TEXTURES OF RARE-METAL GRANITES AS EXPLORATION TOOL

[1]SELTMANN, R., [2]STEMPROK, M. and [3]MÜLLER, A. [1]Natural History Museum, London, UK; [2]Charles University, Prague, Czech Republic; [3]IGDL University, Göttingen, Germany.

Summary

Bodies of mineralized rare-metal (RM) granites are commonly interpreted from geophysical data (gravity, magnetics, seismics) as horizontal or moderately inclined plates connected with the sources of felsic magmas by thin steep feeding channels. Recognizing the nature of upper contacts of these bodies is of importance for mineral exploration as they host most of the deposits of granitic affiliation (Sn, W, Mo, Nb, Ta, Be, Cs, Rb).

Apical parts of granitic bodies of plutonic and batholith size contain in places fine-grained porphyritic and/or aphyric granites, two-phase and aplitic granites as well as specific pegmatitic rims (stockscheiders). Even small granite cupolas are formed by two or more magmatic pulses whose products are commonly overprinted by postmagmatic or late magmatic alterations.

The crystallization of the granites near the upper contact is characterized by rapid cooling and loss of volatiles, thermal contraction, oscillation growth (manifested on quartz by CL), repeated brecciation and metasomatic pervasive and joint controlled alterations related or unrelated to ore mineralizations.

The complex origin of granite textures along the upper contacts is caused not only by the temperature gradient at the time of intrusion across the contact zone and a sudden release of pressure but also by the later emplacement of younger granites along the upper contact of solidified granites and massive alterations caused by orthomagmatic and meteoric fluids circulating in fissures and joints of solid granites.

Introduction

The anatomy of igneous bodies is determined beside geodynamic position, geotectonic setting and timing of the intrusions especially by their structural and compositional characteristics, such as morphology, internal structure, textural patterns and significant changes in chemical and mineralogical compositions leading to zonality and differentiation trends. With the evolution of higher fractionated plutons towards their ore-bearing end-members, especially those reaching shallow levels, an increasing variability of the specific features (Seltmann 1994, 1999) is often connected. Typically for such associations are multiple intrusions, occurrence of pegmatites, breccia pipes and transition to mineralized porphyry systems, and an abundance of associated dykes of bimodal composition. They exhibit a large grain size variation reflected in a zonal arrangement of the crystal size distribution (CSD) of rock-forming minerals, show due to fractionation-triggered volatile enrichment (F, Cl, Li, B) frequently fluid saturation textures and are associated in many cases with RM mineralization (Sn, W, Mo, Nb, Ta, Be, Cs, Rb).

Anatomy of mineralized rare metal granites

The rare metal bearing granitic bodies are defined as being contained within a single contact whose part or its total volume is in apparent spatial and assumed genetical association with endogenous rare metal mineralization. The origin of the granitoid body and ore mineralization belong to the same period of magmatism. The position of mineralization is on the example of Sn, W and Mo deposits on the territory of the former USSR (824 observations; Rundkvist *et al*. 1971) situated at 27.5% in exocontact, at 31.2% in endo-exocontact and at 41.3% in endocontact settings.

Surface studies, especially geological and geophysical mapping, are evidential to collect information on size and shape of the granite outcrops in horizontal and vertical dimensions, on granite petrology, sequence of magmatism, degree of alteration, and minerals on fissures and faults. Identification of the contact nature (development of stockscheiders, explosion breccia pipes, near-contact dykes, enclaves, schlieren, planar foliation, flow banding, tectonic layers) allows conclusions on exsolution reactions of volatile parameters, magma rheology, intrusion mechanism, sequence of intrusive pulses, and magma / country rock interaction.

Volumetric mapping based on gravity and magnetometry data (Dukhovskii *et al*. 1981) is directed to study the vertical dimension of a hidden granitoid intrusion using the knowledge on contact nature, reconstruction of the ancient envelope, and thermal metamorphic aureole. In peraluminous granites maximal depths from 4-9 km are assumed with some very rare exceptions from 15-20 km (Cornubian batholith, South Mountain batholith), while from anorogenic granites 12 km maximal depth extent is reported (Vigneresse 1988). The ore-bearing potential of a pluton depends on the conditions to develop highly fractionated end-member derivates rather than on its volume capacity. Drillings into different rare metal granite bodies (Cinovec / Czech Republic 1596m, Echassiere / France 900m, Eldzhurdin / Russia 1500m, Voznesenskoe / Russia 1200m) show a number of intrusive phases, multiphase origin even of small granite bodies, and a focus of postmagmatic alterations on the apical part of the elevations.

Intrusion body sizes and shapes. The classification of rare metal deposits linked to the size of associated granite bodies shows that small morphological elevations (stocks,

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18 cm

cupolas) control the focussed ascend and deposition of mineralizing fluids in the late to post-magmatic solidification stages of larger plutons. Such cupolas and stocks are defined as small granitoid bodies of synchronously intruded magma formed either as separate intrusion or as part of a larger hidden body. On the outcrop scale intrusion body size is classified as follows: cupolas <1 km^2, stocks 1-50 km^2, plutons 50-200 km^2, batholiths 200-10,000 km^2, superbatholiths > 10,000 km^2 (Stemprok, 1998). Most of the intrusions are floored, and the terminology is based on the shape in cross section: laccolith (lensoid igneous intrusion concordant with stratification), lopolith (large lenticular centrally sunken, generally concordant intrusive body with its thickness approximately one tenths to twentieth of its widths or diameter), phacolith (lense-like body in the middle limbs of the folds), harpolith (cross-cutting body of sicle shape resembling in form a tilted phacolith; preferred form for the ore-bearing granitoids; Dukhovskii *et al*. 1981), and batholith (as unfloored large granite masses represented by the intrusion model of "inverted water drops").

Phasing. Rare metal bearing plutons are considered as a magmatic unit formed by high-silica leucogranites with highly evolved (two-mica, lithium-mica, topaz, tourmaline, alkali pyroxene) members at their margins. The sequence of intrusion phases observed in most of the plutons is usually:

- marginal "carapace" granite porphyry (Plimer 1987), fine-grained porphyritic, exhibits often "two-phase rock" characteristics (Seltmann and Stemprok 1996)
- main intrusive phase, coarse grained,
- complimentary phase, medium-grained or fine-grained
- final phase - aplitic.

There may occur as an erratic addition of later phases to earlier ones in a standard model.

Contacts of ore-bearing granites provide information about fluid-rock reactions and physical solidification parameters in the system magma - host rocks that control either disperse distribution of the metals or their accumulation in ore bodies. Most important contact features are:

- stockscheider - pegmatitic rims,
- marginal "carapace" granites (granite porphyries),
- muscovite granites (vs. products of secondary muscovitization),
- lithium albite granites (vs. products of albitization and lithionitization),
- alkali pyroxene granites (vs. secondary albitization, fenites).

Precursors can be a part of a rare metal bearing batholith. Most common are granitoid precursors (diorites and quartz diorites, granodiorites, monzogranites/adamellites, granite porphyries), to a less extent gabbroic precursors (gabbro, gabbrodiorite), and syenites and granosyenites (rare). Feldspathoids are unknown as precursors. The position of an ore-bearing pluton to its precursors may be isolated as elevation or hidden stock, isolated as ore-bearing pluton, contained within a single batholith with precursors, surrounded by a single precursor or by several bodies of precursors.

Dyke assemblage of rare metal plutons is enclosed in precursors or ore-bearing plutons or/and in the envelope and is very commonly bimodal. Felsic dykes are represented by aplites, pegmatites, fine-grained granites, granite porphyries, quartz porphyries and intra-ore aplites. Petrogenetically they may inform about the ore potential of fractionation products and the metallogenetic significance of felsic dykes is based in their fluid channeling behaviour. As mafic dykes diabases, diorites and lamprophyres/lamproites are widespread and may inform about magma chamber processes (mixing and mingling, cumulate formation, mantle input). Lamprophyres derived from upper mantle, probably metasomatized, testify to access the products of the upper mantle into space of the ore deposits.

Compositional zonation is characterized by various types:

- asymmetric zonation of nested type with separated bodies,
- irregular zonation of nested type with mutual penetration of the bodies,
- concentric zonation with intrusion sequence along a contact and/or sequence of metasomatic alterations.

Possible causes for zonation are plate movements over source zones, moving source zones, alternation in opening of magma feeding zones due to tectonic transport and polarity of strain-stress fields, intrusion along contact, hydrothermal overprint from the contact etc.

Processes that control textures of RM granites

Textural, mineralogical, and geochemical investigations were carried out on subvolcanic intrusions in Eurasian rare-metal granite provinces to study conditions of fluid saturation that led to the formation of associated vein-stockwork, greisen and porphyry deposits. The results indicate that late- to post-magmatic mineralization of the studied felsic systems commonly was controlled by **degassing** of a highly-evolved, fluid-saturated ore-bearing leucogranitic magma. Alternations between open and closed system conditions related to repeated fracturing of surrounding rocks resulted in pressure and temperature fluctuations of the magmatic-hydrothermal system, mixing of meteoric and magmatic waters, and channelized fluid flow as major structural controls of ore accumulation.

Some of the stocks of highly evolved granites show the contraction of the outer shell and in their immediate envelope giving rise to contact-parallel veins, joints or fissures (e.g. Cínovec-Zinnwald in the Krušné hory/Erzgebirge, Panasqueira in Portugal). The contraction is explained to result from volatile degassing and heat loss in solidifying granitic magma with an accompanying volume decrease (Stemprok 1993).

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The intrusion of many highly fractionated Li-F granites into subvolcanic levels (1-4 km intrusion depth) was controlled in part by rapid uplift of the crust (2-7 mm/a) during extension. Rapid cooling and crystallization of these intrusions results in magma quenching and intense fracturing of the carapace in many cases. Due to the so-called **autoclave effect**, a quenched glassy carapace (later recrystallized) was able to sustain overpressures (internal fluid pressures as high as 3-5 kbar) that greatly exceed local lithostatic pressures. Confined to the carapace, the melt crystallizes inward and although initially undersaturated in water, it eventually became fluid saturated. This resulted in late-stage volatile separation beneath the carapace. The passage of the granite system through the water-saturated liquidus boundary involved a volume increase and change in fluid composition.

Multiphase granitic intrusions often show a **textural sequence** (fine-grained, porphyritic to seriate to equigranular textures), in many cases associated with pulses of explosive brecciation and formation of greisen stockworks characterizing the oscillating crystallization regime (Müller *et al*. 2000). Rapid crystallization of these intrusions is characterized by quench textures, such as embayment and skeletal growth of quartz (visible in SEM-CL images), particularly in dikes and in cupolas of the intrusions. Zonal growth of quartz and feldspar, resorption processes and two-phase textures are typical (Figs. 1 and 2). Pegmatitic, miarolitic and rhythmical layered textures (e.g., comb quartz layers and other unidirectional solidification textures / USTs) indicate stages of fluid saturation.

Micrographic intergrowths of quartz and K-feldspar also reflect **undercooled conditions** that may have been related to rapid release of a fluid phase (i.e., pressure quenching). Nucleation-controlled phenomena, including variations in granite textures, however, can result from a multiplicity of causes. Extensive fracture stockworks and breccia pipes around the tops of intrusions, which indicate explosive rupture of an impermeable barrier by the short-term, self-healing igneous system, are characteristic of fluid-saturated rare metal granites.

Closed system conditions in the melt reservoir below the carapace enable fluid saturation, disequilibrium reactions between separated magmatic volatile phases and crystals and melt, and thus catalyze a more effective fractionation. Such volatile-rich, highly evolved magmas result in granitic rocks that commonly show the lanthanide tetrad effect. The enrichment of magmatic volatile phases is reflected in H_2O-, F-, Cl-, B-, Li-,

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