Verh. Geol. B-A.	Jahrgang 1978	Heft 3	S. 369–387	Wien, Dezember 1979
Proceed. 3 rd ISMIDA (Leoben, Oct. 7–10, 1977)			S. 195–213	Wien, Dezember 1979

Time- and Stratabound Early Paleozoic Scheelite, Stibnite and Cinnabar Deposits in the Eastern Alps

By RUDOLF HÖLL*)

With 4 figures and 1 table

Schlüsselwörter
Ostalpen
Scheelit
Stibnit
Zinnober
zeitgebundene Erzlagerstätten
schichtgebundene Erzlagerstätten
Alt-Paläozoikum
Alpine Tektonik

Summary

Scheelite, stibnite and cinnabar occurrences of the Eastern Alps are spatially, temporally and genetically connected with a submarine, basic, locally also ultramafic and acid volcanism, and with igneous-hydrothermal activities from Upper Ordovician to Silurian time. The palinspastic arrangement of these strata- and timebound, Early Paleozoic occurrences seems to reflect parallel belts with different types of ore mineralization, resulting from different ore supplies and specific features of magmatism and facies in probably parallel troughs and uplifts within a basin above a subduction zone system. The cinnabar occurrences were produced near the trench, stibnite, scheelite, stibnite, scheelite-arsenopyrite, and scheelite deposits more to the north. An ubiquitous scheelite mineralization with a complex paragenesis, particularly W, Mo, Bi, Cu, Au, Ag, within an especially thick volcanic rock series, may have resulted from the furthest down-dip ore generation above the subduction zone. This original position within the old sedimentary basin corresponds to the different tectonic units of the Eastern Alps, formed by later tectonic movements, above all by the Alpidian nappe transport. Thus, the major tectonic boundaries in the Eastern Alps are partly sharp boundaries concerning the distribution of the different occurrences of the W-Sb-Hg formation.

1. Introduction

The investigations of ore deposits of the W-Sb-Hg formation in the Eastern Alps began in 1965, following studies of similar ore deposits in Turkey (HÖLL, 1966). Some cinnabar (HgS) occurrences in Carinthia were interpreted as stratabound and genetically related to an Early Paleozoic, submarine, basic volcanism (HÖLL, 1970 b). Also some stibnite (Sb_2S_3) deposits of the Kreuzeckgruppe (Lessnig, Radlberg, Gurserkammer, Edengang, Rabant, and Johannisstollen) proved to be stratabound and connected with probably Early Paleozoic, basic metavolcanic layers. And in all these old known stibnite deposits, a scarce scheelite ($CaWO_4$) mineralization was discovered for the first time. The same genetic explanation was also favoured for the scheelite of the scheelite – sparry magnesite deposit Tux, where fossils in the overlying sparry magnesite bed provided an Upper Silurian to

---

*) Author's address: Dr. R. HÖLL, Institut für Geologie der Universität München, D-8 München 2, Luisenstraße 37.

Lower Devonian age (Höll and Maucher, 1967). These interpretations for the cinnabar occurrences, for the scheelite – stibnite deposits of the Kreuzeckgruppe, and for the ore deposit Tux were in contradiction to the then accepted theories, based on an Alpidian or Variscan origin and mostly on a relationship with granites or their metamorphic representatives.

A review of the literature on all scheelite occurrences of the Eastern Alps up to 1965 revealed 12 outcrops, without the Tux deposit, all discovered by chance. They are distributed in the area of the Hohe Tauern, seven in the eastern and five in the middle section (Höll, 1970 a and 1975). Those in the eastern section lie in different rock series. But the scheelite findings in the middle Hohe Tauern were remarkably restricted to outcrops of the "Habachserie". This series was described as a metamorphic, most probably Early Paleozoic rock series with abundant basic and acid volcanics (Frasl, 1958). The statement, that several scheelite occurrences are apparently restricted to a submarine, most probably Early Paleozoic rock series, rich in different volcanics, was exactly suited to conclusions about Early Paleozoic strata- and timebound scheelite mineralizations. A delimitation of favourable areas for scheelite prospects in the Eastern Alps seemed feasible to me, taking as a basis this genetic interpretation as well as the proved Paleozoic age of the ore deposit Tux and the newly discovered scheelite mineralizations of the Kreuzeckgruppe. Moreover, the Habachserie was regarded as the most favourable rock series for new scheelite discoveries. This idea was published by Höll and Maucher in January 1967. The scheelite prospecting began in summer 1967 and lasted several years, for long times supported by my brother, the mathematician E. Höll. Many new scheelite occurrences in the Habachserie, above all the scheelite deposit Felbertal, and in other areas of the Eastern Alps have been discovered (Höll, 1970 a, 1971, 1975; Höll and Maucher, 1976).

2. General Geology

The Early Paleozoic rock series within the Eastern Alps indicate a locally mobile sedimentary basin with elongated troughs and uplifts, lasting from Cambrian or at the latest from Ordovician to Devonian/Carboniferous time. The original position of the different rock series within this basin corresponds to the different tectonic units of the Eastern Alps, formed by the tectonic movements, especially the Alpidian nappe transport. These tectonic units are, from top to bottom: Upper Austro-Alpine unit, middle Austro-Alpine unit, lower Austro-Alpine unit, and Penninic zone. As presently accepted, the Early Paleozoic rock series of the Penninic zone, e. g. the Habachserie, represent the northernmost depositions on palinspastic schemes, while the Early Paleozoic rock series of the upper Austro-Alpine unit may have been part of the southernmost regions. The major tectonic boundaries within the Eastern Alps are in part also sharp boundaries reflecting the distribution of the different, stratabound, Early Paleozoic ore deposits, particularly of the W-Sb-Hg formation. This distribution is originally linked to specific features of facies and magmatism with distinct ore belts, dependent upon former paleogeographic boundaries of the troughs and uplifts in the Early Paleozoic sedimentary basin above a subduction zone system (Fig. 4).

The formation of Early Paleozoic scheelite, stibnite and cinnabar deposits is genetically, temporally and spatially related to a submarine, basic, in part also ultramafic and acid volcanism and associated igneous-hydrothermal activities. The period of volcanism and ore formation may have extended from Upper Ordovician (Caradocian stage; main phases) to Silurian time.

The Early Paleozoic volcanics of the Eastern Alps are similar to volcanic rocks of marginal basins and volcanic chains within modern island arc systems (HÖLL et al., in press). Geochemical data of volcanic rocks are interpreted as indications for the existence of a contemporaneous subduction zone (LOESCHKE, 1975, 1977). The volcanic processes reflect an evolution from submarine to subaerial stages.

A pre-Upper Ordovician metamorphism is proved in some regions of the Eastern Alps (SCHÖNLAUB and DAURER, 1977). However, no regional unconformity is evident in Uppper Ordovician to Devonian rock series (SCHMIDT, 1977). Thus, Early Paleozoic subduction processes provided favourable conditions for magma emplacement and metallogenesis without transforming the geosyncline into a Caledonian mountain belt. It seems possible, that the old basin gradually evolved into the Variscan geosyncline. The consolidation of the crust was completed later through the Variscan orogeny.

3. Scheelite in the Penninic Zone

Many scheelite outcrops, often associated with minor contents of Mo, Bi, Be, Cu, Au, Ag, and other elements, are known in this tectonic unit, especially in the Habachserie of the middle Hohe Tauern, but also in the basal and central schist cover of the eastern Hohe Tauern, and in the central gneisses.

3.1 Scheelite deposit Felbertal

This deposit, which I discovered in 1967, is the major scheelite deposit of the Eastern Alps and one of the largest tungsten deposits on the earth (Fig. 1 and Table 1, No. 16):

(1) The ore mineralization is stratabound within the Habachserie, whose age is unconfirmed by fossils, but commonly considered Early Paleozoic. The ore deposit was metamorphosed by the Alpidian orogeny under conditions of the "low-stage of metamorphism, isograd (17–20) + hornblende", using the classification of WINKLER (1970).

(2) The Habachserie can be divided into three units (Fig. 2 and 3):

a) Habach phyllites
b) volcanic rock sequence
c) basal schist sequence

The volcanic rock sequence is up to 1500 m thick in the Felbertal valley, and further west and east it thickens to at least 3000 m.

(3) The "scheelite-bearing series" comprises the lowest, up to 400 m wide section of this volcanic rock sequence. Its sole plane to the underlying basal schist sequence is sharp. However, a gradual transition is indicated into the overlying, fairly uniform section of the volcanic rock sequence (primarily tholeiitic basalts) through an irregular decrease in the tungsten content. Yet, this upper section has still about 5 ppm WO_3 in the average, proving the close relationship to the scheelite-bearing series.

(4) The scheelite-bearing series shows intense, alternate bedding and interfingering. It contains ultramafic, tholeiitic, intermediate and acid metavolcanic rocks as well as reassorted material, and precipitates (Fig. 2). The ore supply, the ore deposition, and the diagenetic ore alteration were contemporaneous and conformable with the volcano-sedimentary host rocks.

(5) Dark, chromiumoxide-green hornblendites and coarse-grained amphibolites are characteristic for the scheelite-bearing series of the ore deposit Felbertal and many other scheelite occurrences in the Habachserie. These rock types show high Cr, Ca and Mg, as well as low Al and low alkali metal contents in comparison with tholeiites. They are con-

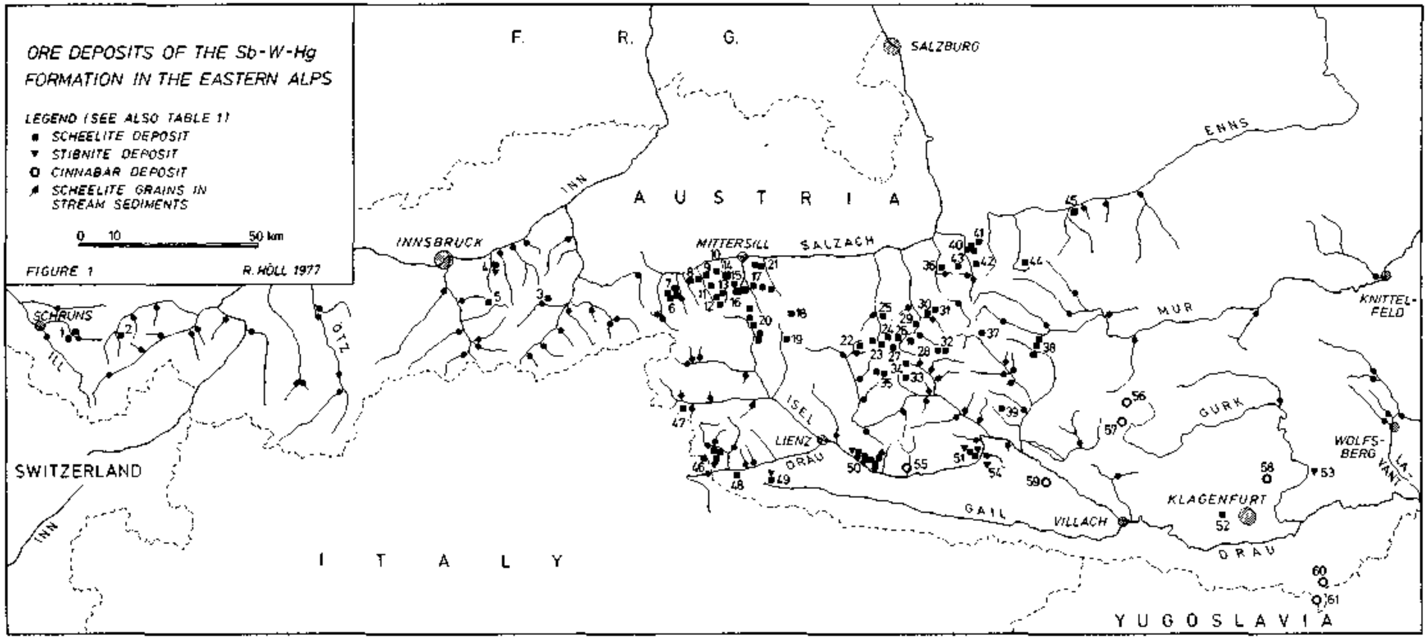
ORE DEPOSITS OF THE Sb-W-Hg FORMATION IN THE EASTERN ALPS
LEGEND (SEE ALSO TABLE 1)
■ SCHEELITE DEPOSIT
▼ STIBNITE DEPOSIT
O CINNABAR DEPOSIT
SCHEELITE GRAINS IN STREAM SEDIMENTS
0 10 50 km
FIGURE 1
R. HÖLL 1977
F. R. G.
SALZBURG
AUSTRIA
INN
INNSBRUCK
MITTERSILL
SALZACH
ENNS
MUR
KNITTELFELD
SCHRUNS
ILL
ÖTZ
ISEL
LIENZ
DRAU
GAIL
VILLACH
GURK
WOLFSBERG
LAVANT
KLAGENFURT
SWITZERLAND
ITALY
YUGOSLAVIA

Fig. 1

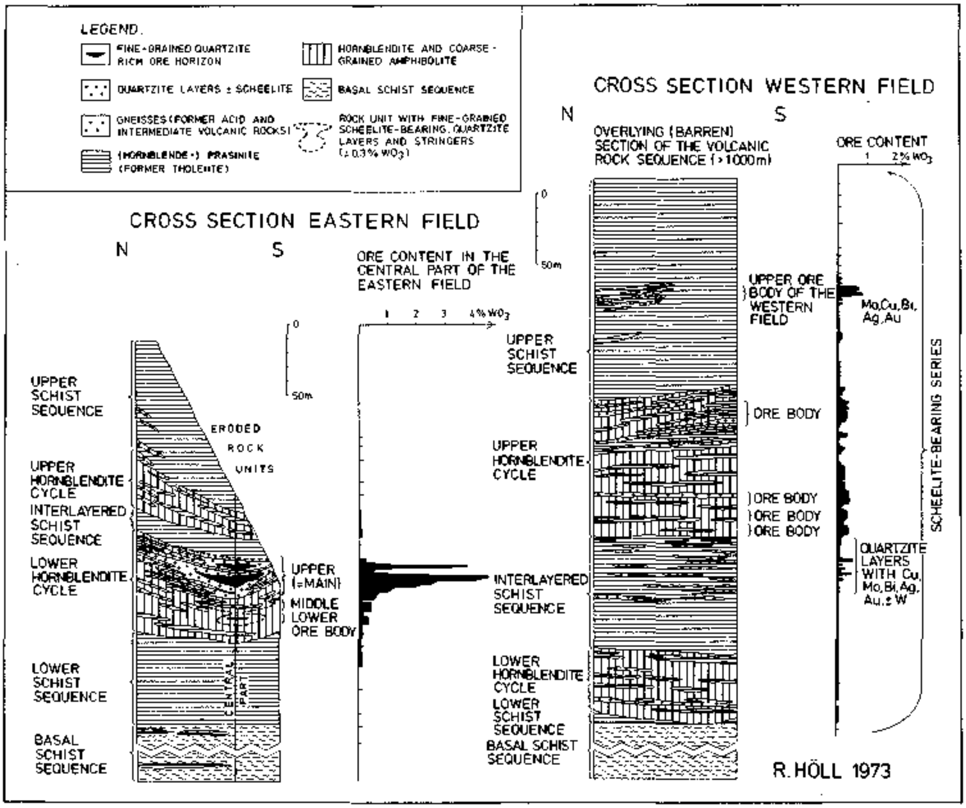

Fig. 2: Schematic Cross Sections through the Scheelite-bearing Series of the Eastern and Western Field of the ore Deposit Felbertal.

centrated within two successive rock units, making feasible the following division of the scheelite bearing-series (from top to bottom; Fig. 2 and 3):

a) Upper schist sequence
b) upper hornblendite cycle
c) interlayered schist sequence
d) lower hornblendite cycle
e) lower schist sequence

The rapid ascent of the ultramafics was overlapped by tholeiitic, intermediate, and acid volcanic activity, and associated by the most intensive igneous-hydrothermal activity within the scheelite-bearing series. The upper, the interlayered and the lower schist sequence consist mainly of former tholeiites, altered to (hornblende-)prasinites (viz. hornblende-chlorite-epidote-albite-oligoclase assemblages) (Fig. 2).

(6) The scheelite deposit Felbertal contains two ore fields, an "eastern field" and a "western field". Two adjoining special troughs along a prominent volcanic trend are regarded as initial troughs for both ore fields (Fig. 2 and 3).

The estimated length of the eastern field is somewhat more than 2.5 km and the mineable zone is hardly more than 100 m wide in the well probed easternmost part. The western field is explored only in its eastern portion, and the width of the mineable zone cannot be calculated exactly because of imbrication, but is much broader than that of the eastern field.

(7) The mineable ore bodies of the eastern field are linked with the lower hornblendite cycle. Those of the western field are associated with the upper hornblendite cycle and with layers in the middle section of the upper schist sequence. Scheelite can be found in all types of rocks of the scheelite-bearing series of both fields (Fig. 2).

(8) The ore minerals are: scheelite, powellite, wolframite, molybdenite, tungstenite-molybdenite solid solutions, pyrrhotite, pyrite, marcasite, pentlandite, sphalerite, galena, tetrahedrite, bornite, cobaltite, arsenopyrite, native Au, native Ag, native Bi, bismuthinite, emplectite, galenobismuthite-cosalite, stibnite, beryl, cassiterite, columbite, ilmenite, hematite, magnetite, chromite, apatite, fluorite, barite. Some of these ore minerals are very rare. Statistical tests show significant differences between the eastern and the western field. The eastern field contains sulfide-poor, and to a large extent high-grade scheelite ores. In the western field, the ores are mostly low-grade and other ore minerals occur frequently. The following elements are significantly enriched at least in some layers: W, Mo, Cu, Bi, As, Sb, Au, Ag, Be, Sn, Ta, Nb, Se, Te, Li, Cs, Ni, Co, Pb, Zn, Cd, Hg, P, F.

The tungsten supply occurred apparently above all as Si-W-heteropoly acids (with minor amount of P, Sb, As, and other elements). The presence of Na_2WO_4-bearing solutions and of W-halogenids seems possible.

(9) Three generations of scheelite are known:

The primary generation represents a syngenetic-diagenetic ore formation. The ore-forming processes are related to complex interactions between igneous-hydrothermal activities and the precipitation and sedimentation processes in the submarine environment.

Recrystallization during the Alpidian regional metamorphism produced scheelite porphyroblasts (second generation), especially in the western field.

Scheelite crystals in fissures (third generation) are rare within the ore deposit Felbertal, but common in some other regions of the Hohe Tauern. These usually Mo-free scheelite crystals must have been formed at lower temperatures than the $CaMoO_4$-bearing scheelite porphyroblasts, after the main period of tectonic activity and metamorphism.

(10) About 90% of the mineable ores of the eastern field are part of the first generation. Fine-grained scheelite (diameter of grains ≤ 0.35 mm) is likewise enclosed in fine-grained quartzite with mosaic texture (diameter of grains ≤ 1 mm). This ore type is linked to two quartzite "rich ore horizons" and to a great number of thin (up to several cm thick), quartzite bands and stringers, interpreted as former scheelitebearing silica gel precipitates upon the sea floor as well as within the rocks just below the sea floor. The rich ore horizons show the best preserved syngenetic-diagenetic fabrics, exhibiting rhythmic sedimentation and submarine gliding (HÖLL et al., 1972, Fig. 6, 7, 8).

These ores are within the middle to the uppermost section of the lower hornblendite cycle. There, three superimposed, elongated ore bodies are defineable, if we take a workable limit of 2 m and a cut-off grade of 0.3% WO_3. The lower and the middle ore body consist of several joint lenses. The upper, main ore body probably forms a continuous mineable ore mineralization along the whole extent of the eastern field trough and contains both rich ore horizons (Fig. 2 and 3).

(11) These three ore bodies reflect the configuration of a single thermal fissure fault with igneous-hydrothermal springs in the central area of the trough. The lenses of the lower and middle ore body are attributed to isolated spots of metal inflows along this thermal fissure fault and to ore deposition in the immediate surroundings. Metal-rich inflows and very favourable conditions for precipitation of scheelite must have existed during the formation of the main ore body, which achieves its greatest thickness (25 m) and its highest average content (up to 1.1% WO_3) along its central axis, coinciding with the thermal fissure fault.

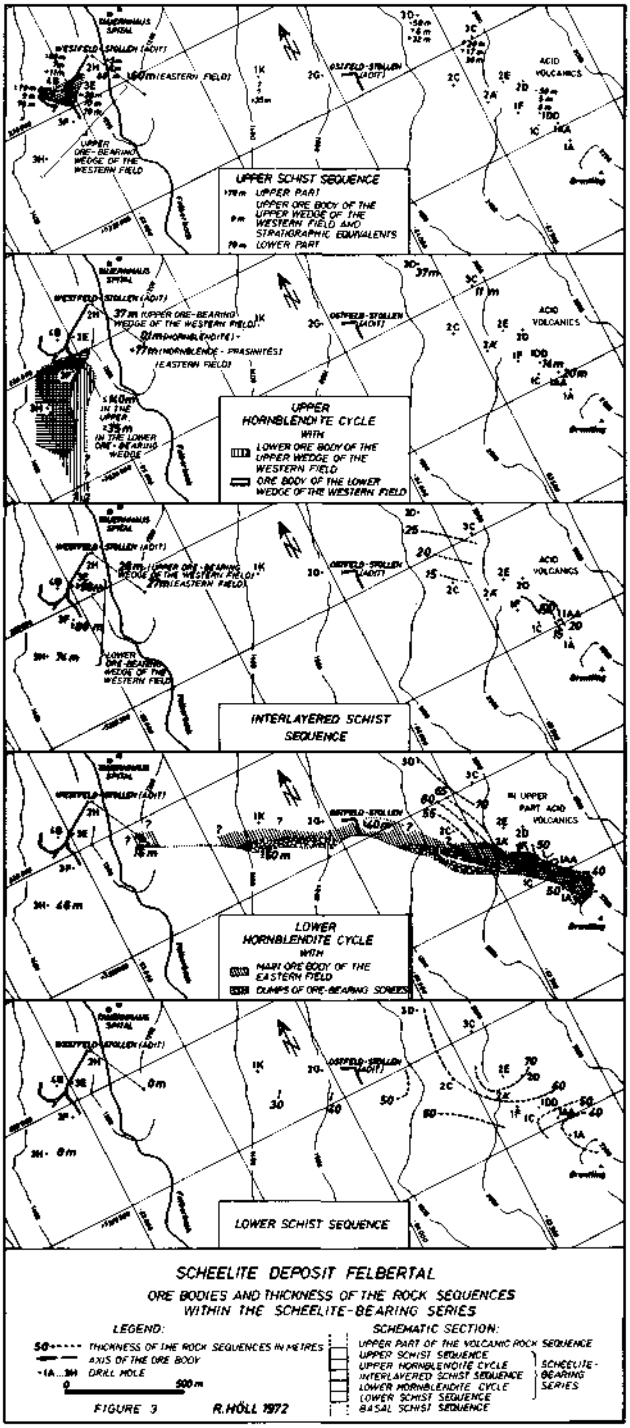
UPPER SCHIST SEQUENCE
UPPER PART
UPPER ORE BODY OF THE UPPER WEDGE OF THE WESTERN FIELD AND STRATIGRAPHIC EQUIVALENTS
LOWER PART
UPPER HORNBLENDITE CYCLE WITH
LOWER ORE BODY OF THE UPPER WEDGE OF THE WESTERN FIELD
ORE BODY OF THE LOWER WEDGE OF THE WESTERN FIELD
INTERLAYERED SCHIST SEQUENCE
LOWER HORNBLENDITE CYCLE WITH
MAIN ORE BODY OF THE EASTERN FIELD
DUMPS OF ORE-BEARING SCREES
LOWER SCHIST SEQUENCE
WESTFELD-STOLLEN (ADIT)
OSTFELD-STOLLEN (ADIT)
ACID VOLCANICS
IN UPPER PART ACID VOLCANICS
UPPER ORE-BEARING WEDGE OF THE WESTERN FIELD
LOWER ORE-BEARING WEDGE OF THE WESTERN FIELD
SCHEELITE DEPOSIT FELBERTAL
ORE BODIES AND THICKNESS OF THE ROCK SEQUENCES WITHIN THE SCHEELITE-BEARING SERIES
LEGEND:
THICKNESS OF THE ROCK SEQUENCES IN METRES
AXIS OF THE ORE BODY
1A...3H DRILL HOLE
0
500 m
FIGURE 3
R. HÖLL 1972
SCHEMATIC SECTION:
UPPER PART OF THE VOLCANIC ROCK SEQUENCE
UPPER SCHIST SEQUENCE
UPPER HORNBLENDITE CYCLE
INTERLAYERED SCHIST SEQUENCE
LOWER HORNBLENDITE CYCLE
LOWER SCHIST SEQUENCE
BASAL SCHIST SEQUENCE
SCHEELITE-BEARING SERIES

Fig. 3

Moreover, the embedded, elongated lower rich ore horizon shows an average below 2% WO_3 at marginal positions, increasing to more than 3.5% WO_3 in the thicker lens centre. It swells abruptly to 8 m and shows intensive submarine gliding fabrics at several localities, considered as the most intensive emergent outlets of igneous-hydrothermal solutions. The precipitation of $CaMoO_4$-bearing scheelite was favoured over the precipitation of silica gel and other ore minerals near the outflow spots, probably in a slightly basic environment. Furthermore, scheelite-poor or barren, Na-rich and/or K-rich, acid volcanic tuffs (metamorphically altered to fine-grained gneisses) were temporally and spatially connected with the igneous-hydrothermal activity (Fig. 2).

(12) The axis of the main ore body is almost parallel to the eastern slope of the Felbertal valley. This ore body is broken into large boulders at the surface, post-glacially. These boulders form two, some hundred metres long dumps of ore-bearing screes above the continuous solid ore-bearing rock piles (Fig. 3).

(13) In the western field, the scheelite is concentrated above all in non-quartzitic rocks of the upper hornblendite cycle. This ore-bearing section was split up tectonically by the Alpidian orogeny into an upper and a lower ore-bearing wedge. Rock sequences containing 0.2–0.25% WO_3 are several tens of meters thick, and lense-shaped ore bodies can be outlined with a 0.3% WO_3 cut-off grade (Fig. 2 and 3). Many erratic igneous-hydrothermal springs must have been active throughout the broad trough.

In the upper schist sequence of the upper wedge, the eastern part of an elongated ore body is up to 10 m thick. The Mo-rich, coarse-grained scheelite mineralization lies in metavolcanic layers of andesitic composition, accompanied by scheelite-poor quartzite lenses.

(14) Several quartzite lenses, especially within the upper two thirds of the interlayered schist sequence of the lower ore-bearing wedge, show remarkably enriched and unusual ore contents besides variable amounts of scheelite, above all Bi (to 1.2%), Mo (to 0.7%), Cu (to 3.3%), Au (to 0.5 ppm), and Ag (to 120 ppm).

(15) The ore reserves are about 2,500,000 t with 0.7% WO_3 (eastern field 1,800,000 t, and western field 700,000 t). A large undrilled area is still in the eastern field, and only a small eastern region has been explored in the western field.

3.2 Scheelite within the Habachserie (outside the scheelite deposit Felbertal)

A sparse scheelite mineralization in the Habachserie is widespread over a distance of 40 km in E-W and up to 25 km in N-S direction (Fig. 1 and Table 1, Nos. 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21). A similar showing exists 2 km north of the village Großarl (No. 36).

The most important differences between the ore deposit Felbertal and all other Habachserie scheelite occurrences are related to the igneous-hydrothermal activities and their metal supply. Thus, quartzite layers and stringers with scheelite and/or sulfide minerals are only rare outside the Felbertal ore deposit. But these scheelite occurrences also lie especially in the lower, up to several hundred metres thick section of the volcanic rock sequence, which is predominantly composed of metabasites. Areas with small scheelite enrichment are usually marked by the presence of dark, chromiumoxide-green hornblendites, hornblende schists and/or coarse-grained amphibolites like in the ore deposit Felbertal. Also small amounts of Mo, Cu, Bi, Sb, As, Be, Au, Ag, Sn, Ni, Co, Zn, Pb, F, Ba, and P can be associated. The identified ore minerals correspond with those of the ore deposit Felbertal. Most scheelite occurrences show only a simple paragenesis with scheelite, pyrite, pyrrhotite, chalcopyrite, and molybdenite. The scheelite grains are usually $CaMoO_4$-bearing.

Scheelite porphyroblasts are mostly concentrated in small layers or stringers, but are apparently also dependent on the sort of the host rocks and on the degree of metamorphism.

It is noteworthy, that also the upper part of the volcanic rock sequence, at all many billion tons of formerly mainly tholeiitic basalts, has an unusual content of tungsten, may be in the average of about 5 ppm WO_3, like in the Felbertal valley.

3.3 Scheelite within the schist cover of the eastern Hohe Tauern

The easternmost scheelite showings of the Habachserie within the middle section of the Hohe Tauern lie on the eastern slope of the Stubachtal. There, Permomesozoic, barren rock series of the Glockner depression cover the Habachserie. Scheelite occurs again east of this depression in the eastern part of the Hohe Tauern, from the Rauristal to the eastern end of the Tauern window. It is ascertained in the imbricated Tauern schist cover, especially in the "basal and central schist cover" (Exner, 1957, 1964, 1971), as well as in the central gneisses.

At least most of the scheelite occurrences in this schist cover (Fig. 1 and Table 1, Nos. 22, 23 partly, 27, 28, 31, 32, 34, 37, 38) correspond with the scheelite deposit Felbertal and the other scheelite occurrences of the Habachserie. They are also often in paragenesis with small contents of Mo, As, Sb, Bi, Be, Au and Ag. Moreover, they are originally stratabound, but syn- and posttectonic, coarse-grained recrystallization of the ore minerals is evident above all in high-grade metamorphic rocks. A genetic relationship to a submarine volcanism, and/or an igneous-hydrothermal activity is often indicated. Thus, they are mostly intimately connected with basic and ultramafic layers. Condordant quartzite layers and lenses, above all with sulfide minerals and small contents of scheelite, are characteristic for a 30 km long row of similar ore deposits ("scheelite-gold-sulfide ore deposit type Schellgaden"), stretching from the upper Murtal to the Radlgraben. These quartzite ores are similar to quartzite layers with sulfide minerals and scheelite in the ore deposit Felbertal, especially within the interlayered schist sequence of the western field.

3.4 Scheelite in the Central Gneisses

Scheelite occurrences of this type are presented in Fig. 1 and Table 1, Nos. 23 partly, 24, 25, 26, 29, 30, 33, 35.

The central gneisses of the Hohe Tauern are usually regarded as Variscan intrusions, which were subjected to the Alpidian regional metamorphism. Genetic evidence for the scheelite mineralization exists particularly in the central gneiss masses of the Sonnblick (No. 35), where scarce scheelite impregnations must be interpreted as original components of the intrusions. During the Alpidian metamorphism, scheelite was mobilized and concentrated along foliation planes, in pockets, fissures, and veinlets, with or without quartz and carbonate minerals. The scheelite of the central gneisses is considered as an ore content out of older, probably Early Paleozoic rock series in connection with a Variscan palingenic magma melting.

4. Scheelite in the Lower Austro-Alpine Unit

The scheelite occurrences within this tectonic unit (Fig. 1 and Table 1, Nos. 3, 4, 5, 40, 41, 42, 43, 44) lie in quartzphyllite series north of the Tauern window. They are similar to each other, but different from the scheelite occurences in the Penninic zone and in the middle Austro-Alpine unit. The scheelite is blue fluorescent and Mo-free. The scheelite-bearing strata are a few decimetres to several metres thick. They are composed of grey and black schists, quartzphyllites, quartzite lenses, carbonate schists, and pure carbonate layers. Fossils prove or favour a Silurian age.

4.1 Scheelite – sparry magnesite deposit Tux

This ore deposit within the Innsbrucker Quarzphyllitserie consists of an up to 3 m thick scheelite-bearing horizon and an overlying dolomite – sparry magnesite bed. Conodonts show that this up to several tens of metres thick carbonate bed started in the high Middle Ludlovian and reached as far as Lower Emsium (HÖLL & MAUCHER, 1967, MOSTLER, 1973). The primary scheelite mineralization may be of Middle or Lower Ludlovian age. The scheelite-bearing horizon contains (carbonate-)quartz lenses, black schists and stratiform laminas, lenses and impregnations of ore minerals. Scheelite, pyrite and apatite are prevailing, whereas tungstenite, wolframite, hydrotungstite, stibnite, molybdenite, galena, sphalerite, bournonite, boulangerite, chalcopyrite, chalcocite, tetrahedrite, bindheimite, malachite, and azurite (WENGER, 1964) are only rare. The ore deposit is characterized by a poverty of Mo.

The metal supply for the tungsten mineralization may be related to an igneous-hydrothermal activity, probably connected with submarine basic volcanic layers in the footwall. The cessation of the stratiform ore mineralization, where the graphitic facies thins out, suggests strong environmental control.

4.2 Scheelite deposits in Kleinarltal and Lambachgraben

The stratabound scheelite mineralization is intensely tectonically disturbed and separated in different ore deposits, which I discovered in 1968 (HÖLL, 1971 a, 1975). These deposits are scattered within an area of 8 km in N-S and 6 km in E-W direction (Fig. 1 and Table 1, Nos. 40, 41, 42, 43), at a distance of about 120 km from the ore deposit Tux. They are confined to the Radstädter Quarzphyllitserie (WAGNER, 1972). Fossils, also within scheelitebearing carbonate host rocks, favour an Early Paleozoic, probably Silurian age (SCHÖNLAUB, 1975).

All these scheelite deposits display conformable characteristics: They are stratabound, in an up to 20 m thick rock sequence, composed of carbonate rocks, above all iron-bearing dolomite, locally also of carbonate schists, impure quartzite intercalations, quartzphyllites, and black and grey phyllites. In massive dolomite bodies, above all near Griespalfen, the scheelite is mainly coarse-grained and irregularly distributed in fissures, lenses and pockets. High ore enrichments adjoin barren host rocks in some places. However, dark bituminous, finely laminated carbonate layers of a quiescent-area facies are dominant in places, where the scheelite-bearing horizon is only thin. There, especially in the Stuhlgraben, the most excellent fabrics of synsedimentary-diagenetic scheelite mineralizations are present (HÖLL et al., 1972, Fig. 2–5). The ore deposits of the Kleinarltal and Lambachgraben contain the purest, Mo-free scheelite mineralization in the Eastern Alps. Pyrite, pyrrhotite and arsenopyrite are rare, and no traces of Au, Ag, Bi, Be, and Sn have been found.

5. Scheelite, scheelite – arsenopyrite, scheelite – stibnite, stibnite and cinnabar occurrences in the Middle Austro-Alpine Unit

The middle Austro-Alpine unit (TOLLMANN, 1963) covers large regions of the Eastern Alps. It shows the greatest variety of parageneses of the W-Sb-Hg formation and accompanying ore minerals.

5.1 Scheelite occurrences

In the westernmost Austria, several scheelite-bearing areas have been delineated between the Swiss-Austrian border and the Brenner Pass. Scheelite was found in the valley northeast of Furkla and in an outcrop west of Fellimännle in the Silbertal (Vorarlberg) (Fig. 1 and Table 1, No. 1), and in an ore deposit just north of the Konstanzer Hütte (at

2100–2200 m a. s. l.) (No. 2). These showings reveal strong features of a high-grade metamorphism with coarse scheelite grains, particularly in fissure veins and pockets within amphibolites and hornblende gneisses of a paragneiss series.

Other scheelite occurrences are known in the Lappgraben (No. 47) (VOHRYZKA, 1968; FRISCH 1972), and near Winklern at the road from Pörtschach am See to Moosburg (No. 52) (MEIXNER, 1973).

5.2 Arsenopyrite–scheelite deposits in the Thurntaler Quarzphyllitserie

In 1969 and 1970, I discovered a widespread scheelite mineralization in the area Sillian – Innervillgraten – Außervillgraten – Panzendorf (Fig. 1 and Table 1, No. 46) and a very small scheelite showing in Sägebach (at 1180 m a. s. l.) (No. 48).

The scheelite is concentrated within a sequence of basic metavolcanics (mainly metatuffs and metatuffites) within the Thurntaler Quarzphyllitserie, whose age is considered as Early Paleozoic and whose metamorphism as pre-Alpidian (Variscan) (HÖLL, 1971; KROL, 1974; HEINISCH and SCHMIDT, 1976). The ore-bearing metavolcanics thicken up to 200 m between the hills Gumriaul and Marchkinkele at the Austrian – Italian border. From there, the axes of these layers plunage to the NE. The maximum scheelite concentration is conformable to these axes as far as the Tafine Graben (HÖLL, 1971, 1975). Laminas, lenses, and impregnations of scheelite represent components of the submarine, basic metavolcanic host rocks and of intercalated phyllites. The same genetic interpretation is favoured for arsenopyrite within these metavolcanics, often together with scheelite. Discordant veins, veinlets, and pockets with quartz, calcite and dolomite, scheelite and arsenopyrite are of lithogene origin. Ore-bearing samples show enrichments of W, As, Au, Ag, Sb, as well as traces of Mo, Cu, Pb, Zn, and Hg. Arsenopyrite and pyrite concentrations in small veins are also present in the upper section of the Thurntaler Quarzphyllitserie, especially around the Thurntaler hill.

Temporal, spatial and genetic relationships exist to neighbouring sulfide deposits (Tessenberg – Panzendorf) with scattered scheelite grains (KROL, 1974). These stratabound sulfide deposits lie within the same basic metavolcanic sequence.

5.3 Scheelite –stibnite deposits of the Kreuzeckgruppe

They are found in two districts. The Rabant district comprises Goming, Marienstollen, Johannisstollen, Rabant, Edengang, Gurserkammer, and Strieden (No. 50). It stretches about 7 km in E-W direction. The Lessnig – Radlberg district is about 30 km to the east and comprises Lessnig, Radlberg, Tränkergraben, and Pirkeben (No. 51).

These scheelite – stibnite deposits, except for the metamorphic lithogene showings Gomig and Marienstollen, are stratabound within an approximately 100 m thick sequence of metavolcanics in the middle section of the Rabantserie. The ore-bearing sequence is composed of concordant layers of metabasites, mica schists, quartzite schists, and the ore mineralization (HÖLL and MAUCHER, 1967; LAHUSEN, 1969, 1972). The parageneses of all stratabound deposits are uniform, with stibnite the prevailing ore mineral. Pyrite, marcasite and arsenopyrite are abundant. Scheelite is usually only subordinate. Pyrrhotite, chalcopyrite, sphalerite, and galena are present. Enhanced contents of Sb, As, W, Au, Cu, and traces of Pb, Zn, Mo, Bi, Be, Ag, and Hg have been found in most deposits. In the Rabant district, stibnite-rich ores are concentrated within a graphite schist horizon, which is locally intercalated by basic metatuff bands. This ore horizon is tectonically disturbed or even mylonitized. In the ore deposit Lessnig, the stibnite is within at least two major graphite schist horizons, separated by layers of metavolcanics, quartzite lenses, and mica schists. The stratiform ores comprise bands and disseminations of ore minerals. Stibnite-rich ore bands interlaminated by graphite schists and thin lenses of metavolcanics are abundant in Rabant, Gurserkammer, and Lessnig. They consist of very fine-grained stibnite, locally associated by thin pyrite and arsenopyrite lenses and traces of scheelite.

The ore supply must be seen in connection with the submarine volcanism and igneous-hydrothermal activities. Fossil debris, found near Lessnig, indicates an Early Paleozoic origin (LAHUSEN, 1969). Veinlets and fissures with coarse stibnite grains, scheelite, quartz, and carbonate minerals are also concentrated within the ore-bearing series. They are metamorphic lithogene products.

A comparison of the Thurntaler Quartzphyllitserie and the Rabantserie displays great similarities, including the stratabound deposits of the W-Sb-Hg formation and the sulfide occurrences within both series. Stibnite is the major, arsenopyrite and scheelite are ubiquitous, but subordinate ore minerals in the Rabant and Lessnig-Radlberg districts of the Kreuzeckgruppe. In the Thurntaler Quarzphyllitserie, scheelite and arsenopyrite are prevailing, and stibnite is scarce.

5.4 Stibnite deposits

Other stibnite occurrences within the middle Austro-Alpine unit are lacking in good exposures, but caved-in galleries, dumps and small outcrops still exist.

A small stibnite occurrence with traces of scheelite about 3 km NW of the village Obertilliach (No. 49) is similar to the scheelite-stibnite deposits of the Kreuzeckgruppe (HÖLL, 1975).

The stibnite deposit Guginock (No. 54) is about 4 km from the scheelitestibnite deposit Lessnig. The ore mineralization is probably stratabound. However, a strong syn- and post-tectonic ore mobilization and recrystallization are evident.

The small stibnite deposit Brückl (MEIXNER and THIEDIG, 1969) (No. 53) lies within host rocks of probably Early Paleozoic age. A genetic conformity with other stratabound, Early Paleozoic ore deposits of the W-Sb-Hg formation may not be excluded.

5.5 Cinnabar deposit Glatschach near Dellach

This collapsed mine in the southern Kreuzeckgruppe (No. 55) is about 10 km east of the scheelite-stibnite deposits of the Rabant district and 20 km west of those of the Lessnig – Radlberg district. It lies in a block, representing a continuation of the Rabantserie. The ore minerals are cinnabar, pyrite, arsenopyrite, marcasite, rare stibnite, chalcopyrite, galena, and sphalerite. The major ore body is a pyritic graphite schist horizon, interbedded by basic metavolcanics. Cinnabarbearing pyrite – arsenopyrite bands alternate with graphitic layers, whereas scarce cinnabar impregnations are prevailing in basic metatuff lenses. The ore-formation is connected with a submarine basic volcanism and an igneous-hydrothermal activity corresponding to the ore-formation of the stratabound scheelite-stibnite deposits to the west and to the east. Moreover, a basic metavolcanic layer in the hanging wall shows low contents of W, Sb, Hg, As, Cu, Pb, Zn (LAHUSEN, 1969), proving a further affinity to the neighbouring scheelite-stibnite deposits.

The other cinnabar deposits of the Eastern Alps are within the upper Austro-Alpine unit. Excepting their lower metamorphic grade and smaller amounts of accompanying ore minerals, conformable characteristics are evident in these proved or probably Early Paleozoic cinnabar deposits.

6. Cinnabar deposits of the Upper Austro-Alpine Unit

This tectonic unit is characterized by cinnabar deposits within Early Paleozoic rock series, above all in Carinthia. However, Prof. Dr. O. M. FRIEDRICH, Leoben, recently discovered also a stratabound scheelite occurrence in Early Paleozoic rocks at Fastenberg near Schladming (No. 45), where scheelite grains in stream samples have been found long ago (Höll, 1971, 1975).

6.1 Cinnabar deposits Hohes Kohr and Rottrasten

They are about 5 km apart and lie in similar rock sequences of the Eisenhut-Schieferserie, which belongs to the Gurktaldecke (nappe). At Hohes Kohr (No. 56), the ore mineralization s stratabound within an up to 15 m thick sequence of basic tuffs and tuffites as well as amygdaloidal rocks. At Rottrasten (No. 57), graphite schists are also present. The host rocks and the ore mineralization of the deposit Hohes Kohr must be older than Wenlockian, probably of Upper Ordovician or Lower Silurian age (Höll, 1970 b). The deposit Rottrasten may be of the same age. Both deposits contain only poor Hg contents: Hohes Kohr 0.05–0.11% Hg, Rottrasten still less (Friedrich, 1965). The ore minerals are cinnabar, pyrite, chalcopyrite, tetrahedrite, bornite, covellite, malachite, azurite, hematite, and magnetite. These ore deposits are no vein type or metasomatic deposits of Alpidian origin (Friedrich, 1965; Petrascheck, 1966), but display characteristics of a synsedimentary-diagenetic deposition, corresponding with many other stratabound cinnabar deposits (Maucher, 1965, 1976; Höll 1966, 1970 b; Maucher and Höll, 1968):

a) Fine-grained cinnabar impregnations within the volcanic rocks indicate a primary origin.

b) Cinnabar enrichments within amygdaloidal infillings (Zirkl, 1955; Höll, 1970 b) at Hohes Kohr prove a diagenetic origin.

c) Thin lenses with cinnabar and pyrite, at Rottrasten also with cinnabar-bearing, siliceous graphite schists, may be seen in connection with submarine igneous-hydrothermal activities and ore formation during a pause of the volcanic deposition.

d) Cinnabar concentration along foliation planes and in irregular pockets reveal a syn- to posttectonic ore mobilization, migration and redeposition.

e) The posttectonic cinnabar content in fissure veins and veinlets must also be regarded as of lithogene origin.

6.2 Mercury in the Magdalensberg area

Names of places containing the word "Zinnober" indicate former cinnabar discoveries in this area (No. 58). However, cinnabar has not been found on dumps in recent years. Geochemical investigations proved poor Hg contents in basic volcanic tuffs of Caradocian or Ashgillian age, similar to those of the cinnabar deposits Hohes Kohr and Rottrasten.

6.3 Cinnabar deposit Stockenboi

This stratabound ore deposit (No. 59) is confined to quartzite layers and adjoining schists within a rock series similar to the proved Early Paleozoic Eisenhut-Schieferserie (Maucher and Höll, 1968; Lahusen, 1969, 1972; Schulz, 1969; Höll, 1970 b).

6.4 Cinnabar deposits Eisenkappel and Vellacher Kotschna

The cinnabar deposit Eisenkappel (No. 60) is several hundred metres SE of the village Eisenkappel at the Leppenberg. Very fine-grained, scarce cinnabar impregnations are within basic volcanic layers and tuffs in a thick volcanic pile of Upper Ordovician age. They represent an original rock component, whereas cinnabar enrichments in fissure veins, veinlets and pockets are concentrated by lithogene processes.

The cinnabar deposit Vellacher Kotschna (No. 61) lies in the southernmost region of Austria, about 11 km SSW of the village Eisenkappel, south of the tectonic boundary between the Eastern and the Southern Alps. Outcrops in Hudibach and a gallery show that this cinnabar mineralization is stratabound within an up to 20 m thick dolomite bed of probably Ladinian age. Temporal, spatial and genetic relationships to other Triassic cinnabar deposits of the Southern Alps, above all to the large cinnabar deposit Idrija, are indicated.

7. Conclusions

a) A widespread metal deposition with W, Sb, Hg, and the associated elements Mo, Bi, Au, Ag, Cu, As, Be, Sn, Pb, Zn, F, P, Ni, Co, Se, Te, Nb, Ta, Li, Cs took place in the Eastern Alps during Early Paleozoic time. The period of mineralization may have extended from Upper Ordovician (Caradocian stage; most ore deposits) to Silurian time.

b) The ore formation is temporally, spatially and genetically related to a submarine, basic, in part also ultramafic and acid volcanism and igneous-hydrothermal activities. These Early Paleozoic volcanics of the Eastern Alps are similar to volcanic rocks of modern island arcs and marginal basins (HÖLL et al., in press). The volcanic processes reflect an evolution from submarine to subaerial stages.

c) The major tectonic boundaries in the Eastern Alps are partly also sharp boundaries concerning the distribution of the different stratabound, Early Paleozoic ore deposits of the W-Sb-Hg formation: The most intensive scheelite mineralization, often accompanied by Mo, Cu, Bi, Au, Ag, Be, Sn (scheelite deposit Felbertal), is within the Penninic zone, usually in very thick volcanic rock sequences. In the lower Austro-Alpine unit, the scheelite mineralization of proven or probably Silurian age, is restricted to a few regions. There, extremely Mo-poor scheelite is present in some layers together with schists and carbonate host rocks (dolomite – sparry magnesite in Tux, Fe-bearing dolomite in Kleinarltal).

In the middle Austro-Alpine unit, scheelite occurrences, arsenopyrite and scheelite deposits with gold and traces of stibnite, several stibnite deposits with scheelite and arsenopyrite, "pure" stibnite occurrences as well as a cinnabar deposit (Glatschach) and sulfide deposits with Cu are present.

The upper Austro-Alpine unit is characterized by several stratabound cinnabar and sulfide deposits. At Fastenberg near Schladming, a scheelite occurrence is also known.

d) These different tectonic units were formed by the Alpidian orogeny. Their arrangement corresponds with the palinspastic position of the Early Paleozoic rock series in a large basin with probably parallel trough systems and intervening uplifts. The rock series of the upper Austro-Alpine unit represent the supposed southernmost depositions. Those of the middle Austro-Alpine unit are sediments more to the north, and those of the lower Austro-Alpine unit still further to the north. The Early Paleozoic rock series of the Penninic zone must have been part of the assumed northernmost regions Fig. 4).

Thus, cinnabar and sulfide deposits were formed preferably in the southernmost deposition areas. Stibnite, scheelite-stibnite, scheelite-arsenopyrite, scheelite, and additional sulfide deposits originated more to the north. Scheelite ores together with carbonate rocks and schists (type Kleinarltal und Tux) were produced still further north. The widespread scheelite occurrences of the Penninic zone with a complex paragenesis lie within an exceptionally thick volcanic rock series of the northernmost areas (Fig. 4).

e) Similar ore assemblages and ore belts are in Circum-Pacific regions connected with subduction systems. The Early Paleozoic arrangement of the scheelite, stibnite and cinnabar deposits in the Eastern Alps may also reflect the ore supplies as well as the specific features of magmatism and facies in different troughs and uplifts as a function of the depth and the angle of a subduction zone system. The cinnabar deposits originated near the trench, whereas the scheelite deposits of the Penninic zone resulted from the furthest down-dip ore generation above the subduction zone.

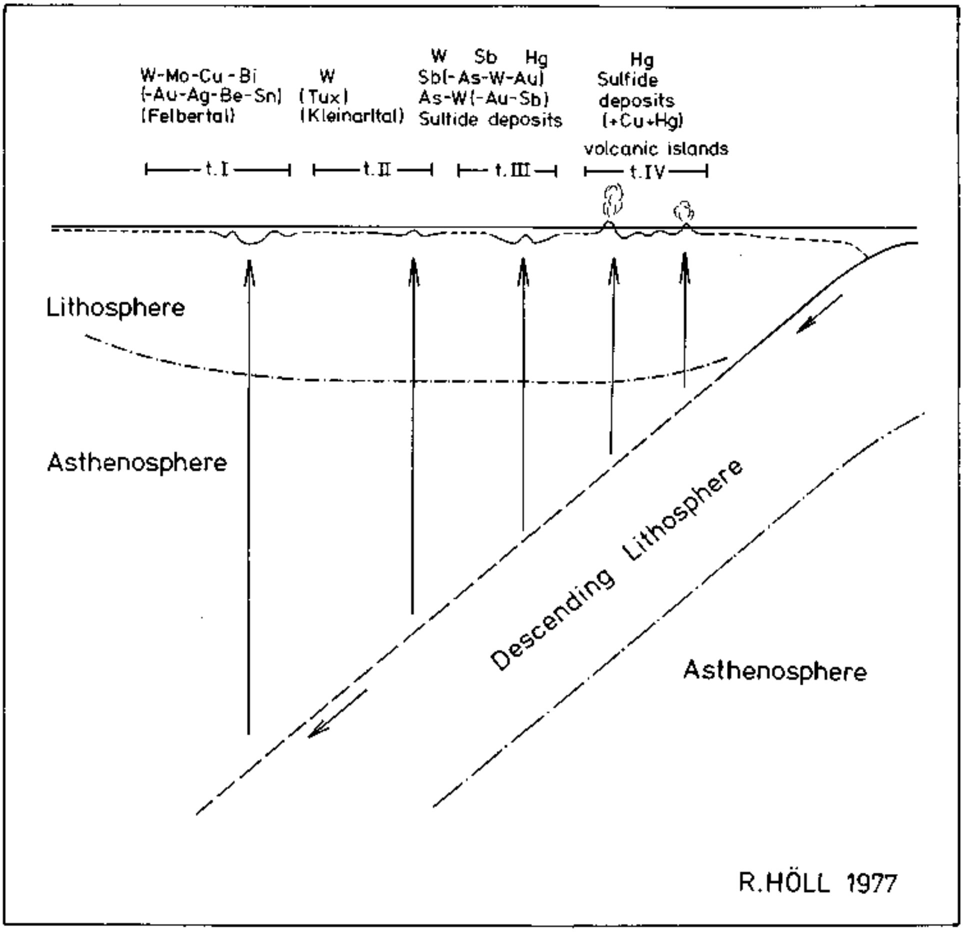

Fig. 4: Schematic Diagram Showing relative positions of ore formation of the different Early Paleozoic W, Sb, and Hg deposits (t I = trough I, presently incorporated in Penninic Zone, t II in Lower Austro-Alpine Unit, t III in Middle Austro-Alpine Unit, t IV in Upper Austro-Alpine Unit).

f) Three models for the source of W, Sb and Hg are open to discussion:

1. Metals have been leached and concentrated from the host rocks within the crust of the upper plate through the influence of hydrothermal solutions, generated by intrusions of hot magmatic bodies. This model cannot be favoured for the Early Paleozoic stratabound W, Sb and Hg deposits. But it is favoured for the Variscan scheelite occurrences within the central gneisses of the Hohe Tauern. These are regarded as mineralizations from probably Early Paleozoic rock series in connexion with Variscan, sialic-palingenic melting.

2. Partial melting of basaltic oceanic crust and metalliferous sediments within the descending plate. Magmas evolved with the formation of metal-rich partial magmas and hydrothermal solutions during the process of ascent, intrusion and extrusion.
3. Metals have been concentrated by partial melting of rocks of the upper mantle within the plate above the subduction zone. The composition and the metal enrichment, especially of the ore deposit Felbertal and its overlying pile of the volcanic rock sequence, may originate from melting episodes and a high degree of melting of mantle source. Acid to basic magmas may have separated from the source rock. The ultramafic magmas may have been formed by further melting of the refractory crystalline residues, possibly at high pressure. The ore metals, above all the tungsten, was partly concentrated in ultramafic magmas, which must have been rich in volatiles. An additional formation of metal-rich partial magmas and of metal-rich hydrothermal solutions may have evolved during the process of ascent, intrusion and extrusion.

g) The Early Paleozoic metallogenesis of the Eastern Alps is timebound, but apparently it did not occur within a geologically very short period. The fact, that stratabound ore deposits of the W-Sb-Hg formation are connected with Early Paleozoic rocks in Alpine-Mediterranean regions does not mean that all stratabound scheelite, stibnite and cinnabar deposits on earth are of Early Paleozoic age. Many stratabound scheelite, stibnite and cinnabar deposits show close temporal and genetic relationships to volcanic rocks of Archean greenstone belts (CUNNINGHAM et al., 1973). Also many younger ore deposits exist. The most important, W-free, but Hg-bearing stibnite deposit of Austria, Schlaining in Burgenland, is stratabound and underlying a basic metavolcanic horizon of Cretaceous age (MAUCHER and HÖLL, 1968; SCHÖNLAUB, 1973).

h) MAUCHER (1965) has extended the Sb-Hg formation to the Sb-W-Hg formation. Worldwide, ore deposits are existent with only Hg, only Sb, and only W, with Hg-Sb, Sb-W, and Hg-Sb-W, but Hg-W deposits without Sb are still unknown. Moreover, Sb is the connecting link between W and Hg on palinspastic arrangements of ore belts. Therefore, the proposal is made to change the Sb-W-Hg formation into the W-Sb-Hg formation. Furthermore, a complex paragenesis of stratabound scheelite deposits (type Felbertal) is known: W, Mo, Cu, Bi, As, Sb, Au, Ag, Be, Sn, Nb, Ta, Se, Te, Hg, Ni, Co, Pb, Zn, Cd, Li, Cs, P, F.

Table 1: List of scheelite, stibnite and cinnabar occurrences in the Eastern Alps, presented in Figure 1

1. Sporadic scheelite mineralizations to the west of Fallimännle and in the valley NE of Furkla (within the Silbertal)
2. Scheelite deposit near Konstanzer Hütte
3. Scheelite – sparry magnesite deposit Tux
4. Run down Cu-Sb mine Volderwildbad with scheelite
5. Scheelite deposit Navistal
6. Scheelite outcrops on the western slope of the Obersulzbachtal (within the southern wedge of the Habachserie)
7. Scheelite outcrops on the western slope of the Obersulzbachtal and on Äußeres Söllnkar (Krimmler Achental) (within the northern wedge of the Habachserie)
8. Scheelite crystals within the old epidote mine Knappenwand (Untersulzbachtal)
9. Scheelite outcrops on both slopes of the Habachtal to the north of the Fazenwand
10. Scheelite mineralizations in the Reichertleiten Alm – Scharrn Alm – Achsel Alm area (Hollersbachtal)
11. Scheelite in the abandoned emerald mine in the Lackbachscharte and at Sedl (Habachtal)
12. Several scheelite occurrences on the eastern slope of the uppermost Habachtal to the south of Noitroi including Knoflachlahner, Blessachkopf and Kratzenberg, as well as on the western slope below Steinkarl

13. Sporadic scheelite showings on the western slope of the Hollersbachtal (Schachern – Marchlecker Kar)
14. Scheelite crystals north of Buchgraben (1350 m a. s. l.) on the eastern slope of the Hollersbachtal
15. Scheelite showings in two wedges on the western slope of the Felbertal
16. Scheelite deposit Felbertal (eastern and western field)
17. Traces of scheelite from Amertal to Stubachtal
18. Scheelite in the area Oberes Rifflkees (Totenlöcher) – Totenkopf – Unteres Rifflkees
19. Scheelite in Laperwitztal and Unteres Fruschnitztal
20. Many scheelite occurrences in the Tauerntal between Felbertauerntunnel and Petersgraben as well as in the Meßelinggraben, in the Dabergraben, near Grüner See and Schwarzer See and in the pipeline tunnel
21. Scheelite within the Wilhelmsdorfer Graben and at Lannbach Asten
22. Scheelite outcrops on the southern slope of the Groß-Fleißtal NW of Gjaidtroghöhe
23. Several scheelite occurrences in the Hüttwinkeltal (Rauristal) from Erfurter Weg to Melcher Böden
24. Many scheelite-bearing veinlets in the accessible western part of the Imhof-Unterbau gallery, above all between gallery meters 3300 and 3970
25. Scheelite in the valley below the Mitterasten Alm
26. Several scheelite occurrences between Oberer Bockhart-See, Kleiner Silberpfennig, Schleierfallstollen (gallery), and Schöneck Alm
27. Scheelite SE of Niedersachsenhütte and within Schlapperebental
28. Scheelite surface outcrops and subsurface mineralization within the Radhausberg, especially in the Heilstollen (between gallery metres 1340 and 1420)
29. Scheelite in the quarry Hirschau SSW of Badgastein
30. Scheelite in the Kötschachtal, above all in the Döferlbach valley (1100–1400 m. a. s. l.)
31. Scheelite in the upper Reitalpengraben (Großarltal) (above all 200 m north of Hetteg Alm)
32. Scheelite outcrops at Elschekamm, Alte Hannoverhütte, Plattenkogel, and uppermost Anlauftal
33. Scheelite in hydro-electric plant gallery between Großer Oschenik-See and Kleiner Oschenik-See
34. Scheelite east of Dr. Rudolf Weißgerber-Hütte in the uppermost Mallnitztal
35. Many scheelite-bearing localities in the hydro-electric plant gallery between Wurtental and Großes Zirknitztal
36. Scheelite about 2 km to the north of the village Großarl
37. Scheelite in upper Kölnbreinkar at Kalte Wandspitz
38. Scheelite-gold-sulfide deposits of the ore deposit type Schellgaden
39. Scheelite 1 km north of the Rupp Alm (hut) at the eastern slope of the Hintereggengraben
40. Scheelite deposit in the Kleinarltal to the south of the Seyfriedgraben near Griespalfen (1100–1250 m a. s. l.) and scheelite outcrop at the Wagrain-Mitterkleinarl road 50 m to the south of the Alpenrose inn
41. Scheelite mineralizations stretching from the Schneeleiten to the Fürbachgraben
42. Two adjacent scheelite occurrences in two brooklets (Stuhlgraben) (1490–1650 m a. s. l.), about 2 km east of the village Mitterkleinarl
43. Scheelite outcrops in Lambachgraben and Plojergraben
44. Traces of scheelite at the Seekar north of the village Obertauern
45. Scheelite occurrence Fastenberg near Schladming
46. Widespread scheelite and arsenopyrite mineralizations within the Thurntaler Quarzphyllitserie in the area Sillian – Innervillgraten – Außervillgraten – Panzendorf
47. Scheelite in Lappgraben
48. Traces of scheelite in Sägebach (1180 m a. s. l.) south of the village Panzendorf
49. Stibnite deposit Obertilliach with traces of scheelite
50. Scheelite-stibnite deposits Gomig, Marienstollen, Johannisstollen, Rabant, Edengang, Gurserkammer, and Strieden at the southern slope of the Kreuzeckgruppe
51. Scheelite-stibnite deposits Lessnig, Radlberg, Tränkergraben, and Pirkeben near Kleblach at the southeastern slope of the Kreuzeckgruppe
52. Scheelite showing near Winklern at the road from Pörtschach am See to Moosburg
53. Stibnite occurrence Brückl
54. Stibnite deposit Guginock

55. Cinnabar deposit Glatschach near Dellach
56. Cinnabar deposit Hohes Kohr
57. Cinnabar deposit Rottrasten
58. Cinnabar mineralization in Magdalensberg area
59. Cinnabar deposit Stockenboi
60. Cinnabar occurrence Eisenkappel
61. Cinnabar deposit Vellacher Kotschna

References

CUNNINGHAM, W. B., HÖLL , R. & TAUPITZ, K. C.: Two new tungsten bearing horizons in the Older Precambrium of Rhodesia. – Mineralium Deposita **8**, 200–203, Berlin 1973.

EXNER, CH.: Erläuterungen zur Geologischen Karte der Umgebung von Gastein; Maßstab 1:50.000, Wien: Geol. B.-A. 1957, 168 S.

EXNER, CH.: Erläuterungen zur Geologischen Karte der Sonnblickgruppe; Maßstab 1:50.000, Wien: Geol. B.-A. 1964, 170 S.

EXNER, CH.: Geologie der peripheren Hafnergruppe (Hohe Tauern). – Jb. Geol. B.-A. **114**, 1–119, Wien 1971.

FRASL, G.: Zur Seriengliederung der Schieferhülle der mittleren Hohen Tauern. – Jb. Geol. B.-A. **101**, 323–472, Wien 1958.

FRIEDRICH, O. M.: Monographien Kärntner Lagerstätten. II. Die Quecksilberlagerstätten Kärntens. 3. Teilbericht und Schluß. – Arch. Lagerstättenforsch. Ostalpen **3**, 71–124, Leoben 1965.

FRISCH, W.: Scheelit-Lagerstätten in Zentral-Afrika und in den Ostalpen – ein genetischer Vergleich. – Österr. Akad. Wiss., Anz. math.-naturw. Kl. **109**, 324–333, Wien 1972.

HEINISCH, H. & SCHMIDT, K.: Zur kaledonischen Orogenese in den Ostalpen. – Geol. Rdsch. **65**, 459–482, Stuttgart 1976.

HÖLL, R.: Genese und Altersstellung von Vorkommen der Sb-W-Hg-Formation in der Türkei und auf Chios/Griechenland. – Bayer. Akad. Wiss., Math.-naturw. Kl., Abh., N. F. **127**, 118 S., München 1966.

HÖLL, R. a: Scheelitprospektion und Scheelitvorkommen im Bundesland Salzburg/Österreich. – Chem. d. Erde **28**, 185–203, Jena 1970.

HÖLL, R. b: Die Zinnobervorkommen im Gebiet der Turracher Höhe (Nock-Gebiet/Österreich) und das Alter der Eisenhut-Schieferserie. – N. Jb. Geol. Paläont. Mh. **1970**, 201–224, Stuttgart 1970.

HÖLL, R.: Scheelitvorkommen in Österreich. – Erzmetall **24**, 273–282, Stuttgart 1971.

HÖLL, R.: Die Scheelitlagerstätte Felbertal und der Vergleich mit anderen Scheelitvorkommen in den Ostalpen. Habilitationsschrift. – Bayer. Akad. Wiss., Math.-naturw. Kl., Abh., N. F. **157 A**, 114 p., München 1975.

HÖLL, R. LOESCHKE, J. et al.: Early Paleozoic Geodynamics in the Eastern and Southern Alps. 4 p. (in press).

HÖLL, R. & MAUCHER, A.: Genese und Alter der Scheelit-Magnesit-Lagerstätte Tux.-Sitzungsber.- Bayer. Akad. Wiss., Math.-naturw. Kl. **1967/1**, 1–11, München 1967.

HÖLL, R. & MAUCHER, A.: The strata-bound ore deposits in the Eastern Alps. – Handbook of Strata-Bound and Stratiform Ore Deposits, Vol. V, 1–36, Amsterdam: Elsevier 1976.

HÖLL, R., MAUCHER, A., WESTENBERGER, H.: Synsedimentary-diagenetic ore fabrics in the strata- and time-bound scheelite deposits of the Kleinarltal and Felbertal in the Eastern Alps. – Mineralium Deposita **7**, 217–226, Berlin 1972.

KROL, W.: Geologisch-lagerstättenkundliche Untersuchungen im Gebiet nördlich von Sillian (Osttirol/Österreich). – Univ. München 1974, 79 S., Diss. Univ. München.

LAHUSEN, L.: Die schicht- und zeitgebundenen Antimonit-Scheelit-Vorkommen und Zinnobervererzungen in Kärnten und Osttirol, Österreich. – München 1969, 139 S., Diss. Univ. München.

LAHUSEN, L.: Schicht- und zeitgebundene Antimonit-Scheelit-Vorkommen und Zinnobervererzungen in Kärnten und Osttirol/Österreich. – Mineralium Deposita **7**, 31–60, Berlin 1972.

LOESCHKE, J.: Spurenelement-Daten von paläozoischen Spiliten aus den Ostalpen und ihre Bedeutung für geotektonische Interpretationen. – Geol. Rdsch. **64**, 62–74, Stuttgart 1975.

LOESCHKE, J.: Kaledonischer eugeosynklinaler Vulkanismus Norwegens und der Ostalpen im Vergleich mit rezentem Vulkanismus unterschiedlicher geotektonischer Positionen: Eine Arbeitshypothese. – Z. dt. geol. Ges. **128**, 185–207, Hannover 1977.

MAUCHER, A.: Die Antimon-Wolfram-Quecksilber-Formation und ihre Beziehungen zu Magmatismus und Geotektonik. – Freiberger Forschungsh. C **186**, 173–188, Leipzig 1965.

MAUCHER, A.: The strata-bound cinnabar-stibnite-scheelite deposits (discussed with examples from the Mediterranean region). – Handbook of Strata-Bound and Stratiform Ore Deposits, Vol. **VII**, 477–503, Amsterdam: Elsevier 1976.

MAUCHER, A. & HÖLL, R.: Die Bedeutung geochemisch-stratigraphischer Bezugshorizonte für die Altersstellung der Antimonitlagerstätte von Schlaining im Burgenland, Österreich – Mineralium Deposita **3**, 272–285, Berlin 1968.

MEIXNER, H.: Neue Mineralfunde in den österreichischen Ostalpen, XXIV. – Carinthia II, **83**, 101–139, Klagenfurt 1973.

MEIXNER, H. & THIEDIG, F.: Eine kleine Antimonitlagerstätte bei Brückl, Saualpe, Kärnten, und ihre Minerale. – Carinthia II, **79**, 60–67, Klagenfurt 1969.

MOSTLER, H.: Alter und Genese ostalpiner Spatmagnesite unter besonderer Berücksichtigung der Magnesitlagerstätten im Westabschnitt der Nördlichen Grauwackenzone (Tirol, Salzburg). – Veröff. Univ. Innsbruck **86** (Festschrift Heißel), 237–266, Innsbruck 1973.

PETRASCHECK, W. E.: Die zeitliche Gliederung der ostalpinen Metallogenese. – Sitzungsber. Österr. Akad. Wiss., Math.-naturw. Kl., Abt. I, **175**, 57–74, Wien 1966.

SCHMIDT, K.: Der altpaläozoische Magmatismus und seine Stellung in der tektonischen Geschichte Mittel- und Südwesteuropas. – Z. dt. geol. Ges. **128**, 121–141, Hannover 1977.

SCHÖNLAUB, H. P.: Schwamm-Spiculae aus dem Rechnitzer Schiefergebirge und ihr stratigraphischer Wert. – Jb. Geol. B.-A. Wien **116**, 35–49, Wien 1973.

SCHÖNLAUB, H. P.: Zum Alter der Radstädter Quarzphyllite (Unterostalpin, Salzburg). – Ann. Naturhist. Museum Wien **79**, 47–55, Wien 1975.

SCHÖNLAUB, H. P., DAURER, A.: Review of pre-Variscan events in the Eastern Alps. – Geodynamics and Geotraverses around the Alps. – Meeting 28. 2.–1. 3. 1977 in Salzburg, Abstracts, 47–49, München, Salzburg 1977.

SCHULZ, O.: Schicht- und zeitgebundene paläozoische Zinnober-Vererzung in Stockenboi (Kärnten). – Sitzungsber. Bayer. Akad. Wiss., Math.-naturw. Kl. **1968**, 113–139, München 1969.

TOLLMANN, A.: Ostalpensynthese. – Wien: Deuticke 1963, 256 S.

VOHRYZKA, K.: Zur Scheelitprospektion in Österreich. – Mitt. Ges. Geol. Bergbaustud. **18**, 447–458, Wien 1968.

WAGNER, H.: Geologisch-lagerstättenkundliche Untersuchungen im Bereich des Kleinarltales, Salzburg, Österreich. – München 1972, 59 S., Diss. Univ. München.

WENGER, H.: Die Scheelitlagerstätte Tux. – Radex-Rdsch. **1964**, 109–132, Radenthein 1964.

WINKLER, H. G. F.: Abolition of metamorphic facies, introduction of the four divisions of metamorphic stage, and of a classification based on isograde in common rocks. – N. Jb. Miner. Mh. **5**, 189–248, Stuttgart 1970.

ZIRKL, E.: Bericht über geologisch-petrographische Aufnahmen in den Gurktaler Alpen. – Verh. Geol. B.-A. Wien **1955**, 85–89, Wien 1955.