

Peraluminous pegmatoids with several thousands of ppm of LREE in the Central Grenville Province

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Abstract. Peraluminous pegmatoids (PGDs) from the central Grenville Province show LREE enrichments up to 7435 ppm hosted in monazite or allanite. These PGD are compared with their migmatitic metapelitic source to elaborate a petrogenetic model for these peculiar magmas.

The leucosome has low Σ REE content (39 ppm) consistent with its Pl+K-Fsp-dominated assemblage. The higher Σ REE contents (259 ppm) and negative Eu anomaly of the melanosome reflects the Bt+Grt-dominated assemblage and minor apatite+zircon+monazite. The strong fractionation of the LREE over HREE in the PGD points to HREE sequestration in the residual garnet. The decreasing Σ REE content and Eu negative anomaly from aplitic to pegmatitic facies are attributed to magmatic differentiation.

REE contents in the various rock types imply that the REE behaved as incompatible elements. Low degrees (<10%) of partial melting of the metapelites would be required to reach the Σ LREE content of the PGD but this is incompatible with melt migration, and with residual peritectic garnet. In turn, fractional crystallization is incompatible with flattening Eu anomaly nor with stable K/Rb ratios and Rb contents of K-feldspar during magmatic evolution. These data provide contradictory constraints on the contributions of partial melting and fractional crystallization in LREE enrichment of the PGD.

1 Introduction

For decades, experimental data and field observations demonstrated that peraluminous melts are not suitable hosts of LREE as shown by the solubility of monazite (Σ REE) that is below ca. 300 ppm (e.g. Montel 1986, 1993). However, Turlin et al. (2017) reported peraluminous pegmatoids (PGD) with up to 7435 ppm of REE hosted either in allanite or monazite. These PGDs were emplaced in the Allochthonous Belt of the central Grenville Province around ca. 1005-1000 Ma (Fig. 1, Turlin et al. 2017, 2019) and were derived by partial melting of Paleoproterozoic-Archean metapelites belonging to the underlying Parautochthonous Belt (Fig.

1, Turlin et al. 2019).

This study aims to (i) compare the petrogeochemical characteristics of several facies of an example of a monazite-bearing LREE-rich PGD and of its metapelitic source (parautochthonous migmatites), and (ii) to discuss the magmatic processes that played a role in such important LREE accumulation in peraluminous melts.

2 Geological context

The Grenville Province is composed of two tectonometamorphic domains: the (i) Allochthonous Belt (terrane accreted to Laurentia during the Mesoproterozoic), and the (ii) Parautochthonous Belt (rocks of the Superior Province and its metasedimentary cover reworked during the Grenvillian Orogeny) (Fig. 1, e.g. Rivers 2008). The former recorded the Ottawa crustal thickening phase as early as ca. 1090 Ma with a HT-HP peak of metamorphism reaching granulite-facies at ca. 1070-1050 Ma (Rivers 2008; Lasalle et al. 2013; Turlin et al. 2018). It subsequently slowly cooled down to close to solidus conditions at ca. 1005-1000 Ma, and down to subsolidus condition of ca. 500°C at ca. 960 Ma (Turlin et al. 2018). The underlying Parautochthonous Belt (Fig. 1) was metamorphosed during the crustal thickening phase (ca. 1005-960 Ma) that reached partial melting conditions up to granulite-facies peak of metamorphism (Jannin et al. 2018; Jordan et al. 2006).

3 LREE-rich PGDs from the central Grenville

The LREE-rich PGDs from the Allochthonous Belt of the central Grenville Province show a strong peraluminous signature with ASI (Aluminum Saturation Index = $Al/(Ca - 1.67 \times P + Na + K)$; Frost et al. 2001; Shand 1943) between 1.18 and 1.36 (Turlin et al. 2017), which is uncommon for LREE-rich magmas. Among them, one PGD shows a Σ LREE content up to 6949 ppm hosted in monazite (Turlin et al. 2017). Its derivation by partial melting of parautochthonous metapelites has been shown by trace elements and U-Pb-Hf-O isotopes of zircon grains (Turlin et al. 2019).

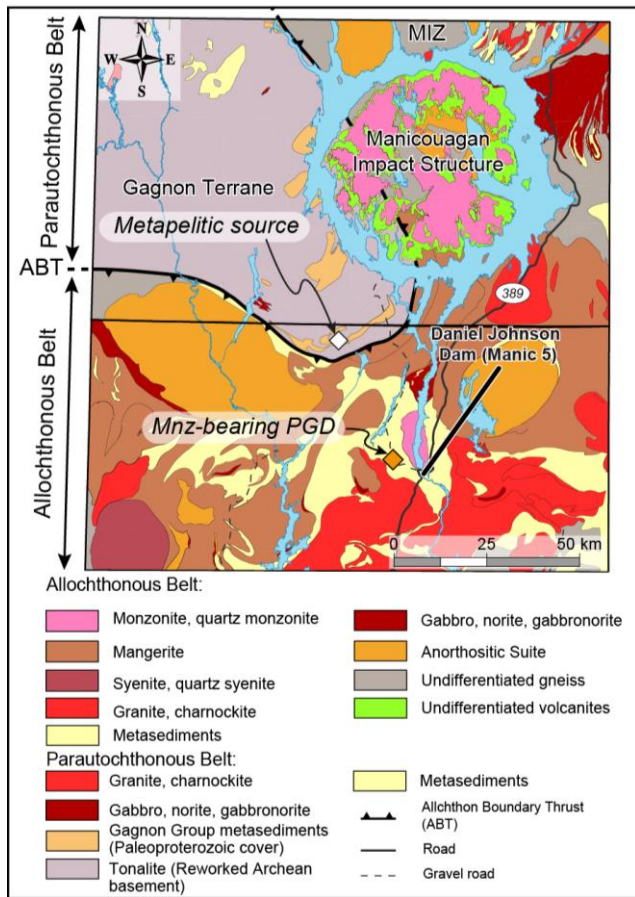


Figure 1. Geological map of the central Grenville Province (Quebec) with the localisation of the investigated LREE-rich pegmatitic granite dyke and of its metapelitic source (modified after Turlin et al. 2017). Abbreviations: MIZ = Manicouagan Imbricate Zone; Mnz = monazite.

4 Petrography

The parautochthonous metapelites correspond to migmatitic paragneisses dominated by the mesosome and the leucosome complemented with a thin melanosome (Fig. 2a). The leucosome is composed of a Pl+K-Fsp+Qtz assemblage (Fig. 2b), the mesosome is composed of a Bt+Grt+Pl+K-Fsp+Qtz assemblage (Fig. 2b), complemented with minor apatite and zircon, and the melanosome is composed of a Bt+Grt+Pl assemblage and minor zircon, apatite and monazite, the latter generally enclosed into garnet (Fig. 2d). Garnet is peritectic as shown by the lack of zonation and their equilibrium with K-feldspar.

The PGD is composed of several facies that range from fine-grained (grain size <1 cm) to pegmatitic (grain size >5 cm). Both are dominated by a Qtz+K-Fsp+Pl assemblage that is complemented with a high proportion of biotite, monazite and zircon in the fine-grained facies (Fig. 2e). In contrast, the pegmatitic facies only shows low proportion of biotite (Fig. 2f) and minor monazite and zircon. Monazite and zircon grains of the PGD do not show any inheritance from the protolith of the PGDs (Turlin et al. 2017, 2019).

5 Genetic link between the metapelites and the PGD

Fractionation of pegmatites from their source can be traced using K-feldspar chemistry (K/Rb ratios and Rb contents, Černý et al. 1985; Hulsboch et al. 2014). Plotted in a K/Rb vs Rb diagram, data should follow a negative exponential distribution if one is fractionated from another (Hulsboch et al. 2014). In this study K and Rb contents of K-feldspar from the leucosome of the migmatites and of the various facies of the PGD were measured using EPMA and LA-ICP-MS, respectively.

The leucosome contains K-feldspar with Rb content of 18 ppm (S.D. of 6 ppm) and K/Rb ratios of 8229 (S.D. of 3868). The K-feldspars from the PGD show Rb contents between 28 and 60 (S.D. < 21) and K/Rb ratios between 2180 and 5798 (S.D. < 4283). The differences in these values is not correlated with magmatic evolution of the PGD from fine-grained to pegmatitic facies.

Plotted in a K/Rb vs Rb diagram, data obtained on K-feldspar from the leucosome of metapelites and from the PGD define a single trend following a negative exponential distribution (Fig. 3). Moreover, data from the PGD show (i) a slight fractionation from the leucosome and (ii) no distinction between the various facies (Fig. 3).

6 Whole rock geochemistry

The metapelites are characterized by a leucosome with a low Σ REE content of 39 ppm, and by a melanosome with a higher Σ REE content of 259 ppm. For the leucosome and the melanosome, the chondrite-normalized REE patterns indicate (i) similar fractionation of LREE over HREE (La_N/Yb_N of 3.4), (ii) no fractionation within the LREE (La_N/Sm_N of 1.1), and (iii) a slight fractionation within the HREE (Gd_N/Yb_N of 2.7) (Fig. 4). The leucosome and the melanosome have chondrite-normalized REE patterns with a strongly positive (Eu/Eu^* of 3.2) or negative (Eu/Eu^* of 0.5) Eu anomaly (Fig. 4), respectively. These features are consistent with the strong proportion of feldspar within the leucosome with no accessory minerals, and with the presence of apatite and monazite within the melanosome (Fig. 2d; Bea 1996). Similarly, the high Σ HREE content in the melanosome is consistent with the presence of garnet and zircon (Bea 1996; Hönig et al. 2014). The mesosome shows intermediate compositions between the leucosome and the melanosome consistent with the intermediate Bt+Grt+Pl+K-Fsp+Qtz assemblage (Fig. 2c) with minor apatite and zircon.

The PGD has a granitic composition (SiO_2 from 60.24 to 73.08 wt.%) and a strong peraluminous signature marked by ASI ranging between 1.12 and 1.36. From the fine-grained to the pegmatitic facies, the chondrite-normalized REE pattern is associated with decreasing (i) Σ REE content (from 7048 to 721 ppm), (ii) negative Eu anomaly (Eu/Eu^* from 0.1 to 0.6), (iii) fractionation of the LREE over the HREE (La_N/Yb_N from 1193 to 223), and (iv) within the HREE (Gd_N/Yb_N from 54 to 11) (Fig. 4). However, the LREE are not fractionated with this magmatic evolution (La_N/Sm_N of 6.8-7.2) (Fig. 4). These

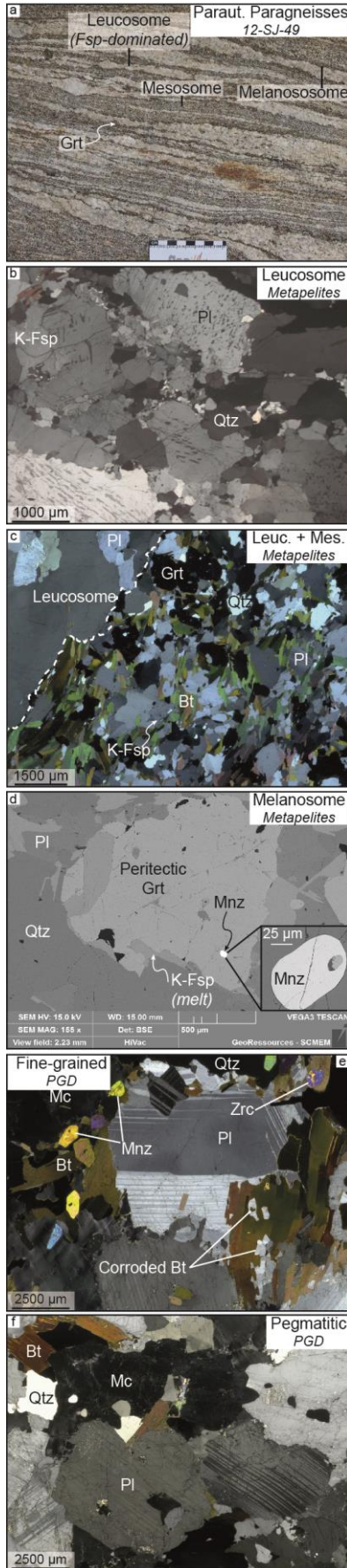


Figure 2. Petrography of the parautochthonous metapelites (a-d) and of the allochthonous-hosted pegmatitic granite dyke (e-f). a: migmatitic paragneisses dominated by mesosome and leucosome; b: leucosome are dominated by a Pl+K-Fsp+Qtz assemblage; c: mesosome are complemented with biotite and peritectic garnet; d: melanosome with prograde monazite enclosed into peritectic garnet; e and f: fine-grained and pegmatitic facies of the pegmatitic granite dominated by a Qtz+K-Fsp+Pl assemblage complemented with high or minor proportions of biotite, monazite and zircon, respectively. Abbreviations: Bt = biotite; Fsp = feldspar; Grt = garnet; Mnz = monazite; Pl = plagioclase; Qtz = quartz; Zrc = zircon.

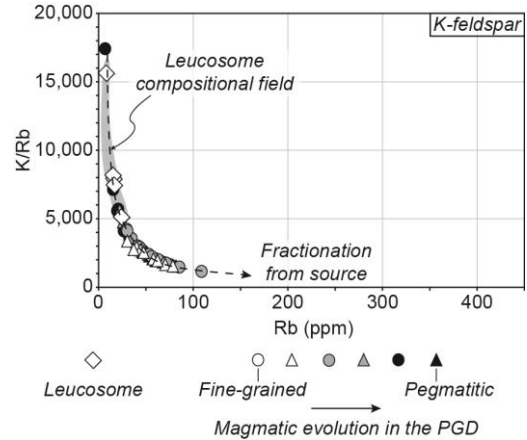


Figure 3. K/Rb vs Rb (ppm) diagram of K-feldspar. Note the little fractionated character of all investigated K-feldspar compared to the model of Hulsbosch et al. (2014) and that K-feldspar from the leucosome show a slightly lower fractionation compared to those from the dyke. No correlation between these fractionations and a specific facies of the latter can be outlined. Abbreviation: PGD = pegmatitic granite dyke.

REE patterns are consistent with the high proportion of monazite hosting the LREE (Bea 1996) in the fine-grained facies and that decreases towards the pegmatitic facies.

7 Discussion

The single trend defined in the K/Rb vs Rb diagram by the K-feldspar from the migmatitic metapelites and the various facies of the peraluminous PGD (Fig. 3) confirm their genetic link by partial melting discussed by Turlin et al. (2019). The peraluminous character of the PGD is not compatible with high proportions of monazite (ΣREE) which solubility in peraluminous melts is below ca. 300 ppm (Montel 1993).

If one considers the melanosome as the relict of the mesosome partial melting, the REE must be strongly compatible and strong REE enrichment is impossible. However, REE contents in the métapelites and in the PGD imply that the REE behaved as incompatible elements. The metapelites do not show strong ΣREE content (not higher than 259 ppm), therefore implying that the genesis of LREE-rich melts with contents up to thousands of ppm (Fig. 3) would result from a low degree (<10%) of partial melting. However, this is incompatible with (i) the lack of inherited monazite and

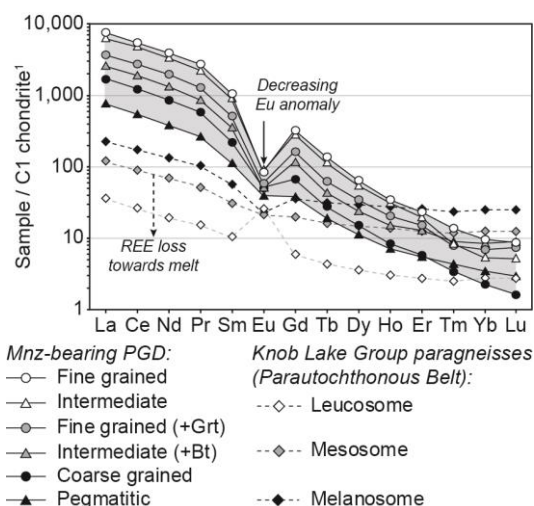


Figure 4. Chondrite-normalized REE patterns of the facies identified in the pegmatitic granite dyke and of the melanosome, mesosome and leucosome of its potential source. Abbreviations: ¹ = McDonough and Sun (1995); Bt = biotite; Grt = garnet.

zircon domains in the PGD that point to their total dissolution in the generated melts (Turlin et al. 2017, 2019), with (ii) the peritectic character of garnet that reflects the biotite destabilization and therefore higher degrees of partial melting, and with (iii) liquid migration in the crust (Vanderhaeghe 2009). In contrast, higher melting rates (>20–25%) would be consistent with the elements discussed above but are incompatible with the LREE enrichment of the PGD. Accordingly, these features point to the role of the fractional crystallization.

The magmatic evolution from fine-grained to pegmatitic facies is associated with a decrease of the REE suggesting fractional crystallization (Fig. 3). However, the decreasing Eu negative anomaly and the stable K/Rb ratios and Rb contents from K-feldspar is in favor of a limited impact, if any, of fractional crystallization (Figs. 3–4).

Accordingly, this study challenges experimental data on LREE behavior within peraluminous melts, but the respective roles of partial melting and fractional crystallization in their genesis from partial melting of REE-unenriched metapelites is still challenging.

Acknowledgements

The authors thank the Ministère de l'Énergie et des Ressources naturelles (Québec, Canada) for technical and financial support for field work and analyses, to Andrei Lecomte (SEM) and Olivier Rouer (EMP) (GeoRessources, Nancy) for support in providing analytical data on SEM and EPMA, and to Chantal (GeoRessources, Nancy) for her help in LA-ICP-MS data acquisition. This work was funded by the Labex Ressources 21 (French National Research Agency – France), program “Investissements d’avenir” (ANR-10-LABX-21–LABEX RESSOURCES 21) and the Région Grand-Est. It benefited from the framework of the DIVEX “Rare earth element” research program.

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