Outline of the Geology of Austria

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Introduction

Austria is part of central Europe and covers an area of 83,849 km^2. 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

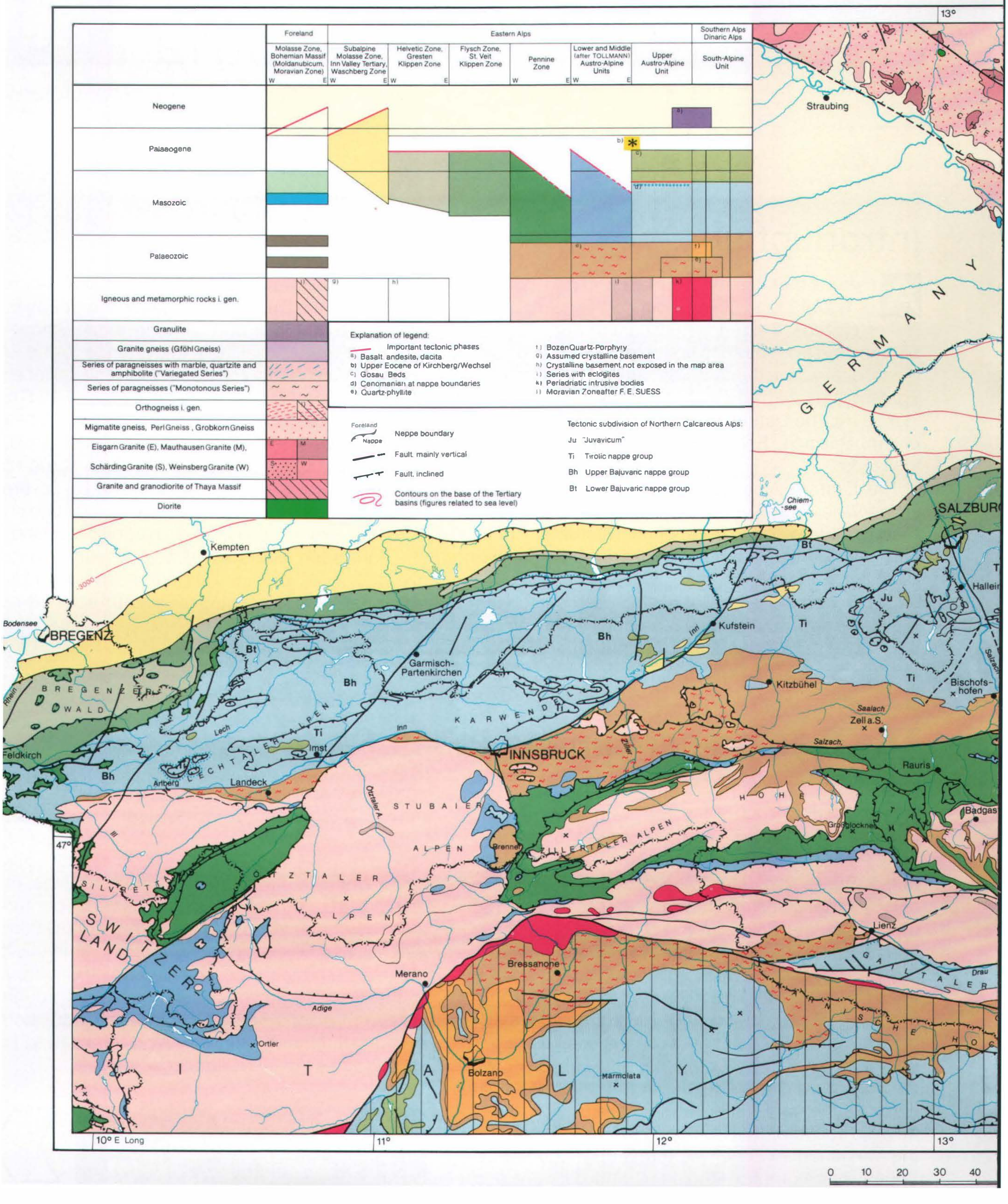
The area north of the Danube River belongs to the Bohemian Massif and represents a former fragment of Northern Gondwana that split off during early Paleozoic time to collide with Avalonia and Baltica during middle Paleozoic time. This block is essentially composed of medium-grade metamorphic rocks of 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.

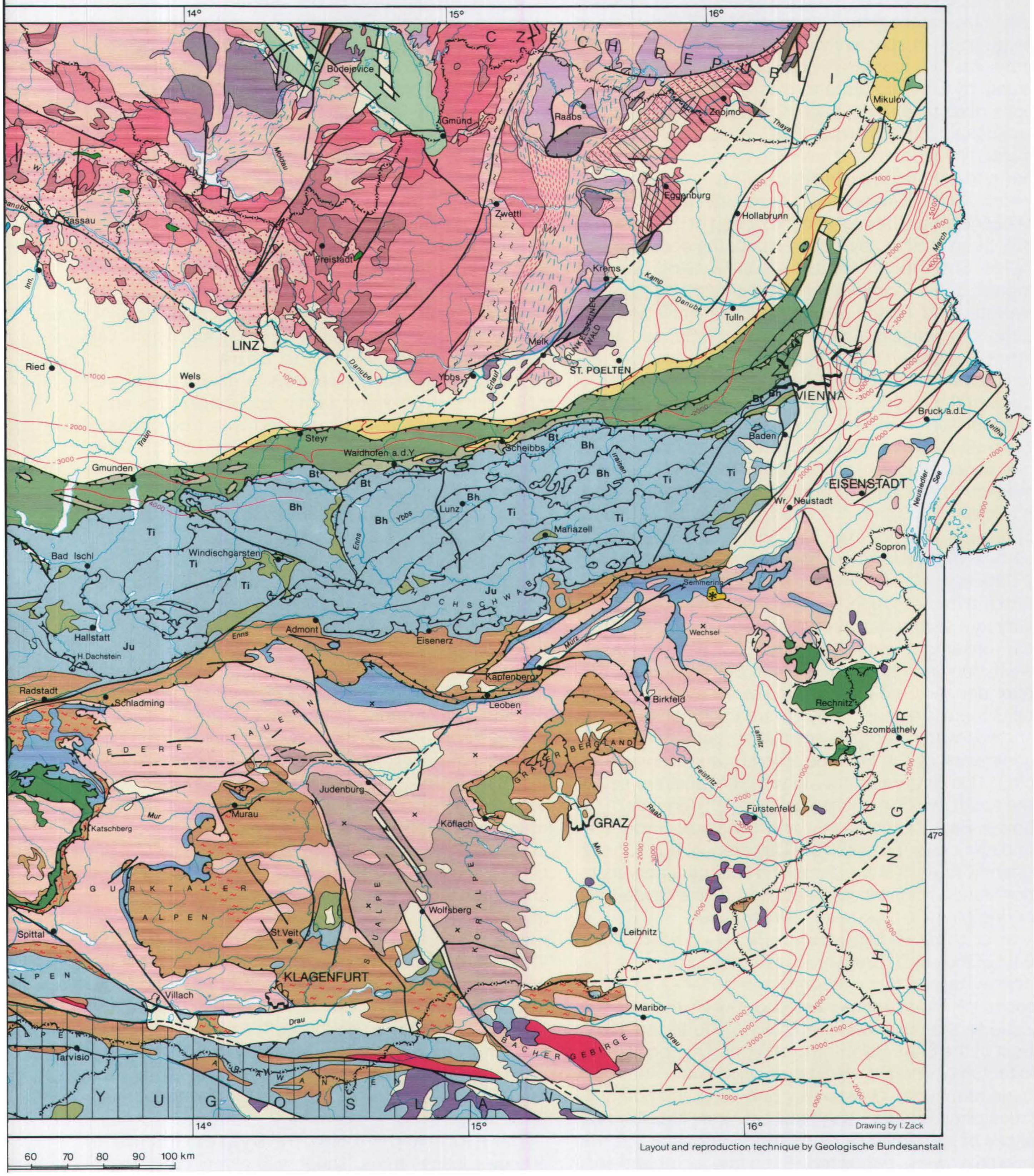
For Fig. 1
(Geological Map of Austria; 1980)
see the following pages 10 and 11.

GEOLOGICAL MAP OF AUSTRIA 1:1,500.000

(WITHOUT QUATERNARY)



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



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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.

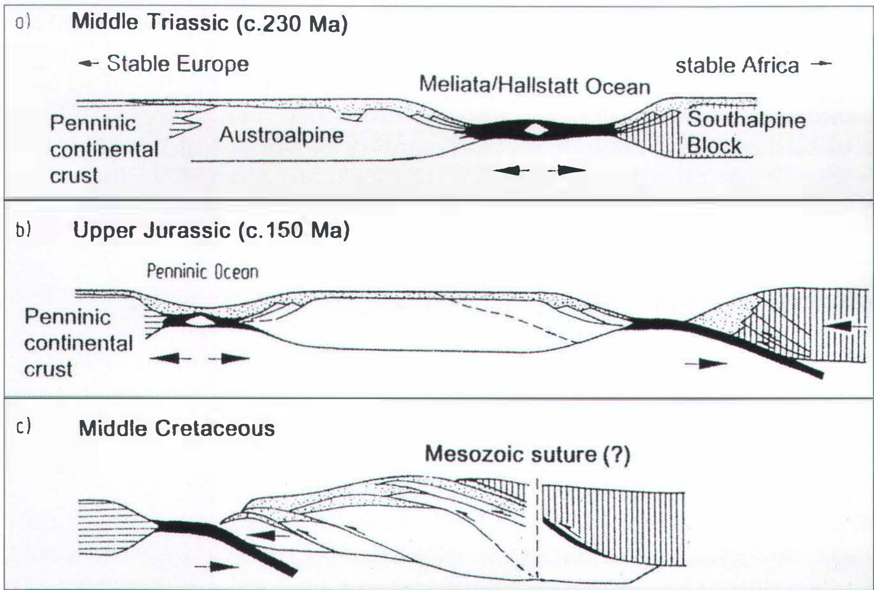
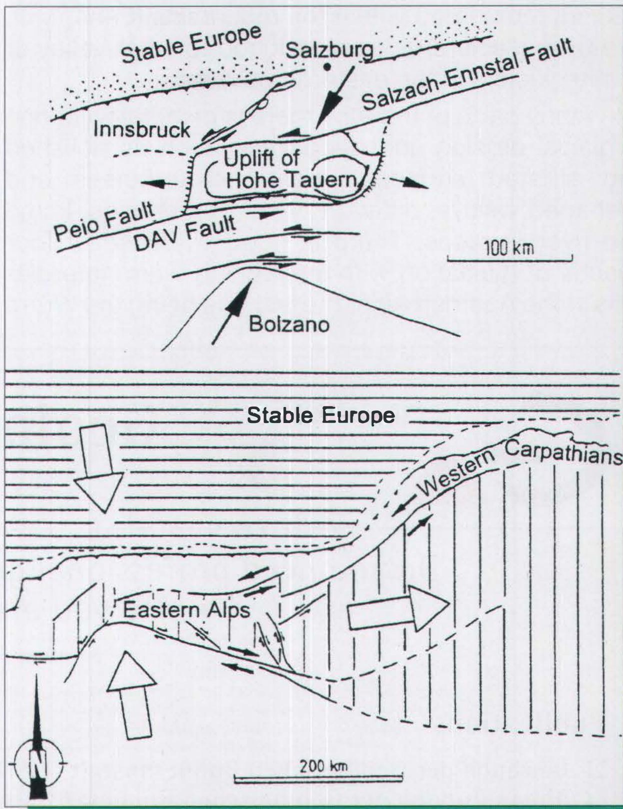


Fig. 2.
Model of the early Alpine tectonic evolution in the Eastern Alps and Western Carpathians.
Modified after NEUBAUER (1994).

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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