# Intensive variables in the Golpejas rare metal granite and their implications for ore mineralization

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## INTRODUCTION

Rare-metal albite granites are a "rara avis" because they are rare in nature, contain critical minerals that are highly valued today, and are absent or very rare in other granites (e. g., columbite group minerals, cassiterite, beryl, topaz, aluminum phosphates, fluorite, lithium minerals), and their genesis is much less understood than that of other granites. One of the least well-known features is the conditions under which these unique magmas consolidate at their emplacement sites, and what role these conditions play in the formation of ore mineralization. This paper addresses these questions for one of the most important Spanish rare metal granites, the Golpejas granite.

## METHODS

Thermometric estimates were constrained by the saturation of zircon (Watson & Harrison, 1983), monazite (Montel, 1993), and apatite (Pichavant et al. 1992), the ternary two-feldspar thermometer (Putirka, 2008; equation 27b), the plagioclase-muscovite of Green & Usdansky (1986), and the whole-rock $Al_2O_3/TiO_2$ ratio thermometer according to Jung & Pfänder (2007). Pressure conditions were estimated using the phengite barometer (Massonne & Schreyer 1987), contact metamorphism associations, and muscovite stability reactions. The water content of the magma was estimated from the empirical model based on the equilibrium $H_2O$ (vapor) = $H_2O$ (melt) of Moore et al. (1998), for an $XH_2O$ in vapor of 1. Samples showing kaolinization and phengitization were excluded.

## RESULTS AND DISCUSSION

The apatite saturation formulation gave very inconsistent and partly unrealistic values, varying between 1010 ºC and 560 ºC, with an average of 705 ºC. Monazite saturation yielded low values, ranging from 527 ºC to 343 ºC (average 429 ºC), which are clearly subsolidus estimates. The absence of any mention of monazite in this granite probably explains these low temperatures. The saturation temperature of zircon gave values intermediate between those of apatite and monazite, with a maximum of 690 ºC and a minimum of 631 ºC and an average of 657 ºC. Moreover, the results obtained with the ternary two-feldspar thermometer for a pressure of 350 MPa are always in non-equilibrium conditions due to the anorthitic component. Neglecting this component in the calculations leads to a maximum value of 405 ºC and an average of 318 ºC, to which should be added about 90 ºC, since the Golpejas feldspar is ordered, while the solvus considered in these thermometers is based on disordered feldspars (see Lee et al., 1995), but still leading to subsolidus conditions (c.a. 500 ºC). As for the plagioclase-muscovite pair, at a pressure of 350 MPa it always produces temperatures below 508 ºC, with an average of 370 ºC, i.e. clearly subsolidus values. With respect to the whole rock $Al_2O_3/TiO_2$ ratio thermometer, its main handicap is the extremely low $TiO_2$ contents of these granites, which are mostly below the detection limits in a normal routine for the determination of major elements. The only available data above the detection limit gives a best-case maximum temperature of 520ºC, confirming titanium mobility. The confining pressure conditions obtained with the primary white mica at the temperature obtained from zircon saturation were 380 ± 100 MPa. This value must be treated with suspicion since the composition of the white mica is essentially muscovite and not phengite. In addition, the aureole of the contact metamorphism of the Golpejas granite produced andalusite, indicating that the granite was emplaced under epizonal conditions. The presence of this aluminosilicate allows us to define the confining pressure of the granite. In fact, it is only necessary to consider the experimental reactions of andalusite formation, in this case from muscovite and quartz, and knowing the temperature of the reaction, the pressure at which it was formed is obtained. Using the

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average saturation temperature of zircon in granite as the temperature of the muscovite reactions (657 ºC), a maximum pressure of 350 MPa is obtained for a mica without fluorine, and a minimum pressure of 120 MPa for a fluorine-rich mica, averaging 235 MPa. The percentage of water calculated in the Golpejas granitic melt for a pressure of 350 MPa and 660 ºC is 9.14%, while for the lowest estimate (120 MPa) the content drops dramatically to 5%, so the pressure strongly influences the solubility of water in the melt. Therefore, the zircon saturation thermometer seems to be the most suitable application to constrain the emplacement temperature of the Golpejas granite, while the other thermometers clearly produce subsolidus conditions. If the zircon saturation temperature represents the emplacement temperature (<690 ºC), one would have to assume not only water saturation conditions of the melt, but also the presence of fluxing elements that lower the melting point (e.g., F, P, and B; see Manning, 1981). This is consistent with the high abundance of P and the presence of topaz in the Golpejas granite. These elements prolong magma crystallization, favoring the timing of fractional crystallization processes to a greater extent than in a more conventional granitic system, which may have promoted the increase of incompatible elements such as Rb, Sn, Nb, Ta, and Li in the melt, i.e., mineralization. Moreover, the pressure estimates of the Golpejas granite are significantly lower than those of the surrounding barren two mica-granites hosted in high metamorphic grade anticlines (460 MPa; López-Moro et al., 2007), but it was emplaced under similar conditions as other nearby post-orogenic granitoids with contact metamorphism and tungsten ore associated with skarn deposits (250-200 MPa, Timón et al., 2007). The low emplacement pressure of the Golpejas granite contributes to the exsolution of the fluid phase in an already water-rich melt, favoring the formation of greisen and subsolidus overprints.

## CONCLUSIONS

The low temperature and pressure emplacement conditions, the high-water content, and the availability of fluxing elements are the main factors for the development of the mineralization process in the Golpejas granite.

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