



## THE ALEY CARBONATITE COMPLEX NORTHERN ROCKY MOUNTAINS, BRITISH COLUMBIA\* (94B/5)

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### INTRODUCTION

The Aley carbonatite complex was discovered in 1980 and staked by Cominco Ltd. in 1982 (Pride, 1983) for its niobium potential. The property is located 140 kilometres north-northwest of Mackenzie, on the east side of Williston Lake, at latitude 56°27' north, longitude 123°45' west.

A brief account of the geology was presented by Pell (1986a, 1986c). This contribution is an outline of an M.Sc. thesis recently completed at The University of British Columbia by the author (Mäder, 1986).

### GEOLOGY

The Aley carbonatite complex intruded Cambrian sediments (Figure 4-5-1) of the continental margin of ancient North America near the shelf/off-shelf boundary prior to the formation of the northern Rocky Mountains (potassium-argon ages of 340 to 350 million years) (Pell, 1986c; Pell, this volume). The youngest unit affected by the intrusion is the Skoki volcanic sequence (mid-Ordovician?).

The carbonatite complex is oval in outline, 3 to 3.5 kilometres in diameter and occupies an area of about 7 square kilometres. The body is cylindrical in the third dimension with a nearly vertical axis and has probably been only slightly tilted from its original orientation.

The complex consists of an older, outer ring of metasomatically altered syenite that occupies one-third of the volume. The core is formed by dolomite carbonatite with minor calcite carbonatite "sweats" and some rare-earth carbonate-rich "sweats". Rare-earth carbonate-rich ferrocarnatite dykes intrude the contact aureole. The contact aureole is composed of recrystallized carbonate rocks characterized by a cream to brownish weathering colour, but is little affected by metasomatism and shows no indication of high-temperature contact metamorphism.

The relationship of nearby lamprophyric dykes and the Ospika diatreme (Pell, 1986b; Pell, this volume) to the carbonatite complex is unclear.

The Aley complex and its contact aureole are part of an imbricate thrust sheet of the northern Rocky Mountains, bounded to the west by a high-angle thrust fault juxtaposing Cambrian rocks of the contact aureole against unmetamorphosed Silurian rocks (Figure 4-5-1). The Silurian rocks form part of the tectonically thinned eastern limb of a tight anticline with a Cambrian core to the west. This structural element is dissected by faults striking at high angles to the Rocky Mountain trend. Along the eastern side of the complex a tectonically thinned, reversed stratigraphic section, with a set of subparallel lower angle thrust faults, is thrust onto an imbricate sheet containing Silurian rocks (to the east of the area mapped). Parts of the carbonatite complex may be faulted out above and below the exposed level. The fault zones along the eastern and western side

of the Aley complex are mapped as two branches of the Burden thrust (Thompson, 1978).

### STRUCTURES RELATED TO THE EMPLACEMENT OF THE COMPLEX

The inner part of the contact aureole forms an annular, cylindrical, ductile shear zone evidenced by "chocolate-tablet" boudinage, shear folds and locally by sheath folds. Horizontal and vertical components of extension near the contact are in the order of 200 to 400 per cent. The ductile shear zone suggests that doming was the major mechanism of emplacement. This is consistent with circular, steeply dipping structural trends in the carbonatite core, outlined by a cleavage and mineral layering (apatite, magnetite, pyrochlore, fersmite, biotite and amphibole). Temperatures within the contact aureole, deduced from calcite-dolomite geothermometry (250°C to 350°C) and metamorphic phase assemblages ( $\leq 400^\circ\text{C}$ ), further support the view that at least part of the complex was emplaced at subsolidus temperatures.

### MINERALOGY AND MINERAL CHEMISTRY

Approximately 50 mineral species are identified in the four major rock types of the Aley carbonatite complex (Table 4-5-1). The list of minerals is still incomplete. Niobium-rich phases of economic interest include fersmite, pyrochlore and columbite.

Tables 4-5-2, 4-5-3 and 4-5-4 list averaged microprobe analyses of selected minerals.

### PETROGRAPHY

#### DOLOMITE CARBONATITE

**Fersmite and pyrite-bearing dolomite-apatite-carbonatite:** Different degrees of deformation and alteration resulted in a variety of textures. Fresh dolomite carbonatite has a large range of grain sizes (0.1 to 4 millimetres) with a granoblastic interlocking texture, almost idiomatic in some parts. Apatite occurs as prismatic crystals or disk-like flattened aggregates oriented parallel to the planar fabric. Fersmite forms fibrous to fine-grained aggregates replacing euhedral pyrochlore (cubic). Primary fersmite (orthorhombic) is rare. Columbite is observed replacing fersmite.

Alteration of dolomite carbonatite includes extensive chloritization and minor silicification of narrow fracture zones with relatively abundant fersmite and/or pyrochlore. Metallic black, granular aggregates are widespread and consist of chlorite-rutile mixtures or dolomite with thin niobian rutile lamellae grown along the rhombohedral cleavage.

#### CALCITE CARBONATITE

**Magnetite, pyrochlore, amphibole, pyrite-bearing calcite-apatite-carbonatite:** Calcite carbonatite typically displays a strong

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.



Figure 4-5-1. Geological map of the Aley carbonatite complex based in part on geological mapping by Cominco Ltd.

TABLE 4-5-1 MINERALOGY

Mineral	Mineral Class	Occurrence
dolomite-ankerite	carbonate	cd, re1, re2, au
calcite	carbonate	cc, au, sy
strontianite (?)	carbonate	re1, cd
alstonite (barytocalcite) (?) BaCa (CO <sub>3</sub> ) <sub>2</sub>	carbonate	re1
aragonite-strontianite ss (?)	carbonate	re1, sy
Sr-Ca-Ba carbonate (?)	carbonate	re1
burbankite (Na, Ca, Sr, Ba, LREE) <sub>6</sub> (CO <sub>3</sub> ) <sub>5</sub>	carbonate	re1
ancylite LREE (Ca, Sr) (CO <sub>3</sub> ) <sub>2</sub> (OH)•H <sub>2</sub> O	carbonate	re1, sy
cordylite Ba (LREE, Ca, Sr) <sub>2</sub> (CO <sub>3</sub> ) <sub>3</sub> F <sub>2</sub>	carbonate	re1, cd
huanghoite BaLREE (CO <sub>3</sub> ) <sub>2</sub> F <sub>2</sub>	carbonate	re, red
bastnasite LREE (CO <sub>3</sub> )F	carbonate	red
Ce-Ba-La-Ca carbonate (?)	carbonate	re1
Ca-La-Nd carbonate (parisite) (?)	carbonate	re2
LREE carbonate (calkinsite, lanthanite) (?)	carbonate	au
Ca-Sr-Ba-Ce carbonate (?)	carbonate	re1, cc
apatite	phosphate	cd, cc, re1, sy
monazite (LREE, Th, Ca)PO <sub>4</sub>	phosphate	cd
rhabdophane (LREE)PO <sub>4</sub> •H <sub>2</sub> O	phosphate	au
cheralite (Th, Ca, LREE)PO <sub>4</sub>	phosphate	cd
rutile	oxide	cd
hematite	oxide	cd, cc, au
magnetite	oxide	cc
baddeleyite ZrO <sub>2</sub>	oxide	cc
thorianite ThO <sub>2</sub>	oxide	cd
pyrochlore (Na, Ca) <sub>2</sub> Nb <sub>2</sub> O <sub>6</sub> (OH, F)	oxide	cc
fersmite (Ca, Na) (Nb, Ta, Ti) <sub>2</sub> (O, OH, F) <sub>6</sub>	oxide	cd, (cc)
columbite Fe (Nb, Ta) <sub>2</sub> O <sub>6</sub>	oxide	cd
zirkelite (?) (Ca, Th)Zr (Ti, Nb) <sub>2</sub> O <sub>7</sub>	oxide	cc
Ta-Ca zirconate-niobate	oxide	cd
quartz	silicate	sy, cc, cd, re2
albite	silicate	sy, cd
potassium feldspar	silicate	sy, re1
chlorite	silicate	cd, cc, di, la
serpentine	silicate	cd
biotite	silicate	cc, di, la
muscovite, phlogopite	silicate	au
magnesio-arfvedsonite Na <sub>3</sub> (Mg, Fe) <sub>4</sub> Fe <sup>3+</sup> Si <sub>8</sub> O <sub>22</sub> (OH, F) <sub>2</sub>	silicate	sy
richterite Na <sub>2</sub> Ca (Mg, Fe <sup>2+</sup> , Fe <sup>3+</sup> ) <sub>5</sub> Si <sub>8</sub> O <sub>22</sub> (OH, F) <sub>2</sub>	silicate	cc
aegirine (Na, Ca) (Fe <sup>3+</sup> , Mg, Fe <sup>2+</sup> , Ti)Si <sub>2</sub> O <sub>6</sub>	silicate	sy
lorenzenite Na <sub>2</sub> Ti <sub>2</sub> Si <sub>2</sub> O <sub>9</sub>	silicate	sy
zircon	silicate	cd
thorite (huttonite)	silicate	cd
cerite (?)	silicate	au
Mg silicate	silicate	cc
barite	sulphate	re1, re2
pyrite	sulphide	cd, re1, re2, cc
galena	sulphide	re1, cd
chalcopyrite	sulphide	sy

List of minerals identified in the Aley carbonatite complex with contributions by P.C. LeCouteur and K.R. Pride (Cominco Ltd.): LREE = light rare-earth elements (La, Ce, Nd, Pr); ss = solid solution; cd = dolomite carbonatite; cc = calcite carbonatite; re1 = rare-earth element carbonatite dykes (north ridge); re2 = barite-rich rare-earth element carbonatite dykes (northwest ridge); red = rare-earth-rich "swears" within the carbonatite; sy = "syenite"; au = metamorphic rocks of the contact aureole.

**TABLE 4-5-2**  
**MINERAL CHEMISTRY, ELECTRON MICROPROBE**  
**ANALYSES OF CARBONATE MINERALS**

Wt %	Do	Cc	Ank
CaO .....	32.11	53.16	28.98
MgO .....	17.03	0.55	14.12
FeO <sup>1</sup> .....	3.50	0.14	7.29
MnO .....	0.33	0.21	3.66
SrO .....	0.00	0.80	0.24
CO <sub>2</sub> <sup>2</sup> .....	46.14	42.87	25.00
Total .....	99.11	97.72	99.29
<b>Mol %</b>			
<b>Normalized Analyses</b>			
CaCO <sub>3</sub> .....	54.61	97.39	50.54
MgCO <sub>3</sub> .....	40.31	1.40	34.26
FeCO <sub>3</sub> .....	4.64	0.20	9.93
MnCO <sub>3</sub> .....	0.44	0.30	5.04
SrCO <sub>3</sub> .....	0.00	0.79	0.23
Total .....	100.00	100.00	100.00

<sup>1</sup> total iron.  
<sup>2</sup> calculated.

Do = dolomite from dolomite carbonatite, Cc = calcite from calcite carbonatite, Ank = ankerite from rare-earth carbonatite dyke.

Samples were analysed with an ARL-SEMQ (University of Calgary) operated at 15 keV and 0.15 μA with a split beam.

**TABLE 4-5-3**  
**MINERAL CHEMISTRY, ELECTRON MICROPROBE**  
**ANALYSES OF ARFVEDSONITE AND AEGIRINE**

	Wt %		Normalized Analyses <sup>1</sup>	
	Arf	Aeg	Arf	Aeg
SiO <sub>2</sub> .....	54.66	52.71	Si .....	8.09 1.98
TiO <sub>2</sub> .....	0.21	5.82	Ti .....	0.02 0.16
Al <sub>2</sub> O <sub>3</sub> .....	0.13	0.52	Al .....	0.02 0.02
FeO <sup>2</sup> .....	11.00	23.24	Fe .....	1.36 0.66
MgO .....	16.31	2.55	Mg .....	0.12 0.01
MnO .....	0.94	0.37	Mn .....	3.60 0.14
CaO .....	2.45	1.25	Ca .....	0.39 0.05
Na <sub>2</sub> O .....	8.34	13.51	Na .....	2.39 0.98
K <sub>2</sub> O .....	1.78	0.01	K .....	0.34 0.00
BaO .....	0.01	0.03	Ba .....	0.00 0.00
F .....	2.45	0.01	F .....	1.15 0.00
H <sub>2</sub> O <sup>3</sup> .....	0.70		OH .....	0.69
			O .....	22.16 6.00
			O,OH,F .....	24.00
Total .....	98.99	100.01		

<sup>1</sup> arfvedsonite normalized to 24 (O, OH, F), aegirine normalized to 6 oxygens.

<sup>2</sup> total iron.

<sup>3</sup> estimated.

Arf = arfvedsonite from "syenite", Aeg = aegirine from "syenite".

Samples were analysed with an ARL-SEMQ (University of Calgary) operated at 15 keV and 0.15 μA.

**TABLE 4-5-4**  
**MINERAL CHEMISTRY, ELECTRON MICROPROBE**  
**ANALYSES OF PYROCHLORE**

	Wt %		Formula A <sub>2</sub> B <sub>2</sub> O <sub>6</sub> (OH,F)	
	Core	Rim	Core	Rim
Nb <sub>2</sub> O <sub>5</sub> .....	61.12	69.08	Nb (B) .....	1.77 1.96
Ta <sub>2</sub> O <sub>5</sub> .....	0.18	0.32	Ta (B) .....	0.01 0.01
ZrO <sub>2</sub> .....	1.44	0.06	Zr (B) .....	0.04 0.00
TiO <sub>2</sub> .....	3.86	0.82	Ti (B) .....	0.18 0.04
			Total B .....	2.00 2.01
CaO .....	16.38	16.33	Ca (A) .....	1.12 1.09
Na <sub>2</sub> O .....	7.34	9.16	Na (A) .....	0.92 1.11
FeO .....	0.36	0.00	Fe (A) .....	0.02 0.00
MnO .....	0.10	0.01	Mn (A) .....	0.00 0.00
La <sub>2</sub> O <sub>3</sub> .....	0.07	0.04	La (A) .....	0.00 0.00
Nd <sub>2</sub> O <sub>3</sub> .....	0.22	0.20	Nd (A) .....	0.01 0.01
Ce <sub>2</sub> O <sub>3</sub> .....	0.89	0.13	Ce (A) .....	0.02 0.00
ThO <sub>2</sub> .....	3.44	0.26	Th (A) .....	0.06 0.00
UO <sub>2</sub> .....	0.01	0.00	U (A) .....	0.00 0.00
Total .....	95.41	96.41	Total A .....	2.15 2.21

Analyses by Dr. G. Perrault, Ecole Polytechnique, Montreal, Quebec.

parallel fabric marked by a cleavage and mineral layering. Calcite forms a granoblastic-polygonal texture and is much finer grained (0.05 to 0.2 millimetre) than dolomite carbonatite. Apatite forms prismatic crystals or disk-like flattened aggregates aligned parallel to the fabric. Biotite forms hexagonal, prismatic, equant crystals associated with magnetite and/or pyrochlore. Pyrochlore displays its octahedral habit and is zoned with rims relatively enriched in niobium. Amphibole of richterite composition is fibrous to acicular and aligned parallel to the fabric. At least part of the amphibole formed metasomatically near the contact with the "syenitic" ring. Accessory minerals include zircon and rare baddeleyite associated with zirkelite.

Calcite carbonatite is more resistant to weathering than dolomite carbonatite. Small amounts of chlorite and secondary quartz may form in zones of higher strain.

#### RARE-EARTH CARBONATITE DYKES

Two dyke swarms occur in the contact aureole of the complex (Figure 4-5-1). The dykes across the north ridge are characterized by orange, ovoid aggregates of rare-earth carbonates (mostly burbankite); those across the northwest ridge have dispersed rare-earth carbonates, abundant barite and secondary quartz.

Burbankite, cordylite and huanghoite are probably primary igneous rare-earth carbonates whereas the hydrous carbonates and various calcium-strontium-barium carbonates are part of the alteration assemblage.

#### RARE-EARTH-RICH "SWEATS" WITHIN THE COMPLEX

Minor rare-earth carbonate-rich differentiates occur at a few localities within the complex. Large (centimetre-scale) irregular crystal aggregates of huanghoite and bastnaesite occur in a dolomite matrix.

#### METASOMATICALLY ALTERED SYENITE

**Aegirine and arfvedsonite-bearing albite-quartz rock to quartz-bearing albite-aegirine-arfvedsonite rock:** This unusual rock displays a great compositional and textural variety. Relict microsyenite textures indicate a primary igneous origin as an

**TABLE 4-5-5**  
**WHOLE ROCK GEOCHEMISTRY,**  
**X-RAY FLUORESCENCE ANALYSES**  
**OF SELECTED WHOLE ROCK SAMPLES**

Wt %	cd	cc	re1	re2	syl	sy2
SiO <sub>2</sub> .....	0.50	2.17	0.65	7.30	66.36	53.00
Al <sub>2</sub> O <sub>3</sub> .....	0.26	0.02	0.21	0.67	4.28	1.33
TiO <sub>2</sub> .....	<0.01	0.04	0.01	0.04	0.68	0.35
FeO (tot) .....	2.95	8.41	10.49	12.00		
FeO .....		0.97				
Fe <sub>2</sub> O <sub>3</sub> .....		1.32				12.91
MnO .....	0.26		4.11	3.30	0.27	0.35
MgO .....	17.34	5.85	11.29	7.91	2.55	16.00
CaO .....	32.89	45.69	28.14	24.59	4.05	3.50
Na <sub>2</sub> O .....	0.63	0.48	1.13	0.79	7.79	7.71
K <sub>2</sub> O .....	0.02	0.05	0.04	0.06	0.24	1.15
P <sub>2</sub> O <sub>5</sub> .....	1.74	4.60	0.14	0.09	0.70	0.68
S .....	0.01	0.21	0.06	1.11	0.02	
Ba .....			0.69	7.74		
LOI .....	43.52	38.71	42.55	33.31	0.84	
Total .....	95.70	99.90	98.77	98.74	98.86	97.88
<b>ppm</b>						
Nb .....	490	3290	<5	29	71	280
Zr .....	66	600	580	96	270	390
Y .....	41	97	13	96	6	21
Sr .....	360	5280	5550	700	300	670
U .....	<9	<20	21	<10	<9	<20
Rb .....	4	<20	<4	<4	<3	<20
Th .....	130	65	28	840	<7	<20
Ta .....	18	<20				
Ba .....	39	315			1340	540
La .....	310	315	2670	2290	63	235
Ce .....	750	710	4760	7210	170	110
Nd .....	240		1020	3580	56	
Ce/La .....	2.4	2.3	1.8	3.1	2.7	2.1
Ce/Nd .....	3.2		4.7	2.0	3.0	

cd = dolomite carbonatite, cc = calcite carbonatite, re1 = rare-earth carbonatite dyke (north ridge), re2 = rare-earth carbonatite dyke (northwest ridge), syl = "syenite", sy2 = "syenite".

Analyses cc and sy2 by Cominco Ltd.

arfvedsonite and quartz-bearing syenite. Alkali metasomatism resulted in extensive overgrowth of fine-grained acicular aegirine and prismatic arfvedsonite and replacement of primary igneous textures by metamorphic textures.

Rounded orthoquartzite xenoliths and minor microsyenite xenoliths occur in various parts of the ring structure and may be more abundant locally (see Pell, 1986a). Xenoliths commonly show absorption features and reaction rims.

#### CONTACT AUREOLE

White mica and potassium feldspar are the only common metamorphic minerals observed in impure marbles, marls and silts. Talc and calc-silicates appear to be absent.

Silicification and growth of richteritic amphibole is observed within 10 to 40 centimetres of the contact. There is no mineralogical evidence for major mass transfer within the contact aureole. Trace element abundancies (Nb, REE, Th, F) and radioactivity can however be correlated with the apparent intensity of alteration. The fluid phase responsible for the formation of the contact aureole was probably highly volatile (CO<sub>2</sub>, H<sub>2</sub>O, F) and did not affect major element concentrations significantly.

#### GEOCHEMISTRY

Dolomite carbonatite is very low in silica, alumina and alkalis but high in phosphorus (Table 4-5-5). It is enriched in the incompatible elements thorium, uranium, niobium, tantalum, zirconium and light rare-earth elements but is low in titanium, rubidium, potassium and lead. Dolomite carbonatite is relatively depleted in heavy rare-earth elements and the siderophile and chalcophile metals.

Average calcite carbonatite is higher in silica, phosphorus and sodium than dolomite carbonatite. The trace geochemistry is similar to dolomite carbonatite.

Barium, strontium and total rare-earth elements may reach major element concentrations in the rare-earth-rich carbonatite dykes. The dykes may represent residual, low-temperature liquids derived from a dolomite carbonatite-like parental melt.

The metasomatically altered syenite has variable major element concentrations. Its trace element geochemistry is of "diluted" carbonatite character.

#### STABLE ISOTOPE RATIOS

Samples of calcite, dolomite and ankerite (mostly single crystals) from calcite carbonatite, dolomite carbonatite and a rare-earth carbonatite dyke respectively, were analysed for oxygen and carbon isotope ratios (Figure 4-5-2). All the <sup>13</sup>C ratios show values typical of primary igneous carbonatites of mantle origin (Taylor *et al.*, 1967; Pineau *et al.*, 1973). The <sup>18</sup>O values are variable, a feature commonly observed in carbonate minerals. An elevated <sup>18</sup>O signature, in comparison with mantle values, is usually taken to be indicative of postmagmatic recrystallization and deuteric alteration (Taylor *et al.*, 1967). Both processes preferentially affect carbonate minerals (rather than silicates) and oxygen isotope ratios rather than carbon isotope ratios. The extremely fresh samples of calcite carbonatite from drill cores are not affected at all by alteration. Dol-

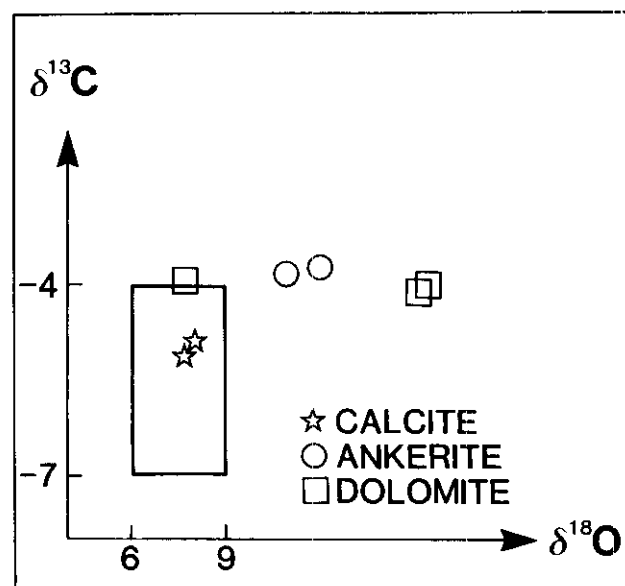


Figure 4-5-2. Stable isotope diagram of selected carbonate minerals (analyses by Dr. K. Muehlenbachs, University of Alberta, Edmonton, Alberta). δ<sup>13</sup>C ratios normalized to per mill PDB, δ<sup>18</sup>O ratios normalized to per mill SMOW. Box outlines the range of primary igneous carbonatites unaffected by weathering or deuteric and hydrothermal alteration (Taylor *et al.*, 1967).

omite, carbonatite, almost always with a brownish tint due to weathering, shows  $^{18}\text{O}$  values typical of mantle origin and elevated  $^{18}\text{O}$  values due to recrystallization and deuterium alteration. Ankerite from carbonatite dykes rich in rare-earth elements shows somewhat elevated  $^{18}\text{O}$  signatures, but  $^{13}\text{C}$  values of mantle character.

## DISCUSSION

The Aley is one of the best exposed and preserved alkaline-carbonatite complexes in the world. Besides its niobium potential the complex provides insight into problems of alkaline-carbonatite rock genesis: mode of emplacement, diversification of alkaline magmas, nature of the mantle source, processes in the mantle source region and metallogenesis.

## ACKNOWLEDGMENTS

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