Sn-W-Mo polymetallic behaviour during magmatic evolution of Late Devonian Mount Douglas leucogranites, southwestern New Brunswick, Canada

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Abstract: The Mount Douglas intrusive suite consists of an assemblage of peraluminous leucogranites located along the eastern part of the Saint George Batholith in southwestern New Brunswick, Canada. This late Devonian suite extends from Red Rock Lake to Mount Douglas, and is interpreted to represent the subvolcanic portion of the Mount Pleasant Sn-W-Mo-Bi-In-Zn deposits. The magmatic systems in the Mount Douglas suite have undergone extreme differentiation producing three distinct phases, including Dmd1, Dmd2, and Dmd3, and are associated with various granophile-element occurrences, such as Sn, W, and Mo. It seems the three phases might originate from a single source that evolves with increasing fractionation from the earliest unit (Dmd1) to the youngest unit (Dmd3).

Metal behavior during fractional crystallization is one of the most important factors affecting the types of mineral occurrences associated with the Mount Douglas granites. To establish the metal behavior in the Mount Douglas suite, analytical data from Malcolm McLeod's 1990 report was used in this study. The most incompatible element, Ta, has been selected for defining partition coefficients (D) using the Allegre method. Based on their D values, as expected, Sn with Rb, Y, Nb, LREE [La, Ce, Nd, and Sm], HREE [Tb, Dy, Tm, Yb, and Lu], Pb, Th, and U behave as incompatible elements; showing the Mount Douglas Granite could be considered for exploration of Sn deposits as previous studies have mentioned. However, W and Mo accompanied with the other elements, such as Li, P, Sc, Ti, Cu, Zn, Sr, Zr, Cs, Ba, Eu, and Hf seem to act as compatible elements during magmatic evolution, although melt - supercritical fluid evolution can easily affect W, Mo, Cs, and Li abundances. The apparent compatibility of W and Mo is in contrast with the expected results in which they might act as incompatible elements for developing considerable potential for W-Mo deposits. However, W and Mo concentrations increased with the degree of fractionation and show a significant enrichment in the Mount Douglas granites relative to other granitoid suites in the region; thus their compatibility may be the result of leaching or partitioning out during volatile exsolution, or low pressure fractionation. Furthermore, very low K/Rb (average 102.7), Nb/Ta ($\leq$ 6.83), and Zr/Hf ($\leq$ 35.58) ratios, and high Ti/Sc (125.3 $\leq$) ratio in Dmd3 compared to Dmd1 possibly reflect significant involvement of extreme low T crystal fractionation or even fluid fractionation in the last-stage magmatic differentiation. Consequently, although much more analytical data are needed for exact evaluation of the mineral occurrences in the Mount Douglas Granites, Dmd3 as the most highly differentiated phases might be considered a superior candidate for hosting of Sn-W-Mo deposits.

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Sn-W-Mo-Polymetallic Behaviour during Magmatic Evolution of Late Devonian Mount Douglas Leucogranites, Southwestern New Brunswick, Canada

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ABSTRACT

Metal behavior during fractional crystallization is one of the most important factors affecting the types of mineral occurrences associated with the Mount Douglas granites. The most incompatible element, Ta, has been selected for defining partition coefficients (D) using the Allegre method. Based on their D values, Sn behaves as incompatible elements; showing the Mount Douglas Granite could be considered for exploration of Sn deposits. However, W and Mo act as compatible elements during magmatic evolution, although melt-supercritical fluid evolution can easily affect W, Mo, Cs, and Li abundances. The apparent compatibility of W and Mo is in contrast with the expected results in which they might act as incompatible elements for developing considerable potential for W-Mo deposits. However, W and Mo concentrations increased with the degree of fractionation and show a significant enrichment in the Mount Douglas granites relative to other granitoid suites in the region; thus their compatibility may be the result of leaching or partitioning out during volatile exsolution, or low pressure fractionation.

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INTRODUCTION

The Mount Douglas intrusive suite consists of an assemblage of peraluminous leucogranites located along the eastern part of the Saint George Batholith in southwestern New Brunswick, Canada (Fig. 1). This late Devonian suite extends from Red Rock Lake to Mount Douglas, and is interpreted to represent the subvolcanic portion of the Mount Pleasant Sn-W-Mo-Bi-In-Zn deposits. The magmatic systems in the Mount Douglas suite have undergone extreme differentiation producing three distinct phases, including Dmd1, Dmd2, and Dmd3, and are associated with various granophile-element occurrences, such as Sn, W, and Mo.

MAJOR AND TRACE ELEMENTS STUDIES

The samples from the Mount Douglas (MD) granites are characterized by high contents (wt.%) of SiO_2 (68-78), K_2O (3.5-7.8), $(Fe_2O_3+FeO)/MgO$ ratio (average 8.7), and alkalis; low CaO and MgO, and very low P_2O_5 and TiO_2. The Dmd3 shows the highest amount of SiO_2 with an average of 76.4 wt. %. With regards to their trace elements, the MD leucogranites are strongly enriched in the incompatible elements, such as F, Li, Rb, Cs, U, Th, and Nb; this enrichment is correlated with an obvious depletion in compatible elements (e.g., Ca, Mg, Ti, Sr, Ba, and Eu). Compared to the Dmd2 and Dmd3, the Dmd1 has the lowest amounts of compatible trace elements, the smallest negative Eu anomalies, as well as Ba, Sr, P, and Ti; however, they have enriched chondrite-normalized REE patterns [$(La/Yb)_N$ = 4.321.8]. Normalized to the least-evolved sample of the MG granites (Dmd1), the Dmd3 unit is the most enriched in Rb, Th, U, Ce, Ta, Pb, Nd, Sm, Dy, Y, Yb, and Lu, and show extreme reduction in Ba, Sr, P, Zr, Eu, and Ti content (Fig. 2), thus reflecting fractionation from Dmd1 to Dmd3. Rb-Ba-Sr diagram (Fig. 3) shows a clear progressive differentiation from Dmd1 to Dmd3. On the plot of Nb vs. Sr (Fig. 4), the samples mainly fall in the field between fractional crystallization and assimilation-fractional crystallization (r= 0.2) curves.

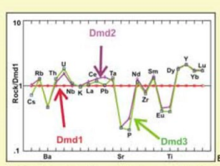

Fig. 2: Enrichment-factor diagram of the three units of the Mount Douglas granites. Dmd1 to Dmd3 data are based on the average composition of all samples from each normalized to Dmd1 as the least-evolved granite.

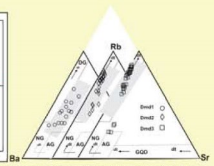

Fig. 3: A clear progressive differentiation of the Mount Douglas Granites from Dmd1 to Dmd3 on the Rb-Ba-Sr diagram. GGD: granodiorites, quartz diorites, and diorites NG: Normal Granites, DG: Strongly Differentiated Granites, dt: differentiation trend.

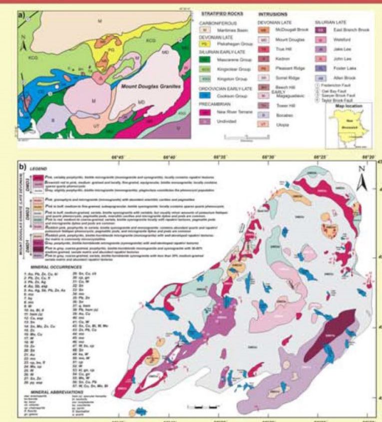

Fig. 1: a. Geological map of southwestern New Brunswick (modified after McLeod et al., 1994) and location of the studied leucogranite suite (Mount Douglas). b. Geological setting of the Mount Douglas suite and the related mineral occurrences (modified after McLeod, 1990).

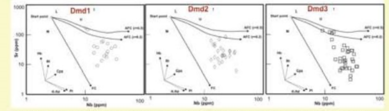

Fig. 4: Nb vs. Sr diagram for granitoid samples of the Mount Douglas Granites. The Mount Douglas samples mainly fall in the field between fractional crystallization and assimilation-fractional crystallization (r=0.2) curves (see Yang et al., 2003).

METAL BEHAVIOUR

To establish the metal behavior in the Mount Douglas suite, analytical data from Malcolm McLeod's report (1990) was used in this study. Ta has been selected for defining partition coefficients (D) using the Allegre method. Based on their D values, Sn with Rb, Y, Nb, LREE [La, Ce, Nd, and Sm], HREE [Tb, Dy, Tm, Yb, and Lu], Pb, Th, and U behave as incompatible elements; however, W and Mo accompanied with the other elements, such as Li, P, Sc, Ti, Cu, Zn, Sr, Zr, Cs, Ba, Eu, and Hf seem to act as compatible elements (Fig. 5). Furthermore, very low K/Rb (average 102.7), Nb/Ta ($\leq$ 6.83), and Zr/Hf ($\leq$ 35.58) ratios, and high Ti/Sc (125.3 $\leq$) ratio in Dmd3 compared to Dmd1 possibly reflect significant involvement of extreme low T crystal fractionation or even fluid fractionation in the last-stage magmatic differentiation.

CONCLUSION

Petrochemical data show that the subunits of Mount Douglas Granites, Dmd1, Dmd2, and Dmd3, have within-plate geochemical character with possibility of hybrid I- and S-type affinity. It seems that they have been produced by fractional crystallization of the same parental magma with different magmatic evolution. Extreme fractional crystallization and fluid involvement during formation of these units have been the most important factors affecting the magma evolution, producing three different units, compositionally. Although W and Mo apparently act as compatible elements comparing to Ta, their concentration increase is accompanied with the degree of fractionation. On the other hand, these metals show a significant enrichment, and their compatibility may be the result of leaching or partitioning out during volatile exsolution. Consequently, although much more analytical data are needed for exact evaluation of the mineral occurrences in the Mount Douglas Granites, Dmd3 as the most highly differentiated phases might be considered for hosting of endogranitic Sn-W-Mo deposits.

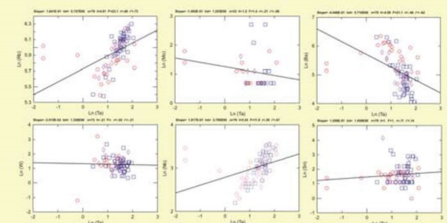

Fig. 5: Representative logarithmic variation diagrams (ppm) for samples from the Mount DouglasGranites.

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