ALPINE GEODYNAMICS, EPIGENETIC MINERALIZATIONS AND ELEMENT MOBILITY IN THE EASTERN ALPS

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Abstract: In the Alpine orogenic cycle of the Eastern Alps the generation and circulation of mineralizing fluids were strongly controlled by the changing geodynamic conditions. Important for mineralizations were metamorphogenic fluids shortly after the peak of metamorphism (Cretaceous and Paleogene) and extensional stages at the beginning (Permotriassic) and at the end (Tertiary) of the Alpine cycle when surface derived water could circulate in the extended crust.

Key words: Eastern Alps, Alpine geodynamic, epigenetic mineralization, element mobility

Introduction

In the Eastern Alps mineralizations are related to pre-Alpine and Alpine evolutionary stages. The inventory of the mineralizations (WEBER et al., 1997 a, b) and modern geodynamic concepts (NEUBAUER et al., 2000) stressed, that during the Alpine cycle mineralization and transport of elements/components were strongly controlled by the changing geodynamic conditions. Therefore the "mobility program" supported by the Austrian Academy of Sciences is focussed to these aspects. In the following the frame of this project and some results are outlined.

Alpine zoning of the Eastern Alps

The Tertiary sediments of the molasse and some intramontane basins were formed at the end of the Alpine orogeny when the Alpine belt was thrusted above the European continent and strike slip and escape tectonics worked parallel to the axis of the belt. The external (Helvetic and Rhenodanubian Flysch) units devoid any important mineralizations. In the internal zones the Penninic units are thrusted by the Austroalpine nappe system. All internal zones include a pre-Alpine ± metamorphosed basement and a Permomesozoic (Alpine) sedimentary cover. The Mesozoic Penninic units with Jurassic to Cretaceous/Paleogene oceanic environments are contrasting the Austroalpine Mesozoic environment of a passive continental margin. The border to the Southern

Alps is the Periadriatic lineament zone which has a complex history. Lastly it acted postdating Oligocene intrusive rocks as a dextral strike slip zone.

Cretaceous metamorphism in the Austroalpine units is due to the Alpine nappe stucking and increases to the south up to amphibolite and locally the eklogite metamorphic facies. In the Penninc units relics of a Late Cretaceous to Early Tertiary hP metamorphism are known which are followed by a younger regional (Tertiary) metamorphic event.

Geodynamic evolution and epigenetic mineralizations

The changing geodynamic conditions are important for fluid generation/migration. The following scenarios are discussed in order to the major Alpine evolutionary stages as important for component mobility and mineralizations:

- *Permian to Early Triassic rifting*

Post-Variscan Permian continental clastic sediments with acid volcanic materials are widely distributed at the base of the Calcareous Alps and the Permo-Triassic "Central Alpine" quartzite formations. They host stratiform U-mineralizations (± Cu, Mo, Co, As, Pb) as the result of leaching and metal transport by the migrating superfical water.

Late Permian rifting indicated the beginning of the Alpine cycle. The evaporitic "Haselgebirge" in the Northern Calcareous Alps with economic halite and gypsum/anhydrite deposits was formed in rift-related transtensional basins (with metabasalts of oceanic tholeiitic character). The crustal extension continued with less velocity until Middle Triassic time. In the Austroalpine domain this extension is related with a hT/lP metamorphism.

It is striking that some evidently epigenetic mineralizations (Fe, F, Ba, Mg) are hosted in Permotriassic sediments up to early Middle Triassic stratigraphic levels.
The ubiquitous Permotriassic evaporitic environments with enriched residual bitter brines and the extensional tectonics caused the circulation of high salinity fluids (concentrated in Br, Mg, K and SO_4) in the crust. Constrained from the chemism of leached fluids and salts PROCHASKA (in EBNER et al., 2000) established models for the epigenetic formation of siderite (Erzberg type) and magnesite (Veitsch type) within Austroalpine basement units. According to this model magnesite was formed in higher (more oxidizing) levels. At deeper levels acid and reducing fluids had the capacity to leach Fe from the country rocks and to form metasomatic siderite bodies within

Paleozoic carbonate rocks and vein type siderite-hematite-sulfide mineralizations within metapelitic and metavolcanic rocks. Presently leaching tests
(L. WEBER) are running in the Academy "mobility program" to investigate the interaction of sandy shales (Skythian Werfen Fm.) and Paleozoic porphyroidic rocks with water, disoved evaporites etc.

- *Cretaceous and Tertiary collision*

The Alpine orogeny in the Eastern Alps is governed by a two-stage (Cretaceous and Tertiary) collsional process. The Cretaceous collision is triggered by the subduction of the Penninic ocean and caused the nappe stucking and the Cretaceous metamorphism in the Austroalpine units and Late Cretaceous to Early Tertiary hP metamorphic events in the Penninic units. The final Eocene – Oligocene collision is the result of the oblique indentation of the Apulian plate. During this the Austroalpine units were thrusted above the Penninic units, which were effected now by a greenschist to amphibolite facies metamorphic overprint. Uplift and exhumation of crust arose from several processes starting shortly after the peak of metamorphism during Late Cretaceous and Tertiary (NEUBAUER et al., 2000).

During the Cretaceous compressional stage synorogenic fluids of high salinity were formed by metamorphic devolatilization of subducted Penninic rocks or were expulsed from deeper Austroalpine tectonic units. Their circulation started after the peak of metamorphism related to the exhumation of the Austroalpine metamorphic core complexes. The fluids were focussed along thrust/shear zones and low angle normal faults above uprising metamorphic cores (POHL & BELOCKY, 1999). In account of radiometric ages and the knowledge of the tectono/thermal evolution the Cu-vein deposit of Mitterberg and some deposits of talc and leucophyllite (Lassing, Rabenwald; Kleinfeistritz) were attributed to this period.
Prerequisites to form talc deposits of economic dimension were: (i) the existence of Si-rich hydrothermal fluids, (ii) Mg-rich rocks (dolomite, magnesite), and (iii) ductile shear and fracture zones along which fluid circulation and rock/fluid interaction were possible. The formation of leucophyllite happened along shear zones and low angle normal faults in the Austroalpine crystalline complexes where gneiss host rocks altered to phyllonite rocks, mainly consisting of quartz, muscovite and ± chlorite. The temperature of leucophyllite formation was between 400 – 500^{o}C and the mica K-Ar ages of the phyllonite are identical with regional cooling ages around 90 Ma (PROCHASKA in EBNER et al., 2000).

- *Oligocene Periadriatic intrusions*

During the Late Oligocene the slab break off of the subducted Penninic crust triggered the intrusion of the Periadriatic magmatic rocks and associated dike swarms along the later Periadriatic lineament zone and within the Austroalpine metamorphic basement S of the Tauern window. Mineralizations directly bound to the Periadriatic magmatic intrusion are of subordinate importance. Nevertheless heat flow related to the intrusions is discussed as the motor for hydrothermal mineralizations. They are hosted in a great variety of metamorphic rocks, are clearly controlled by late Alpine fault, shear and extensional tectonics and subdivided into Au-As and Sb(As-Au-Pb-Cu) ore paragenesis. Postmetamorphic alterations occur along the mineralized zones in the metamorphic host rock and also in some sites in the Oligocene magmatic rocks.

- *Tertiary postcollisional uplift and escape tectonics*

Result of final Eocene-Oligocene continent collision was the overriding of the European continent, the tectonic unroofing and exhumation of the Tauern window and the eastwards escape of the Austroalpine tectonic wedge. This wedge is confined in the north by a sinstral wrench corridor and the dextral Periadriatic lineament to the south.Tertiary metallogeny is controlled by the uplift of the Penninic metamorphic dome, the eastward moving and extended Austroalpine wedge, and a distinct paleothermal evolution. The post collisional Early/Middle Miocene heat flow pattern is governed by the uplift of the Tauern metamorphic core after tectonic denudation and magmatic activities in the Styrian Basin.

The character of the mineralizing fluids is best explained by the circulation of surficial water in the brittle crust along fault systems and mixing with metamorphic water derived from the cooling metamorphic complexes. They are charcterized by appreciable content of CO_2 and low to moderate salinities (POHL & BELOCKY, 1999). Mineralizations are concentrated to the uplifting metamorphic dome of the Penninic Tauern Window and along the fault zones inside the extruding Austroalpine wedge.

The gold-veins of the Tauern window are well investigated by PAAR (in EBNER et al. 2000). They generated during the uplift and a late cooling stage of the Tauern metamorphic core complex. During this process decompression and extension opened NE-SW to NNE-SSW trending veins in which the mineralizations were formed. The mineralizations are hosted within late-Variscan granitoids, in clastic and carbonatic rocks of the Permomesozoic sedimentary cover, and in

Jurassic/Cretaceous ophiolithic serpentinites and oceanic metabasites. Ar/Ar ages of Au-quartz veins are clustering around 19 Ma.

The Tauern gold veins can be classified as metamorphogenic deposits, which were formed along deeply reaching structures and from fluids generated from hydrothermal convection cells during retrograde leaching of suitable host rocks. The veins have a obvious vertical zonation with a silver-enriched base metal assemblage dominating in the upper levels and an increase of gold in association with arsenopyrite, pyrite and quartz below that. Replacement ore bodies are dominated by As-Ag-Cu-ores. A temperature range of 370-420°C was determined for the formation of the gold-rich, and 200-260°C for the silver-dominated paragenesis (PAAR in EBNER et al. 2000).

In the Austroalpine domain east of the Tauern window hydrothermal fluid circulation along Tertiary fault zones was responsible for the formation of some Au-arsenopyrite vein mineralizations, the overprint of older polymetallic (Fe-Pb-Zn-Ag-Ba) ore districts and the formation of the Hüttenberg siderite district. Linked to the same metallogenic event, but formed by fluids with more oxygenated surface waters there are some hematite (specularite) mineralizations along the Lavant- and Sölk fault zone (PROCHASKA in EBNER et al. 2000).

In the Styrian Basin the Miocene volcanism is producing a distinct heat flow anomaly but ore mineralizations are not known. Only the stibnite deposit of Schlaining hosted in Penninic units was confirmed to be related to fluid convection above an hypothetic buried Miocene volcano.

- **Evidence of metallogenetic heritage**

In some cases there is clear evidence of metallogenetic heritage and metal transport from pre-Alpine mineralizations during Alpine events:

- Remobilization of older metals (Pb-W-Au) along low angle ductile normal faults along the upper margin of the Tauern metamorphic core complex.
- In the Felbertal scheelite deposit (Tauern window) crosscutting veins have an age of 29±17 Ma. They are mobilized from the pre-Alpine deposit during the Early Tertiary metamorphism (EICHHORN 2000 in EBNER et al., 2000).
- Metal mobilization and transport is obvious along the Mitterberg cu-vein. The quartz-carbonate-chalcopyrite vein is crosscutting Paleozoic phyllites (hosting syngenetic stratiform Cu-mineralizations) and continues discordantly into Permian clastic rocks (with stratiform U-

mineralizations). The vein is dated by the U/Pb method with 90±5 Ma at nodules of uraninit in high positions (WEBER et al. 1997 a).

- In the Paleozoic of Graz crosscutting quartz-cabonate-gaelna veins are mobilized from Devonian stratiform Pb/Zn and Ag-rich mineralizations during final episodes of the Alpine orogeny (WEBER et al., 1997 a).

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