A mantle metasomatic injection event linked to Permo-Carboniferous lamprophyre magmatism and associated rare metal ore deposition (Sn-W-Mo-Li-Sc-In / Ag(-Au)-In-base metal) in the eastern European Variscides

Thomas Seifert[1]

[1] *TU Bergakademie Freiberg, Freiberg, Germany, thomas.seifert@mineral.tu-freiberg.de*

Introduction

Lamprophyres which are of mantle origin in subduction zones and continental rift settings are reported as components of bimodal dike suites in a number of hydrothermal Au-polymetallic, Au-Cu, Ag-base metal, Ag(-Au)-Sb, Sb-Hg and fluorite deposits (Rock 1991; Seifert 2007, 2010; Geißler and Seifert 2009). Significant is the association of Sn-W, Sn-sulfide, Sn-In-polymetallic and Ag(-Au)-In-Sb-base metal deposits with Paleozoic and Mesozoic magmatism in the Erzgebirge, Central Asia, and Yakutia which includes granitoids and abundant mafic dikes (Seifert 2008; Seifert et al. 2011, Štemprok and Seifert 2011).
The traditional model for the genesis of late-Variscan deposition of Sn-W-Mo ores in the eastern Variscides favored a crustal-derived, syn- to late-collision granite magmatism (Tischendorf 1986). An alternative model suggests a mantle-related magmatic pulses and associated high-temperature and rare metal-enriched fluids as a source of late-Variscan Sn-, In-, and Ag-polymetallic mineralization in the Erzgebirge-Vogtland metallogenic province (Seifert 2008, 2015). Calc-alkaline lamprophyres (CAL) of the present study crop out in rock quarries, outcrops at roads and railway lines, and often in underground mines of old mining districts (15th to 20th century).

Geology of late-Variscan lamprophyric intrusions

The calc-alkaline lamprophyric dikes and sills (CAL) in the Erzgebirge-Vogtland region are typically 0.5 – 5 m wide, rarely exceeding 30 m. The most CAL occur in areas of crosscutting deep fault zones and lineaments which also act as conduits for post-collisional, F-enriched granitic/rhyolitic intrusions and host post-magmatic Sn-W-Mo-Li-Sc-In, Sn-In-base metal, Ag(-Au)-Sb-base metal, and U deposits (e.g., crosscutting area of the NW-SE Gera-Jáchymov fault zone and the NE-SW Saxonian Lineament; cf. Seifert 2008). CAL took place in the Erzgebirge/Krušné hory-Fichtelgebirge anticlinorium (cf. Seifert 2008 and references therein) and Fichtelgebirge/Smčiny pluton (Gümbel 1874) in different host rocks (ortho- and paragneisses, mica-schists, phyllites, meta-basalts, meta-carbonates, meta-black shales and late-Variscan granites/rhyolites) in NW-SE, NE-SW/NNE-SSW, and ENE-WSW trending dikes.

Petrology and relatively age relationships

The calc-alkaline lamprophyric intrusions in the Erzgebirge are divided by Seifert (1997, 2008, this study) using criteria of relatively age relationships to different late-Variscan granite intrusions and associated aplites, rhyolitic and lamprophyric dikes, and late-Variscan rare metal mineralization stages as well as petrographic and geochemically criteria (LD1 - LD3, Fig. 1):
(1) The late-collisional LD1-type lamprophyres (330 Ma) are intruded by late-collisional granites (e.g., Ehrenfriedersdorf Sn-W district, Schlema-Schneeberg U-Ag district) and are characterized by transitional type kersantitic/spessartitic dike intrusions. They predate all Permo-Carboniferous mineralization stages in the Erzgebirge-Vogtland area and are possibly unrelated to late-Variscan ore deposition processes. LD1 show similarities to lampropyhric dikes in the Elbe Zone with K-Ar ages of c. 330 Ma (Kurze et al. 1998).
(2) LD2-type lamprophyres (320-300 Ma) postdate the late-collisonal (“Eibenstock type”) granite intrusions and occur widely in the Sn-W-U district Gottesberg-Mühlleithen, U-Ag district Schlema-Schneeberg, Sn-In-Ag-U districts Marienberg-Pobershau and Annaberg, and probably in the Ag-In-Sn-

base metal district Freiberg. LD2 are dominated by mica-minette dike intrusions with strike lengths up to 7 km and a thickness up to 10 m. They are crosscutt by Sn-polymetallic, Ag(-Au)-In-Sb-base metal, U, fluorite-barite, and Bi-Co-Ni-As-Ag(-U) mineralization.
(3) LD3-type lampropyhres (310-300? Ma) are identified in the Pobershau Sn-W-Ag ore field and represented by feldspar-phyric kersantitic lamprophyres. LD3 in the Pobershau ore field show post-Sn mineralization age and are crosscutt by barite-Bi-Co-Ni-Ag veins

The texture of the LD2-type lamprophyres is partly richly porphyric (phlogopite), with a fine-grained grey-black groundmass. In some LD2-samples from the Marienberg and Freiberg districts a F-enriched phlogopite is the dominated mineral. LD2 in the Tannenberg-Mühlleiten district show low phyric textures and nearly glassy groundmass. Typically for LD1-type lamprophyres are mica-, amphibole-, and feldspar-microphyric textures. The contact between the lamprophyre dikes and host rocks is always sharp and c. 2 – 20 mm chilled margins are often present. The most lamprophyres are characterized by early-magmatic (micro)phenocrysts of Mg-biotites/phlogopites with typical zonation and/or amphibole (micro)phenocrysts. They mostly contain clinopyroxene (diopside, augite) and, locally, olivine. Olivine may enclose Cr-spinel, but is often pseudomorphosed of secondary carbonate, chlorite, amphibole, and talc. Mica-minettes (LD2) have higher modal abundances of alkali feldspar, phlogopite and apatite than LD1 and LD3. This characterization is similar to mafic volcanics of the Sub-Erzgebirge basin (MVSEB). Fluor-apatite is the most common accessory mineral in LD2 and MVSEB.

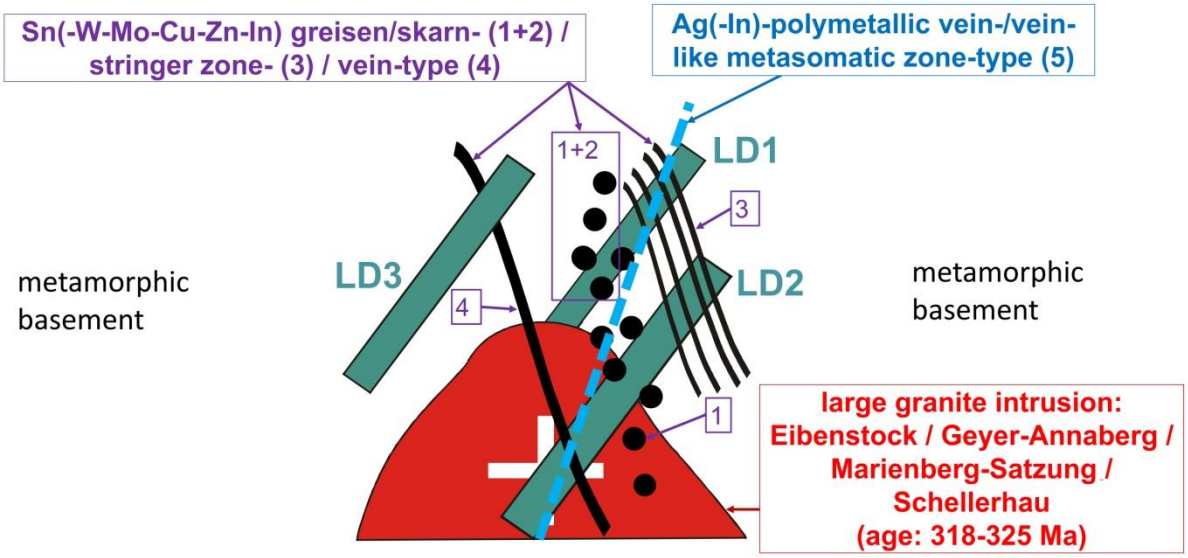

Figure 1: Relatively age relationships of late-Variscan large granite intrusions (western Erzgebirge: Eibenstock; central Erzgebirge: Ehrenfriedersdorf-Geyer-Annaberg / Marienberg-Pobershau-Satzung; eastern Erzgebirge: Schellerhau) and lamprophyric dike intrusions (LD1, LD2, LD3) and rare metal mineralization (1 to 5) in the Erzgebirge-Vogtland region (modified from Seifert 2010, 2015).

Geochemistry

Geochemically LD2 (phlogopite-phyric minette and transitional type kersantite/minette) show a typically ultrapotassic composition similar to the majority of MVSEB. The high concentration of LILE (up to 8.74 wt.% K_2O, 1,100 ppm Rb, 100 ppm Cs, 5,020 ppm Ba, 2,030 ppm Sr) and HFSE (up to 3.7 wt.% TiO_2, 1.3 wt.% P_2O_5, 30 ppm Sc, 1,070 ppm Zr, 35 ppm Hf, 115 ppm Nb, 95 ppm Th, 75 ppm Y, 700 ppm LREE) and the enriched radiogenic isotope composition of LD2 and MVSEB ($^{87}Sr/^{86}Sr_i$ = 0.70401 to 0.71038; εNd_i = -6.4 to -0.2) indicate melting of a metasomatically enriched mantle. High concentrations of LILE and HFSE, and the 'primitive' bulk geochemistry indicated by high mg# (76 – 88) and Cr (up to 890 ppm), Ni (up to 470 ppm), and Co contents (up to 55 ppm) exclude significant crustal contamination as the cause of their enrichment. High volatile contents (CO_2 up to 7.3 wt.%, H_2O^+ up to 7.92 wt.%, F up to 4,600 ppm, Cl up to 1,700 ppm, S up to 3,160 ppm, P_2O_5 up to 1.33

wt.%) in whole rock samples and high H_2O^+, F and Cl contents of early magmatic phlogopites and apatites are typical for post-collisional lamprophyres in the Erzgebirge (especially LD2) and shoshonitic/ultrapotassic mafic volcanics in the Sub-Erzgebirge basin.
A carbonate-rich mica-lamprophyre from the nearby Berga anticlinorium (drill hole 4215-76 of SDAG Wismut) is characterized by extremely high CO_2 (12.20 wt.%), P_2O_5 (2.28 wt.%), F (3,200 ppm), Sr (2,940 ppm), Th (135 ppm), and ∑REE (1,400 ppm) contents (Seifert 2008) and show in the Sm-Ce/Yb and Sm-La/Yb diagram (Rock 1991; Mitchell and Bergmann 1991) a clear tendency to the lamproite field.

Bimodal post-collisional magmatism and metallogenic importance for rare metal mineralization

The bimodal lamprophyre-rhyolite assemblage in the Erzgebirge/Sub-Erzgebirge basin area was formed during intracontinental rifting in a 'Fast Extension' setting by melting of a metasomatic enriched mantle source. The emplacement of fluid-enriched lamprophyric and rhyolitic intrusions at the same time is possibly associated with decompression melting of updoming asthenosphere and a mantle plume with a peak magmatic activity from 300 to 280 Ma (cf. Seifert 2009). The metallogenetic importance of post-collisional lamprophyres (especially type LD2) and MVSEB is indicated by their high volatile concentrations and relationships to post-collisional high-F granitic intrusions and high-F (partly high-Sn) subalkaline rhyolites/rhyolitic ignimbrites and late-Variscan rare metal ore deposition.

References

Geißler L, Seifert T (2009) Geology, Mineralogy and Geochemistry of Gold-bearing Polymetallic Sulfide-Quartz Veins and Associated Intrusions in the French Gulch-Deadwood District, California. Freiberger Forschungshefte C 533

Gümbel CW (1874) Die paläolithischen Eruptivgesteine des Fichtelgebirges. Franz, München

Kurze M, Seifert T, Weber H, Henjes-Kunst F (1998) Petrographie, Geochemie und Altersstellung der Lamprophyr-Gänge des Elbtalschiefergebirges (Sachsen). Z. Geol. Wiss. 26: 193-202

Mitchell RH, Bergman SC (1991) Petrology of lamproites. Plenum Press, New York, London

Rock NMS (1991) Lamprophyres. Blackie, Van Nostrand Reinhold, Glasgow, New York

Seifert T (1997) Mantle metasomatism and associated late Variscan Sn and base metal mineralization in the Erzgebirge (Germany). In: Hatton CJ (ed) Plumes, Plates and Mineralisation, proceedings volume, University of Pretoria, pp 89-90

Seifert T (2007) Metallogenetische Bedeutung von Kalkalkali-(CA-)Lamprophyren – Beitrag zur Genese und Exploration von Sn-W-Mo-, Ag-Polymetall- und U-Lagerstätten am NW-Rand des Böhmischen Massivs (DE, CZ). Habilitation, TU Bergakademie Freiberg

Seifert T (2008) Metallogeny and Petrogenesis of Lamprophyres in the Mid-European Variscides. IOS Press BV, Amsterdam

Seifert T (2009) Late-Variscan polymetallic ore deposits in central Europe and their relationships to large igneous provinces (LIP) and mantle plume magmatism. Large Igneous Provinces Commission of IAVCEI. http://largeigneousprovinces.org/09oct. Accessed October 2009

Seifert T (2010) Contributions to the metallogenetic importance of lamprophyres – examples from polymetallic Au-, Sn-W-Mo-Li-In-, As-Zn-Sn-Cu-In-Pb-Ag- / Ag-Sb-, and U-ore clusters. MINERALOGIA – SPECIAL PAPERS 37: 55-58

Seifert T (2015) Paragenesis, geochemistry and age of late-Variscan Sn, In and Ag mineralization in the Marienberg district and its relationship to mafic and acidic magmatic events, Erzgebirge. In: André-Meyer AS et al (ed) 13th SGA Biennial Meeting 2015, France, Proceedings, Volume 2, pp 843-846

Seifert T, Pavlova GG, Borisenko AS (2011) Types of Ag-polymetallic/Ag-Sb vein-type mineralization in the European Variscides, Yakutia, Altai, Tien Shan, and Pamir. In: Geology, Tectonics and Minerogeny of Central Asia, VSEGEI, St. Petersburg, Russia, conference CD

Štemprok M, Seifert T (2011) An overview of the association between lamprophyric intrusions and rare-metal mineralization. MINERALOGIA 42: 121-162

Tischendorf G (1986) Variscan ensialic magmatism and metallogenesis in the Ore Mountains - Modelling of the process. Chemie der Erde 45: 75-104