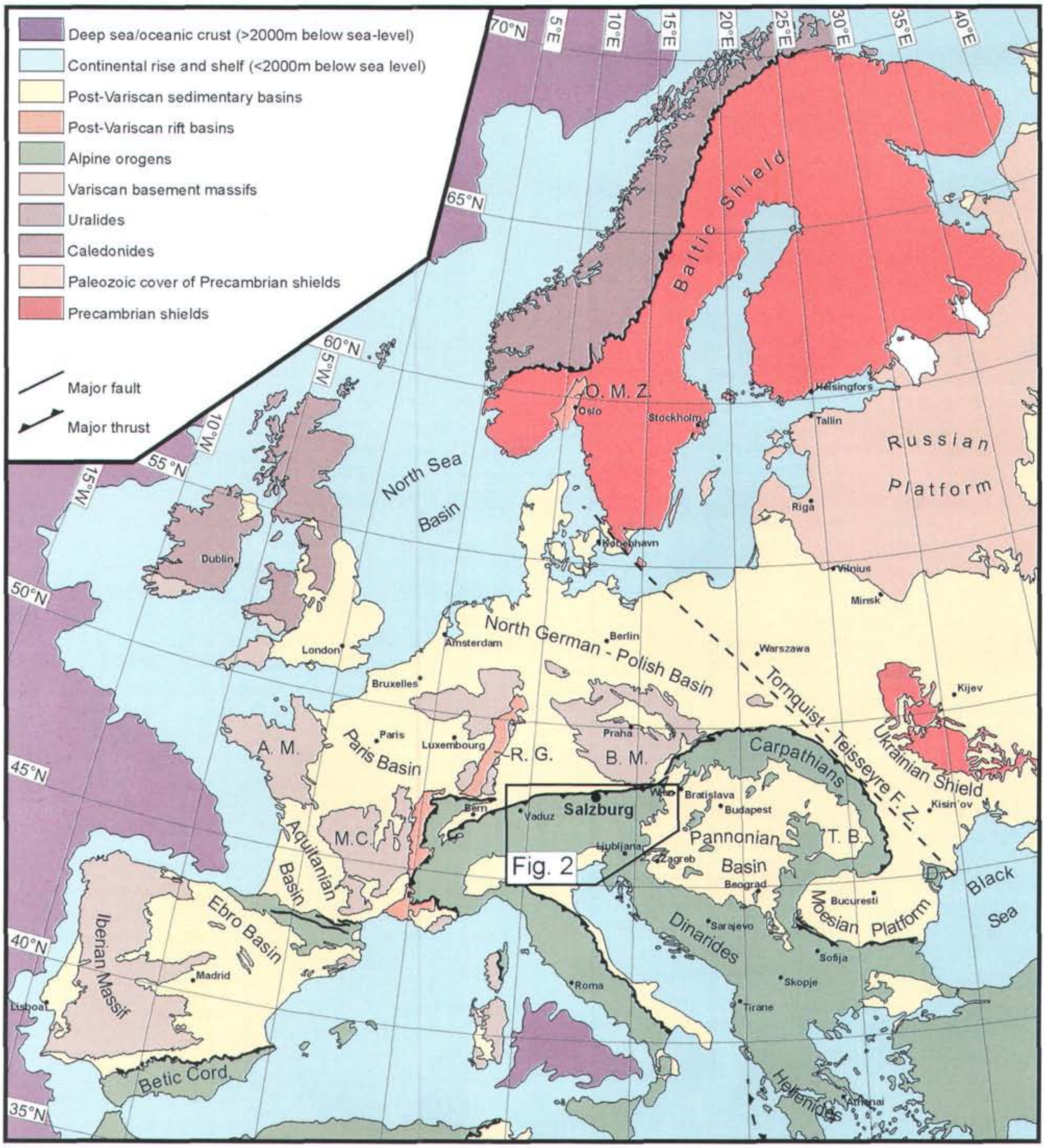


Fig. 1
Simplified geological map of Central, Western, Northern, and Southern Europe. Abbreviations: A.M. – Armorican massif, B.M. – Bohemian massif, F.Z. – fault zone, M.C. – French Massif Centrale, O.M.Z. – Oslo-Mjösen zone, R.G. – Rhine graben, T. B. – Transylvanian basin.

late to dextral wrenching between Eurasia and Gondwana (e.g., MATTE, 1986).

The Permian Tethys shallow sea underwent a strong subsidence during Middle Triassic times, and consequently the Meliata oceanic tract formed (see MANDL, this volume). A second stage of rifting during the Jurassic was initiated by the disintegration of Pangea and formation of the Mid-Atlantic ocean. The opening of the Mid-Atlantic induced a number of rifts in southern Europe by transform faulting (e.g., DERCOURT et al., 1992), which later widened to the Penninic oceanic through. At the same time, the Meliata oceanic tract closed. Several stages of accretion of continental microplates were associated with the consumption of older, Tethys-derived, as well as newly formed ocean basins between the Triassic and Neogene. Convergence and collision were largely controlled by the relative motion, mainly convergence, of Africa and Eurasia (e.g., DEWEY, 1989; STAMPFLI, 1996; STAMPFLI and MOSAR, 1999). These processes led to the partial closure of the newly formed ocean basins. The process is still ongoing, as active subduction in the Hellenic arc and collision- and strike-slip related earthquakes in Southern Europe indicate (e.g., BALLING and BANDA, 1992).

Austrian geology

Northernmost Austria is part of the southern sectors of the Variscan Bohemian Massif and the Alps, including the northern peripheral foreland basin (Fig. 2). In the Alps continuous Ordovician to early Late Carboniferous sections are known from several units. Their paleogeography is well-studied in the Carnic Alps. SCHÖNLAUB and HISTON (this volume) describe the paleogeographic evolution and their plate tectonic relationships showing evidence for the northward drift of the Carnic Alps in the southern hemisphere between the Ordovician and Devonian. Biogeographic relationships of marine shallow water fossils are the essential evidence, as HUBMANN (in PILLER et al., this volume) also demonstrates.

The basement within the Alps underwent orogeny during Variscan times, suggesting a close genetic relationships between the Alps and their northern foreland as exposed in the Bohemian Massif. These relationships are discussed in the paper by NEUBAUER and HANDLER (this volume), who describe strong dissimilarities between these two belts based on older evidence and recent data. Post-Variscan successions contain famous Tethys-derived fossils like fusulinids. Their depositional environment and evolution is described in the contribution by FORKE in PILLER et al. (this volume).

The main cover sequences in Eastern Alpine continental units are Triassic shelf sequences deposited at the Austroalpine/Southalpine margin along the southern margin of stable Europe. These sequences are highly variable in facies (MANDL, this volume) and contain many well-studied groups of fossils, specifically the richest ammonoid faunas from a single location in the world (e.g., KRYSTYN and PILLER in PILLER et al., this volume). The overlying Jurassic successions in the Austroalpine unit are somewhat mysterious, as they comprise remnants of olistolites derived from the closure of the Meliata ocean, according to MANDL (e.g., MANDL, this volume). During the Jurassic, rifting led to the separation of the Austroalpine domain from stable Europe, as the Penninic ocean opened. FAUPL and WAGREICH (this volume) describe the complex Cretaceous to Eocene paleogeography and tectonic processes, explaining the interference of distensional and compressional movements mainly from the perspective of sedimentary successions. NEUBAUER et al. (this volume) give an overview on the Alpine tectonic evolution of the Eastern Alps and describe the two principal stages of orogeny, Cretaceous and Paleogene, each with convergence, collision and subsequent lateral extrusion. The chronology of some processes is still controversial, although many new data were accumulated during the last decade. The high diversity of Cretaceous and Cenozoic environments resulted in various shallow to pelagic habitats, which are described in detail in the contributions by SANDERS et al. in PILLER et al. (this volume). The formation of the peripheral Molasse Basin along the northern margins of the Alps during the Late Eocene-Oligocene and of pull-apart basins (like the Vienna Basin) during the Neogene, as well as eastward extrusion are steps in the continent-continent collisional process. These basins were part of the isolated Paratethys sea with a specific stratigraphy and evolution of depositional environments (STEININGER and WESSELY, this volume), in which many detailed studies were performed on facies, ecology and paleontology of both marine and terrestrial environments (KOVAR-EDER, PERVESLER et al., and PILLER and HARZHAUSER in PILLER, this volume). Moreover, Miocene Primates are well-studied from a number of localities (DAXNER-HÖCK in PILLER et al., this volume).

Quaternary

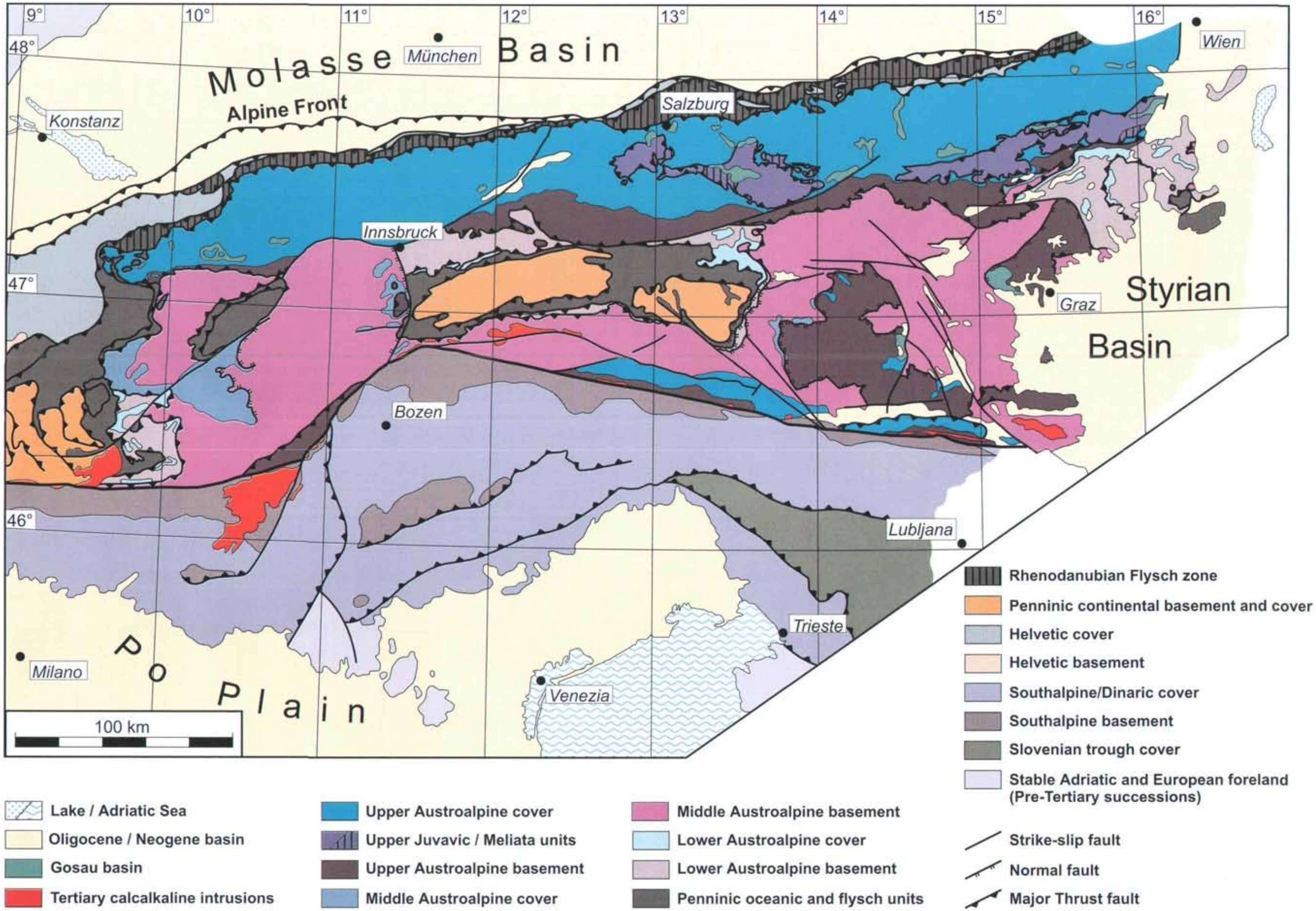
The Alps were almost entirely covered by ice during Quaternary glaciation, well-known since the classic work by PENCK and BRÜCKNER (1909). The glaciation had immense influence on geomorphology by reshaping valleys, creating post-glacial slope instabilities and leaving behind moraines and lake deposits, mostly of clay. Details of glaciation effects are described in the contribution of VAN HUSEN (this volume), who also reviews the present knowledge about the extent and decay of glaciers and the related Quaternary evolution. Specific glacial/interglacial habitats also influenced the evolution of man and bears, as is described for bears in the contribution by NAGEL and RABEDER in PILLER et al. (this volume). The knowledge of Quaternary geological processes has immense meaning for applied technical geology, as Quaternary deposits and processes control settling and land-use of the area.

Resources

Mining in the Austrian territory dates back to the Neolithic Era, as silex was mined near Vienna and salt in the Northern Calcareous Alps (ca. 4,500 years before present; TOLLMANN, 1986). Intense production of salt and copper started during the Hallstatt culture (ca. 2,700 years ago). The exploration and exploitation of mineral resources, ores and industrial minerals played an important role during the last centuries. In present-day measures "Austria is rich in poor deposits". The main period of mining is over, although several major deposits are still mined including a few, which were discovered after the Second World War. Present-day mining includes mainly salt, scheelite, iron, talc, magnesite and clay. The contribution of EBNER et al. (this volume) describes the distribution of ore deposits in the context of their geodynamic control and evolution through Variscan and Alpine geodynamic cycles.

Coal has played an important role during the period of industrialization. As elsewhere in Central Europe, coal was mainly formed during three distinct time periods: The Late Carboniferous, Late Cretaceous and Neogene. Coal formation was largely controlled by climate and specific geodynamic/tectonic conditions (SACHSENHOFER, this volume). Furthermore, coal formation is a good monitor of subse-

Fig. 2 →
Simplified geological overview map of the Eastern Alps.


9°
10°
11°
12°
13°
14°
15°
16°
48°
47°
46°
Molasse Basin
München
Wien
Salzburg
Konstanz
Alpine Front
Innsbruck
Graz
Styrian Basin
Bozen
Lubljana
Trieste
Venezia
Milano
Po Plain
100 km
Rhenodanubian Flysch zone
Penninic continental basement and cover
Helvetic cover
Helvetic basement
Southalpine/Dinaric cover
Southalpine basement
Slovenian trough cover
Stable Adriatic and European foreland (Pre-Tertiary successions)
Lake / Adriatic Sea
Oligocene / Neogene basin
Gosau basin
Tertiary calcalkaline intrusions
Upper Austroalpine cover
Upper Juvavic / Meliata units
Upper Austroalpine basement
Middle Austroalpine cover
Middle Austroalpine basement
Lower Austroalpine cover
Lower Austroalpine basement
Penninic oceanic and flysch units
Strike-slip fault
Normal fault
Major Thrust fault

quent tectonothermal processes, as the overprint relates to specific post-collisional processes.

The peripheral foreland Molasse and Vienna Basins (STEININGER and WESSELY, this volume) include major hydrocarbon deposits. Their formation is largely controlled by the geodynamic evolution of the region (collision tectonics and related extrusion tectonics). The exploration efforts led to the detection of world-class hydrocarbon deposits (e.g. the Matzen field) and include one of the deepest commercial wells, the Zistersdorf well ÜT2A, which was drilled 1980/81 (HAMILTON et al., this volume) and reached a depth of 8,553 meters. The contribution mentioned here also describes the present state of exploration and possible future tasks, which mainly consist of deep exploration targets beneath the Northern Calcareous Alps (Fig. 2).

Water represents one of the most important resources, although this matter required little attention in the past. However, the construction of water supplies for major cities like Vienna or Innsbruck quickly led to the development of new techniques, such as tracer techniques in karstified areas (see SCHUBERT, this volume; ZÖTL and GOLDBRUNNER, 1993). This progress and the disclosure of deep ground waters often combined with geothermic projects (GOLDBRUNNER, this volume) resulted in a high level of expertise in Austrian hydrogeology (ZÖTL and GOLDBRUNNER, 1993).

Engineering geology and environmental geology

As Austria is a mountainous country, the foundation of major technical constructions is a strongly geology-related task. The engineering geology for railways and highways, specifically tunnel constructions, as well as hydro-power plants have a long tradition and have led to highly refined skills in these areas (TENTSCHERT, this volume). Among these, the development of the New Austrian Tunneling Method is the most prominent achievement. The method was developed to minimize costs and maximize safety by careful observation of geology and by continuous measurement of rock deformation.

A further aspect of applied geology is environmental geology. Great efforts have been taken to bring together all aspects of environmental issues in the Austrian Federal Agency of Environment. KRALIK (this volume) describes the comprehensive integrated approach to dealing with the environment in Austria from the perspective of geology for the first time.

Major current projects

Currently, several major national and international projects are in progress. The international TRANSALP deep seismic profile combining the efforts of Austria, Germany and Italy, appears to be the one of most importance among these. This project made a ca. 270 km long N-S deep seismic line extending from the east of Munich, crossing the Tauern window to the southern margins of the Alps. Another important project is the ongoing refraction seismic network CELEBRATION 2000, which includes 16 shooting and recording lines and covers an area of approximately 500000 km^2. The lines extend from Poland, Slovakia and Hungary to Austria, Czechia and even Germany.

Many Earth Science research projects are funded by several Austrian research agencies, including the FWF (Austrian Funds for Scientific Research), the Austrian Academy of Sciences and the Austrian National Bank. Their contributions and support make research possible and fruitful.

Austrian scientists continue to participate in many international projects, including the International Geological Correlation Program (IGCP) since the Seventies, in the Euopean Community within the Fourth and Fifth Framework Programmes and those of the European Science Foundation. Among the latter, the Europrobe project explores the tectonic evolution of Europe.

Many major projects were finished over last years. These include:

- The project "Pre-Alpine Crust in Austria", devoted to the evolution of the basement exposed both in the Bohemian Massif and within the Eastern Alps (HÖCK and STUMPFL, 1997).
- The new edition of the metamorphic map of the Alps (FREY et al., 1999), which compiled the present knowledge of metamorphic crust in the Alps.
- The minerogenetic map of Austria, along with an explanation (WEBER, 1997), compiled the present knowledge of mineral resources in Austria.
- Besides the standard mapping work, the Austrian Geological Survey compiles maps in the scale of 1:200,000 covering the whole of Austria. All maps are now produced in a digitalized form, which allows rapid updating.

Challenges for the future

Following the period of research, in which the focus was on orogenic structures, geological research is gradually concentrating its efforts on surface structures and geomorphology as these topics are important for society. In applied geology, Quarternary geology and related applied aspects now receive more attention, as does environmental geology. Another intriguing area of interest is geomorphological evolution, which includes a lot of work in low temperature thermochronometers.

However, there is an increasing need to raise the awareness about the Earth Sciences through popular brochures and modern information technologies. It would be advantageous for society to know about the contributions of the Earth Sciences for its own development and economic welfare. Earth scientists did not pay much attention to these aspects in the past. Even though there is some apparent change, as we can see by the increase in publications of popular material, a lot remains to be accomplished. Earth scientists have to inform the public about the geosciences as the main source of knowledge to protect the environment and to give the decision-makers and politicians tools for their work in a language they understand.

Austrian Earth scientists are becoming increasingly involved in nature conservation issues and measures like geotopes, national parks and geoparks, including the conservation and development of geological heritage in Austria.

Acknowledgements

We would like to acknowledge discussions with Werner JANOSCHECK on the importance of Austrian geology. We would especially like to thank Hans-Peter SCHÖNLAUB for critical remarks on an earlier version of the manuscript and Lisa STALEY for correcting the English in this publication.

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Manuscript received: 12. 04. 2000 ●
Revised version received: 18. 04. 2000 ●
Manuscript accepted: 21. 04. 2000 ●