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The Importance of Tectonic Setting in Understanding Granitic Pegmatites

ROBERT F. MARTIN

Dpt. of Earth and Planetary Sciences, McGill University, 3450 University Street, Montreal, QC H3A 2A7, Canada, bobm@eps.mcgill.ca

ABSTRACT

The contrasting patterns of rare-element enrichment in granitic pegmatites are a direct result of petrogenetic processes at work before, during, and after the anatectic reactions that went on in the mantle and lower to middle crust. The processes leading to evolved granitic pegmatites of LCT and NYF types differ in important ways. I focus here on the reasons for the patterns of trace-element enrichment expected in quartz and the K-rich and Na-rich feldspars of LCT and NYF suites.

Keywords: NYF granitic pegmatites, LCT granitic pegmatites, anatexis, fractionation, metasomatism.

INTRODUCTION

With advances in the areas of 1) detailed mineralogy and crystal chemistry of the accessory phases and 2) simulations of paths of crystallization in experimental petrology, one's understanding of the workings of granitic pegmatites has reached a rather high level. I am here to report on a neglected aspect, the interplay of tectonic setting and petrological processes, insofar as they affect patterns of crystallization in granitic pegmatites. In this review, I will focus on an explanation of LCT and NYF pegmatites, and explore ramifications in patterns of trace-element enrichment.

NYF AND LCT GRANITIC PEGMATITES

Petr Černý was first to recognize two contrasting patterns of enrichment manifested in the most evolved members of suites of granitic pegmatites. His 1991 paper has become a benchmark contribution. The NYF pegmatites show a relative enrichment in niobium, yttrium and fluorine, whereas LCT pegmatites show a relative enrichment in lithium, cesium and tantalum. Černý (1991) and Černý & Ercit (2005) attempted to place these two types of granitic pegmatite in the context of regional prograde metamorphism and to identify, in a P–T diagram, the relevant depth-zones where LCT and NYF suites could be expected to form. In my opinion, the depth-zone approach does not work with granite plutons, nor does it work for granitic pegmatites.

Martin & De Vito (2005) simply extended the tectonic classification of granite magmatism to the study of granitic pegmatites, and proposed that NYF pegmatites are genetically part of A-type suites of felsic magmatic manifestations. Here, A stands for Anorogenic, not for Anhydrous, and not necessarily for Alkaline. All peralkaline granites are of A-type, and but some A-type granites and NYF pegmatites are peraluminous, to the point of crystallizing topaz and aluminum fluorides. Some A-type granites are associated with nepheline-normative suites and carbonatites; nepheline-bearing pegmatites associated with these suites show the same pattern of enrichment in Nb, Y (and associated high-field-strength elements), and F as NYF pegmatites. Such suites, either quartz-bearing or not, are emplaced in areas of the crust undergoing extension.

In marked contrast are the better-known and better-understood LCT granitic pegmatites, which form part of orogenic suites associated with crustal shortening, in zones of subduction and instances of continental collision. To the LCT signature should be added relative enrichment in P and B, manifested in a rich suite of primary and secondary phosphates and prominent tourmaline-group minerals.

The literature on LCT and NYF pegmatites makes clear the involvement of a mantle component and a crustal component in most situations. In other words, both LCT and NYF pegmatite suites might be found to contain isotopic indications of a mixed crust + mantle source. How is this possible if the quartzofeldspathic products are geochemically so distinct?

THE PETROGENESIS OF LCT SUITES

The standard approach to explain an LCT pegmatite is to propose a close link with a batholithic mass of granitic magma formed above a subduction zone. The progressive dehydration of the descending slab, made of rocks that have been subjected to close interaction with seawater in a protracted residence-period on the seafloor, produces an aqueous fluid phase that rises through the mantle wedge with a complement of Cl, dissolved base metals, Na, Li and B. Anatectic reactions begin in the hydrated peridotite of the mantle wedge, whence basaltic to andesitic magmas rise into the crust. They will fractionate on the way up, and will induce anatexis of the crust suitably heated from below. The resulting granitic magmas will fractionate as they rise. The metaluminous to mildly peraluminous derivative magmas will progressively become enriched in the incompatible Li, ^{III}B, and P, such that at the pegmatitic stage, these will give rise to "lepidolite", spodumene, tourmaline-group minerals, and a rich suite of primary and secondary phosphates that may well have formed from an immiscible phosphate melt. The late relative enrichment in Ta remains a mystery!

THE PETROGENESIS OF NYF SUITES

Zones of extension in the crust occur above zone of anomalous upper mantle and active degassing. Whereas the fluid in the LCT case is dominantly H_2O, the mantle in this case is producing a mixture of H_2O, CO_2, and CH_4. As a result, the trace elements being mobilized upward into the attenuated crust include the rare earths, both alkalis, Nb, Ta, Zr, Ti, U and Th. The lower and middle crust are locally alkali-metasomatized prior to anatexis, such that anatexis of the crust produces a metaluminous to mildly peralkaline melt. At the same time, a mantle-derived OIB-type basalt will rise and permeate into the distended crust, which will promote the progress of anatexis. The uncontaminated basaltic magma may fractionate in a classic way, and its derivative magmas may be expected to mix with similar magmas produced by partial melting of metasomatized crust. The most evolved products may well show a pegmatitic texture, but the minerals will be distinct in some way from those that characterize LCT pegmatites.

QUARTZ IN LCT AND NYF SUITES

One of the challenges facing pegmatologists is to explain the quartz core that can be expected in both LCT and NYF evolved pegmatites. The quartz core may consist wholly or in part of rose quartz, the color being cause by filaments of a dumortierite-type phase exsolved (?) along the *c* axis of quartz (Ma *et al.* 2002). This phenomenon seems to imply the incorporation of Ti, Al, Fe, and B (presumably ^{IV}B) in the quartz. Rose quartz can be found in evolved members of either LCT or NYF types. Isotopic studies (B, O) could be used to test the hypothesis that the presence of rose quartz is a clear signal of the involvement of crustal rocks in the petrogenetic scheme.

As NYF pegmatites are more strongly enriched in U and Th, smoky quartz is more likely there than in LCT pegmatites. Smoky quartz involves Al replacing Si, and ionizing radiation acting on the charge-compensating monovalent cation.

ALKALI FELDSPARS IN LCT AND NYF SUITES

As hinted at above, there is a buildup in P in peraluminous LCT suites, and this leads to the incorporation of P in the feldspars, up to 1.5% P_2O_5 or so. Thus LCT feldspar-group minerals provide a sink for phosphorus [$2\,\mathrm{Si} \rightarrow \mathrm{Al} + \mathrm{P}$]. In a real sense, the P-rich feldspars themselves become peraluminous.

For boron to enter a feldspar, it must have a tetrahedral coordination, which is favored by somewhat alkaline conditions. Thus although the buildup in boron in an LCT suite is typical, none of it is likely to enter the K- and Na-rich feldspars. The second locality of reedmergnerite, $NaBSi_3O_8$, is the Dara-Pioz peralkaline (*i.e.*, tourmaline-free) NYF pegmatite, in Tajikistan.

The levels of the light rare-earth elements (LREE) and ferric iron are likely to be greater in alkali feldspar of NYF suites. Larsen (2002) has used the ICP–MS approach to characterize regional patterns of LREE enrichment in K-feldspar of NYF pegmatites in southern Norway. The incorporation of Fe^{3+} in K-feldspar makes it slightly peralkaline, and causes it to cathodoluminesce bright red. And as enrichment of Ga is diagnostic of any A-type granite, I expect the K-feldspar of NYF suites to be gallium-enriched.

Why is amazonitic K-feldspar typical of NYF pegmatites? The buildup of Pb in a felsic melt, a sulfur-poor environment, forces the K-feldspar to accept Pb according to two possible schemes of substitution: 1) $\mathrm{Pb} + \mathrm{Al} \rightarrow \mathrm{K} + \mathrm{Si}$, and 2) $\mathrm{Pb} + \square \rightarrow 2\,\mathrm{K}$. Ionizing radiation acting on the occupant of the vacancy, likely H_2O, induces the characteristic coloration. Martin *et al.* (in press) have proposed that it is the higher level of Pb, U and Th in a NYF pegmatite of anatectic origin that promotes the development of the characteristic coloration of the K-feldspar in the most evolved portions of the system.

IMPORTANCE OF SUBSOLIDUS MODIFICATIONS

Both LCT and NYF granitic pegmatites are subject to near-solidus hydrothermal overprints that partly destroy and reprocess primary products of crystallization. One major subsolidus reaction involves the patchy replacement of perthitic K-rich feldspar by pseudomorphic muscovite + albite. The reaction proceeds at a high subsolidus temperature, and seems to involve the preferential mobilization of Ta, Sn and Li. This is a poorly understood reaction of great economic significance, and the source of ongoing controversy.

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REFERENCES CITED

Černý, P. (1991) Rare-element granitic pegmatites. II. Regional to global enviroments and petrogenesis. *Geosci. Can.* **18**, 68-81.

Černý, P. (2005) The classification of granitic pegmatits revisited. *Can. Mineral.* **43**, 2005-2026.

Larsen, R.B. (2002) The distribution of rare-earth elements in K-feldspar as an indicator of petrogenetic processes in granitic pegmatites: examples from two pegmatite fields in southern Norway. *Can. Mineral.* **40**, 137-151.

Ma, Chi, Goreva, J.S. & Rossman, G.R. (2002) Fibrous nanoinclusions in massive rose quartz: HRTEM and AEM investigations. *Am. Mineral.* **87**, 269-276.

Martin, R.F. & De Vito, C. (2005) The patterns of enrichment in felsic pegmatites ultimately depend on tectonic setting. *Can. Mineral.* **43**, 2027-2048.

Martin, R.F., De Vito, C. & Pezzotta, F. (in press) Why is amazonitic K-feldspar an earmark of NYF-type granitic pegmatites? Clues from hybrid pegmatites in Madagascar. *Am. Mineral.*

Wise, M. (1997) Characterization and classification of NYF-type pegmatites. *Can. Mineral.* **37**, 802-803.