Rb/Sr GEOCHRONOLOGY OF GARNET - BIOTITE MINERALIZATION IN IRON-QUARTZITES FROM THE GAIVA-RAMALHOSO SECTOR OF MARÃO REGION (NORTHERN PORTUGAL)

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Resumo
As mineralizações de Sn/W no sector de Gaiva-Ramalhoso (Marão) relacionam-se com intrusões aplíticas, estando associadas ao desenvolvimento de turmalina e halos metassomáticos de garnada-biotite-grunerite na unidade de quartzitos com ferro. Cálculos geotermométricos e de equilíbrio de fases indicam que o metassomatismo gerador de granada-biotite-grunerite teve lugar a 450 – 500 ºC, sob condições de muito baixa pressão (≤ 0.5 kbar). A datação radiométrica (Rb/Sr) de granada-biotite a 293 Ma é contemporânea do plutonismo granítico tardi-Varisco (D_4), sugerindo que a instalação dos diques aplíticos e metassomtismo/mineralizações associados corresponda a manifestações superficiais da mesma actividade plutónica.

Abstract
The Gaiva-Ramalhoso (Marão) Sn/W mineralizations are associated with development of metassomatic tourmaline and garnet-biotite-grunerite in iron quartzites at the vicinity of aplite dike intrusions. Geothermometry and phase equilibria calculations indicate that the development of garnet-biotite-grunerite metassomatic rocks took place under very low pressures (≤ 0.5 kbar), at 450 – 500 ºC. Garnet-biotite Rb/Sr dating at 293 Ma overlaps the age range of late-Variscan (D_4) granitic plutonism, suggesting that the aplite dikes and associated mineralizations could correspond to shallow level manifestations of the same plutonic activity.

Introduction and Geological Setting

Within the Gaiva-Ramalhoso sector of Marão region (Fig.1), lode and skarn-type tin-tungsten mineralizations are associated with development of garnet-biotite-grunerite-tourmaline metassomatic rocks in the vicinity of late Variscan apatite-rich aplite dike intrusions (Duarte, 2002). In this study we address the physical (P-T) conditions and geochronology (Rb/Sr) of the garnet-forming metassomatic event, which is related with mineralization.

Main stratigraphic and tectonic features of the studied area are shown in figure 1. The stratigraphic sequence consists of four main Cambro-Ordovician meta-sedimentary formations (Coke et al., 2003): The *Desejosa Formation* of Cambrian age exhibits a turbiditic facies. It is a very monotonous multilayer sequence where millimetre-to centimetre-thick phyllite layers are interbedded with siltstones. The *Vale de Bojas Volcano-Sedimentary Formation*, of lower Ordovician age, rests unconformably on the Desejosa Formation. It has two essentially conglomeratic members with volcaniclastic contribution: the lower Bojas Conglomerate and the upper Impure-Quartzites. The *Quartzite Formation*, also of lower Ordovician age, has three members with a total thickness close to 350 m. The lower member, Iron-free Quartzites, is composed of decimetre-to metre-thick quartzite and conglomerate layers interbedded with pelites. The middle member, designated as Iron-Quartzites, is characterized by the absence of the conglomeratic component and the presence of abundant magnetite disseminated in the decimetre-thick quartzite horizons. The upper member of this formation is represented by the Upper Psammites, composed by a multilayer of quartzites and pelites of millimetre-to centimetre-thick layers. The *Slaty Formation* of middle Ordovician age consists entirely of rather monotonous black pelites. Preserved meso-structures record the effects of the main (D_1) Variscan deformation phase (Ribeiro et al., 1990; Coke et al., 2003). Strong strain partitioning during this transpressional deformation led to pervasive left-lateral WNW-ENE wrench faults that bound sectors where major structures are folds with a NE facing axial planar cleavage sub-parallel to the boundary faults.

In the Ramalhoso sector, the Freitas wrench fault connects to the Mina fault (Fig. 1) resulting in a complex shear band; deflection of the continuous Freitas fault is caused by wall rock heterogeneity (enhanced by increasing stress during D_1), promoting favourable conditions for local extension and increase of effective permeability of the rocks. Late Variscan reactivation of these structures allowed intrusion of aplitic dikes, which reflect deeper emplacement of granitic bodies. Several generations of mineralized (arsenopyrite, pyrite, ferberite and cassiterite) aplite dikes were recognized in the area by Duarte (2002). Metassomatic development of tourmaline is seen in iron-quartzites, particularly in the vicinity of apatite-rich aplite varieties. The generation of garnet-biotite-grunerite rocks are associated with tourmalinization and correspond to a late-stage on the evolution of the metasomatic processes (Duarte, 2002).

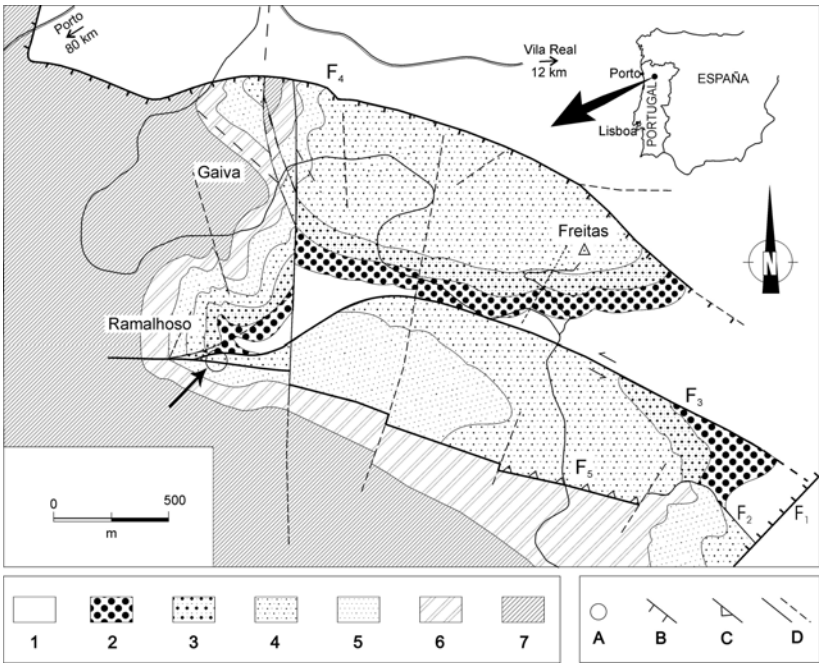

Figure 1 – Geological map of of the South branch of the Marão region and location of the Gaiva-Ramalhoso sector. 1- Desejosa Fm. of Douro Group; 2-3- Volcaniclast Vale de Bojas Fm. (2- Bojas Conglomerate; 3- Impure Quartzites); 4-6, Quartzite Fm. (4- Iron-free Quartzites; 5- Iron Quartzites; 6- Upper Psammites); 7- Slaty Fm.. A- Sample location; B- Wrench fault; C- Thrust fault; D- Strike-slip fault and nonspecific fault F_1- Bojas fault; F_2- Mina fault; F_3- Freitas fault; F_4- Pena Suar fault; F_5- Ribeira das Cestas

Petrography, mineral chemistry and phase equilibria of garnet-grunerite-biotite rocks

Studied samples have porphyroblastic textures, with relatively large (1-10 mm) garnet poikiloblasts (including quartz, biotite, apatite, tourmaline and zircon) set in a (isotropic) matrix composed of quartz, (anhedral, brown to blue yellow) tourmaline (with pyrite ± arsenopyrite inclusions), (dark brown to pale yellow, pleochroic) biotite and acicular (colourless) amphibole, sometimes displaying a decussate type arrangement. Late stage chlorite fills fractures within some garnet crystals. New microprobe mineral analyses confirm the results reported by Duarte (2002). Garnet is always almandine rich (typically, alm > 95 %; pyr ~ 1 %; gros < 3 %), but larger porphyroblasts display, rim-core-rim, bell-shaped spessartite (11 % → 1 %) compositional zoning, typical of prograde growth. Biotites are low-Ti (TiO_2 = 0.47 – 1.47 wt%) annite-rich (X(Fe) = 0.87 – 0.93) varieties, whereas amphibole is almost pure grunerite (X(Fe) ~ 0.95; Al_2O_3 ≤ 3 wt%) and tourmalines correspond to schorlites. Coexisting Fe-Mg silicates display iron enrichment in the order, tourmaline < biotite < amphibole < garnet, with Kd (Fe/Mg), $garnet_{rim}$- tourmaline = 14.9 – 17.0, $garnet_{rim}$-biotite = 10.8 – 13.2 and $garnet_{rim}$-amphibole = 7.2.

Geothermometric calculations (TWEEQU - Berman, 1991; THERMOCALC - Powell & Holland, 1994) indicate that garnet + biotite equilibrated at about 450 – 500 ºC; however, the observed mineral assemblages are not readily amenable to conventional geobarometric analyses. To partially circumvent this difficulty, we explored garnet + cummingtonite-grunerite (+ quartz-H_2O) phase relations by using pseudosection analysis (Powell et al., 1998). Assuming that K_2O (an exclusive component of biotite) have little effect on phase equilibria relationships among the remaining Fe-Mg minerals, a P-T pseudosection was calculated in the model system FMASH for an appropriate Fe-rich bulk composition (Al_2O3 : FeO : MgO = 20.2: 77.7 : 2.0). Phase stability fields in figure 2 are dominated by the univariant reaction chlorite + garnet = amphibole + cordierite (+ quartz – H_2O), which terminates on the trivariant garnet + amphibole at about 499 ºC, 0.5 kbar. As shown in figure 2, the stability of the critical garnet-amphibole assemblage is strongly temperature dependent.

However, for the temperature range of interest (450 – 500 ºC), results in figure 2 indicate that the garnet-grunerite assemblage is restricted to very low pressures, suggesting that the studied rocks may have formed at very shallow crustal levels (probably less than 0.5 kbar).

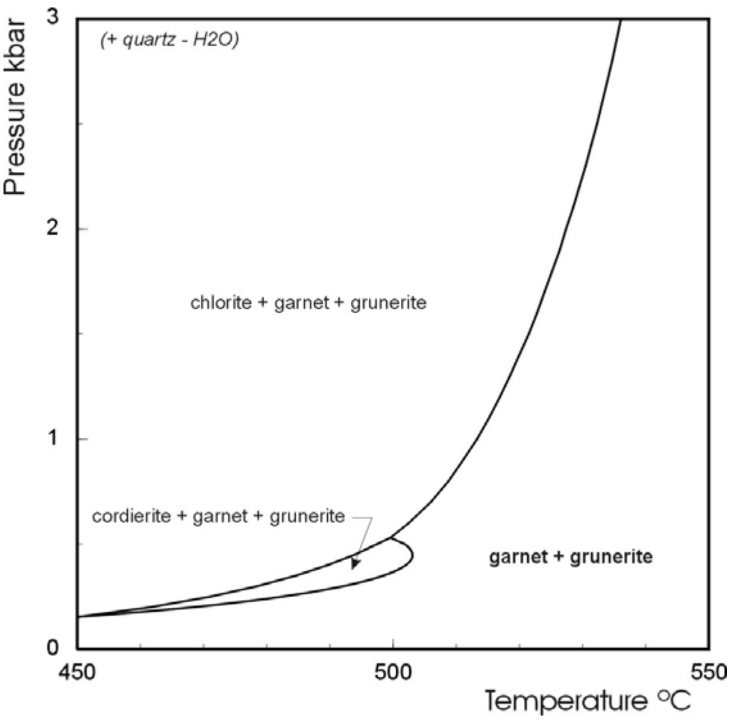

Figure 2: P-T pseudosection in FMASH (+ quartz-H_2O; calculated by THERMOCALC) for the specified bulk composition (see text), depicting phase relations on the univariant garnet +chlorite+ cordierite + cummingtonite-grunerite. End-member compositions and solution activity models were taken from Vance & Holland (1993), Holland & Powell (1996; 1998) and Holland et al. (1998).

Rb/Sr and Sm/Nd isotope geochemistry

Purified garnet and biotite mineral separates from sample T-2 (garnet-biotite-grunerite-tourmaline) were subjected to Rb-Sr and Sm-Nd isotopic analysis. Abundant micro-inclusions in garnet precluded reliable Sm-Nd radiometric dating. Garnet-biotite $^{87}Sr/^{86}Sr$ - $^{87}Rb/^{86}Sr$ data ploted in

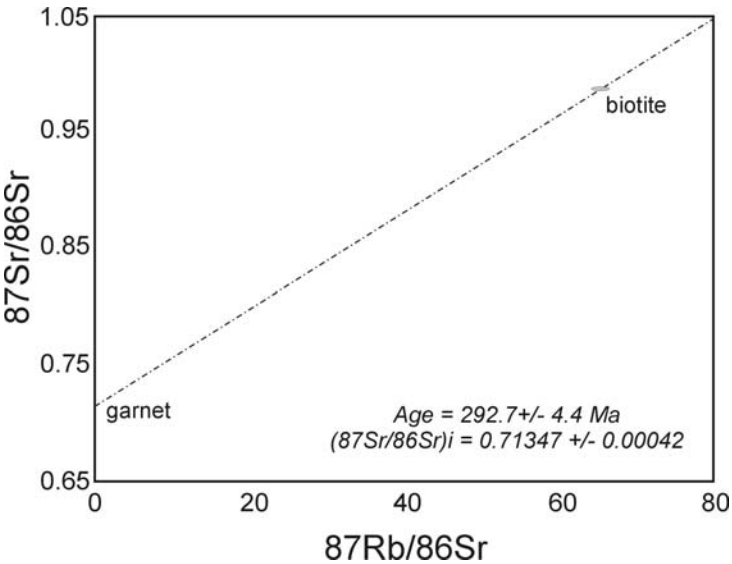

Figure 3: Garnet-biotite $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ isochron diagram.

figure 3 yield an age of 292.7 ± 4.4 Ma. Given the relatively low recrystallization temperatures, this age should be close to the age of the garnet-forming metassomatic event and associated mineralizations. Initial $^{87}Sr/^{86}Sr$ = 0.71347 ± 0.00042 and $^{143}Nd/^{144}Nd$ = 0.511714 ± 0.000011, preclude any significant contribution from mantle sources and indicate a large crustal component for ore-forming fluids in the Gaiva-Ramalhoso deposits.

Conclusions

In the Gaiva-Ramalhoso sector of Marão, tin-tungsten lode mineralizations are associated with development of metassomatic tourmaline and garnet-biotite-grunerite in iron-quartzites that occur in the vicinity of apatite-rich aplite dike intrusions. Development of garnet-biotite-grunerite merassomatic rocks took place under very low pressures (probably less than 0.5 kbar) and relatively low temperatures of 450 – 500 ºC. Garnet-biotite Rb/Sr dating at 293 Ma, overlaps the age range of regional subalkaline ferro-potassic plutonism (296 – 290 Ma; Dias et al., 1998), suggesting that aplite dikes and associate mineralizations could correspond to shallow level manifestations of the same late-Variscan plutonic activity.

Acknowledgements

Thanks are due to Prof. J. Machado Leite and Dr. J. M. Farinha Ramos and Eng. Fernanda Guimarães for microprobe facilities in the IGM, Oporto. This study is a contribution to research projects MODELIB (POCTI/35630/CTA2000-FEDER) and POCA-PETROLOG (Centro Geologia U. Lisboa, UI: 263; POCTI/FEDER)

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