

## ZAJACITE-(Ce), A NEW RARE-EARTH FLUORIDE FROM THE STRANGE LAKE DEPOSIT, QUEBEC-LABRADOR

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### ABSTRACT

Zajacite-(Ce) is a new mineral that occurs as anhedral grains, 1–2 mm across, sparingly disseminated in hypersolvus granite at the Strange Lake Zr–Y–REE–Nb–Be deposit, on the Quebec–Labrador boundary northeast of Schefferville, Quebec. The new mineral is colorless to pale pink, has a vitreous luster, white streak, conchoidal fracture, H (Mohs) 3½, no cleavage,  $D(\text{meas.})$  4.44(1) g/cm<sup>3</sup>, and is uniaxial positive, with indices of refraction of  $\omega$  1.483(1),  $\epsilon$  1.503(1). Zajacite-(Ce) is a fluoride; electron-microprobe analyses of seven grains gave a mean of Na 6.4, Ca 11.5, Y 2.2, La 11.3, Ce 22.0, Nd 8.0, Sm 1.1, Gd 2.9, Dy 0.4, F 35.4, total 101.2 wt.%, corresponding to  $\text{Na}_{0.90}[(\text{REE})_{1.12}\text{Ca}_{0.92}]_{\Sigma 2.04}\text{F}_6$ , wherein Ce is the predominant REE. Single-crystal X-ray study showed the mineral to be trigonal, space group  $P\bar{3}$ ,  $a$  6.099(1),  $c$  11.064(2) Å, as refined from a Gandolfi pattern, with strongest lines [ $d$  in Å( $hkl$ )] at 5.29(70)(100), 3.036(100)(110,103), 2.146(70)(203), 1.757(80)(300,213), 1.152(40)(410), and 0.9189(40)(513). The new name honors geologist Ihor Stephan Zajac, who led the exploration group that discovered the Strange Lake deposit, and who first recognized the presence of the new mineral.

**Keywords:** zajacite-(Ce), new mineral species, Na–Ca–REE fluoride, chemical composition, X-ray data, gagarinite, Strange Lake deposit, Quebec–Labrador, Canada.

### SOMMAIRE

La zajacite-(Ce), nouvelle espèce minérale, se présente comme phase accessoire en grains xénomorphes de 1 à 2 mm de diamètre dans le granite hypersolvus de Strange Lake, hôte d'un gisement de Zr–Y–TR–Nb–Be (TR: terres rares) sur la frontière Québec–Labrador au nord-est de Schefferville, Québec. C'est un minéral incolore à rose pâle, dont l'éclat est vitreux, la rayure, blanche, la cassure, conchoïdale, et la dureté (échelle de Mohs), 3½; il n'y a pas de clivage. La densité mesurée est 4.44(1); la zajacite-(Ce) est uniaxe positive; les indices de réfraction sont  $\omega$  1.483(1),  $\epsilon$  1.503(1). Il s'agit d'un fluorure; la composition moyenne de sept grains (analyses à la microsonde électronique) correspond à Na 6.4, Ca 11.5, Y 2.2, La 11.3, Ce 22.0, Nd 8.0, Sm 1.1, Gd 2.9, Dy 0.4, F 35.4, total 101.2% (en poids), c'est-à-dire  $\text{Na}_{0.90}[(\text{TR})_{1.12}\text{Ca}_{0.92}]_{\Sigma 2.04}\text{F}_6$ . Dans cette formule, le Ce est la terre rare prédominante. Une caractérisation sur cristal unique montre que la symétrie est trigonale, groupe spatial  $P\bar{3}$ ,  $a$  6.099(1),  $c$  11.064(2) Å (méthode de Gandolfi). Les raies les plus intenses du spectre de diffraction [ $d$  en Å( $hkl$ )] sont 5.29(70)(100), 3.036(100)(110,103), 2.146(70)(203), 1.757(80)(300,213), 1.152(40)(410), et 0.9189(40)(513). Le nom honore le géologue Ihor Stephan Zajac, directeur de l'équipe d'exploration responsable de la découverte du gisement de Strange Lake, qui le premier reconnut la présence de la nouvelle espèce minérale.

**Mots-clés:** zajacite-(Ce), nouvelle espèce minérale, fluorure de Na–Ca–TR, composition chimique, données de diffraction X, gagarinite, gisement de Strange Lake, Québec–Labrador, Canada.

## INTRODUCTION

The Strange Lake rare-earth-element (*REE*) deposit, on the Quebec–Labrador border, about 250 km northeast of Schefferville, Quebec, occurs within a Precambrian peralkaline granitic complex that was initially described by Zajac *et al.* (1984a, b) and Currie (1985), and later by Miller (1986, 1990). The deposit is reported to contain 52 Mt amenable to open-pit mining at a grade of 2.93%  $ZrO_2$ , 0.31%  $Y_2O_3$ , 0.38%  $Nb_2O_5$ , 0.54% *REE*, and 0.08% BeO (data from G.P. Venkatswaran, in Miller 1988). The geology and history of discovery of the deposit were summarized by Sinclair *et al.* (1992), and recent interpretations of the petrology, mineralogy, and genesis of the complex have been presented by Salvi & Williams-Jones (1990, 1991, 1992, 1995), Birkett & Miller (1991), Birkett *et al.* (1992), Pillet *et al.* (1993), Boily & Williams-Jones (1994), and Miller (1996).

In this paper, we describe zajacite-(Ce), a new mineral that occurs in hypersolvus granite peripheral to the potentially mineable zone. The host granite consists largely of quartz, perthite, and arfvedsonite, and has also been referred to as inclusion-rich leucogranite and as inclusion-bearing exotic granite (*e.g.*, Salvi & Williams-Jones 1990, Zajac *et al.* 1984a, b). The new mineral name honors geologist Dr. Ihor Stephan (Steve) Zajac (b. 1935), who led the exploration group

that discovered the Strange Lake deposit, and who first recognized the mineral. We adopt, with the agreement of the person we honor, the North American pronunciation ZAJ–AK–ĪTE, although in some European countries the phonetic name would be ZĪ–ATS–ĪTE. The mineral and name have been approved by the Commission on New Minerals and Mineral Names, International Mineralogical Association. Type specimens of zajacite-(Ce) have been deposited in the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, Ottawa. A polished section containing seven grains used for the chemical analyses is designated the holotype (NMC 67314).

## PHYSICAL AND OPTICAL PROPERTIES

Zajacite-(Ce) occurs sparingly as xenomorphic grains, typically 1.5 to 2 mm across, that are disseminated within the granite, which also contains accessory vlasovite, narsarsukite, willemite, and fluorite. There are no indications of a precursor phase, and zajacite-(Ce) is interpreted to be a primary mineral. Presumably the inclusions of gagarinite reported by Roelofsen & Martin (1996) to occur with associated inclusions of zircon and monazite within arfvedsonitic amphibole in hypersolvus granite at Strange Lake are zajacite-(Ce).

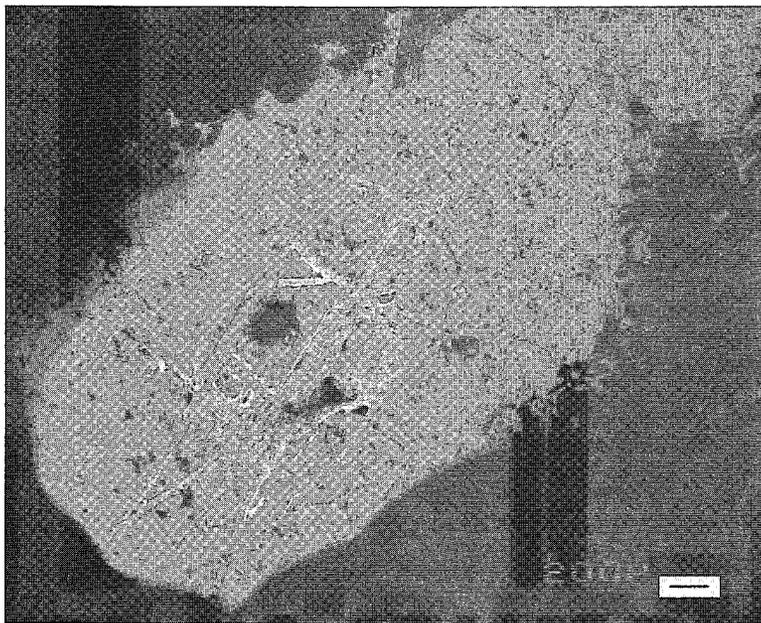


FIG. 1. Back-scattered-electron image of zajacite-(Ce), showing the typical anhedral outline and partial replacement by veinlets of bastnäsite-(Ce). Circular hole (black) near the center of the grain is an area from which material was extracted for a powder-diffraction pattern. Bar scale represents 200  $\mu$ m.

Fresh grains of zajacite-(Ce) are colorless to pale pink and completely homogeneous. In the specimens examined, however, most of the grains have been veined by bastnäsite-(Ce), with variably minor to extensive replacement (Fig. 1). The megascopic color of zajacite-(Ce) becomes pinkish, then more orange as the degree of alteration by heterogeneous mixtures containing bastnäsite-(Ce) increases. Zajacite-(Ce) is transparent, brittle, and nonfluorescent in both short- and long-wave ultraviolet light; it has a vitreous luster, white streak, no cleavage, a conchoidal fracture, and a Mohs hardness of 3½. A density of 4.44(1) g/cm<sup>3</sup> was determined using a Berman balance and two groups of hand-picked grains, one weighing 26 mg and the other weighing 21 mg. The mineral is insoluble in water, unreactive in cold, dilute HCl, and is slowly dissolved by hot HCl.

In transmitted light, zajacite-(Ce) is colorless and nonpleochroic. The mineral is uniaxial positive, with  $\omega$  1.483(1) and  $\epsilon$  1.503(1) as measured at 589.9 nm.

#### CHEMICAL COMPOSITION

A concentrate of zajacite-(Ce) was prepared by crushing about 1 kg of granite; the heavy fraction was separated in methylene iodide, followed by magnetic separation to remove amphibole. The principal contaminants in the concentrate were fluorite, small adhering particles of quartz, and bastnäsite-(Ce), the last occurring with zajacite-(Ce) as veinlets and rims that impart a pinkish turbidity to the affected grains. Only clear, transparent grains of zajacite-(Ce) were hand-picked, and the resulting concentrate was examined under a petrographic microscope to

TABLE 1. ELECTRON-MICROPROBE COMPOSITIONS OF ZAJACITE-(Ce)

Grains	1	2	3	4	5	6	8	Mean	Formula ratios
wt.% Na	6.8	6.1	7.4	5.7	5.7	5.7	7.3	6.4	0.90
Ca	10.8	11.4	11.0	11.6	11.6	11.9	11.9	11.5	0.92
Y	2.2	2.3	1.9	2.2	2.3	2.2	2.0	2.2	0.08
La	10.8	11.1	11.6	11.4	11.2	11.5	11.5	11.3	0.26
Ce	21.9	22.0	21.6	22.2	22.6	22.4	21.5	22.0	0.51
Nd	7.8	8.2	8.1	8.5	8.0	8.3	7.4	8.0	0.18
Sm	1.2	1.2	0.9	1.2	1.2	1.1	0.9	1.1	0.02
Gd	2.8	3.1	2.6	2.9	3.1	3.2	2.9	2.9	0.06
Dy	0.2	0.4	0.3	0.3	0.5	0.5	0.3	0.4	0.01
F	36.0	—	34.7	—	—	—	35.4	35.4	6.00
	100.5	—	100.1	—	—	—	100.2	101.2	

eliminate isotropic grains, which were determined by Debye-Scherrer X-ray patterns to be fluorite.

A wet-chemical analysis of a 30-mg sample by the Geological Survey of Canada gave 33.2 wt.% F. Seven hand-picked grains were mounted in polished section and analyzed by electron microprobe at CANMET. The following standards were used: NaNbO<sub>3</sub> (Na), CaTiSiO<sub>5</sub> (Ca), YFeO<sub>3</sub> (Y), LaAlO<sub>3</sub> (La), CeO<sub>2</sub> (Ce), NdAlO<sub>3</sub> (Nd), SmAlO<sub>3</sub> (Sm), Gd<sub>3</sub>Fe<sub>5</sub>O<sub>12</sub> (Gd), REE4 (Dy), and CaF<sub>2</sub>, PrF<sub>2</sub>, and MgF<sub>2</sub> for F. The correction programs employed were ZAF and EMPFIL, the latter a version of EMPADR.

The results of the electron-microprobe analyses are given in Table 1. Values for F varied with the standard: with PrF<sub>3</sub>, the average F was 32.91 wt.% (range 29.3–35.2); with MgF<sub>2</sub>, the range was 31.4–31.7 wt.%; data using CaF<sub>2</sub> are given in Table 1 because the results from the use of this standard and the energy-

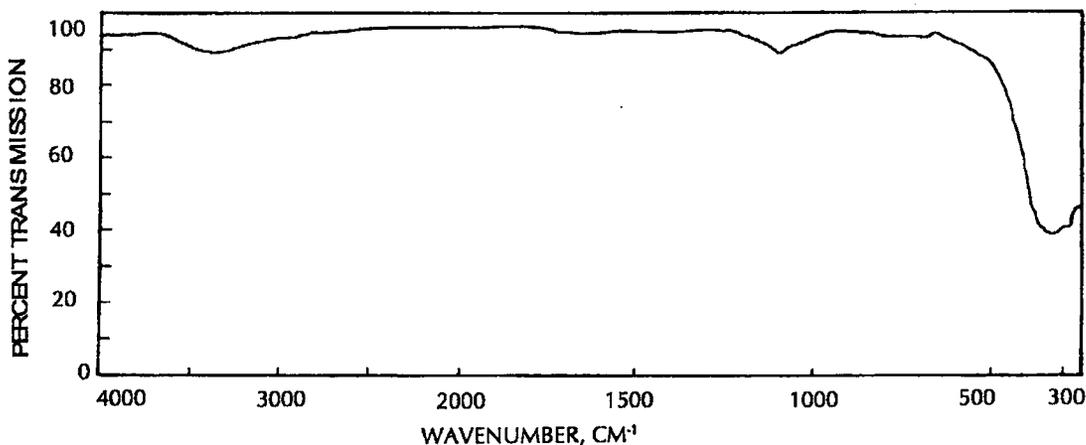


FIG. 2. Infrared spectrum of zajacite-(Ce).

TABLE 2. X-RAY POWDER DATA FOR ZAJACITE-(Ce)

$l_{\text{est}}$	$d_{\text{meas}}$	$d_{\text{calc}}$	$hkl$	$l_{\text{est}}$	$d_{\text{meas}}$	$d_{\text{calc}}$	$hkl$
70	5.29	5.28	100	25	1.273	1.273	306*
5	4.77	4.77	101	5	1.243	1.243	403
100	3.036	3.050	110	10	1.197	1.197	109*
		3.024	103	10	1.175	1.175	226*
20	2.633	2.641	200	40	1.152	1.153	410*
30	2.351	2.350	113*	10	1.149	1.147	316*
70	2.146	2.147	203*	20	1.115	1.115	209*
20	1.994	1.996	210*	10	1.073	1.074	406*
20	1.842	1.844	006*	30	1.047	1.047	219*
80	1.757	1.761	300	10	1.016	1.017	330
		1.756	213			1.016	503
10	1.740	1.741	106*	10	1.013	1.013	326*
20	1.577	1.578	116*	30	0.9775	0.9774	416*
20	1.523	1.525	220*	30	0.9635	0.9635	423*
10	1.509	1.512	206	5	0.9488	0.9847	510
5	1.466	1.465	310	25	0.9419	0.9417	319*
30	1.361	1.361	313*	40	0.9189	0.9187	513*
20	1.355	1.355	216*				

\* Line used for cell refinement. Data obtained with 114.6-mm Gandolfi camera,  $\text{CoK}\alpha$  X-radiation; indexed with  $a$  6.099(2),  $c$  11.064(2) Å. Film corrected for shrinkage; no internal standard.

dispersion mode rather than the wavelength analytical mode gave the best anion:cation charge balance and conformity with the crystal-structure formula. The empirical formula, calculated on the basis of  $F = 6$ , is  $\text{Na}_{0.90}[(\text{REE})_{1.12}\text{Ca}_{0.92}]_{\Sigma 2.04}\text{F}_6$ , simplified as  $\text{Na}(\text{REE}, \text{Ca})_2\text{F}_6$ . The single-crystal X-ray structure study (J.T. Szymański, in prep.) revealed that Ca and the REE preferentially occupy different sites; thus, the formula is  $\text{Na}_1[\text{REE}_{0.65}\text{Ca}_{0.35}][\text{REE}_{0.48}\text{Ca}_{0.52}]\text{F}_6$ , which can be generalized as  $\text{Na}_1[\text{REE}_x\text{Ca}_{1-x}][\text{REE}_y\text{Ca}_{1-y}]\text{F}_6$ , where  $x \neq y$ . The calculated density is 4.55  $\text{g}/\text{cm}^3$  for  $Z = 3$ . An infrared spectrum of the mineral shows few features (Fig. 2). A saucer-shaped, shallow (~6% maximum absorption) band centered at 3400  $\text{cm}^{-1}$  extends from >3600 to ~2900  $\text{cm}^{-1}$ , and is attributed to adsorbed  $\text{H}_2\text{O}$ . A weak band (~7%) is present at 1090, and a strong (~55% absorption) band is centered at 335  $\text{cm}^{-1}$ .

#### X-RAY DATA

Zajacite-(Ce) has similarities to gagarinite, and in the initial stages of this study, the mineral from Strange Lake was informally referred to as "gagarinite-like". The unnamed mineral of composition  $\text{Na}_{1.23}\text{Ca}_{0.12}\text{Y}_{1.28}\text{REE}_{0.24}\text{F}_6$ , described by Kabalov *et al.* (1993), is inferred to be isostructural with gagarinite-(Y). Zajacite-(Ce) differs from gagarinite-(Y) not only in the predominance of Ce, but also in X-ray crystallography.

#### Zajacite-(Ce)

Precession photographs of a fragment of zajacite-(Ce) extracted from a polished thin section showed trigonal symmetry, space groups  $P3$  or  $P\bar{3}$ ,  $a$  6.08,  $c$  11.03 Å. The cell dimensions were subsequently refined from the indexed powder-diffraction pattern, as given in Table 2. The crystal-structure study gave  $a$  6.0942(3),  $c$  11.048(1) Å, and indicated that the space group is  $P\bar{3}$ . The precession X-ray photographs revealed a pronounced subcell, with  $a' = a$  and  $c' = c/3$ . This subcell approximates the true cell of gagarinite-(Y). Details of the structural relationships of gagarinite-(Y) and zajacite-(Ce) will be given by Szymański (in prep.). The X-ray powder patterns of the two minerals are readily distinguishable and, after microprobe analyses, all of the grains listed in Table 1 were confirmed to be zajacite-(Ce).

#### Gagarinite-(Y)

Initial X-ray structure work on gagarinite-(Y) by Voronkov *et al.* (1962) indicated  $a$  5.99(3),  $c$  3.53(2) Å, with  $P\bar{3}$  as the most probable space-group, but with pronounced  $P6_3/m$  pseudosymmetry. The formula was concluded to be  $\text{Na}(\text{REE}, \text{Ca}, \text{Na})_2\text{F}_6$  (Pyatenko & Voronkov 1962). Dib *et al.* (1987) concluded that gagarinite-type compounds have the space group  $P3$  or  $P\bar{6}$ . Hughes & Drexler (1994) and Frank-Kamenetskaya *et al.* (1994) solved the structure in space group  $P6_3/m$ . All authors agree that the unit cell of gagarinite-(Y) has approximate dimensions of  $a$  5.9–6.0,  $c$  3.5–3.6 Å, with  $Z = 1$ .

The cell dimensions of gagarinite-(Y) were confirmed by us by single-crystal X-ray study using fragments of material from the unspecified type locality (Stepanov & Severov 1961) in Kazakhstan (National Mineral Collection NMC 16503), and from Washington Pass, Okanogan County, Washington (Royal Ontario Museum M35831). Both fragments showed six-fold symmetry. Although there is some ambiguity concerning extinctions for 00 $l$  reflections, the results otherwise are in accord with  $P6_3$  or  $P6_3/m$  and the data of Frank-Kamenetskaya *et al.* (1994) and Hughes & Drexler (1994). An X-ray powder pattern of gagarinite from Lake Gjerdingen, Norway (Smithsonian Institution 134664; Raade & Haug 1980) showed no deviations from the patterns of other specimens. The indexed pattern gave  $a$  6.004(2),  $c$  3.553(1) Å, whereas that from Okanogan County (M35831) gave  $a$  5.999(1),  $c$  3.549(1) Å, and that from Kazakhstan (NMC 16503) gave  $a$  6.006(1),  $c$  3.548(1) Å.

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