Petrogenetic classification of rare earth enriched pegmatites, with reference to their REE mineralogy and Australian occurrences

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Granitic pegmatites are well known for the cornucopia of their mineralogy, which includes silicates, phosphate and oxide species of both common and rare elements, some only found in granitic pegmatites. The wide variety of mineralogy, texture and chemistry of these pegmatites inherently necessitates a classification scheme.

The classification of granitic pegmatites, particularly those enriched in rare metals, including rare earths, has been a vexed issue for some time, due to the complex interplay between factors relating to geochemistry, mineralogy and tectonic environment. Initial classification of granitic pegmatites, and much of modern pegmatite science, goes back in time to the former USSR after the Second World War. Repeated revisions of this classification schema, most recently by Petr Cerny, have culminated in the work of Cerny and Ercit (2005; and references therein).

Essentially, the classifications of Cerny use two approaches: (1) an eclectic combination of pegmatite internal structure, pressure-temperature conditions of crystallization, geologic environment, and the occurrence of characteristic minerals. This classification allows the hierarchical division of pegmatites into five classes: abyssal, muscovite, muscovite–rare-element, rare-element, and miarolitic. Most of these classes have been further subdivided into types based primarily on their rare element mineralogy. In the case of rare earth elements, these are the light rare earth elements (LREE) and heavy light rare earth elements (HREE) subclasses of the abyssal class, the REE subclass of the muscovite class, and the allanite-monazite, euxenite and gadolinite subclasses of the rare element class.

The second approach (2) utilizes bulk geochemistry related to petrogenetic setting, and igneous (granitic) parentage of pegmatites, where such can be inferred from field relations. This approach divides pegmatites between the NYF (Nb-Y-F) petrogenetic family of granitic pegmatites and the LCT (Li-Cs-Ta) petrogenetic family (Table 1). The NYF petrogenetic family of pegmatites are typically enriched in REE, and are thus focussed on here. In addition to REE, Nb, Y and F, NYF pegmatites are also typically enriched in U, Th, Ti and Zr, and to a lesser or variable degree Be, Sc, Ba, Fe, Mg, Ta and Ga.

We focus here on the NYF pegmatite family, as a convenient grouping to study most rare earth bearing pegmatites of mineralogical interest in Australia. The NYF pegmatite family embraces the rare element and miarolitic pegmatite classes from Cerny’s first classification (1). Use of the second approach of Cerny avoids potentially excessive ‘pigeonholing’ inherent in the first approach. As pointed out by Simmons (2005), many rare metal pegmatites “do not fall nicely into…categories”. For example, in the case of NYF pegmatites, some may be enriched in Nb but not Y, and vice versa. Also minor amounts of non-characteristic elements, and therefore minerals, may be present within individual pegmatites of larger pegmatite populations. As a point of clarity, mentioned by Ercit (2004), the LCT and NYF terminology is best applied to scaled pegmatite groupings, rather than individual pegmatites. It is more appropriate to describe individual pegmatites as being enriched in
particular elements, e.g. (Nb, REE)-enriched, to allow a more precise description of pegmatite geochemistry.

The imputed non-magmatic origin of at least some of the REE-enriched pegmatites of the abyssal and muscovite classes was originally considered to limit the application of the LCT-NYF classification to the rare element class of Cerny’s first classification approach. However, Ercit (2004) proposed to allow the abyssal and muscovite classes to be considered within the LCT-NYF classification system, based upon relating pegmatite class classification to emplacement depth, exclusive of igneous affiliation as indeed the mineralogy of the abyssal class pegmatites lends itself to an affiliation with NYF pegmatites.

The distinctive characteristics of the LCT-NYF two petrogenetic families, in terms of geochemistry and source origin, are laid out in Table 1. The practical implications of the LCT-NYF classification are displayed in Table 2, including characteristic field, mineralogical and geochemical features. In contrast to the NYF family of pegmatites, the LCT family contains the bulk of mineral species of interest to mining companies, scientists and collectors. The LCT family includes well known giant sized rare metal orebodies of economic interest, such as Greenbushes and Wodgina in Western Australia, Bikita in Zimbabwe and Tanco in Canada.

Further subdivision of LCT and NYF into petrogenetic subdivisions based upon their source granites (the I, S and A granite types; e.g., Chappell and White, 1974, 2001; Whalen et al., 1987) has been proposed by Cerny and Ercit (2005), but progress on further subdivisions has stalled because of a lack of detailed studies, as well as controversy regarding interpretation of palaeotectonic settings (Table 1). Notwithstanding this, much recent research work has strived to link granitic pegmatites with their tectonic source regions, with some degree of success (e.g. Martin and De Vito, 2005).

The most important rare earth bearing minerals of NYF pegmatites, ordered by relative abundance (Ercit, 2004), are allanite, the (Y, HREE)-dominant members of the euxenite, aeschynite, samarskite and fergusononite groups, gadolinite, monazite-(Ce), ceriopyrochlore-(Ce), and xenotime-(Y) and –(Yb). A host of minor borates, carbonates, silicates, borates and vanadates are also known, mostly of secondary (typically alteration of primary minerals) origin. A particularly striking indicator or divider between the LCT and NYF family end-members is provided by the distinctly different (paragenetically) primary Ta-Nb species encountered in each family (Table 2).

Australian examples of NYF pegmatite groupings are principally encountered in the Pilbara and Yilgarn Cratons (Table 2), with other examples known in the Proterozoic Albany Fraser Orogen, W.A. (Jacobson et al., 2007) and Proterozoic allanite–monazite bearing pegmatites from the Harts Range, Arunta Block, Northern Territory (Hussey, 2003). Economic exploitation of some of these pegmatites for REE minerals has been done only on a small scale in the Pilbara Craton, mostly prior to 1950. Much of this REE production has come from alluvial or eluvial sediments derived from these pegmatites, rather than hard rock mining of the pegmatites themselves (Sweetapple, 2000).

In general, these Australian examples are poorly documented, with studies limited to mineralogical examinations of their REE-bearing minerals. These pegmatites appear to be
small in size, compared with examples of the LCT family of economic significance. In the case of the Pilbara Craton, NYF pegmatites may be up to 200 metres long, with a maximum thickness of 2 metres, with the exception of a pegmatite of the Abydos district which is up to 40 metres thick. These sizes may limit the potential of NYF pegmatites as exploration targets, except perhaps when they occur in localized swarms.

In terms of our scientific knowledge base, it is important to point out that there is a very substantial gap between our knowledge of the systematics and genesis of NYF pegmatites compared with LCT pegmatites, on a worldwide basis. Even less is known about ‘crossbred’ LCT-NYF pegmatite occurrences. Documentation and description of key REE bearing minerals has been carried out, but a lack of systematic studies of districts and provinces is lacking. Certainly this is due in large part to the wider range of minerals of economic and collector interest in LCT pegmatites, coupled with the smaller sizes and less spectacular ranges of minerals typical of many NYF pegmatites.

References:
Table 1: The three petrogenetic families of rare element pegmatites, based on geochemical criteria, and different crustal sources of rare elements (adapted from Cerny, 1993; Cerny and Ercit, 2005). Peralkaline pegmatites are not included in this schema.

<table>
<thead>
<tr>
<th>Family</th>
<th>Dominant Pegmatite Subclasses</th>
<th>Geochemical Signature</th>
<th>Pegmatite Bulk Composition</th>
<th>Associated Granites Bulk Composition</th>
<th>Source Lithologies</th>
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<tbody>
<tr>
<td>LCT</td>
<td>REL-Li MI-Li</td>
<td>Li,Rb, Cs,Be,Sn,Ga Ta &gt; Nb(B,P,F)</td>
<td>peraluminous</td>
<td>mostly late orogenic; S,I or mixed S+I types</td>
<td>undepleted upper-to middle-crust supracrustals and basement gneisses</td>
</tr>
<tr>
<td>NYF</td>
<td>REL-REE MI-REE</td>
<td>Nb &gt; Ta,Ti, Y,Sc,REE, Zr,U,Th, F</td>
<td>subaluminous-metaluminous (to subalkaline)</td>
<td>mostly anorogenic; A and (l) types</td>
<td>depleted middle to lower crustal granulites, or undepleted juvenile granitoids</td>
</tr>
<tr>
<td>Mixed</td>
<td>“Cross-bred” LCT and NYF</td>
<td>mixed</td>
<td>(metaluminous to) moderately peraluminous</td>
<td>(postorogenic to) anorogenic; mixed geochemical signature</td>
<td>Mixed protoliths; or assimilation of supracrustals by A(or I) type granites</td>
</tr>
</tbody>
</table>

Definitions: peraluminous $\frac{A}{CNK}>1$; subaluminous $\frac{A}{CNK}~1$; metaluminous $\frac{A}{CNK}<1$ and $\frac{A}{NK}>1$; subalkaline $\frac{A}{NK}~1$, where $A = \text{molecular } \text{Al}_2\text{O}_3$, $CNK = \text{Ca}_2\text{O} + \text{Na}_2\text{O} + \text{K}_2\text{O}$, and $NK = \text{Na}_2\text{O} + \text{K}_2\text{O}$

REL = Rare element pegmatite class, MI = miarolitic pegmatite class
### Table 2: Summary of characteristic differences between LCT and NYF petrogenetic pegmatite family endmembers (adapted from Vanstone, 2010).

<table>
<thead>
<tr>
<th></th>
<th><strong>LCT (Lithium-Caesium-Tantalum)</strong></th>
<th><strong>NYF (Niobium-Yttrium-Fluorine)</strong></th>
</tr>
</thead>
</table>
| **Relationship to source granites** | • Pegmatitic granite phase is required for pegmatite development.  
• Typically forms part of regional zonation pattern | • No pegmatitic granite phase  
• Mostly lack of regional zonation patterns |
| **Chemical signature**          | • Ta > Nb  
• (Very) low REE contents  
• Enriched in boron and alkali elements.  
• Sn content can equal Ta content.  
• U and Th levels tend to be low. | • Nb > Ta  
• Enriched in the light and heavy rare earth elements (REE’s).  
• Sn is not commonly enriched.  
• May be enriched in U and Th. |
| **Mineralogy**                  | • Fluorite is rare (F bound in topaz, lepidolite, amblygonite)  
• Lithium and phosphate minerals are common.  
• Tourmaline is common  
• Generally simple Ta-Nb oxides ± Sn without essential REE  
• Beryl can be present | • Fluorite is common  
• Lithium and phosphate minerals are rare  
• Tourmaline is relatively rare; restricted compositional range  
• Complex oxides of Nb, Ta and REE’s, viz., euxenite, fergusonite, samarskite, aeschynite mineral groups  
• Beryl can be present. |
| **Western Australian pegmatite examples** | Wodgina district, Pilbara Craton  
Tabba Tabba field, Pilbara Craton  
Greenbushes field, Yilgarn Craton  
Londonderry district, Yilgarn Craton | Cooglegong district, Pilbara Craton  
Abydos district, Pilbara Craton  
Mukinbudin district, Yilgarn Craton  
Fraser Range group, Albany Fraser Orogen |

*Principal references for examples: Sweetapple and Collins (2002); Jacobsen et al. (2007)