MONAZITE-(Sm), A NEW MEMBER OF THE MONAZITE GROUP FROM THE ANNIE CLAIM #3 GRANITIC PEGMATITE, SOUTHEASTERN MANITOBA

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ABSTRACT

Monazite-(Sm) was found in the Annie Claim #3 pod of lepidolite-subtype granitic pegmatite within the Greer Lake intrusion of pegmatitic leucogranite, in the Archean Bird River Subprovince of the Superior Province, in southeastern Manitoba. It occurs as tabular crystals ≤0.4 mm in diameter, associated with manganocolumbite, quartz, albite and lithian muscovite. Monazite-(Sm) is yellowish, translucent, with a white streak, vitreous to greasy luster, and no observed fluorescence. One good cleavage is present, tenacity is brittle, and the fracture is uneven. Monazite-(Sm) has no observable pleochroism; α 1.768 (5), β 1.771(3), γ > 1.808(3); $2V_{meas}$ 29(8)°, $X = b$, $Z \wedge c = 9°$ (β obtuse). It is monoclinic, space group $P2_1/n$; a refinement from single-crystal and *powder* (Gandolfi) X-ray-diffraction data gave a 6.725(1), *6.739(3)*, b 6.936(1), *6.951(3)*, c 6.448(1), *6.462(3)* Å, β 104.02(1)°, *104.03(4)*°, V 291.8(1), *293.6(2)* Å^3, $Z = 4$; D_{calc} derived from average chemical composition is 5.512 and *5.478* g/cm^3. The strongest six lines of the (Gandolfi) X-ray-diffraction pattern [d in Å$(I)(hkl)$] are: 4.647(5)(011), 4.164(8)($\bar{1}$11), 3.492(4)(111,020), 3.264(7)(200), 3.065(10)(120), and 2.857(9)($\bar{1}$12,012). The monazite-(Sm) contains, in wt.%, up to 14.29 Sm_2O_3, 13.48 Gd_2O_3 and 6.28 Nd_2O_3, and moderate percentages of the huttonite and brabantite components. The most Sm-rich composition gives $(Sm_{0.197}Gd_{0.179}Ce_{0.148}Th_{0.125}Ca_{0.107}Nd_{0.090}La_{0.030}Y_{0.030}Pr_{0.023}Tb_{0.017} Zr_{0.017}Dy_{0.016}Pb_{0.016}U_{0.002})_{\Sigma0.997}$ $(P_{0.963} Si_{0.044})_{\Sigma1.007} O_4$. Adjustment of U and Th of the monazite-(Sm) to their original contents 2.64 Ga ago slightly improves the stoichiometry and proves that all the Pb present is radiogenic. The middle-*REE*-dominant signature of the Annie Claim #3 monazite-(Sm) is shared with the broadly associated $Y(Ta,Nb)O_4$ mineral (formanite?) and dysprosian xenotime-(Y); this exotic pattern of *REE* abundances is possibly generated by selective and differential complexing of *REE* in the granite-to-pegmatite sequence of solidification.

Keywords: monazite-(Sm), new mineral species, rare-earth elements, granitic pegmatite, Annie Claim #3, Manitoba, Canada.

SOMMAIRE

Nous avons découvert la monazite-(Sm) dans la lentille de pegmatite granitique à lépidolite dite Annie Claim #3, au sein du massif intrusif du lac Greer, dans la sous-province de Bird River de la Province du Supérieur, dans l'Archéen du sud-est du Manitoba. Elle se présente en cristaux tabulaires atteignant 0.4 mm en diamètre, associée à manganocolumbite, quartz, albite et muscovite lithinifère. Les cristaux de monazite-(Sm) sont jaunâtres, translucides, ayant une rayure blanche, un éclat vitreux à résineux, sans fluorescence. Nous décelons un bon clivage; la ténacité est cassante, et la fracture, inégale. La monazite-(Sm) ne montre aucun pléochroïsme observable; α 1.768 (5), β 1.771(3), γ > 1.808(3); $2V_{meas}$ 29(8)°, $X = b$, $Z \wedge c = 9°$ (dans l'angle β obtus). Elle est monoclinique, groupe spatial $P2_1/n$; un affinement des paramètres réticulaires à partir des données prélevées sur monocristal et sur *poudre* (méthode de Gandolfi) a donné a 6.725(1), *6.739(3)*, b 6.936(1), *6.951(3)*, c 6.448(1), *6.462(3)* Å, β 104.02(1)°, *104.03(4)*°, V 291.8(1), *293.6(2)* Å^3, $Z = 4$. La densité calculée à partir de la composition moyenne est 5.512 et *5.478* g/cm^3. Les six raies les plus intenses du spectre de diffraction X (Gandolfi) [d en Å$(I)(hkl)$] sont: 4.647(5)(011), 4.164(8)($\bar{1}$11), 3.492(4)(111,020), 3.264(7)(200), 3.065(10)(120), et 2.857(9)($\bar{1}$12,012). La monazite-(Sm) contient jusqu'à 14.29% Sm_2O_3, 13.48% Gd_2O_3 et 6.28% Nd_2O_3 (poids), et des proportions appréciables des composantes huttonite et brabantite. La composition la plus enrichie en Sm donne $(Sm_{0.197}Gd_{0.179}Ce_{0.148}Th_{0.125}Ca_{0.107}Nd_{0.090}La_{0.030}Y_{0.030}Pr_{0.023}Tb_{0.017} Zr_{0.017}Dy_{0.016}Pb_{0.016}U_{0.002})_{\Sigma0.997}$ $(P_{0.963} Si_{0.044})_{\Sigma1.007} O_4$. Un ajustement des teneurs en U et Th de la monazite-(Sm) à leurs teneurs originelles il y a 2.64 Ga améliore légèrement la stœchiométrie et prouve que tout le Pb est radiogénique. L'enrichissement de ce minéral en terres rares moyennes se voit aussi dans un minéral associé de composition $Y(Ta,Nb)O_4$ (formanite?) et le xénotime-(Y) enrichi en dysprosium

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à Annie Claim #3. Cet enrichissement inhabituel pourrait bien refléter la complexation sélective et différentielle des terres rares au cours de la solidification progressive sur l'intervalle granite–pegmatite.

<div align="right">(Traduit par la Rédaction)</div>

Mots-clés: monazite-(Sm), nouvelle espèce minérale, terres rares, pegmatite granitique, Annie Claim #3, Manitoba, Canada.

INTRODUCTION

There are three known members of the monazite group *sensu stricto*. They contain as dominant trivalent cations the three lightest, largest and geochemically most abundant rare-earth (*REE*) elements, La, Ce and Nd, in accord with their preference for the monazite structure (Ni *et al.* 1995). Monazite-(Ce) is by far the most widespread member, whereas monazite-(La) is rarely observed, and monazite-(Nd) seems to be known so far from only three localities (Gaines *et al.* 1997, Anthony *et al.* 2000).

Here we report on a new monazite-group mineral, the *REE* composition of which is distinctly shifted toward the middle *REE* (*MREE*): monazite-(Sm) in fact has Gd a close second in importance to Sm. Moreover, Tb is the third most abundant *REE* in terms of chondrite-normalized values. The new mineral is named in accordance with recommendations of the Commission on New Minerals and Mineral Names of the International Mineralogical Association for *REE* minerals. The species and the name were approved by the above Commission (IMA 2000-001). The polished section analyzed by electron microprobe (EMPA), the single crystal used for X-ray diffraction (XRD) and optical study, and the three microchips used for Gandolfi XRD are catalogued under #M7181 in the R.B. Ferguson Museum of Mineralogy, Department of Geological Sciences, University of Manitoba.

THE PARENT PEGMATITE

Monazite-(Sm) was found in the Annie Claim #3 granitic pegmatite, a zoned body of the lepidolite subtype located in the southwestern margin of its parent Greer Lake pegmatitic granite. This LCT-family granite and derived pegmatites, dated at 2640 ± 7 Ma (Baadsgaard & Černý 1993), were intruded in metabasalts of the Lamprey Falls Formation of the Bird River Greenstone Belt, in the Bird River Subprovince of the western part of the Superior Province of the Canadian Shield; the geographic location is 1.2 km northwest of Greer Lake in southeastern Manitoba, close to Winnipeg River, at latitude 50°21'12"N and longitude 95°20'18"W. Černý *et al.* (1981) provided details concerning the regional geology.

The subellipsoidal, subhorizontal body of the pegmatite is approximately 7 × 10 meters in size, with distinct concentric zoning (Masau 1999). The zones show an inward progression, changing in texture and mineral assemblage, exemplified by a border-to-core succession of five main types of mica (from muscovite to lithian muscovite to lepidolite), associated mainly with albite and quartz. Microcline perthite is sporadic in the outermost zones and absent from the intermediate and inner zones. Accessory minerals include spessartine, cesian beryl, cassiterite with exsolved zirconian–hafnian wodginite (Masau *et al.* 2000a), manganocolumbite, manganotantalite and rare primary wodginite, microlite, uranpyrochlore, ferrotapiolite, probable formanite-(Y), fluorapatite, zircon, coffinite, uraninite, dysprosian xenotime-(Y) (Masau *et al.* 2000b) and monazite-(Sm). The pegmatite and the parent pegmatitic granite do not contain any minerals of B or phosphates of Li, Al, Fe or Mn, and sulfides are extremely rare.

EXPERIMENTAL

Monazite-(Sm) was analyzed using a Cameca SX–50 electron microprobe in wavelength-dispersion mode, under the following conditions: operating voltage 20 kV, beam current 40 nA, beam size 3 μm. Counting times for peak and background determinations were 20 s and 10 s, respectively, for Si, P, Ca, Zr, Dy, Pb, Th and U; for the remaining elements, the values were 40 and 20 s, respectively. Monazite-(Sm) was analyzed using the following standards: $SmPO_4$ ($PK\alpha$, $SmL\beta$) and other individual synthetic phosphates APO_4 ($L\alpha$ for Y, La, Ce, Nd and Tb, $L\beta$ for Pr, Gd and Dy), zircon ($SiK\alpha$, $ZrL\beta$), mimetite ($PbM\beta$), ThO_2 ($ThM\alpha$), UO_2 ($UM\beta$) and Wilberforce apatite ($CaK\alpha$). Concentrations of Ho, Er and Tm [the last adjusted for overlap with Sm using the method of Åmli & Griffin (1975) and Nagy (1993)] were found to be below detection limits (0.03, 0.02 and 0.04 wt.%, respectively, at 100 nA and 100 s). Contents of Yb and Lu were at about their respective limits of detection under these conditions (0.02 and 0.05 wt.%); Na, K, Mn, Fe, Mn, Ba, Sr, As, S, F, Nb and Ta were not detected. The analytical data were reduced and corrected by the *PAP* method of Pouchou & Pichoir (1984, 1985). Chondritic *REE* values of Taylor & McLennan (1985) were used to normalize the *REE* contents.

Single-crystal data were collected on a Bruker automated four-circle diffractometer equipped with a CCD detector, using $MoK\alpha$ radiation with λ = 0.71073 Å. Unit-cell dimensions were refined from 106 diffraction maxima (I/sig > 10) with 2θ up to 60°. Powder data were recorded with a 114.6 mm Debye–Scherrer camera with Gandolfi attachment, using Ni-filtered $CuK\alpha$ radiation with λ = 1.5418 Å.

Monazite-(Sm)

Monazite-(Sm) was found to be closely aggregated with platy crystals of manganocolumbite in the inner intermediate zone of the parent pegmatite. The aggregate is associated with quartz, "cleavelandite" and curvilamellar lithian muscovite. No other *REE* minerals are present in close proximity to monazite-(Sm), although some do occur elsewhere in the pegmatite, as mentioned above.

Platy subhedral crystals of monazite-(Sm) attain a maximum dimension of 0.4 mm (Fig. 1). They are brittle, yellowish and translucent to transparent, with vitreous to slightly greasy luster and white streak. Microscopic fragments show one good cleavage and, otherwise, uneven fracture-surfaces. No fluorescence was observed in UV light. Density and hardness could not be measured. However, density calculated from the average chemical composition is 5.512 and 5.478 g/cm^3 for unit-cell dimensions derived from X-ray diffraction single-crystal and powder (Gandolfi) data, respectively. Optical properties measured at a wavelength of 589.9 nm are α 1.768(5), β 1.771(3), γ > 1.808(3) [no immersion liquid with n > 1.808 was available to the authors; γ calculated from α, β and 2V (measured) is 1.818]. The measured (+)2V is 29(8)°; the value calculated using 1.808 as a minimum for γ is 32°; $X = b$, $Z \wedge c$ = 9° (β obtuse). Microscopic fragments of monazite-(Sm) are colorless.

The chemical composition of monazite-(Sm) is shown in Table 1. The average composition of the fragments used for XRD and optical study (Table 1, #1) yields a formula with Sm distinctly dominant over Gd, Ce, Th and Ca, with subordinate to minor contents of other *REE*. The dominance of Sm and Gd over other cations is even better expressed in the most Sm-enriched composition (Table 1, #2): $(Sm_{0.197} Gd_{0.179} Ce_{0.148} Th_{0.125} Ca_{0.107} Nd_{0.090} La_{0.030} Y_{0.030} Pr_{0.023} Tb_{0.017} Zr_{0.017} Dy_{0.016} Pb_{0.016} U_{0.002})_{\Sigma 0.997} (P_{0.963} Si_{0.044})_{\Sigma 1.007} O_4$. However, note that this extreme composition was not obtained on any of the grains extracted from the polished section for XRD work and determination of physical properties.

Slight improvement of stoichiometry and charge balance is achieved by calculation of the original U and Th contents of the monazite-(Sm) as they were at the time of crystallization 2.64 Ga ago (Table 1, #1* and 2*). The virtually identical atomic content of present-day Pb (0.023 and 0.016 in #1 and 2) with those of decayed U + Th (0.023 and 0.018; 1* less 1 and 2* less 2,
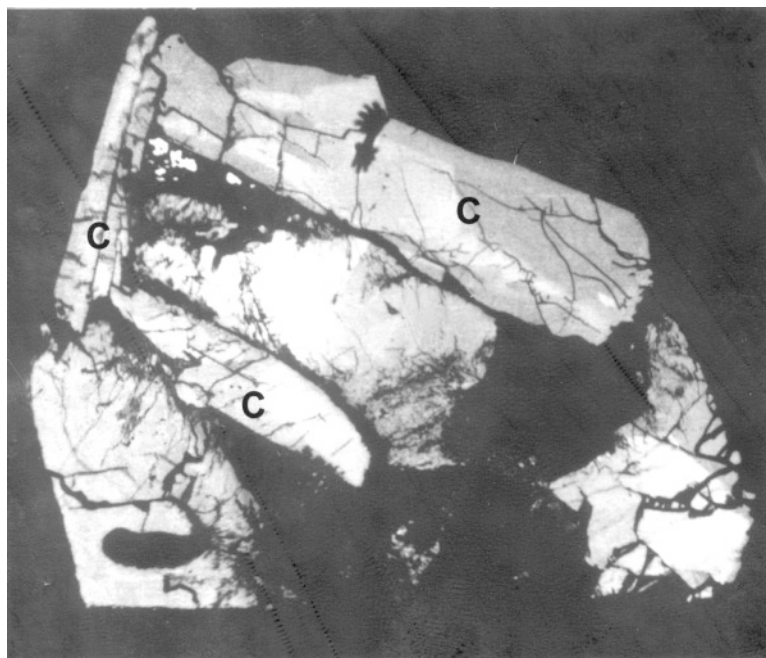

FIG. 1. Back-scattered electron image of the main aggregate of monazite-(Sm) and manganocolumbite (C) embedded in quartz (black). Variations in brightness of the monazite-(Sm) are controlled by the Th content, whereas the ratio Nb/Ta affects manganotantalite. The aggregate is 0.8 mm across.

respectively) shows that all Pb is radiogenic, and that any potential loss of Pb from the monazite structure has been negligible.

The current content of Th is substantial, but it gives only 4 to 10 mole % of the huttonite component $ThSiO_4$ and 10 to 14 mole % of the brabantite component $CaTh(PO_4)_2$, when split between the available Si and Ca, respectively. The stoichiometry of the brabantite and

huttonite components in solid solution is confirmed by the good alignment of atomic Si *versus* (Th + Zr + U – Ca) in Figure 2A, although slightly shifted in favor of the latter elements. Good analytical totals and stoichiometry calculated on an anhydrous basis indicate that any potential role of a tetrahedral array of (OH) groups must be negligible, if any, in both the current and original compositions. Figure 2B shows that the *A*:(P + Si) ratio equals 1 within the limits of analytical error.

Unit-cell dimensions were derived from single-crystal and *powder* data: *a* 6.725(1), *6.739(3)*, *b* 6.936(1), *6.951(3)*, *c* 6.448(1), *6.462(3)* Å, β 104.02(1)°, *104.03(4)°*, *V* 291.8(1), *293.6(2)* Å^3, *Z* = 4. The XRD powder data are shown in Table 2. Systematically absent diffraction-maxima in the single-crystal and powder data are consistent with space group $P2_1/n$. Both the unit-cell dimensions and the powder data closely match those available for other monazite-group minerals (*e.g.*, Ni *et al.* 1995). However, the substantial contents of Th and Ca do not permit direct comparison with cell-parameter values calculated on the basis of occupancy by the *REE* alone (Ni *et al.* 1995).

GEOCHEMICAL CONSIDERATIONS

As noted in the introduction, dominance of La or Nd is rather rare in monazite-group minerals, although both these elements are commonly the second and third most abundant *REE* in monazite-(Ce). The extent of enrichment in Sm (and Gd) shown in Figure 3 for monazite-(Sm) has not so far been reported. The highest Sm_2O_3
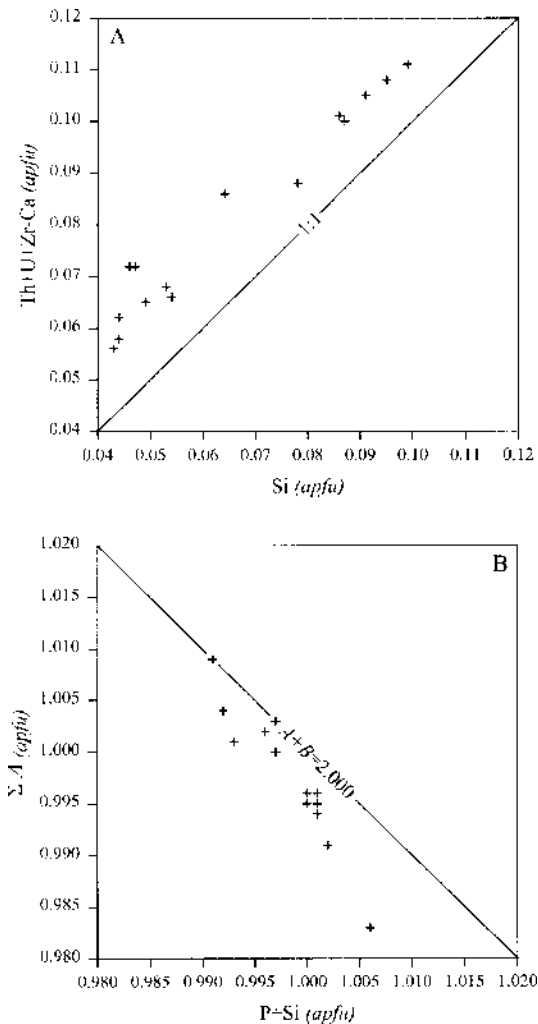
FIG. 2. (A) Th + Zr + U – Ca *versus* Si (atoms per formula units) in monazite-(Sm) adjusted for 2.64 Ga of U and Th decay; close adherence to the 1:1 ratio confirms solid solution toward the huttonite and brabantite components. (B) Sum of *A* cations *versus* P + Si (atoms per formula unit normalized to four atoms of oxygen) in monazite-(Sm); except for a single point, all data correspond to the ideal 1:1 ratio within experimental error.

TABLE 1. REPRESENTATIVE COMPOSITIONS OF MONAZITE-(Sm)

	1	2	1*	2*		1	2	1*	2*
P_2O_5	27.48	28.39	27.48	28.39	P	0.942	0.963	0.936	0.958
SiO_2	1.53	1.09	1.53	1.09	Si	0.062	0.044	0.062	0.043
					ΣB	1.004	1.007	0.998	1.001
ZrO_2	0.71	0.89	0.71	0.89	Zr	0.014	0.017	0.014	0.017
ThO_2	16.27	13.69	18.50	15.56	Th	0.150	0.125	0.169	0.141
UO_2	0.62	0.28	0.99	0.44	U	0.005	0.002	0.009	0.004
Y_2O_3	1.29	1.40	1.29	1.40	Y	0.028	0.030	0.028	0.030
La_2O_3	2.10	2.02	2.10	2.02	La	0.032	0.030	0.031	0.030
Ce_2O_3	10.04	10.07	10.04	10.07	Ce	0.149	0.148	0.148	0.147
Pr_2O_3	1.58	1.60	1.58	1.60	Pr	0.023	0.023	0.023	0.023
Nd_2O_3	6.03	6.28	6.03	6.28	Nd	0.087	0.090	0.087	0.089
Sm_2O_3	13.02	14.29	13.02	14.29	Sm	0.182	0.197	0.181	0.196
Gd_2O_3	12.06	13.48	12.06	13.48	Gd	0.162	0.179	0.161	0.178
Tb_2O_3	1.14	1.28	1.14	1.28	Tb	0.015	0.017	0.015	0.017
Dy_2O_3	1.18	1.21	1.18	1.21	Dy	0.015	0.016	0.015	0.016
Yb_2O_3	0.02	0.01	0.02	0.01	Yb	-	-	-	-
Lu_2O_3	0.05	0.05	0.05	0.05	Lu	-	-	-	-
CaO	2.75	2.49	2.75	2.49	Ca	0.119	0.107	0.119	0.106
PbO	2.14	1.45	-	-	Pb	0.023	0.016	-	-
					ΣA	1.004	0.996	1.000	0.994
Total	100.01	99.97	100.40	100.50	$\Sigma(A+B)$	2.008	2.003	1.998	1.995

1: wt.% average of 3 grains used for collecting physical, optical and crystal data; 2: composition in wt.% with the highest content of Sm_2O_3; 1* and 2*; compositions 1 and 2 adjusted for 2.64 Ga of radioactive decay of U and Th; atomic contents normalized to 4 oxygen atoms. Not detected: Na, K, Mg, Mn, Fe, Ba, Sr, Sc, Eu, Ho, Er, Tm, As, Nb, Ta, S, F.

content noted to date is 9.7 wt.% (accompanied by 4.3 wt.% Gd_2O_3), associated with extreme Nd in monazite-(Nd) from its type locality, where it occurs as a hydrothermal mineral in Alpine veins; Graeser & Schwander (1987), Demartin *et al.* (1991). High Sm and Gd also were reported in an incompletely analyzed sample from Chernaya Salma in Karelia (Vainshtein *et al.* 1956, quoted in Neumann *et al.* 1966). Otherwise, Sm invariably is subordinate to minor with respect to the major *REE*, as is Gd. This is abundantly documented in general reviews of monazite (*e.g.*, Neumann *et al.* 1966, Fleischer & Altschuler 1969), as well as in statistically extensive studies of monazite from a variety of specific petrological environments: granitic suites, granitic pegmatites, tin deposits, Alpine fissures, sediments and metamorphic rocks (*e.g.*, Lee & Bastron 1967, Donnot *et al.* 1973, Petruk & Owens 1975, Burnotte *et al.* 1989, Wark & Miller 1993, Watt 1995, Förster & Rhede 1995, Franz *et al.* 1996, van Emden *et al.* 1997, Förster 1998).

What may be the reason for the unique enrichment of the Annie Claim #3 monazite-(Sm) in Sm and Gd? Crystal-chemical factors would favor Ce > La > Nd over and above the *MREE* and *HREE*. Partitioning of these three elements into competing minerals cannot be invoked, as the associated minerals are not prominent *REE* carriers. The close similarity of ionic radii of Th, Sm and Gd, invoked by Förster *et al.* (2000) to explain the enrichment of Sm and Gd in huttonite, cannot be responsible, as monazite is routinely enriched in Th, but its concentration is not correlated with the content of Sm or Gd.

A significant clue to the puzzle is the abundance of the *MREE* in the other *REE* minerals in the Annie Claim #3 pegmatite: xenotime-(Y) is strongly enriched in Dy,

Gd and Tb (≤14.88, 7.59 and 3.31 wt.% oxides, respectively; Masau *et al.* 2000b), and a mineral with composition of $Y(Ta,Nb)O_4$ [probable formanite-(Y)] contains, in wt.%, 9.05 Gd_2O_3, 7.18 Dy_2O_3 and 3.22 Sm_2O_3 (unpublished data of the authors). These two minerals also defy the crystal-chemical preferences of their structures, and they occur isolated from any potentially competing phases.

The enrichment of all three minerals in *MREE* strongly suggests that this signature was a general feature of the parent pegmatite-forming melt from which the Annie Claim #3 pod solidified. The magma, residual after crystallization of a sizeable body of *REE*-poor leucogranitic parent, was significantly enriched in H_2O, F, Li (and probably also CO_2, the abundance of which is documented in late fluid inclusions). Such a volatile-rich environment of a highly hydrous melt could have been conducive not only to probable promotion of the tetrad effect (Masau *et al.* 2000b; see also Fig. 3), but to complexing of the *REE* as early as during the solidification of the parent granite. Complexing, selective in terms

TABLE 2. X-RAY POWDER DIFFRACTION (GANDOLFI) DATA FOR MONAZITE-(Sm)

I_{est}	d_{meas} Å	d_{calc} Å	hkl	I_{est}	d_{meas} Å	d_{calc} Å	hkl
40	5.191	5.198	$\overline{1}01$	<10	2.378	2.381	220
50	4.647	4.655	011	<10	2.330	2.329	$\overline{1}22$
80	4.164	4.163	$\overline{1}11$	20	2.174	2.173	031
30	4.064	4.066	101	20	2.146	2.147	$\overline{1}03$
40B	3.492	3.506	111	20	2.127	2.126	$\overline{3}11$
	"	3.475	020	20	2.106	2.106	221
70	3.264	3.269	200	30	1.950	1.949	212
<10	3.136	3.134	002	<10	1.920	1.919	301
100	3.065	3.069	120	10	1.885	1.884	$\overline{2}31$
10	2.952	2.958	210	30	1.865	1.864	$\overline{1}32$
90	2.857	2.860	$\overline{1}12$	10	1.847	1.846	320
	"	2.857	012	10	1.790	1.791	023
10	2.600	2.599	202	10	1.758	1.756	$\overline{3}22$
20	2.430	2.434	$\overline{2}12$	20	1.728	1.727	132
	"	2.429	112	10	1.678	1.679	140

114.6 Debye-Scherrer camera with Gandolfi attachment. CuKα X-radiation (Ni-filter), λ = 1.5418 Å, visually estimated intensities; not corrected for film shrinkage, no internal standard; all lines used for unit-cell refinement cited in the text; B = broad line.
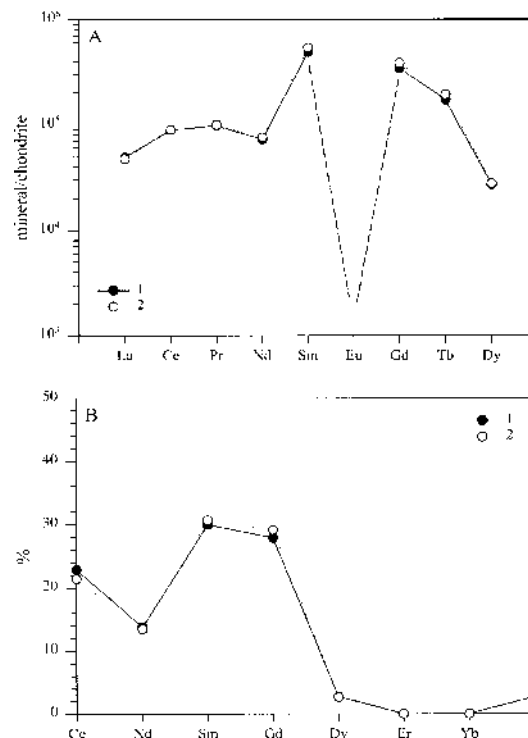

FIG. 3. *REE* abundances in three grains of monazite-(Sm): (A) chondrite-normalized pattern using values of Taylor & McLennan (1985); (B) concentrations of even-numbered *REE* and Y (wt.%) normalized to a total of 100 (as used by Vlasov 1966). Note the prominence of Sm and Gd in both diagrams, and the high value of chondrite-normalized Tb.

of individual *REE* and differential in terms of complex stabilities, proposed by Gramaccioli & Pezzotta (2000; see also Pezzotta *et al.* 1999, Gramaccioli *et al.* 1999) could have generated the *MREE*-enriched signature of the residual pegmatite. Despite the recent progress in studies devoted to *REE* complexing at relatively low temperatures (*e.g.*, Wood 1990, 1996), experiments under magmatic conditions bordering to supercritical are desirable to address problems such as that posed by our *MREE*-dominant minerals. Moreover, granitic pegmatites are notorious for disequilibrium crystallization, the *REE* minerals are rare and isolated from each other in the pegmatite examined, and the analytical data are incomplete for the *REE*. Consequently, any further discussion of the possible role of the tetrad effect *versus* the F-controlled enhancement or dispersal of different *REE* in fluid and solid phases (C.M. Gramaccioli, pers. commun., 2001) seems to be futile at present.

Minerals of the monazite and xenotime groups are very scarce in, and rarely recovered in any quantities from, highly fractionated granitic pegmatites rich in Li, Rb, Cs, F, B and P (mainly the lepidolite, spodumene and petalite subtypes of rare-element pegmatites of Černý 1991). Any finds of these phases from such environments should be thoroughly examined, as their *REE* patterns may help to shed light on fractionation of these elements in highly evolved, complex and ligand-rich environments. *REE* abundances in accessory minerals, which currently seem to represent only a few exotic anomalies, may prove to be typical of specific categories of pegmatite and the conditions of their derivation and consolidation.

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