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Mineral Deposits of the Eastern Alps

(An Excursion Guide)

by

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H. F. HOLZER and E. F. STUMPFL

Contens

A. Introduction

The territory of Austria comprises about 84.000 square kilometers. Roughly two thirds are covered by the Eastern Alps, a section of the Tertiary Alpine-Himalayan orogenic belt, the rest is represented by parts of the Hercynian "Extra-Alpine Basement" ("Bohemian Massif") as well as the Tertiary basins and forelands.

A mineral distribution map of Austria (LECHNER, HOLZER et al., 1964) shows several hundred locations in the Eastern Alps where minerals were mined in the past or are presently being exploited.

The multitude of mineral deposits in various geologic units, many of them quite small by international standards, attracted the attention of numerous researchers for the past hundred years. Consequently, a wealth of papers on this subject has been published. Origin and age of the Alpine deposits remained a central theme until now and several convincing theories were presented. Much, however, is still to be investigated before the "Alpine enigma" (EVANS, 1975) will be solved.

The first, and for many years generally accepted, explanation of the origin of the Alpine deposits was elaborated by W. PETRASCHECK (1926): the roughly symmetric and spatially zonal arrangement of the deposits (Au in centre, Fe, Cu, Mg gradually further distant from a hypothetic core, and Pb-Zn in the peripheral sectors) was assumed to have originated from a geologically young (Tertiary) magmatic dome underneath the Central Alps. The zonal pattern was seen as indicative of a decrease in the temperatures of the ore-forming fluids towards the marginal zones. This theory of a "uniform-Alpidic" metallogenesis (in the sense of an epigenetic origin in Late Cretaceous-Tertiary times) was later modified by a number of authors (CLAR, FRIEDRICH, W. E. PETRASCHEK and others). They assumed that many ore-bearing solutions originated not from magmatic bodies, but from young centres of crystallization during the Alpine regional metamorphism, the thrust planes of nappes being the preferred channels of emplacement.

SCHNEIDERHÖHN (1952) suggested that the metal content of the Alpine deposits was derived from Hercynian granites; the resulting deposits would thus have to be considered as "copied" Hercynian deposits.

The concept of a uniform, predominantly "Alpidic" metallogenesis was increasingly attacked by researchers who, on the basis of detailed studies, concluded that the great majority of the deposits are strata-bound, formed more or less contemporaneously with their host rocks in Palaeozoic to infra-Triassic times (HÖLL, MAUCHER, SIEGL, SCHROLL, SCHNEIDER, SCHULZ, TUFAR and others).

These authors described metamorphic-, syn-sedimentary and diagenetic fabrics and postulated syngenetic models of ore deposition. In 1968 FRIEDRICH reviewed the Alpine deposits again and distinguished pre-Hercynian, Hercynian-, and Alpidic deposits, the latter divided into mineralizations of the geosynclinal stage, syn-orogenetic type-deposits and mineralization related to subsequent magmatic suites.

The new concept of global tectonics and plate movements has so far been applied only tentatively to the Eastern Alps (W. E. PETRASCHECK, 1975, FRISCH, 1976). EVANS (1975) suggested that the apparent paucity of post-Hercynian mineralizations, especially the absence of porphyry copper and Cyprus-type massive sulphides, could best be explained by the assumption that subduction of oceanic crust did not take place on any significant scale during the evolution of the Alpine geosyncline or its subsequent deformations.

TISCHLER and FINLOW-BATES (1980) conclude that "the notably limited post-Hercynian mineralization of the Eastern Alps is shown to be a direct function of the particular plate tectonic history of the region".

There can, by now, be no doubt that plate tectonics have played a significant role in the evolution of the Alpine orogeny as in other orogenic systems worldwide. The recent series of earthquakes in the Italian region of Friuli and in adjoining parts of Carinthia, Austria, can be interpreted as a result of the continuing northward movement of the African plate. The recognition of the ophiolite nature of major Paleozoic ultramafic massifs in the Central Alps of Styria (EL AGEED, SAAGER and STUMPFL, 1979), for the first time provides evidence for plate tectonic processes connected with the Hercynian orogeny in the Eastern Alps. A considerable amount of research work is still required until a comprehensive model for the plate tectonic evolution of the Alps will be available.

The present authors consider the Alpine mineral deposits as products of a poly-cyclic development in which the Alpine orogenesis had an important role. They comprise various genetic types and range in age between pre-Hercynian to late Tertiary.

Mining in Austria has a long history: in prehistoric times, Illyric and Celtic miners produced considerable quantities of copper. The total output of "black" copper between 1800 B.C. and 100 B.C. is estimated at about 50.000 tonnes. Graphite has been used in Neolithic ceramics and rock-salt was mined in the Alps since about 900 B.C. ("Hallstatt"-period, 800—400 B.C.). The Celtic people of "Noricum" were famous for their iron and the "ferrum Noricum" was a commodity much in demand in the Roman Empire.

Gold and silver were mined since Roman times at numerous locations; these activities flourished particulary between A. D. 1480 and 1560. The mines in Tyrol and Styria were then the leading silver producers in Europe. The "Holy-Ghost"-shaft at the Tyrolean Röhrerbühel Cu/Ag deposit had in A. D. 1600 a depth of 886 meters; it remained the deepest shaft in Europe for 300 years.

At present, 100 mines and quarries are in operation in Austria. The production data for 1978 are (Österr. Montan-Handbuch 1979, 53. Jg., Wien 1979):

lignite	3,075.680 metric tons	
iron ore	2,788.435 metric tons	
hematite ore	10.560 metric tons	(solely used for corrosion-resistant paints, etc.)
tungsten ore	291.140 metric tons	
lead-zinc ore	476.340 metric tons	
antimony ore	23.602 metric tons	
gypsum	626.475 metric tons	
anhydrite	139.490 metric tons	
baryte	242 metric tons	
graphite	40.501 metric tons	
oil shale	970 metric tons	(for pharmaceutical products only)
talc	106.848 metric tons	
kaolin	275.695 metric tons	
magnesite	982.320 metric tons	
clay	32.538 metric tons	
expanding clays	395.103 metric tons	
quartz, quartzite	203.096 metric tons	
quartz sand	821.325 metric tons	
feldspar	2.886 metric tons	
diatomite	536 metric tons	
trass	8.944 metric tons	
salt brine	1,702.876 m^3	
rock salt	1.173 metric tons	
crude oil	1,790.312 metric tons	
nat. gas	2,413.915 (1000 m^3_n)	

B. The Excursion

Excursion 080 C is intended to show some of the major mineral deposits of Austria; the "Styrian Ore Mountain" (Steirischer Erzberg), one of the few large European open pit and underground siderite mines, the open cast lignite mine of Oberdorf in the west-Styrian coal district, the ultramafic complex of Kraubath near Leoben, where some chromite and cryptocrystalline magnesite was mined in the past, the excavations of Magdalensberg in Carinthia, an ancient settlement next to an iron ore deposit worked since Celtic-Roman times, the large underground zinc-lead mine of Bleiberg ("Lead Mountain") in Carinthia, the newly developed tungsten mine of Mittersill, Salzburg, which made Austria an important tungsten exporting country, and the underground salt mine of Hallein, Salzburg, situated in an area where salt has been produced for more than 2500 years.

The originally planned visit to the uranium deposit of *Forstau* near Radstadt had to be cancelled as exploration activity in this mine has been interrupted recently; the adits are temporarily abandoned.

The excursion leaves Wien (Vienna), the capital of Austria, by bus on Saturday, July 19, in a south-western direction through Lower Austria, crossing the Semmering Pass (elevation 985 meters) to the Mürz valley and to the city of Leoben on the Mur river (541 meters) in Styria, seat of the University of Mining and Metallurgy. From Leoben, bus trips to the Erzberg iron mine and Oberdorf coal mine are undertaken.

The tour continues in a south-western direction via Kraubath, Judenburg and the Perchauer Sattel (995 meters) into Carinthia, onwards through the towns of Friesach and St. Veit to Magdalensberg, along the outskirts of Klagenfurt (capital of Carinthia) and the shore of Lake Wörthersee to Villach and Bleiberg. After visiting the Bleiberg mine, the excursion continues to the north-west through the lower Drau Valley and the upper Möll Valley and on the scenic Grossglockner Hochalpenstraße over the Hochtor (elevation 2575 meters) into the province of Salzburg, then along Fuscher- and Salzach valley to Mittersill (fair weather route only). Poor weather route: through the upper Drau valley to the town of Lienz (Eastern Tyrol), along the river Isel to Matrei and through the recently built road tunnel (Felber Tauern, 2481 meters) to Mittersill in Salzburg province. Both routes cross the Alps in a south-northern direction, offering views of geologic and scenic interest.

From Mittersill, the route follows the river Salzach, passes Zell am See, Schwarzach, and, after Bischofshofen, intersects the Northern Calcareous Alps in south-north direction to Hallein. After a visit to the Hallein salt mine, the excursion reaches the famous city of Salzburg (birthplace of Mozart) and returns on the "West-Autobahn" to Vienna (Wien) in the afternoon of Sunday, July 27.

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C. Route Description

Day 1

Route: Wien / Vienna to Leoben

The route from Vienna to Leoben is along the western fringe of the Vienna basin, an intra-Alpine Tertiary basin, filled with marine to lacustrine and fluvial Miocene and Pliocene-Pleistocene sediments (marls, clay, sands and gravel).

The wooded hills in the west are the outliers of the Eastern Alps, downthrown along deep-reaching faults which are marked by several hot springs (spa's) at Baden, Bad Vöslau and Bad Fischau.

Roughly between Mödling and Wiener Neustadt, the range of hills in the west consists of Mesozoic limestones and dolomites of the "Northern Calcareous Alps", an Upper-East Alpine unit which extends uninterrupted from the Rhine to Vienna in a 20—40 km wide belt of mainly Triassic (and minor Jurassic and Cretaceous) carbonate sequences of complicated nappe structures.

To the south of Wiener Neustadt, the route crosses into a lower tectonic unit of the Eastern Alps; the Upper East-Alpine Greywacke Zone which underlies the Calcareous Alps over a distance of more than 400 kilometers in east-west direction. The Greywacke Zone is comprised predominantly of phyllites, quartzites and metavolcanics such as metadiabase and quartz-porphyries. At places, carbonate rocks are intercalated. Stratigraphically, rocks range from the Ordovician to the Upper Carboniferous.

Numerous ore deposits occur within this unit (Fe, Cu, graphite, talc, magnesite). In the eastern sector it can be separated into two thrust sheets. Abandoned magnesite mines are close to the road southwest of Gloggnitz.

Before entering the narrow gorge at Klamm, the route enters into another tectonic unit, the "Semmering-Wechsel-System", attributed to the Lower East-Alpine nappe pile. Along the winding road to the Semmering pass there are occasional outcrops of

Triassic limestones, dolomites, cellular dolomites and Upper Triassic sericite schist.

Several small mines in the Semmering area produced high-grade gypsum. A barite mine south of Schottwien presently maintains a small production.

Southwest of the Semmering pass, the forested hills on both sides of the road consist of Mesozoic carbonate rocks, phyllites, and, in the vicinity of Mürzzuschlag, "grobgneiss", a coarsegrained granitic gneiss of ? Carboniferous age. In the Mürz valley small slices of Upper Tertiary sediments of lacustrine origin contain seams of lignite, locally mined in the past.

West of Mürzzuschlag, the road via Mitterndorf-Bruck and Kapfenberg to Leoben runs mainly through the above mentioned "Greywacke Zone" which, in this sector, contains several abandoned siderite mines and the large magnesite mine of Veitsch, closed down several years ago because of the Fe-content of its ore.

Stop 1. Leoben

The city of Leoben, (population about 40.000 including the suburb of Donawitz, seat of a large steel mill of the Vöest-Alpine Corporation) developed from a medieval iron- and steel trading settlement.

The LD-oxygen blast steel-making process, now in use world-wide, was developed at Linz and Donawitz ("LD-System"); however, Leoben with its brewery at Goess is much better known in Austria for its famous "Goesser Beer".

In 1840, a school of mining and metallurgy was founded at Vordernberg, about 20 kilometres west of Leoben. It was moved to Leoben in 1849. The present "Leoben University of Mining and Metallurgy" (student population about 1100) offers degree courses in the following subjects: mining engineering, petroleum engineering, metallurgy, mining geology, mine surveying, mining machinery, material sciences, plastics technology, refractory- and glass technology. There is also a post-graduate course in mineral exploration for graduates from developing countries.

Leoben (elevation 544 meters) is situated on the river Mur. Miocene sediments in the vicinity contain seams of brown coal which were mined until a few years ago at the large Seegraben mine at the outskirts of the city. Carboniferous rocks of the Greywacke Zone (phyllites, banded limestones and sandstones) underly the wooded hills surrounding Leoben. Further to the northwest and southeast, the higher mountain ranges of the Seckauer Alpen and the Gleinalpe consist of granitic rocks, migmatites and orthogneiss, enclosed in strongly metamorphosed metasediments (gneiss, micaschist, marbles, amphibolites). These units are attributed to the "Middle East-Alpine System" of the Central (Eastern) Alps. The emplacement of the granitoids is still under discussion: a Hercynian age was suggested by many authors, others considered an early Alpidic (i. e. Jurassic) age for the crystallisation of the granite bodies.

Day 2

Route: Leoben — (Gaberl) — Köflach, lignite open pit mine of Oberdorf — Graz — Gleinalm Tunnel — Leoben.

The excursion leaves Leoben in a southwestern direction through St. Michael (Neogene sediments in the Mur valley) and on a secondary road over the Gaberl Pass (1547 meters) to the town of Köflach. The winding mountain road crosses the Gleinalm massif: its plagioclase-rich gneiss core is surrounded by a mesozonal sequence of amphibolites, serpentinites and micaschists with widespread marble bands and pegmatites (Middle East-Alpine System). Frank et al. (1976) have performed age determinations of the plagioclase gneisses and obtained ages of 500 ± 45 m.y.

Stop 2. Oberdorf Lignite Mine

The coal-bearing strata of the Köflach-Voitsberg basin represent a near-shore facies of the Miocene Upper Helvetian (Carpatian) of the west-Styrian embayment of the Styrian Basin. In lower parts of the west-Styrian embayment, east and southeast of the coal district, clastic sediments of limnic-fluvial origin with tuff layers were deposited during the Carpatian but do not contain mineable coal horizons.

The Tertiary coal basin of Köflach-Voitsberg (maximum thickness about 300 m) is divided into several troughs by the considerable relief of the pre-Tertiary basement, originating mainly from strong karstification of carbonate rocks.

The basement consists of metamorphic rocks in the west and south, and of Paleozoic and Mesozoic carbonate rocks in the north, northwest and east. On its top red soil and iron-oxyhydrate-incrusted debris were encountered in various places, overlain by Neogene fluvial-limnic sands, clay and gravel. Erosion and karstification on one hand and deposition of Tertiary sediments on the other were accentuated by tectonic movements during the "Early Styrian Phase" in the Lower Carpatian. During the Upper Carpatian, monotonous, finegrained clastic sediments were laid down from the southwest and north, enclosing three productive seams which, in the east only, are followed by a fourth seam (the "Zangtal top seam"). The seams vary in thickness between 3 and 70 meters.

The coal-bearing Carpatian is overlain by mainly fluvial, coarsegrained sediments of Tortonian (Badenien) age.

The coal of the Köflach-Voitsberg district is light to dark brown. Specific gravity is 1,2 to 1,3. In the international brown coal classification scheme (A. Lissner & E. Rammler, 1965) it ranks under code number 1310.

The Oberdorf coal contains between 36.9 to 38.3 % H_2O, 8—11% ash and has a calorific value between 2900 and 3150 kcal per kg. The average chemical composition of the Oberdorf coal is: 65—67% C, 5,56—

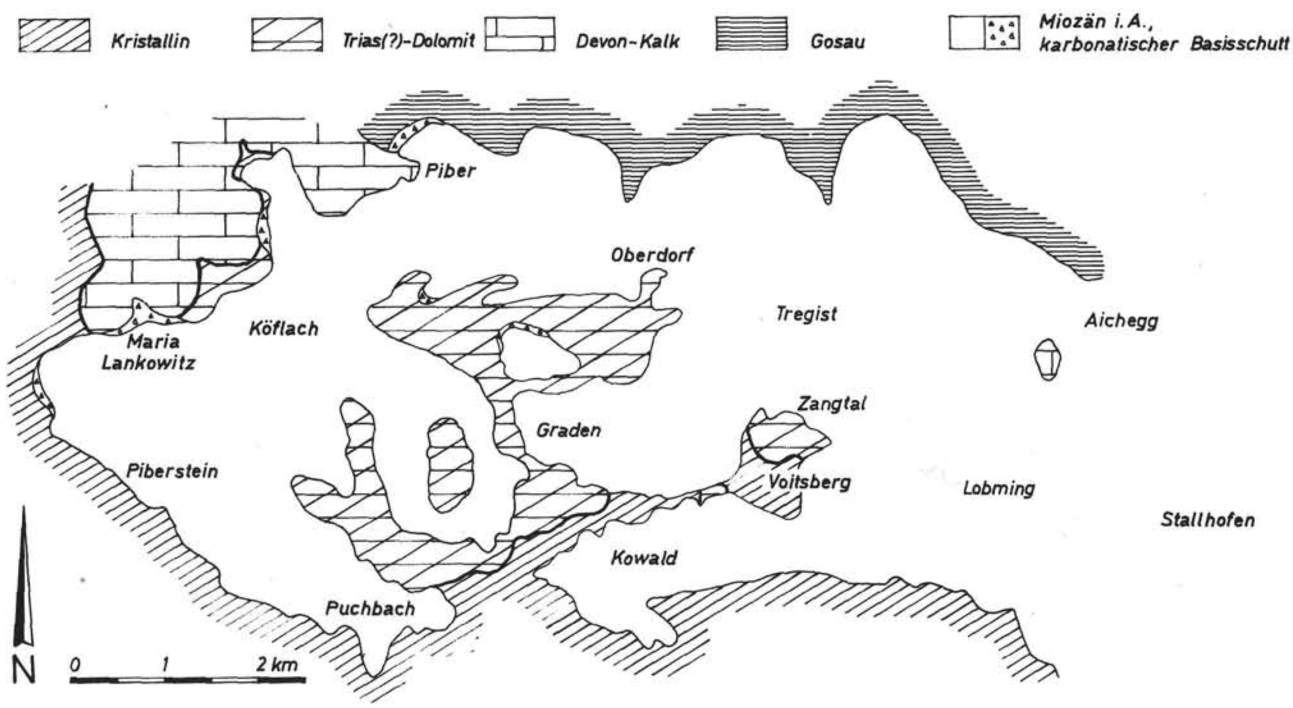

Fig. 1: Geological map of the lignite basin of Köflach—Voitsberg. After W. POHL, 1976.

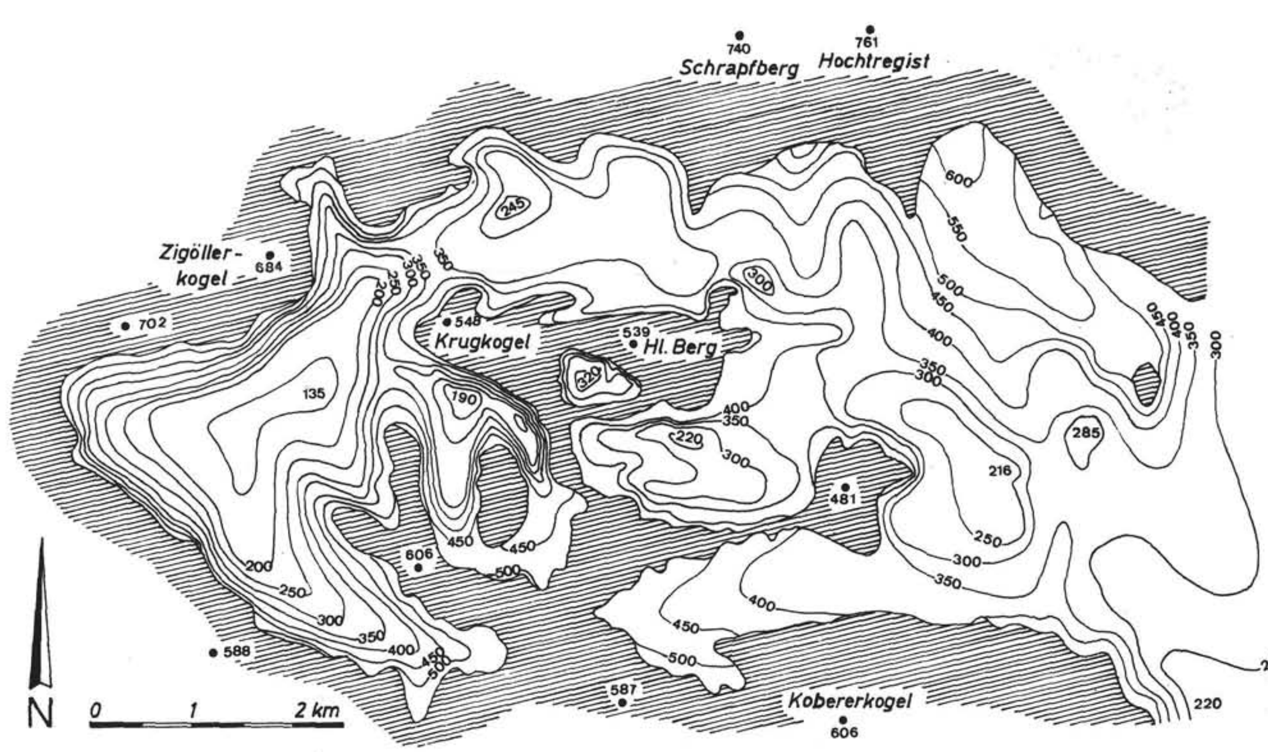

Fig. 2: Map of the pre-Tertiary relief of the lignite basin of Köflach—Voitsberg. After W. POHL, 1976.

5,80% H, 0,84—1,03% S, 26,30—28,51% O + N. The coal of the Köflach-Voitsberg district shows slight differences in its original peat facies as well as in rank. In the western part of the basin, the peat is derived mostly from angiosperma, in the east from conifer forests, with a transition between both in the central part.

The earliest mining activity was recorded in 1716. However, large scale mining started in 1860 when the Graz-Köflach railroad was completed. At present, 5 mines of the Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft (GKB), an affiliated company of Voest-Alpine Corporation are in operation with a total production of nearly 1 mio. t in 1978.

The recently developed Oberdorf deposit consists of a western and an eastern trough, separated by a basement ridge.

The overburden has a maximum thickness of 150 meters; the average thickness of the coal is 35 meters. The Oberdorf seam is divided by a barren layer into a top seam and a lower seam, underlain by sandy clay. The coal produced is used as steam coal to feed the electric power station at Voitsberg 3 (330 MW). The reserves are calculated at 35 mio t. Fig. 3 shows the geologic situation.

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The tour continues with a visit to Graz.

The city of Graz, capital of the province of Styria (population 260.000, elevation 365 meters) is situated on Neogene sediments, overlying a Paleozoic sequence of weakly metamorphosed sediments, ranging from the Middle Ordovician to the Upper Carboniferous (Westfalien), represented by fossiliferous shales, greenschist, sandstones, limestones and dolomites.

After sightseeing in Graz, the excursion returns via Übelbach and the Gleinalm Tunnel to Leoben.

In the vicinity of Übelbach, a number of small mines intermittently produced lead-zinc ores between the 16th and the early 20th century. Among the ore minerals, galena and spalerite dominate, accompanied by pyrite, chalcopyrite, freibergite, polybasite and magnetite, barite, and ankerite; the gangue is dolomite and quartz. Recent investigations (KÜRZL, H.: M. Sc. Thesis, Mining University, Leoben 1979) indicate syngenetic stratabound Pb-Zn-mineralization in Paleozoic shales and greenschist. A drilling program in 1978/79 gave positive results, exploratory tunneling will start in 1980.

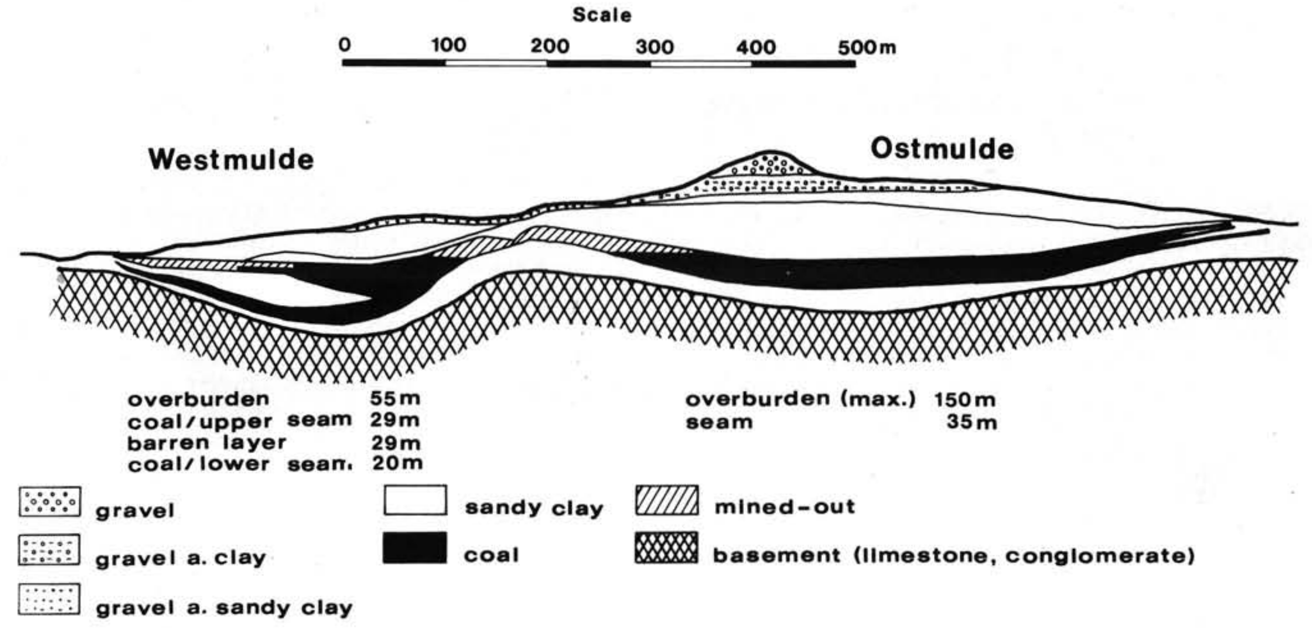

Fig. 3: Cross section of the lignite basin of Köflach—Voitsberg.

Day 3

The excursion leaves Leoben via Donawitz (steel mill of Voest-Alpine Corp.) and Vordernberg to the Präbichl Pass (1232 metres). Neogene sediments lie in the Trofaiach area; phyllites and Lower Paleozoic carbonate rocks of the Greywacke Zone form the mountains West of the road.

The conspicuous steep peaks in the North are Mesozoic carbonate rocks of the Northern Calcareous Alps.

Stop 3. Steirischer Erzberg Siderite Mine

(Operated by Vöest-Alpine Corporation)

The valley of Eisenerz is surrounded by numerous peaks higher than 2000 meters. The Erzberg (roughly 1500 meters) towers over the small mining town of Eisenerz, which is one of the oldest mining settlements of Austria (market-rights granted at the beginning of the 13th century).

Mining of iron ore dates back to the 3rd century A. D. The first smelters were built between 1150 and 1260, and mining continues until today. The highest annual production (13,8 million tons) was reached in 1943; the output in 1978 was 2,6 million tons of ore.

The Erzberg operations are managed by Voest-Alpine Corporation, Austria's largest industrial enterprise.

The total ore reserves (proved + probable) of Erzberg are estimated at 200 million tons.

Geology

The deposit is situated at the northern fringe of the "Greywacke Zone", near its border to the superimposed thrust nappes of the Northern Calcareous Alps. A synclinal structure, plunging 15 to 30° towards the northeast is cut by the transgressive basal rocks of the Triassic.

Silurian slates are overlain by a layer of metamorphosed quartz keratophyre (Ordovician) followed by mineralized Devonian limestone (Lower to Upper Devonian).

A barren "Zwischenschiefer" of Carboniferous age ("slate layer") separates a lower and a higher part of the deposit. This was interpreted by some authors as sedimentary repetition, by others as tectonic duplication. The overall synclinal structure is cut by an important fault ("Christof Hauptverwurf") into an upper and a lower block. The transgressive basal beds of the Triassic are represented by coarse breccia, at places mineralized, and by reddish, sandy-argillaceous Werfen beds.

For many years, the Erzberg deposit was seen as a typical example of a metasomatic replacement deposit, the carbonate rocks having been transformed into siderite and ankerite by thermal, Fe- and Mg (Mn)-bearing solutions.

Recent investigations have proven the presence of Hercynian structures, age-differences between siderite and ankerite (the main mass of the former being older) and chemical differences between finegrained, alternating layers of siderite ores, indicating a primary sedimentary origin in Paleozoic times, with subsequent remobilization and recrystallization during Alpine orogenesis. Mineral assemblage: siderite, $FeCO_3$, ankerite, Ca (Fe, Mg, Mn) $(CO_3)_2$, accompanied by minor amounts of hematite, quartz, calcite, arsenopyrite,

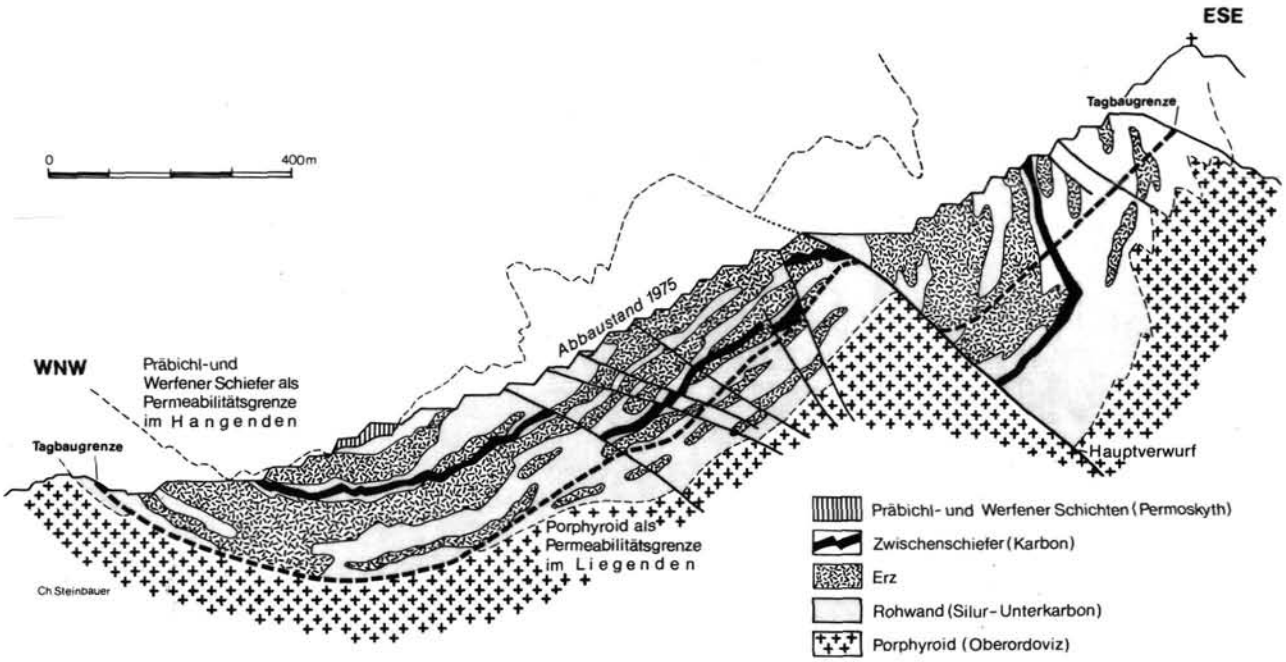

Fig. 4: Cross section through the Erzberg deposit. After Vöest-Alpine Corp.

chalcopyrite, tetrahedrite, cinnabar, pyrite. Secondary minerals: limonite, malachite, azurite, aragonite.

The shipping ore contains about 32% Fe, up to 2% Mn and traces of S and P. It consists of 40% run-of-the mine ore and of 60% upgraded ore (heavy media separation). 22% of the total production is mined underground, 78% by open pit mining.

Return to Leoben.

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Day 4

The Excursion leaves Leoben in south-western direction along the Mur river to Kraubath (appr. 18 km). At Kaisersberg/St. Stefan, an underground mine produces 12,000 tpa of microcrystalline graphite from Upper Carboniferous phyllites of the Greywacke Zone.

Stop 4. Ultramafic Massif of Kraubath

Ultrabasic rocks occur in the Austrian Province of Styria along a line extending for more than 100 km

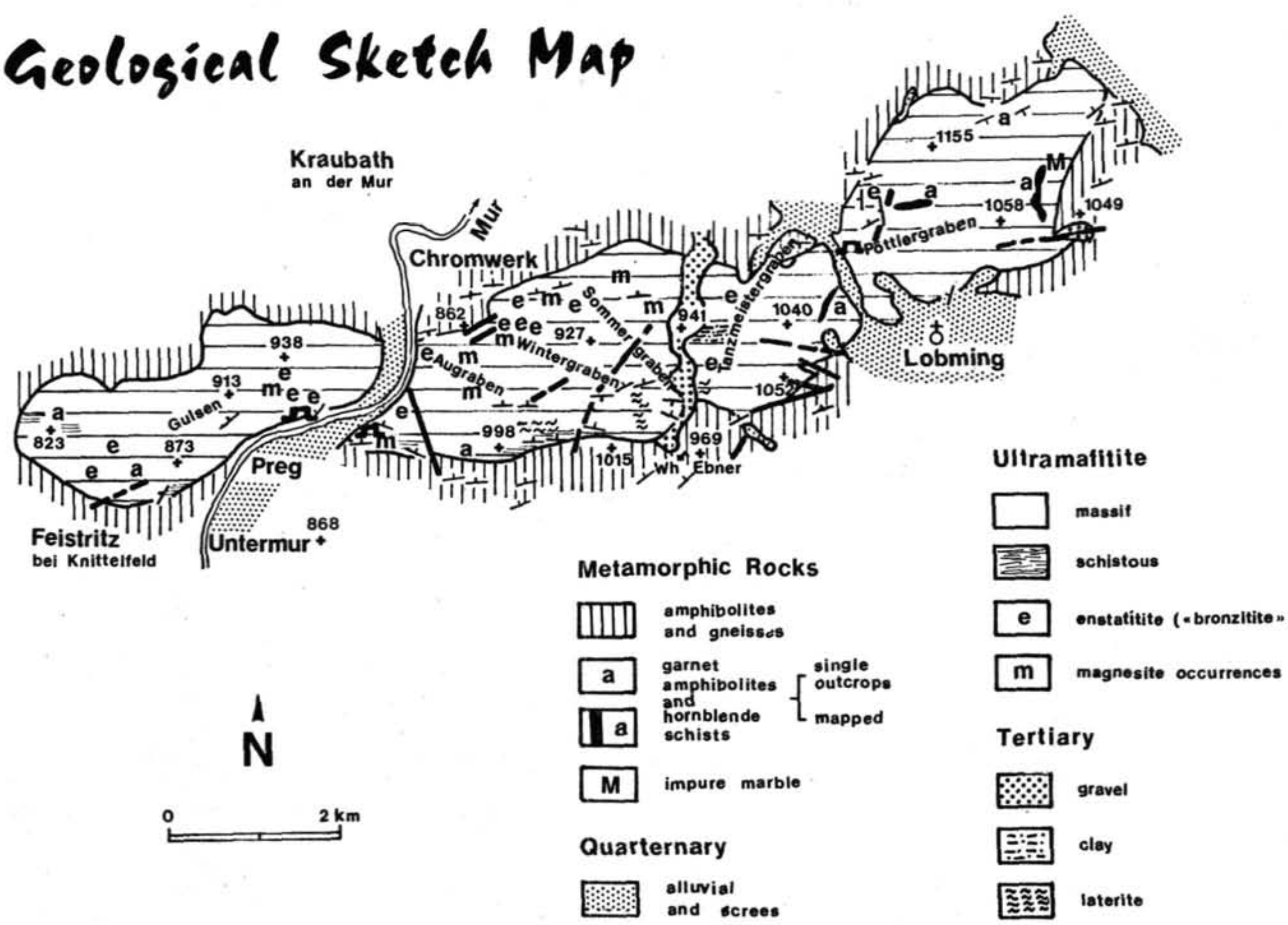

Fig. 5: Geological sketch map of the Kraubath ultramafic massif. After J. G. HADITSCH et al., 1980.

in WNW direction from north of Graz to Liezen. The two major occurrences are those of Kraubath (13 × 2 km; Fig. 5) and Hochgrössen (2 × 3 km). A detailed geochemical and petrological investigation of these has recently been performed within the context of a project entitled "Mineral Resources of Styria" (Steirische Rohstoff-Reserven). Generous support of the Provincial Government of Styria is gratefully acknowledged. The aim of this work was to contribute to our knowledge of the mineral potential of these ultrabasic massifs, and to delineate their evolution and their relationship to host rocks.

bodies within the Schist Covers of these gneiss massifs is considered significant and will be discussed later.

The investigations which have contributed the results summarized here included field mapping, sampling, transmitted and reflected light microscope, x-ray fluorescence analysis of major and minor elements, electron probe analysis (particularly of spinels and sulphides), and neutron activation analysis of rare earth elements (REE).

Low sulphur fugacity obtained throughout the complex history of both massifs and thus prevented the formation of significant nickel sulphide mineralization, although the average Ni-content of ultrabasic rocks in Kraubath and Hochgrössen is in the range of 0.2—0.4%. Chromite lenses which may, at some earlier stage of evolution, have occupied continuous bands have been thoroughly disjointed in the course of four phases of tectonism (two Paleozoic, two Alpine), and there is now little hope to discover economically viable concentrations.

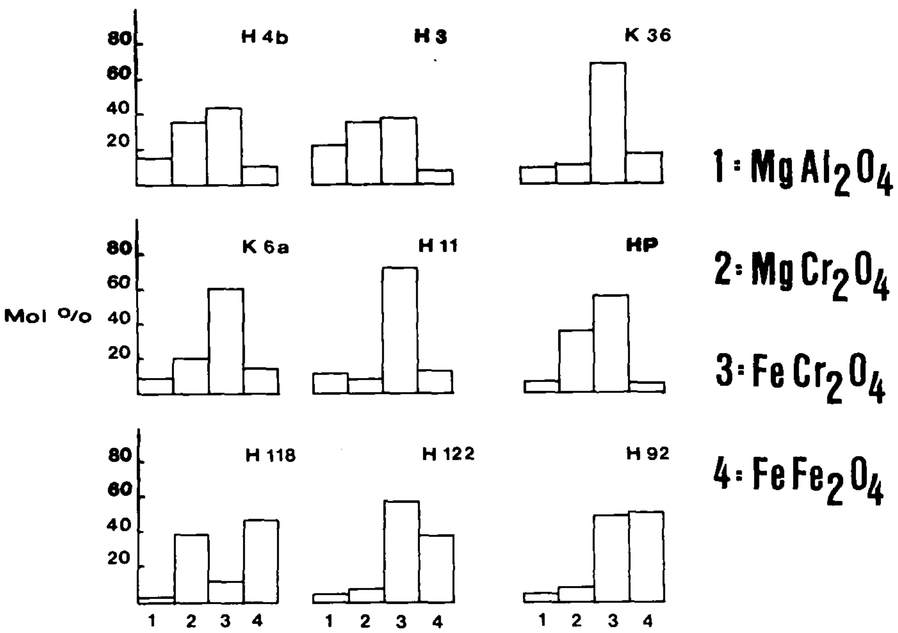

Fig. 6: Molecular proportions in chromites from the Kraubath (K 36, K 6 a) and Hochgrößen ultramafic massifs (analysis numbers with prefix "H"), calculated from electron microprobe analyses (EL AGEED, 1979).

Note high Fe contents and Cr/Al ratios in Kraubath spinels, suggesting residual character. The low-Fe mixed crystal spinels of Hochgrößen (magnesiochromite + aluminochromite + subord. ferrochromite) indicate cumulus environment.

About 300,000 tons p. a. of ultramafic rocks are presently quarried at Kraubath for use as road metal and ballast; the possibility of hydrometallurgical extraction of Ni, Mg and Si is being investigated (HADITSCH et al., 1980).

Both, Kraubath (± serpentinized peridotite, bronzitite and harzburgite) and Hochgrössen (serpentinized dunite, serpentinite) are rootless bodies and display tectonic contacts to the closely associated gneisses and amphibolites. The latter form part of the "Lower Schist Cover" (500 ± 45 m.y., FRANK et al., 1976) of the Gleinalpe gneiss complex (Kraubath) and of the "Amphibolite Series" cover of the Seckau gneiss complex (Hochgrössen), respectively. The location of ultramafic

Dominant rock types are peridotite, harzburgite and bronzitite at Kraubath, and serpentinized dunite and serpentinite at Hochgrössen. Whole-rock analyses do not reveal significant differences in the major element contents of rocks from the two complexes. They resemble compositions recorded from metamorphic peridotites and cumulate ultramafics in ophiolite complexes. Enrichment in Ni, Co and Cr, and depletion in Ti and Cu corresponds to the characteristic trace element distribution of metamorphic peridotites. The geochemistry of associated amphibolites corresponds to that of tholeiitic basalts; FRANK et al. (1976) suggested mantle derivation in view of low initial ratios.

There emerges a distinct pattern of REE-fractionation with Kraubath representing the refractory residue, Hochgrössen the cumulate portion, and the associated amphibolites basaltic rocks. Combined geological and geochemical evidence thus suggests that Hochgrössen and Kraubath are parts of a dismembered Paleozoic ophiolite complex, which has been emplaced in pre-

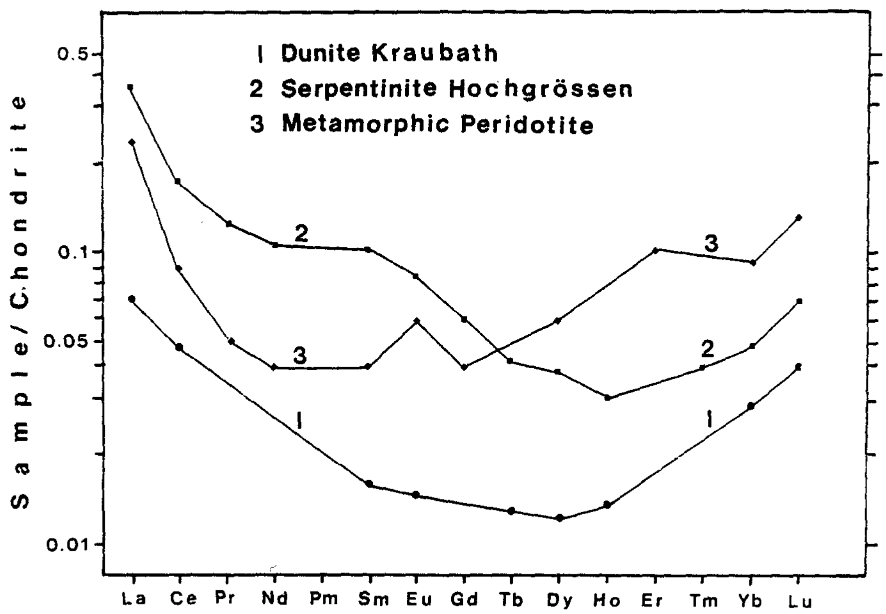

Fig. 7: Rare earths elements (REE) in Kraubath and Hochgrössen ultramafic rocks (from EL AGEED, SAAGER and STUMPFL, 1980). Note that, compared to Kraubath, average light REE abundances of Hochgrössen ultramafics are higher by a factor of 4. This suggests fractionation from an REE-enriched liquid and underlines the refractory nature of the Kraubath rocks.

Primary spinels at Kraubath occur as podiform concentrations and as disseminations. They have provided the basis for small-scale mining operations in the past and carry higher (55% Cr_2O_3) Cr and Fe, but lower Al and Mg than their counterparts from Hochgrössen (Fig. 6). The former can thus be interpreted as residual, the latter as cumulate chromites. The complex metamorphic history of the massifs is reflected in the formation of secondary ferrit-chromites and chromiferous magnetites.

Another aspect of this evolutionary trend is manifested by the rare earth element (REE) distribution: in ultramafics at Kraubath, REE are heavily depleted (Fig. 7); this is typical of metamorphic peridotites in ophiolite complexes. At Hochgrössen the respective values are four times higher, and characteristic of the cumulate portions of ophiolites. REE distribution in the associated garnet amphibolites can be correlated with that of typical ocean-ridge subalkaline basalts. They carry about 110 times higher REE contents than the Kraubath ultramafics.

Variscan times and exposed to two major phases of tectonism and metamorphism; Variscan and Alpine. These data thus present the first quantitatively documented indication of Paleozoic obduction movements in the Eastern Alps.

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From Kraubath via Knittelfeld and Zeltweg the route follows the Mur valley; Neogene sediments underlain by crystalline rocks of the Gleinalpe-Stubalpe (see Stop 1) in the southwest and, of the Seckauer Tauern in the northwest. The latter consist of granites to tonalites of dominantly gneissic texture, enclosed in fine-grained paragneiss-biotite schist, amphibole gneiss and amphibolites, micaschist and marbles. They are, like the Gleinalpe Series, attributed to the Middle-East-Alpine System.

West of Zeltweg, the large mine-dump of the recently closed Fohnsdorf underground brown coal mine can be seen.

Unzmarkt-Neumarkt-Friesach: Between Scheifling and south of Neumarkt, the road crosses to the south Lower Paleozoic sequences of the "Gurktal Nappe", an Upper East-Alpine unit, consisting of metadiabase, quartz phyllites, calcareous and carbonaceous phyllites, limestones and dolomites (Ordovician to Devonian). This area is presently being explored for base metal occurrences by members of the Leoben Mining University. Near Friesach in Carinthia, mesozonal metamorphic rocks underlying the Paleozoic Gurktal series are exposed.

Between Althofen and St. Veit, the route crosses the plain of Krappfeld, an area where about 2000 meters of Upper Cretaceous to Eocene sediments were laid down on Lower Palaeozoic rocks and Triassic sequences.

Stop 5. Historical Site: Excavations of Celtic-Roman relics on Magdalensberg

Geologically, the so-called "Magdalensberg Series" consists of Ordovician metavolcanics (diabase and pyroclastics) and slates, overlain by tuffaceous beds with brachiopods of Caradocian-Ashgillian age, forming parts of the sequence of the above mentioned Gurktal Nappe.

In 1502, a farmer unearthed here the beautifully executed bronze statue of a young man, 1,83 meters high (now in the Museum of Fine Arts, Vienna), probably the most important find of a large antique sculpture north of Italy. It is an excellent copy of a Greek original, made in the early 1st century B. C. in Italy.

Archaeological excavations on Magdalensberg began in 1908 and, since 1948, systematic digging revealed the remains of a important Celtic-Roman settlement.

In the 3rd century B.C., Celtic tribes migrated into this part of Austria and, in the 2nd century, formed the kingdom of Noricum. A Roman embassy was established in 170 B.C. and in the first half of the 1st century B.C., Roman merchants built houses on Magdalensberg, by then a flourishing trading center. In 15 A.D., the Romans peacefully annexed Noricum and moved their legions to the Danube border. Around 45 A.D., Noricum became a Roman province. During this time, various houses, temples, a forum and other structures were built on Magdalensberg from where the Romans administered the province of Noricum in peaceful coexistence with the Celtic population. Later, the administrative capital was moved to adjacent Virunum near Klagenfurt.

In the 2nd and 3rd century A.D., Germanic tribes raided this area, and in the 6th century, East Goths, Franks, Langobards and East Romans ruled Noricum. The late-antique tradition was interrupted by waves of Slavic tribes which moved northwards into Noricum.

The Celtic population of Noricum had successfully mastered the metallurgical art of forging steel as proved by numerous artifacts and the remains of shaft furnaces on Magdalensberg. Plinius compared the "ferrum Noricum" favourably with steel from China and Persia. The ore was probably brought from the nearby Hüttenberg area, another siderite deposit mined since ancient times.

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Route: Klagenfurt — Villach — Bleiberg

Neogene and Quarternary sediments of the Klagenfurt basin. Along the autobahn to Villach, occasional exposures of mesozonal metamorphic rocks, strongly sheared in places, belong to the Middle East-Alpine system. Towards the south, the light coloured, steep and conspicuous peaks of the Karawanken-Gailtaler Alpen range consist of Triassic carbonate rocks which are encountered again on route to Bleiberg.

Day 5

Stop 6. Bleiberg Zinc-Lead Mine

(Operated by Bleiberger Bergwerks-Union)

Introduction

Bleiberg is presently the only Pb-Zn producing mine in Austria; the total metal content (comprising past production and present reserves) amounts to 2.5 million tons combined Pb + Zn. Mineralization is linked to lagoonal carbonate sediments of Triassic age ("Wettersteinkalk" and "*Cardita* Carbonates"). Cross-cutting and stratabound orebodies are associated with a graben structure and can be followed over an east-west distance of ten kilometres. Average annual output presently is in the order of 400.000 t of ore grading 6—7% combined metal.

Mining activities at Bleiberg date back to the 12th century. The present underground workings have been opened up in the period since 1880 during which a continuous expansion of production has taken place. The managing company, Bleiberger Bergwerks-Union, was formed in 1867 when the resources and the assets of previous small operators were combined to facilitate large-scale development and introduction of modern mining methods.

Apart from its position as Austria's leading base metal producer (providing 50% of the country's Pb and 90% of Zn consumption), Bleiberg has a long-standing tradition as one of the testing grounds of the "hydrothermal" versus "sedimentary" hypothesis — providing, as it does, features to support either genetic view unless a comprehensive outlook is taken. SCHNEIDERHÖHN (1941) discussed Bleiberg under the heading "metasomatic lead-zinc ores of the Eastern Alps" and concluded that "the mineralization reveals most clearly ("aufs deutlichste") its origin by metasomatic replacement"; FRIEDRICH (1953) catalogued it under the heading "ore deposits of magmatic derivation" ("Lagerstätten der magmatischen Abfolge"); in 1964, however, he suggested that metal-bearing solutions, originating from a deep source, may partially have reached the sea-floor, resulting in a syn-sedimentary component.

On the other hand, BECHSTÄDT (1975) suggested that "the first metal enrichment in the separated lagoonal basins was derived from denudation of emerged areas". A wealth of new data and observations has accumlated during the past 20 years and we shall consider questions of genesis after a general description of the deposit.

General geology

The total thickness of Triassic sediments in the Bleiberg area exceeds 3000 m; they overlie the Permian "Gröden sandstone". Deposition of calcareous sediments commenced during the Anisian stage with "Alpine Muschelkalk". The latter changes gradually into the "Wetterstein-Dolomite" of Ladinian age, which grades into the partly dolomitized "Wetterstein-limestone" of Upper Ladinian and Lower Carnian age.

Bleiberg is not the only major lead zinc deposit in this area as similar carbonate sequences extend into the adjoining territories of Yugoslavia and Italy. Evaluation of various genetic aspects of the Bleiberg deposit is facilitated if its mid-Triassic limestone hosted counterparts in Yugoslavia (Mézica) and Italy (Raibl/Cave di Predil and Salafossa) are also considered. These four deposits account for more than 75% of total Pb-Zn production in the Eastern Alps; Fig. 8 shows them to be situated in the vicinity of one of the Alps' most impressive tectonic lineaments, the "Periadriatic suture": Bleiberg and Mézica to the North, Salafossa and Raibl to the South of it. The association, in some way or other, of major stratabound base metal concentrations with major tectonic lineaments has been documented on a world-wide scale (Tynagh, Ireland; Mt. Isa, Qld.; Sullivan, B.C.) and is considered significant in this context.

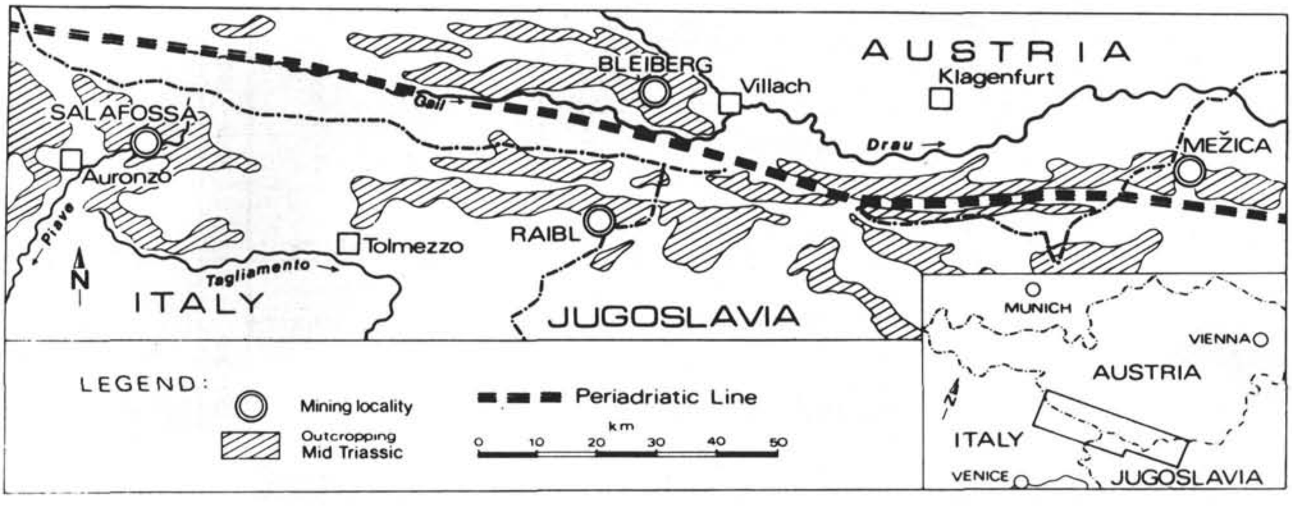

Fig. 8: Location map of the lead-zinc mines of Bleiberg, Mežica, Salafossa and Raibl. From L. BRIGO et al., 1977.

Mineralization at Bleiberg is confined to four distinct stratigraphic levels (Fig. 9) within the upper 250 m of the Wetterstein sequence and the overlying Raibl beds. The occurrence of stromatolites, rhythmites, black resedimented breccias, calc-arenites and green marls of possible volcanic derivation indicates deposition in a shallow lagoon. Cyclic sequences ("Cyclothemes") are characteristic in this context; they consist of litoral sediments (sub-inter-supratidal) and include evaporite layers with baryte, anhydrite and fluorite.

Mine geology

The deposit has been developed by various adits and by five shaft systems, Antony, Max, Stefanie, "West-Shaft" and Rudolf, to a depth of 900 m below surface.

The lateral and vertical extent of the mineralization is best demonstrated by the glass model at the mine office; in this context, it is useful to remember that the underground workings are linked by the 8,2 km long Leopold Erbstollen and by the 12,6 km long Franz Josef-Stollen. The total length of underground tunnels, levels and crosscuts exceeds 1000 km.

Local geology is dominated by Wettersteinkalk, *Cardita* Shale with intermediate dolomite layers ("Zwischendolomit") and main dolomite ("Hauptdolomit"), all of which strike WNW and have been intensely fractured by the graben-type Bleiberg fracture zone ("Bleiberger Bruch"). This resulted in, amongst others, stratigraphic repetitions and considerable changes in dip which varies from 20° S to 70° S (Figs. 10, 11).

Mineralization is limited to a stratigraphic thickness

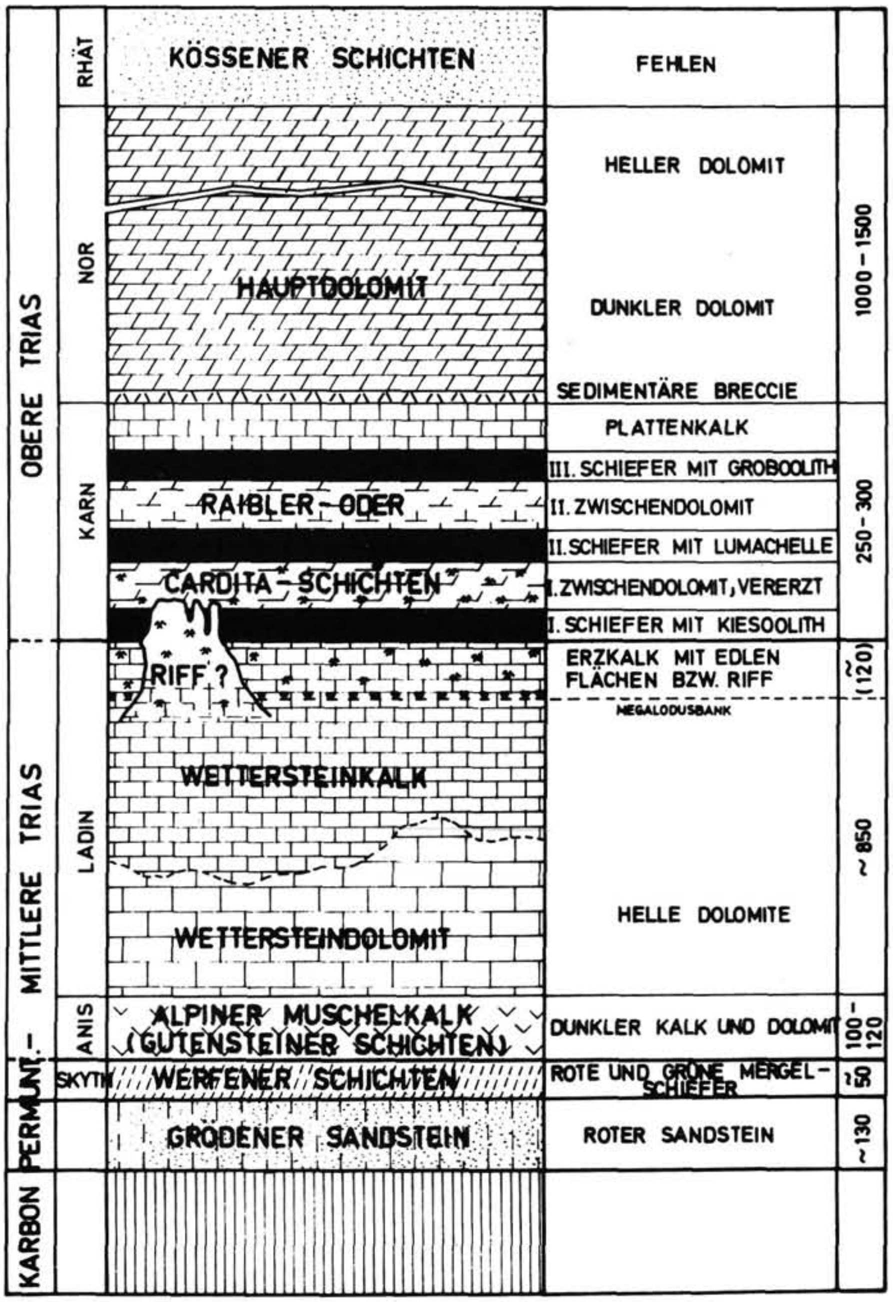

Fig. 9: Stratigraphy of the Triassic in the Bleiberg area (from M. Bouvier et al., 1972). Crossed hammers indicate mineralized zones.

not exceeding 300—400 m. There are four mineralized stratigraphic levels:

1. Below the "*Megalodus*-Bank", about 200 m below the first *Cardita* marker, there are stratiform orebodies of limited size (100 m diameter, 1 m thick).
2. The uppermost Wetterstein-Limestone, between "*Megalodus*-Bank" and First *Cardita* marker. Both conformable ore "runs" (BRIGO et al., 1978) and veins can be traced over several hundred meters, with thicknesses of several meters ("runs") and up to 20 m (veins).
3. The First *Cardita* "Zwischendolomit" carries orebodies, more than 5 m thick, and of several 100 m diameter.
4. The calcareous and dolomitic sediments in the hanging wall of the Third *Cardita* Shale.

Most of present production is derived from stratiform and breccia orebodies within the uppermost Wetterstein Limestone and the "Zwischendolomit". As indicated above, mineralization occurs as stratabound lenses with distinct synsedimentary features, and also as crosscutting vein and pipe-shaped zones and breccia orebodies. The irregular distribution of payable orebodies and considerable variations in grade have been a major problem since the early days of mining in the area. At Bleiberg, ore is certainly not "where you find it"; this has led to an early recognition of the necessity of comprehensive geoscientific investigations. Exploration costs have been halved by the acceptance, about 20 years ago, of the concept of stratabound ore distribution. By 1964, two new orebodies were discovered in the Western Bleiberg-Kreuth section.

Main ore minerals are galena, sphalerite with minor amounts of pyrite (partly framboidal), marcasite, baryte and siderite. Only PbS and ZnS are of economic significance. Silver contents in galena are in the 1—30 ppm range and, thus, considered negligible. Gangue minerals include calcite, fluorite and barite.

A large variety of secondary minerals has been recognized in the oxydation zone at Bleiberg, wulfenite ($PbMoO_4$) being one of the more spectacular species. Cerussite ($PbCO_3$), anglesite ($PbSO_4$), descloizite (Pb(Zn, Cu) [OH/VO_4]) vanadinite ($Pb_5(Cl/VO_4)_3$), hemimorphite ($Zn_4(OH)_2/Si_2O_7)H_2O$), smithsonite ($ZnCO_3$) and jordisite (X-ray amorphous MoS_2) should also be mentioned.

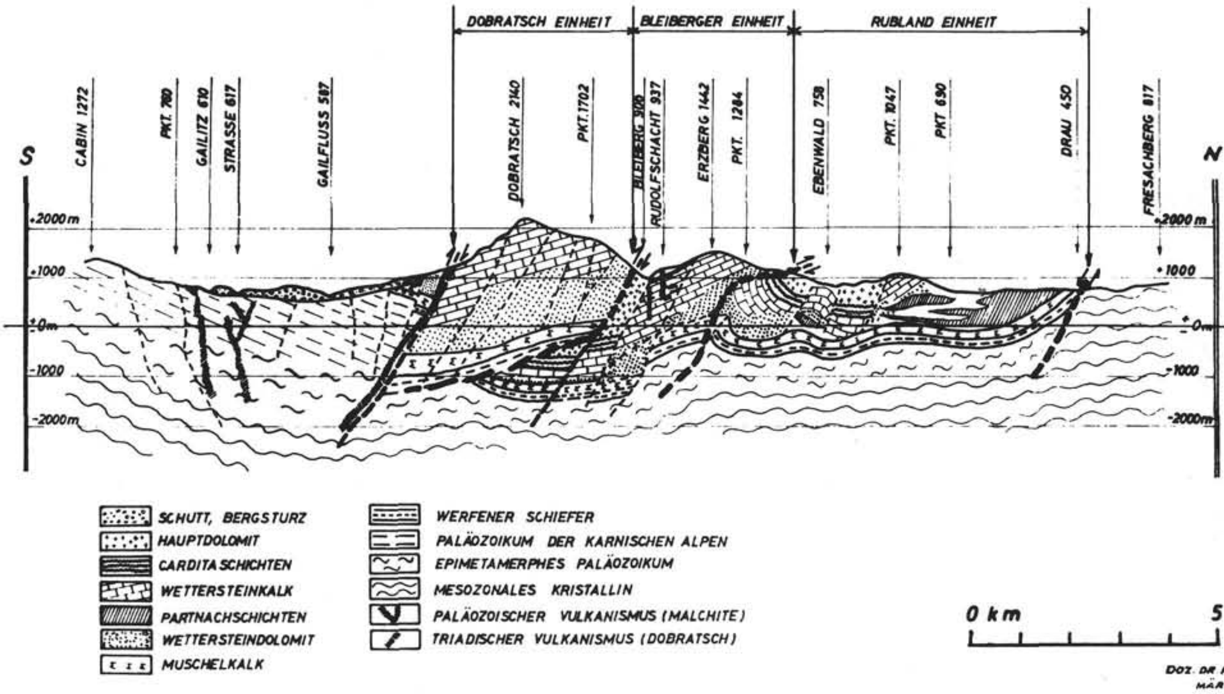

Fig. 10: North-South section from the Drau valley to the Gail valley, illustrating the general geology of the Bleiberg area (from M. BOUVIER et al., 1972). "Schutt, Bergsturz" = gravel, rock slide.

Production

Average production ores carry 1.7 to 4.5% Pb and 4 to 8% Zn. In recent years, some of the old dumps which still contain 2.4 to 4.0% Zn have also been re-worked. The sulphides are recovered by flotation (capacity: 40 t/h); annual output in 1978 was 476.340 t of ore from underground workings. The average grade of this material was 1.2% Pb and 5,37% Zn, and output totalled 5.971 t lead concentrates and 39.471 t zinc concentrates.

Genesis of the Deposit

Within the general framework of syngenetic stratabound ore genesis, which has replaced earlier magmatic or metasomatic concepts, various modes of metal supply are presently being considered. As at Mt. Isa or Tynagh (FINLOW-BATES, 1978), no direct connection between thin tuff horizons and mineralization can be established. New geochemical data have recently become available (SCHROLL, 1978); they are considered significant in this context. Sphalerite carries average values of 100 ppm Tl, 200 ppm Ge and 2000 ppm Cd; As varies from 10—5000 ppm, concentrations of Mn, Fe, Co, Cu, Hg, In and Ga are low. In galena, only As and Tl are characteristic trace elements. Sulphur isotope data from grey anhydrite from Bleiberg ($\delta\,^{34}S = +16{,}1‰$) correspond to those from Upper Triassic seawater; values of sulphides are negative and indicate a derivation by bacterial reduction from seawater sulphate. These results

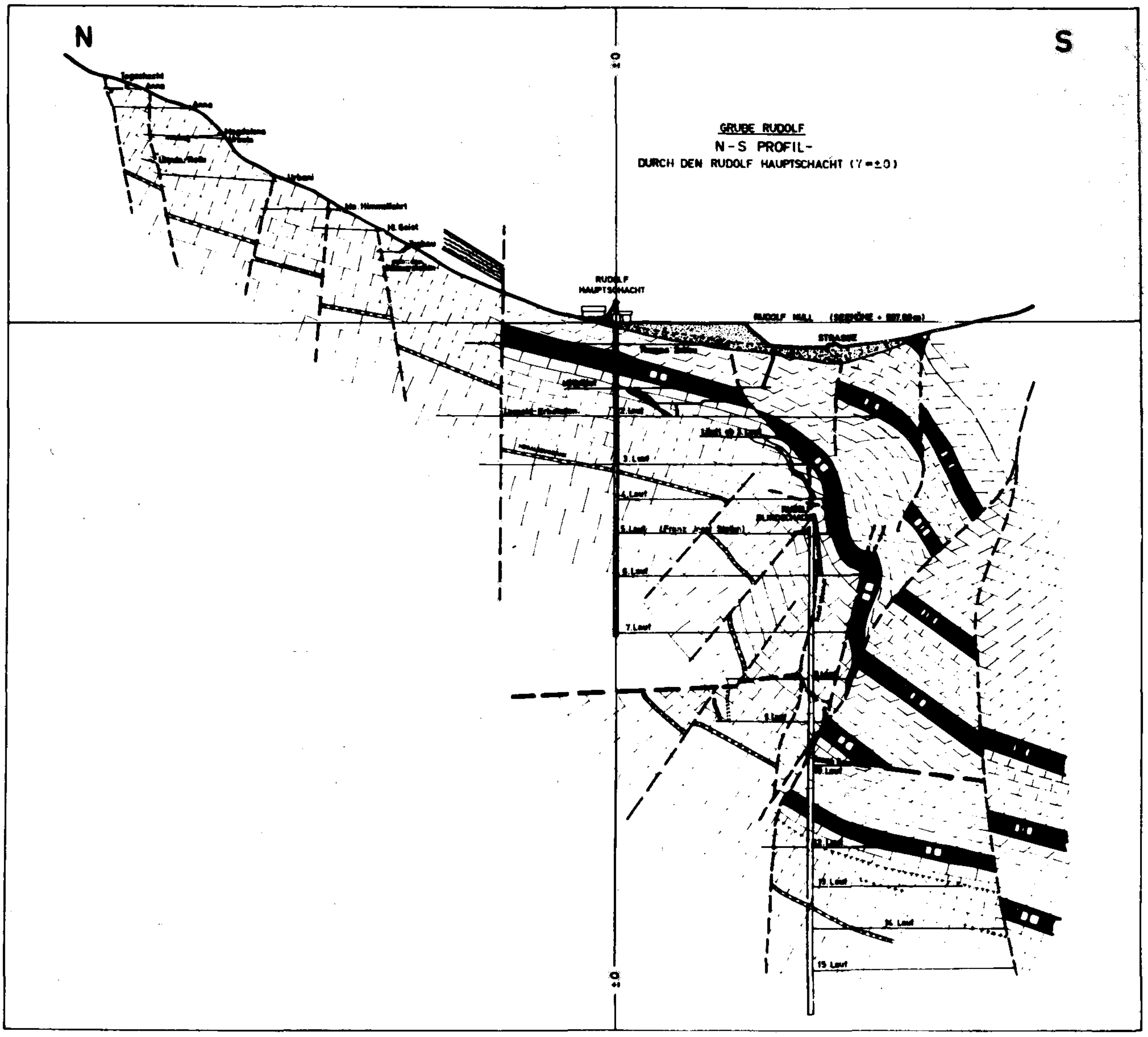

Fig. 11: Bleiberg Lead-Zinc Mine. Section through the workings of the Rudolf Shaft (after BOUVIER et al., 1972). Note the *Megalodus* Bank, an important stratigraphic marker. "Lauf" = level.

suggest low-temperature mineralization (< 150° C) and are supported by temperature estimates on the basis of Sr-contents of calcite, fluorite, barite and anhydrite which indicate a similar maximum value.

Lead isotope data (Köppel and Kostelka, 1976) do not reveal any differences between galena from stratabound or crosscutting orebodies. Lead within the Bleiberg deposit is thus isotopically homogeneous; it is characteristic B(leiberg)-type lead, giving a model age of 300 m. a. The localisation of orebodies in the vicinity of a major, and very old, fracture zone, the presence of both stratabound and crosscutting mineralization, and indications of volcanic activity, are features which Bleiberg has in common with other major base metal deposits. A concept of introduction of metals into the Triassic Sea by weathering solutions from adjacent continental terranes accords well with presently available geochemical data, although a possible contribution by metalliferous brines, related to volcanic activity, should not be excluced. Precipitation of metals took place as sulphides on the sea-floor and was followed by complex diagenetic processes. Crosscutting ore is not necessarily related to tectonic features and is interpreted as being due to later remoblization, which may also have played a significant role in the formation of breccia orebodies.

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Day 6

Route: Bleiberg to Mittersill

Heading first north through the Mesozoic carbonate sequences of the Gailtal Alps, the route then continues along the Drau valley towards northwest. In the North, the mountain range of the Nockberge/Radentheiner Gebirge consist mainly of garnet-mica-schist with subordinate amphibolites and marbles. On Millstätter Alpe (off the excursion route), a magnesite mine of the Austro-American Magnesite Corporation produces about 250.000 t per year. The upper Drau- and Möll valleys follow an important young fault zone ("Drau—Möll-Linie"), very conspicuous on satellite imagery.

Sachsenburg — Kolbnitz — Obervellach — Winklern: Towards south and west, the mountains of Kreuzeckgruppe consist of epi-to mesozonal metamorphic rocks of the Middle East-Alpine System (metasediments and -volcanics, some orthogneiss, cut by Tertiary dykes of mafic to tonalitic composition). In this sector, numerous small mines working auriferous sulfide ores were of considerable importance during medieval times.

In the north, the high mountain ranges expose the deepest unit of the East Alpine tectonic pile, the "Tauern Window", belonging to the Pennine Zone. It is overlain in the south by a narrow, imbricated zone of epi- to mesozonal metamorphic rocks of mainly Mesozoic age, the so-called "Matrei Imbricate Zone", attributed by most authors to the Lower East-Alpine Sheet.

The Pennine Zone (Penninikum) comprises a series of strongly deformed phyllites, schists and gneisses, forming the autochthonous and parautochthonous basement over which the East-Alpine sheets rode from south to north. The Penninikum consists of two main lithological units, the Central Gneiss and the "Schieferhülle" (= "Schist Cover"). The former is dominantly orthogneiss of granitic to tonalitic or granodioritic composition. A late Hercynian age of emplacement was recently confirmed by K/Ar and Rb/Sr age determinations.

The dome-, tongue- and lamella-shaped Central Gneiss units are overlain and enveloped in metasediments and metavolcanics of the strongly foliated Schieferhülle (Schist Cover). This unit, in the middle sector of the Tauern Window, has been devided into:

Bündner-Schiefer Series	Jurassic-Lower Cretaceous?
Carbonate rock Series	Triassic
Wustkogel Series	Permo-Triassic
Habach Series	} pre-Mesozoic
"Altkristallin Series"	

Ultramafic rocks within the Schieferhülle are interpreted as remnants of oceanic crust.

The route on the Grossglockner-Hochalpen Strasse crosses the central sector of the Tauern Window in generally south-northern direction.

Grossglockner Hochalpenstrasse

South of Heiligenblut, the Matrei Imbricate Zone is represented by calc-micaschist, phyllites and greenschist with serpentinites, almost identical in facies and grade of metamorphism to the "Schieferhülle Series" of the Penninikum, therefore interpreted by FRANK (1969) as "South-Pennine Element".

The winding mountain road to the Franz Josefs-Höhe (2369 meters) traverses the "Glockner Nappe" of the Upper Schist Cover (Obere Schieferhülle), composed of calc-micaschist, various greenschists and phyllites of Jurassic- to Lower Cretaceous age. The summit of Grossglockner, Austria's highest peak (3798 meters) consists of prasinite (greenschist, derived from metatholeiites and alkali-basalts, interpreted as remnants of ocean floor).

View from Franz Josefs Haus to the Pasterze glacier.

From the Hochtor tunnel area (elevation 2505 meters) and northwards to the Fuscher Ache valley, the road runs in metamorphic rocks of the "Seidlwinkl Nappe" constisting of phyllites, Permo-Triassic quartzites, marbles, dolomites and chloritoid schist. Around Fusch, the route crosses the so-called Fuscher Schieferhülle, represented by meta-sediments of the originally southernmost facies trough of the Penninikum: metaclastites (meta-arkose, -quartzite, dolomite-breccia) and wide-spread, dark coloured phyllites and calc-phyllites with intercalations of greenschist.

From Bruck, the road to Mittersill follows the east-west-trending Salzach valley. In the North there are outcrops of Lower Paleozoic phyllites of the Greywacke Zone, south of the river are phyllites and greenschist of the Penninikum.

Alpine-Type Vein Minerals

by H. WENINGER *)

The excursion route traversing the main Alpine divide passes through an area which, amongst mineralogists, has for some time been famous for the occurrences of a large variety of vein-type minerals. Although time does not permit a visit to some of these occurrences, a few comments on this topic are considered appropriate.

The formation of Alpine-type vein mineral associations is closely related to the geological and tectonic evolution of the Central Alps. Accordingly, "Alpine-type vein minerals" are defined as having formed in open spaces within silicate rocks which have been exposed to one or several phases of regional metamorphism. The veins in question opened up during the late stages of orogenesis and provided suitable spaces for the deposition, from circulating waters, of a large variety of minerals. Analytical data suggest that these waters were largely sodium chloride solutions, which have been heated up in comparatively shallow depth, possibly in zones of increased heat-flow linked to plate tectonic processes.

These hydrous solutions have reacted with the country rock, resulting in selective leaching. The chemical composition of the country rocks and of the mineral content of the respective veins reveals significant similarities; this supports the above interpretation.

Within the Austrian Central Alps, more than 140 mineral species have been described from vein-type occurrences. These include both, wellknown minerals such as rock crystal, smoky quartz, feldspars (adularia, albite-pericline), rutile-anatase-brookite, sphene, epidote, fluorite, but also rare species such as aeschynite (Ce, Th, Ca, ...) (Ti, Nb, Ta)$_2$O$_6$; synchisite (CaCe F/(CO$_3$)$_2$; xenotime Y(PO$_4$), monazite Ce(PO$_4$), gadolinite Y$_2$FeBe$_2$(O/SiO$_4$)$_2$, bazzite (Sc-beryl), etc. All these provide important data for genetic considerations.

Mineralized veins occur mainly within the Zillertal Alps and in the Hohe Tauern (Central Gneiss and Schist Cover); there are distinct regional differences in the intensity of vein distribution.

In addition to mineralogical results, the continuing investigation of vein-type minerals includes the study of fluid inclusions and rare earth (REE) contents. REE analyses of alpine vein-type fluorites indicate hydrothermal conditions of formation and are in good agreement with the results of SCHNEIDER et al. (1977). PAAR et al. (1980) convincingly argue genetic links between pre-Variscan stratabound and Alpine vein-type mineralization. These data are indicators for ore forming processes and thus assist the erection of a genetic model of alpine mineralization.

Gold Mining (H. F. HOLZER)

The eastern sector of the Tauern Window was for many centuries the center of Austria's gold mining. In the Ankogel-Sonnblick range with the Goldberg Gruppe near Rauris and Gastein, numerous ancient adits, pits, dumps and relics of mine settlements are still observable. Neolithic and Bronze-age finds indicate that this area was populated in prehistoric times, and STRABO quotes POLYBIUS as saying that in 130 BC, news of rich gold finds by the then Celtic population triggered a veritable gold rush in Italy. In the 10th, 11th and 12th century, gold mining in this area is documented, and for 1300 to 1385, an annual production of 50 kg gold was calculated.

The production in the early 16th century was estimated at about 2600 kg/year. Climatic changes brought an advance of the glaciers at the end of the 16th century and many pits were deserted in consequence.

Gold mining continued intermittently until 1943. The gold deposits of the eastern Tauern are structurally controlled veins along distinct faults. The veins consist of a quartz-carbonate-chlorite rock with auriferous quartz, -pyrite and -arsenopyrite, accompanied by chalcopyrite and argentiferous galena, sphalerite and siderite, traces of tetrahedrite, pyrrhotite and antimonite.

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Day 7

Stop 7. Mittersill Scheelite Mine

(Operated by Wolfram Bergbau- und Hüttengesellschaft m. b. H.)

Introduction

The distribution of major scheelite occurrences in Austria is shown in Fig. 12; Mittersill is presently the only producing mine. It is situated 9 km south of the town of Mittersill in the Central Hohe Tauern (Eastern Alps) at an altitude from 800 to 2.200 m. The deposit is topographically divided by the Felbertal into two sections, the Ostfeld and the Westfeld. The deposit was discovered in 1967 in the course of a prospecting campaign conducted by Prof. MAUCHER and Dr. HÖLL of the Department of Geology and Mineralogy of Munich University. This discovery was remarkable because it was the first successful demonstration of MAUCHER's (1965) theories on the syngenetic formation of tungsten, antimony and mercury deposits. By 1973, the orebody had been explored by two exploration adits, several exploration shafts and 6.400 m of core drilling. Mining activities commenced in 1975, the ore dressing plant started operations in 1976. Scheelite concentrates are further processed in the Bergla tungsten smelter, Styria. The latter and the mine are operated by Wolfram Bergbau- und Hüttengesellschaft m. b. H., which is owned by Metallgesellschaft Frankfurt, W. Germany (47,5%), Voest-Alpine Corporation, Austria (47,5%) and Teledyne Corporation, USA (5%). Production in 1978 was 291.140 tons of ore with an average grade of 0,65% WO_3, yielding a WO_3-content of 1.954 tons.

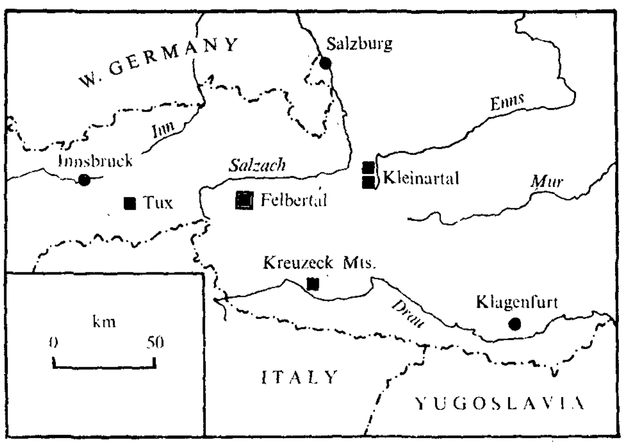

Fig. 12: Major scheelite occurrences in Austria (from STUMPFL, 1977). Felbertal (Mittersill) is, at present, the only producing mine.

Geology and Petrology

The Mittersill Scheelite deposit is situated in the Pennine Unit of the Lower Schist Cover of the Hohe Tauern (Fig. 13); locally the term "Habach Series" has been applied to that unit. The general situation on the northwestern flank of the Granatspitz Dome results, in the "Ostfeld", in medium to steep northerly dips with east-west strike. The "Westfeld" is situated lower and shows 45—95° dip to the north-west, with 70—90° strike. The "Habach Series" is several 1000 m thick and consists of metamorphosed clastic sediments and submarine lavas and tuffs (termed "The Eruptive Sequence"), of probably lower Paleozoic age. The Eruptive Sequence can be subdivided into Footwall Schist, Lower Hornblendefels Cycle, Intermediate Schist, Upper Hornblendefels Cycle and Hanging Wall Schist. Its total thickness exceeds 1500 m. Mineralization is stratabound and confined to the lower part of the Eruptive Sequence. It can be followed in strike over several kilometers and over a thickness of 400 m.

The scheelite bearing series is characterized by distinct intercalations of volcanic rocks of varying composition. These include ultramafics (now hornblendites and amphibolites), tholeiites (now schists and "prasinites"), quartz keratophyres (now albite gneisses) and rhyodacites (now porphyroid gneisses). A characteristic feature of the Mittersill deposit is the stratabound intercalation, or cross-cutting penetration of all the above main rocks types with finegrained quartzites, which are not encountered anywhere outside the ore zones. There appears to be a distinct spatial and, probably, genetic association of quartz content and mineralization.

The distinct structural and compositional differences between the Ostfeld and the Westfeld are ascribed to the complex interplay of volcanism, sedimentation and mineralization taking place in two adjacent sub-basins. These are separated by a palaeogeographic ridge which did, however, not prevent the joint evolution of major features, such as the two Hornblendefels cycles.

Ore mineralogy

Major ore minerals include scheelite, which frequently dominates quantitatively; it may occur as isomorphous intergrowths with powellite. Pyrrhotite may be the most widespread opaque mineral in some ore types; chalcopyrite, molybdenite and bismuth minerals are wide-

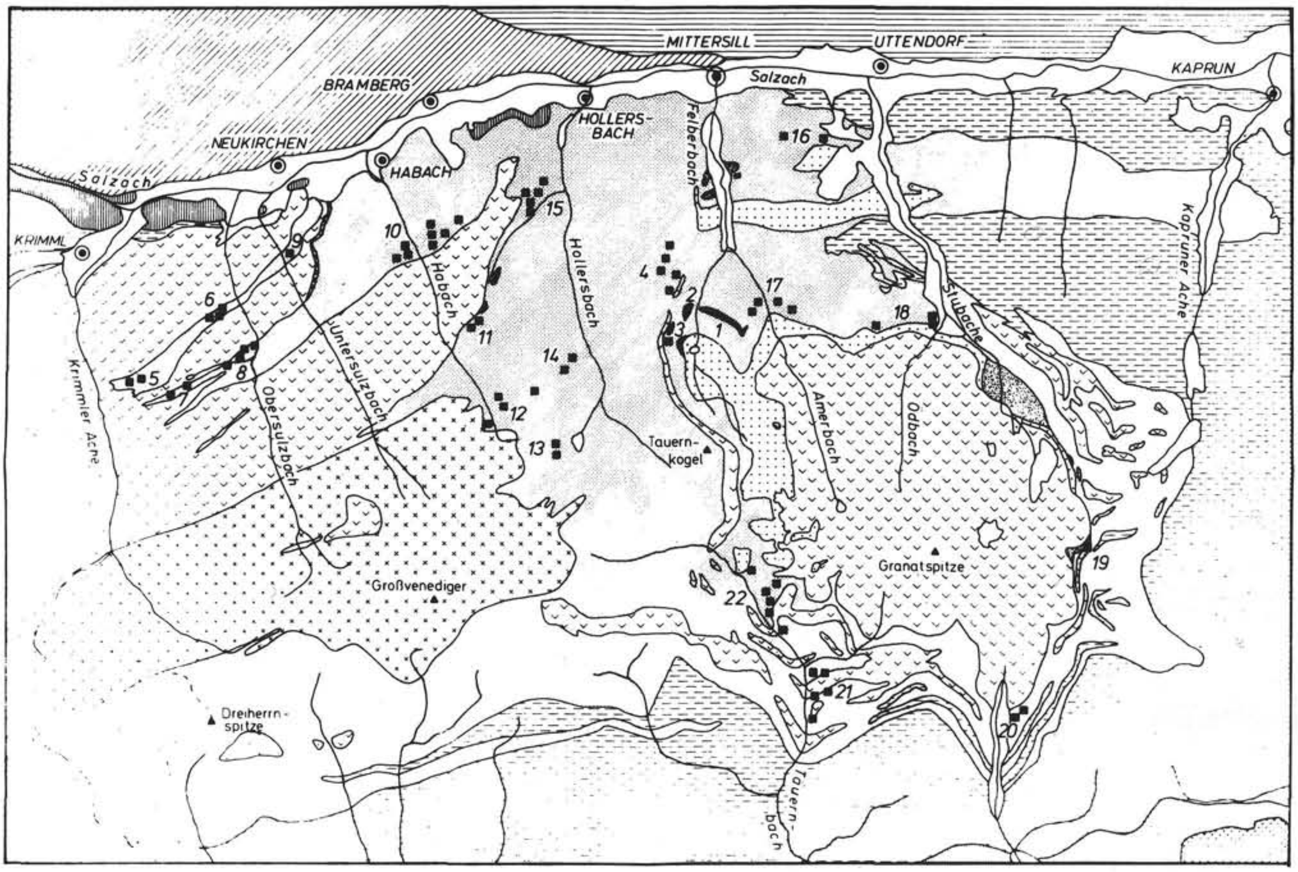

Fig. 13: Scheelite occurrences in the Hohe Tauern area (from HÖLL, 1975). Finely dotted = Habach Series within the Schist Cover; x = granitic and v = tonalitic Central Gneiss; coarsely dotted = basal amphibolites; horizontal stripes = Greywacke Zone, diagonal stripes = Quartz Phyllite Zone. "1" = Felbertal deposit, Ostfeld; "2" = Felbertal deposit, Westfeld. Other numbered occurrences are presently not of economic significance. Scale: width of map = 47 km.

spread but rarely dominant. Pyrite is rare; the prevalence of pyrrhotite can be interpreted as a primary depositional feature as defined by FINLOW-BATES (1978) and n o t as a result of metamorphism. In the "Ostfeld" sulphide ores are rare, in the "Westfeld" they may contribute up to 5% to the bulk of the ore, thus attaining some economic significance. Molybdenum contents in scheelite do not exceed 1% of total WO_3.

Three generations of scheelite may be distinguished:

a) About 95% of the scheelite in the "Ostfeld" occurs in layers with medium grainsize of 0,05 mm in a quartzite matrix. These mineralized quartzites occur as concordant horizons with up to 5 m thickness, or as repetitive bands and lenses of cm thickness in all the abovementioned rocks of basic to acid composition. Excellent sedimentary fabrics are revealed by this type of scheelite if viewed in UV-light and have been discussed by HÖLL et al. (1972).

b) In the "Westfeld" scheelite of second generation prevails; up to cm-size scheelite-powellite porphyroblasts occur stratabound in banded quartz stockworks, together with sulphide ores.

c) In the "Westfeld" molybdenum-free, up to several tens of centimeters large scheelite crystals of the third generation are found in so-called "Alpine-type mineral veins", in association with quartz, beryl and carbonates. This scheelite is not of economic significance.

Minor constituents of the ore mineral association include sphalerite, galena, Hg-bearing tetrahedrite, arsenopyrite, galenobismutite ($PbBi_2S_4$), cassiterite, tantalite, as well as Bi, Ag and Au.

M i n e G e o l o g y

The location of the two main areas of mining activity is shown in Fig. 14.

a) Ostfeld: Economic mineralization in the Ostfeld, which extends from 800 m to 2.200 m above sea-level is limited to a 50—100 m thick sequence within the "Lower Hornblendefels Zyklus". Within a 2000 m long, and 50—150 m thick area there are several elongate

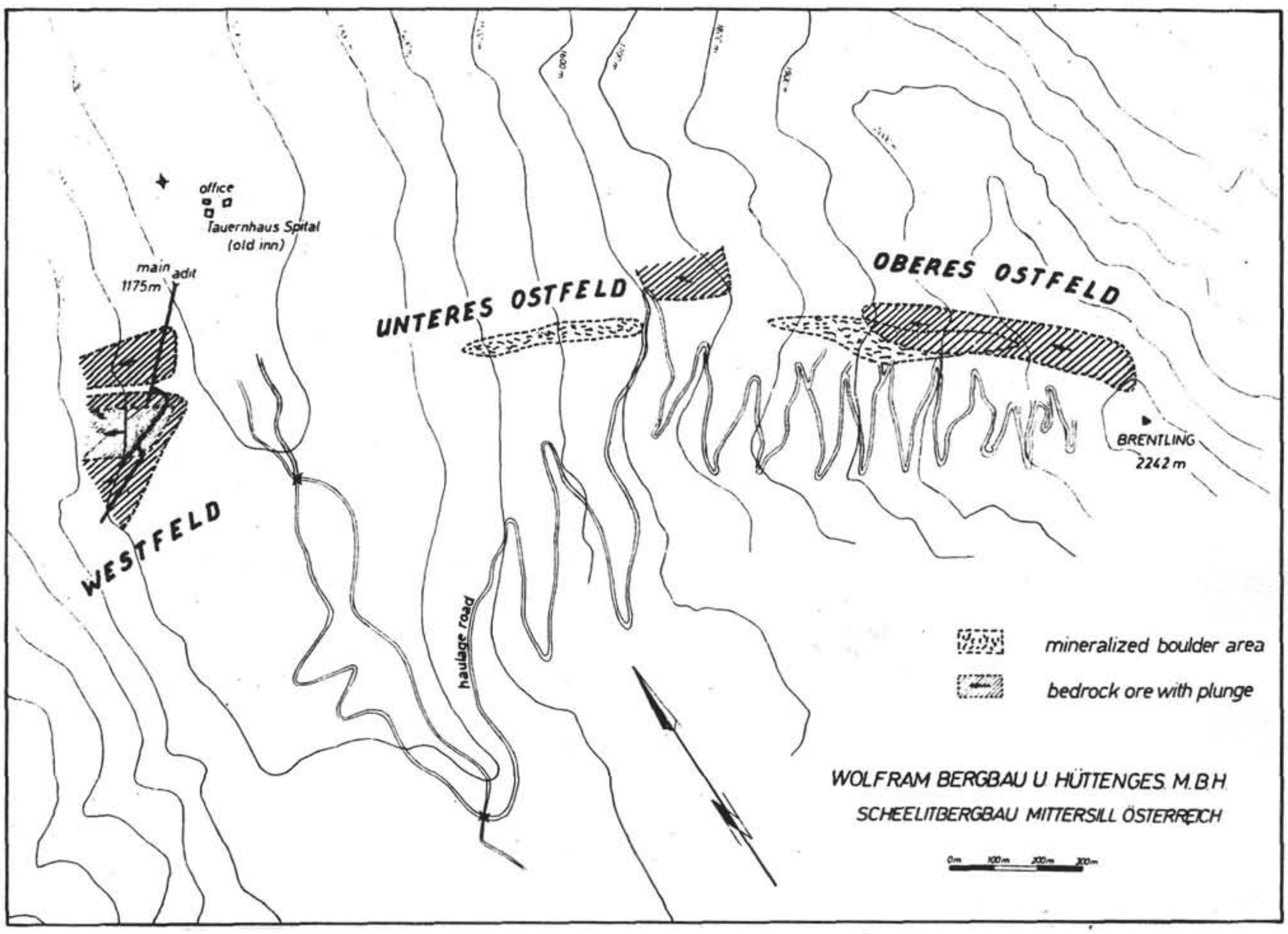

Fig. 14: Locality map, Mittersill Scheelite Mine. Difference of altitude is almost 1100 m over a horizontal distance of 2000 m. (Courtesy, Dr. R. Vaché, Wolfram Bergbau GmbH).

lense-shaped orebodies with several 100 m in length and a maximum thickness of 30 m. The "compositional axis" of the orebodies in the Ostfeld runs parallel to the Eastern slope of the Felbertal; up to 90% of the ore in these orebodies can therefore be recovered by opencast methods. Medium WO_3-contents average 0,75%, in pure ore quartzites this may increase to 3,5% WO_3.

A part of the outcropping deposit has been removed in postglacial times from its original geological context and occurs as a coarse scree below the outcrops. It was in these scree slopes that mining activities commenced in 1975.

b) Westfeld: In the Westfeld the upper Hornblendefels-Zyklus and part of the hanging wall schists are mineralized. The mineralized series has been separated into two parts by the tectonic emplacement of unmineralized "Basisschiefer". The Westfeld deposit outcrops over 500 m. Within a mineralized thickness of 300 m (Fig. 15), six economic horizons have been established so far. Within these horizons mineralization occurs in 60—200 m long and 3—20 m thick orebodies, the compositional axis of which dips towards the northwest. Economic mineralization (which should be at least 2 m thick at a cut-off grade of 0,3% WO_3) is not sharply differentiated from the country rock, neither vertically nor laterally. Intercalated "barren" rocks frequently carry 0,15—0,25% WO_3 over thicknesses of tens of metres. Mineralization of the Westfeld with an average content of 0,45% WO_3 is not as rich as the higher concentrations of ore in the Ostfeld (Fig. 16). However, the total potential reserves of the Westfeld are expected to be significantly larger than those of the topographically limited Ostfeld. Underground mining in the Westfeld commenced in October 1978 by opening up various adits and inclines; the official opening ceremony took place in September 1979.

Genesis

The Mittersill deposit is interpreted as a typical example of time- and stratabound syngenetic minerali-

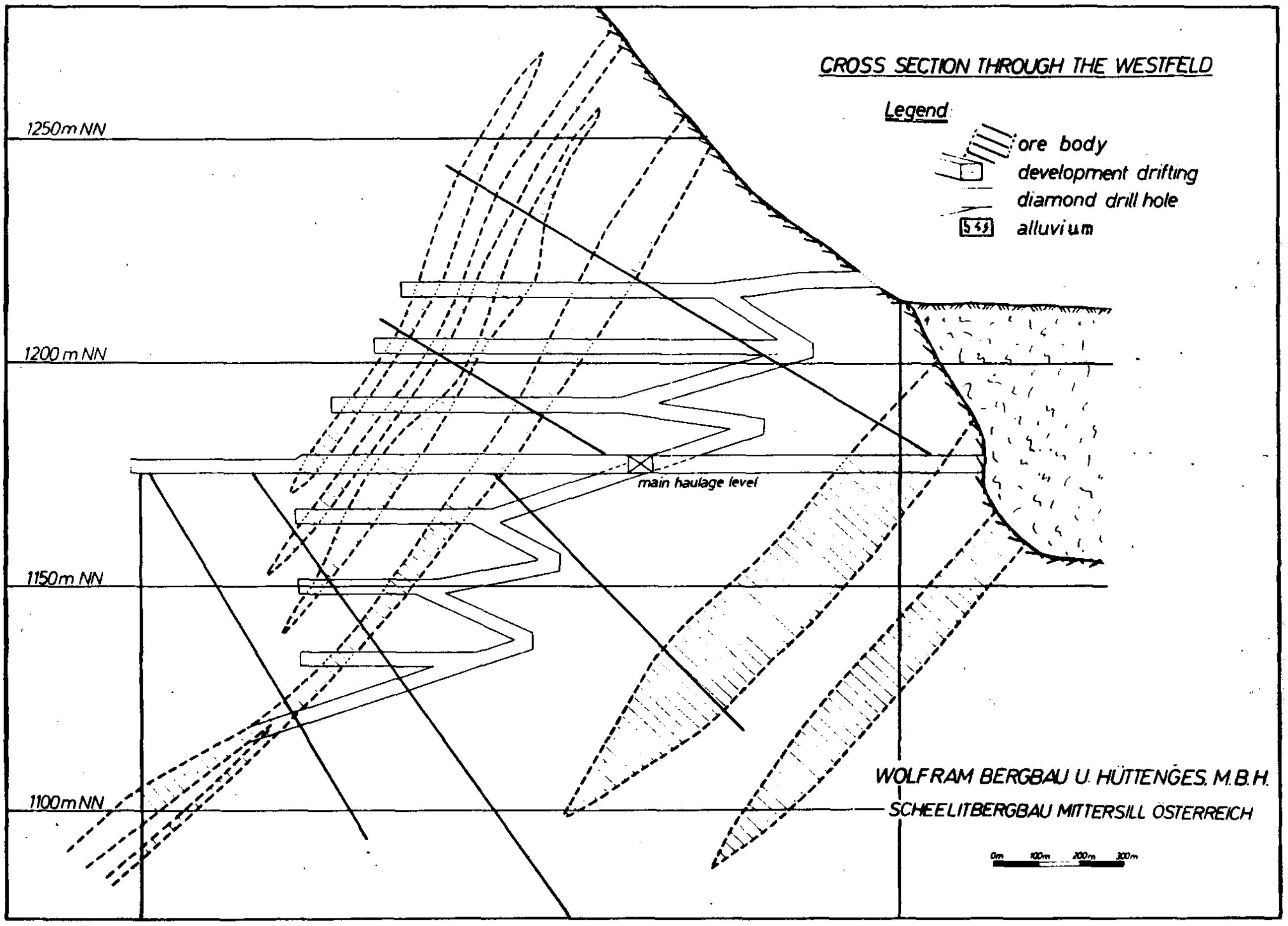

Fig. 15: Mittersill Scheelite Mine, section through the Westfeld (Courtesy, Dr. R. Vaché, Wolfram Bergbau GmbH).

zation linked to mafic submarine volcanism. Intense Lower Paleozoic (? Ordovician — Silurian) magmatic activity culminated in the two Hornblendefels cycles. It was associated with the development of hydrothermal systems which led to the issue of metalliferous solutions through vents on the seafloor. These were rich in SiO_2 and deposited metal-rich silica gels — the precursors of the present ore quartzites. The extensive distribution of (non-economic, $< 0{,}3\%$ WO_3) scheelite mineralizition in a l l rocktypes of the series testifies to the continuity

Table 1: Major ore minerals, host rock, metamorphic grade and age of some stratabound tungsten deposits *)

deposit	mineral	host rock	metamorphic grade	age Ma
Felbertal, Austria	scheelite	volcano-sedimentary	almandite-greenschist	400—500
Kleinarltal, Austria	scheelite	carbonate rock in phyllites	almandite-greenschist	400—500
Kreuzeck Mts., Austria	scheelite-stibnite	schists and metavolcanics	greenschist	400—500
Bindal, N. Norway	scheelite	hornblende-biotite-gneiss and reaction skarns	amphibolite	500
O'okiep District, S. Africa	ferberite	quartz veins in gneiss	granulite	1200
Ørsdalen, S. Norway	ferberite and scheelite	cordierite-garnet-schist	granulite	1480
Bulawayan Formation, Rhodesia	scheelite	carbonate rock	greenschist-amphibolite	2900

*) After STUMPFL (1977).

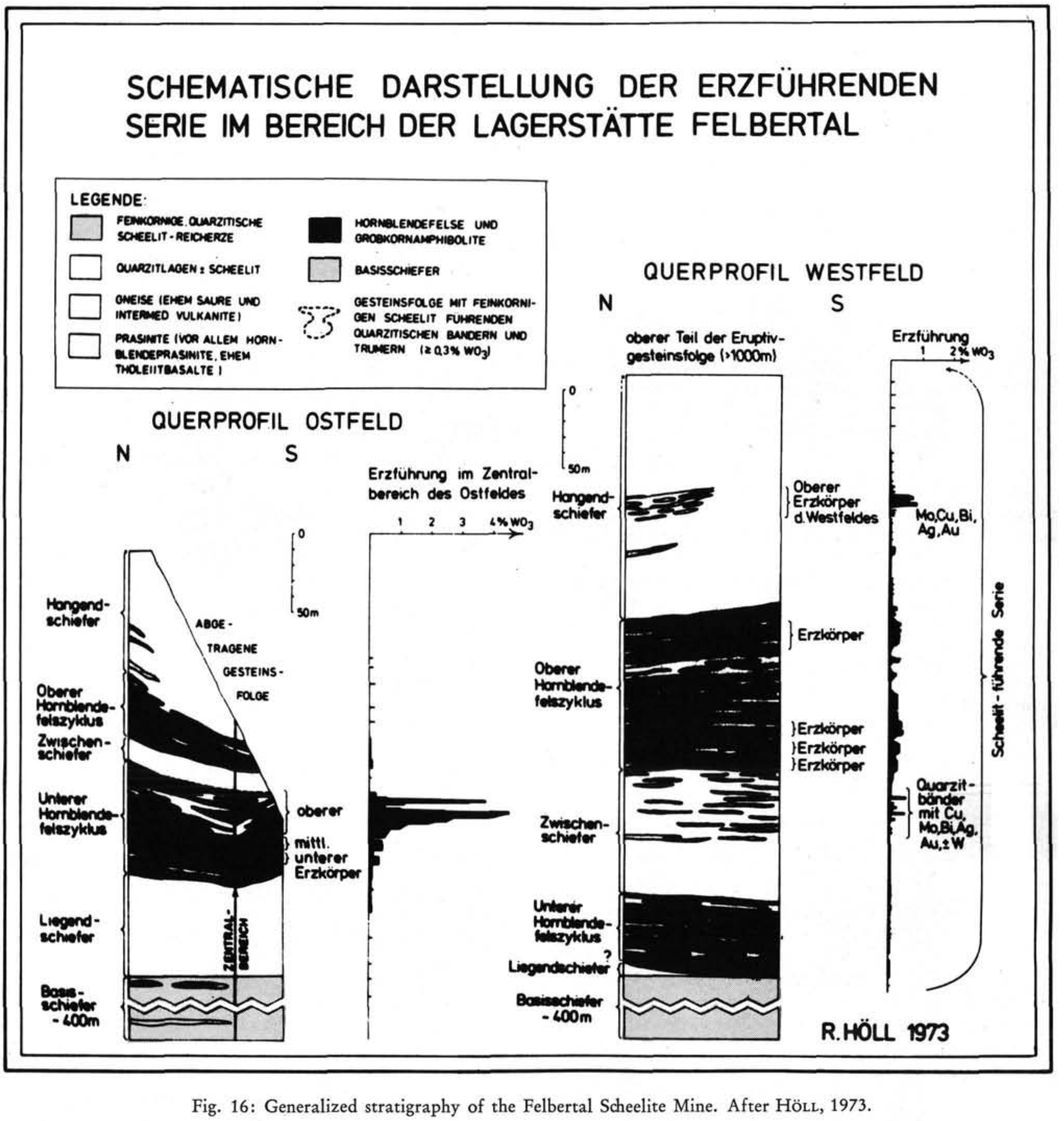

Fig. 16: Generalized stratigraphy of the Felbertal Scheelite Mine. After HÖLL, 1973.

of these processes and explains the fact that most orebodies are not sharply delineated, but defined by cut-off grade. Cross-cutting mineralization may present both, remnant "mini-stockworks" established during the early stages of mineralization, and remobilization during the Variscan and Alpine metamorphic events.

A definition of the plate tectonic situation of the deposit (tholeiites + ultramafics = spreading situation?) requires further comprehensive research. This should include both, large-scale regional considerations of the evolution of the Penninic ocean, and strategic geochemical studies, including REE distribution patterns.

It is interesting to note that the Habach Series is similar to the Lower Paleozoic Sequences of New England, Australia. The latter contain a suite of scheelite deposits associated with cinnabar, stibnite and auriferous arsenopyrite; most of these have been remobilized but there is an apparent association of mineralization with mafic volcanic rocks (PLIMER, 1977). Stratabound tungsten deposits are not limited to the Paleozoic. Precambrian examples of this type of mineralization have, in recent years, been discovered in Norway, South Korea, Rhodesia and South Africa. STUMPFL (1977) has summarized some relevant aspects.

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Day 8

Route: Mittersill — Bruck — Bischofshofen — Hallein — Salzburg.

From Mittersill to Bischofshofen, the route runs along the southern border of the (western) Greywacke Zone. It is separated from the Penninikum (and Lower East-Alpine units) in the south by a distinct east-west-trending fault ("Tauernnordrandstörung"). The Greywacke Zone is represented by monotonous grey phyllites with intercalated metavolcanics (mainly diabase, spilite, gabbroic rocks, keratophyres) and few dolomite-marbles. The sequence ranges in age from Ordovician to Upper Silurian.

Small occurrences of pyrite-chalcopyrite ores were mined in earlier times in this sector.

The metamorphic rocks of the Penninikum to the South ("Fuscher Schieferhülle") are mainly calcareous-argillaceous metasediments, quartzites, limestones, dolomites and epidote-chlorite schist of Jurassic (? Cretaceous) age.

North of Bischofshofen, the road enters the basal sequence of the Northern Calcareous Alps (the town of Werfen is locus typicus of the lower Triassic "Werfen Beds": mainly argillaceous, red and green sandstones and shales) and continues northward through the Calcareous Alps ("Hagen-Tennengebirge-Scholle", "Lammer Einheit", "Göll Scholle" of the "Tirolikum" nappe pile). The mountains traversed by the route are in places very conspicuous and consist dominantly of Upper Triassic and some Jurassic carbonate rocks.

Stop 8. Hallein/Dürrnberg Salt mine

Salt mining in the Alps began in Neolithic times as proved by numerous archaeological finds in Hallstatt and Hallein (in 1573 and 1616 the bodies of two prehistoric miners were detected, well preserved in the salt) and continues until today. In 1978, 270.000 m^3 of salt brine was produced at Hallein, of which 34% were obtained by bore hole solution mining.

The proven and probable reserves of salt rock in Hallein exceed 6 mio. t.

Geology

Austria's salt deposits are restricted to the "Hallstatt facies" of the Calcareous Alps, a deep-water facies of pale-coloured, red and black shales and pelagic limestones. Locally there are manganiferous horizons. The fauna consists of ammonites, monotids and microfossils. The thickness of this Triassic sequence may reach 1000 metres.

The Upper Permian is represented by the thick saliferous (gypsum, anhydrite and halite), argillaceous "Haselgebirge" beds, followed by Lower Triassic Werfen Beds and Gutenstein Limestone and -dolomite. In the Middle and Upper Triassic, the Halobia Beds and the Zlambach Marls are distinct argillaceous units; the Hallstatt Limestone is the main carbonate rock. Some Liassic marls complete the sequence in the Hallein sector.

The Haselgebirge was subdivided by SCHAUBERGER (1955) into various sub-units (grey, green, black Haselgebirge, Rotsalzgebirge, etc.). Some authors interpreted this rock as a sedimentary breccia, others invoke a tectonic origin. Mafic tuffs and isolated diabase were encountered in the saline strata.

The nappe-structure of the Hallein area can best be described in the following, simplified way:

The salt deposit of Dürrnberg/Hallein with its thick saliferous Haselgebirge belongs to the lower „Juvavikum" pile, a tectonic sheet of well-defined facies. It rests upon a broad syncline of the "Tirolikum" sheet, main element of the Northern Calcareous Alps, and represented in the Hallein area by Neocomian, Jurassic and Triassic beds.

The saline strata lie in deep troughs of the Tirolikum syncline, separated by ridges of Tirolikum marls ("Lobkowitz intercalation" in the Hallein mine). The Hallein

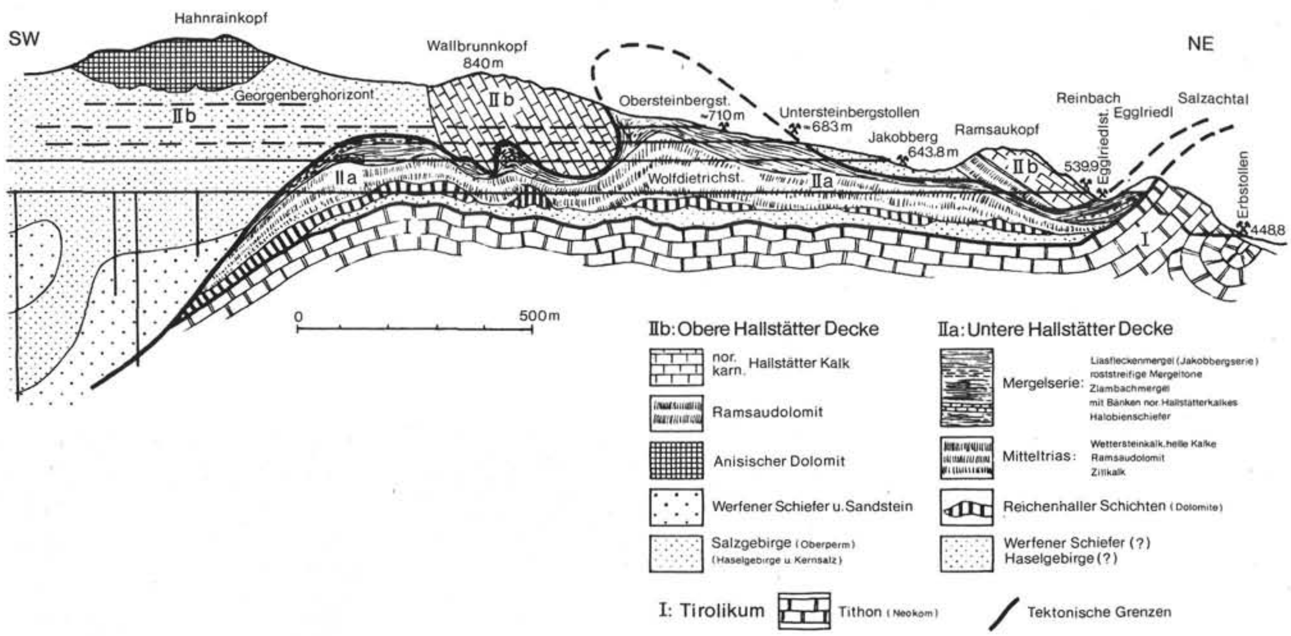

Fig. 17: Geological cross section through the Hallein Salt Deposit. After MEDWENITSCH, 1963.

syncline is limited in the south by Upper Jurassic-Neocomian rocks dipping steeply north.

Within the Dürrnberg sector, MEDWENITSCH (1963) recognized two, lithologicaly different, superimposed sheets of the Lower Juvavikum: the "Lower" and the "Upper Hallstatt Nappe".

Higher units of the Juvavikum ("Hochjuvavikum") were thrust upon the saliferous Lower Juvavikum, causing the complex internal structures of the salt deposit with its many barren intercalations. Halokinetic movements further complicated the tectonic situation.

Mineralogy

The Haselgebirge is an untextured argillaceous sediment of brecciated appearance: rounded fragments of dark and reddish clay and shale, marl and argillaceous sandstone of varying size are embedded in a matrix of haliferous clay. In places, this rock grades into dark, bituminous shale ("Glanzschiefer" = lustrous shale). The Haselgebirge encloses halite crystals and irregular masses of dense halite (white, grey, red), often accompanied by anhydrite and minor amounts of polyhalite, glauberite and astrakhanite (bloedite). Loeweite, kainite, langbeinite, vanthoffite, kieserite and sylvine are rare.

Salt minerals:

halite $NaCl$
anhydrite $CaSO_4$
polyhalite K_2SO_4, $MgSO_4$, $2\ CaSO_4$, $2\ H_2O$
glauberite Na_2SO_4, $CaSO_4$
astrakhanite (bloedite) Na_2SO_4, $MgSO_4 . 4\ H_2O$
loeweite $2Na_2SO_4 . 2\ MgSO_4 . 5\ H_2O$
kainite $K\ Cl . MgSO_4 . 3\ H_2O$
langbeinite $K_2SO_4 . 2\ MgSO_4$
vanthoffite $3\ Na_2SO_4 . MgSO_4$
kieserite $MgSO_4 . H_2O$
sylvine KCl

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Hallein to Salzburg

The road from Hallein to the city of Salzburg, situated on the northern fringe of the Calcareous Alps, follows the Salzach valley. In the west, the carbonate rocks of the Upper Juvavikum pile form conspicuous mountains; the hills in the east consist of Jurassic sequences of the Tirolikum. The southern frame of the basin of Salzburg is represented by Upper Cretaceous to Paleogene limestones and marls. North of the city, the nappes of the Calcareous Alps are thrust over the sandstones and shales of the Flysch Zone (Lower Cretaceous to Upper Cretaceous-Paleocene).

Sightseeing in Salzburg

Day 9

Excursion returns to Vienna/Wien on the West-Autobahn.

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