

**CHEMICAL CHARACTERISTICS OF THE K1-K3 METAGRANITOID IN THE
FELBERTAL SCHEELITE DEPOSIT (AUSTRIA)**

by

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Introduction

In 2012 Austria produced 706 metr. t W (tungsten), representing a share of 0.87% of the global tungsten market (REICHL et al., 2014). This output originated entirely from the Felbertal scheelite deposit, the only active tungsten mine in Austria. Since its discovery 50 years ago by Rudolf Höll and a group of students from the University of Munich, the genesis of the Felbertal deposit is still controversially discussed with two contrasting models trying to explain the ore forming processes.

According to the syngenetic/synsedimentary stratabound model, scheelite precipitated from exhalative hydrothermal fluids released during Early Palaeozoic submarine mafic volcanism (e.g., HÖLL, 1975). On the contrary, the epigenetic model links the mineralisation to the intrusion of a highly differentiated orthogneiss of Early Carboniferous age (K1-K3 orthogneiss) and subsequent hydrothermal overprint by circulating granite-derived fluids (e.g., BRIEGLEB, 1991). Similar geological models relating W-mineralisation with silicic magmatism are proposed for a great number of deposits worldwide (e.g., Erzgebirge-Slavkovský les, BREITER et al., 1999; Shizhuyuan, JINGWEN et al., 1996; Cantung, RASMUSSEN et al., 2011), where tungsten mineralisation is associated with the emplacement of highly evolved granitic melts, enriched in volatiles (F, Li, Be), and subsequent hydrothermal alteration of the country rocks.

Anyway, both genetic models for the Felbertal deposit highlight the importance of magmatic-hydrothermal fluids from which scheelite precipitated to form stockwork-like scheelite-quartz veins and masses. This study presents new chemical data for the mineralised K1-K3 metagranitoid in the Felbertal deposit and its related scheelite-quartz veins and discusses the results in the context of granite and fluid chemistry.

The K1-K3 orthogneiss

The K1-K3 orthogneiss is a fine- to medium-grained felsic microcline-phengite monzogranite with low-grade mineralisation in form of scheelite-quartz veinlets and disseminations of scheelite.

In the past high-grade ores were mined from quartz-rich ore zones (K1, K3) developed at the contacts of the orthogneiss with the host rocks. The orthogneiss is exposed underground in the western ore field where two varieties of the K1-K3 metagranitoid can be distinguished in the field. The dark K1-K3 orthogneiss type is characterised by a higher biotite content compared to the bright variety with less biotite but higher modal abundances of phengitic muscovite. Additionally, dm- to m-thick layers of leucocratic aplite gneisses are intercalated in the metabasic host rocks. All three gneisses are distinct in terms of various geochemical criteria but they display a common evolutionary trend.

When studying granitic rocks, the aluminium saturation index (ASI, ratio of molar $\text{Al}_2\text{O}_3/[\text{Na}_2\text{O}+\text{K}_2\text{O}+\text{CaO}]$) is an important parameter to draw conclusions on possible magma sources and the melting history of the granite (FROST et al., 2001). The ASI for the dark K1-K3 orthogneiss variety ranges from 0.93 to 1.03 (one outlier at 1.14) with $\text{Al}_2\text{O}_3 > \text{Na}_2\text{O}+\text{K}_2\text{O}$, indicating a metaluminous to transitional peraluminous character (Fig. 1a). In the bright orthogneiss variety the ASI increases to values between 0.99 and 1.08 (one outlier at 1.19) and achieves its maximum in the aplite gneiss (ASI = 1.11-1.12). Both the bright K1-K3 and the aplite gneiss can therefore be classified as weakly peraluminous.

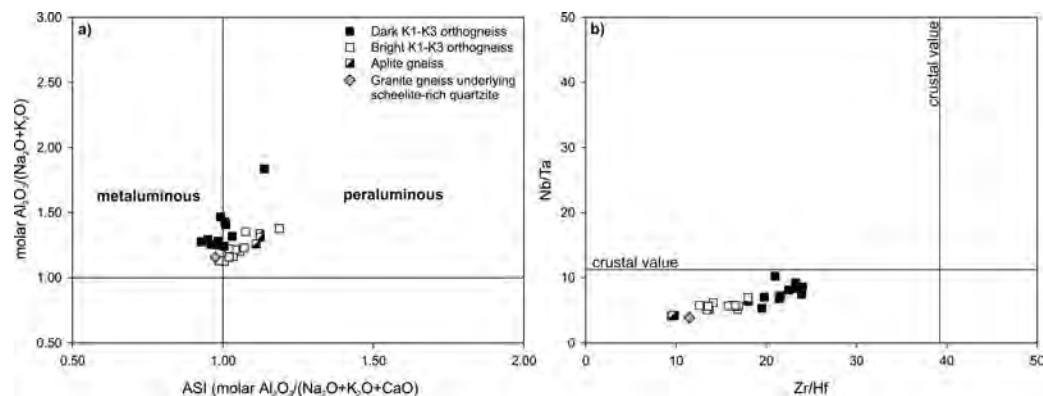


Fig. 1a

ASI vs. molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O}+\text{K}_2\text{O})$ displaying an increase in the ASI from the dark K1-K3 orthogneiss (0.93-1.03) to the bright K1-K3 orthogneiss (0.99-1.08) and the aplite gneiss (1.11-1.12). b): plot of Zr/Hf vs. Nb/Ta showing a linear trend and decreasing ratios from the dark K1-K3 to the bright variety and the aplitic gneiss.

A systematic trend becomes apparent when plotting Zr/Hf vs. Nb/Ta (Fig. 1b). Both ratios decrease from the dark K1-K3 orthogneiss (Zr/Hf = 18-24, Nb/Ta = 6-10, n = 11) to the bright K1-K3 variety (Zr/Hf = 13-18, Nb/Ta = 5-7, n = 11). The aplite gneiss is characterised by the lowest values (Zr/Hf = 9-10, Nb/Ta = 4, n = 3). Additionally, one published analysis for a leucogranitic gneiss underlying the laminated scheelite-quartz ores (“scheelite-rich quartzite”) in the eastern ore field (HÖLL & EICHHORN, 2000; p. 244 therein, rightmost sample) is included in the data set due to its close chemical similarities with the K1-K3 orthogneiss.

The systematic variation within the K1-K3 series is also illustrated in the following multielement-spiderplots and REE-distribution diagrams (Fig. 2). Normalized to average upper continental crust, the dark K1-K3 metagranitoid shows a more or less uniform distribution of many elements except for Cs, Rb, U, and Ta. These elements are enriched, in the case of U up to 10 times, whereas Sr and Ti are slightly depleted. When comparing the bright K1-K3 orthogneiss to the dark K1-K3 variety, we observe a decrease in Ba, Sr, P, Zr, Ti, and the LREE in the bright variety. Only Ta and Si (not shown here) increased slightly and the other elements roughly remained constant. The aplite gneiss is strongly depleted in Ba, K, LREE, Sr, P, and Ti. Tantalum increased significantly but also Nb, Hf, and the HREE are enriched as compared to both K1-K3 orthogneiss varieties. The pattern of the granite gneiss underlying the scheelite-rich quartzite in the eastern ore field matches exactly those of the aplite gneisses from the western ore field. A striking feature of all samples is the unusual high U concentration (up to 74 ppm), which is unique for granites known from the Tauern Window.

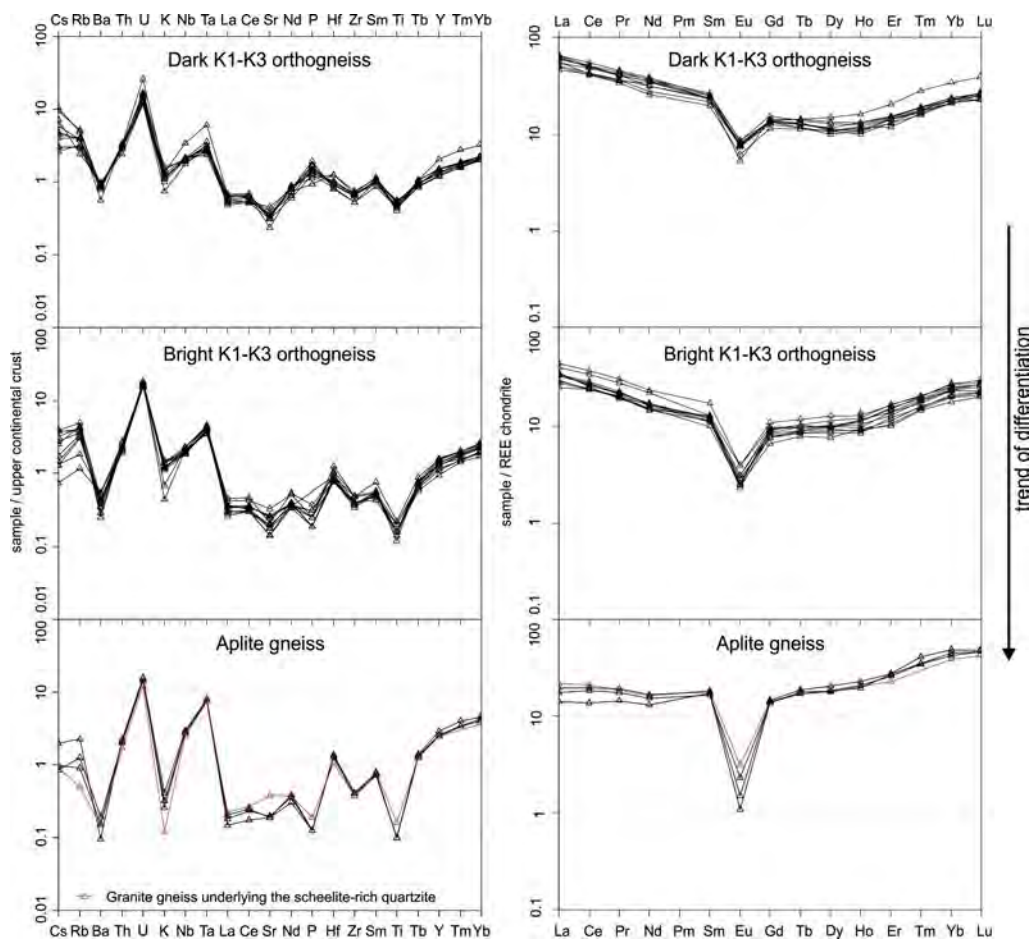


Fig. 2

Multielement-spiderplots and REE patterns for the dark and bright K1-K3 orthogneiss, the aplite gneiss and the granite gneiss underlying the scheelite-rich quartzite.

Differences among the orthogneiss varieties and the aplitic gneiss are also expressed in the chondrite-normalized REE-distribution plots. All K1-K3 gneiss samples are characterised by a distinct negative Eu-anomaly ($\text{Eu}/\text{Eu}^* = 0.013\text{-}0.026$) and decreasing concentrations of the LREE with evolution of the metagranitoids from the dark to the bright variety. The most pronounced negative Eu-anomaly ($\text{Eu}/\text{Eu}^* = 0.004\text{-}0.009$) is developed in the aplite gneiss. The progressive decrease in LREE concentrations with the evolution of the gneisses due to magmatic differentiation is significant when comparing the dark K1-K3 orthogneiss ($\text{La}_N/\text{Yb}_N = 1.93\text{-}3.11$) with the aplitic gneiss ($\text{La}_N/\text{Yb}_N = 0.33\text{-}0.41$). The correlation of the granite gneiss underlying the scheelite-rich quartzite with the aplite gneiss is also revealed by its REE pattern.

Discussion

It is often recognised that very felsic granitic rocks may be weakly peraluminous, whereas more mafic granites belonging to the same suite are metaluminous. CHAPPELL (1999) showed for fractionated felsic I-type granites from the Lachlan Fold Belt that their abundant peraluminous character ($\text{ASI} = 1.06$) results from mineral fractionation and that initially Al-undersaturated melts may become saturated in Al with progressive fractionation.

Concluding therefrom (and other chemical parameters), the bright K1-K3 orthogneiss and the aplite gneiss were derived by mineral-melt fractionation processes from the more mafic K1-K3 melt. The variation in ASI of the K1-K3 orthogneiss series displays a close to Al-saturated source for the least fractionated K1-K3 melt ($\text{ASI} = 0.93\text{-}1.01$ of the dark K1-K3 orthogneiss variety). The K1-K3 melt became saturated in Al with increasing differentiation, reflected by the weakly peraluminous character of the higher evolved orthogneisses. Partitioning of trace elements between main/accessory minerals and the melt is also responsible for producing the systematic variation observed in the multielement-spiderplots and REE-distribution patterns. The low P concentrations of the leucocratic varieties are a consequence of apatite fractionation. Crystallisation of feldspar and biotite controls the variation in Ba, Sr, Eu, and K furthermore. The decrease in the LREE contents is related to early segregation of allanite, being the main carrier of the LREE in the more primitive dark K1-K3 orthogneiss. The variation of the high field strength elements (HFSE) Zr, Hf, Nb, and Ta and the HREE can be attributed to fractionation of zircon and late crystallisation of Nb-Ta-Ti-U-oxides.

The latter are frequently associated with the granite-related scheelite-quartz veins. The occurrence of niobium- and tantalum-mineralization also suggests extreme fractionation processes that are necessary to reach Ta-saturation in a peraluminous residual granitic melt (LINNEN, 1998). The Nb/Ta ratios decrease with ongoing differentiation from the dark K1-K3 orthogneiss to the aplite gneiss, while Nb- and Ta-concentrations systematically increase during melt evolution. The shift in melt composition towards lower Nb/Ta ratios reflects the higher solubility of manganotantalite over manganocolumbite in granitic melts (LINNEN, 1998). This means that Ta gets fractionated over Nb due to different solubilities of their respective oxides, irrespective of the similar incompatible geochemical behaviour of Nb and Ta. Additionally, the chemical composition of the melt acts as an influencing factor. High fluorine concentrations of the melt also contribute to the behaviour of Nb and Ta in granitic melts, since F will increase the solubility product of Ta-oxides and therefore delays the precipitation of the respective oxides (LINNEN, 1998).

The consequence is that the Ta-concentration will increase with progressive differentiation. The common presence of fluorite in scheelite-quartz veins as well as the high F concentrations of biotite and titanite from the K1-K3 metagranitoid confirms that F was present in the granitic melt and mineralising hydrothermal system (KOZLIK & RAITH, 2013). Moreover the occurrence of minute fluorite inclusions within Nb-Ta-Ti-U-oxides documents the influence of fluorine on Nb-Ta-oxide precipitation. The higher solubility of hafnon relative to zirconium causes the decrease in the Zr/Hf ratio of the granitic melt with increasing fractionation, similar to the decrease of the Nb/Ta ratio (LINNEN, 1998).

Conclusions

The K1-K3 orthogneiss in the Felbertal scheelite deposit represents a geochemically highly evolved metagranitoid, which has clearly undergone extensive magmatic differentiation processes. The systematic trend in a multitude of elements and their respective ratios indicates that crystal-melt fractionation controlled the evolution of the K1-K3 magma during differentiation. The source for the more primitive dark K1-K3 orthogneiss was undersaturated or nearly saturated in aluminium, but the melt attained Al-saturation and became peraluminous with increasing evolution. The close geochemical similarities between the granite gneiss underlying the laminated scheelite-quartz ores in the eastern ore zone and the aplite gneisses in the western ore zone reveal the presence of highly evolved K1-K3 equivalent material also in the eastern ore field. The precipitation of Nb-Ta-Ti-U-oxides in scheelite-quartz veins indicates that granite-derived magmatic-hydrothermal fluids were enriched in HFSE together with W and that both Nb and Ta fractionated into the fluid phase during transition from the magmatic to the hydrothermal stage.

References

- BREITER, K., FÖRSTER, H.-J., SELTMANN, R. (1999): Variscan silicic magmatism and related tungsten mineralization in the Erzgebirge-Slavkovský les metallogenic province. - *Mineral. Deposita*, 34, 505-521.
- BRIEGLEB, D. (1991): Ein epigenetisches Modell der Scheelitlagerstätte Felbertal (Land Salzburg). - *Ber. Deutsch. Miner. Ges., Beih. Europ. J. Mineral*, 3, 43.
- CHAPPELL, B.W. (1999): Aluminium saturation in I- and S-type granites and the characterization of fractionated haplogranites. - *Lithos*, 46, 535-551.
- FROST, R.B., BARNES, C.G., COLLINS, W.J., ARCULUS, R.J., ELLIS, D.J., FROST, C.D. (2001): A geochemical classification for granitic rocks. - *J. Petrol*, 42, 2033-2048.
- HÖLL, R. (1975): Die Scheelitlagerstätte Felbertal und der Vergleich mit anderen Scheelitvorkommen in den Ostalpen. - *Abh. Bayer. Akad. Wissensch., Mathemat. Naturwiss. Kl.*, 157a, 1-114.
- HÖLL, R., EICHHORN, R. (2000): Tungsten mineralization and metamorphic remobilization in the Felbertal scheelite deposit, Central Alps, Austria. - In: Spry, P.G., Marshall, B., Vokes, F.M. (eds): *Metamorphosed and metamorphogenic ore deposits*. Society of Economic Geologists, 233-264.
- JINGWEN, M., HONGYAN, L., SHIMAZAKI, H., RAIMBAULT, L., GUY, B. (1996): Geology and metallogeny of the Shizhuyuan skarn-greisen deposit, Hunan Province, China. - *Intern. Geol. Rev.*, 38, 1020-1039.

- KOZLIK, M., RAITH, J.G. (2013): Hydrothermally induced fluorine enrichment in metagranitoids of the Felbertal scheelite deposit (Austria). Proceedings to the 12th SGA Biennial Meeting 2013, 1271-1274.
- LINNEN, R.L. (1998): The solubility of Nb-Ta-Zr-Hf-W in granitic melts with Li and Li + F; constraints for mineralization in rare metal granites and pegmatites. - *Econ. Geol.*, 93, 1013-1025.
- RASMUSSEN, K.L., LENTZ, D.R., FALCK, H., PATTISON, D.R.M. (2011): Felsic magmatic phases and the role of late-stage aplitic dykes in the formation of the world-class Cantung Tungsten skarn deposit, Northwest Territories, Canada. - *Ore Geol. Rev.*, 41, 75-111.
- REICHL, C., SCHATZ, M., ZSAK, G. (2014): *World-Mining-Data*, 29, 251.