Polymetallic U-Ag veins at Port Radium, Great Bear magmatic zone, Canada: main botryoidal pitchblende stage cuts 1.74 Ga diabase dykes and has REE signatures diagnostic of unconformity-type deposits

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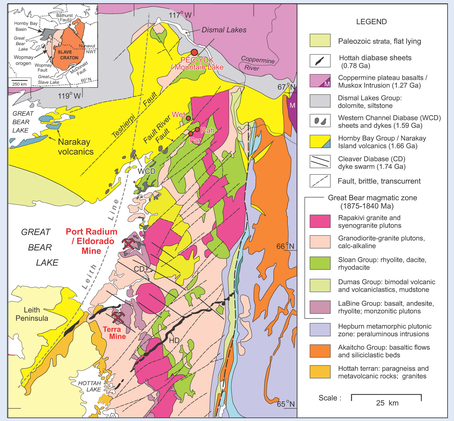
ABSTRACT

The Eldorado mine at Port Radium produced 6,223 tonnes of U and 8 million ounces of Ag from 1942 - 1982, with smaller amounts of Ra, Co, Ni, Cu, Ag and Bi. Mining reached a depth of 511 m. The adjacent Echo Bay mine produced 25.5 million ounces of Ag.

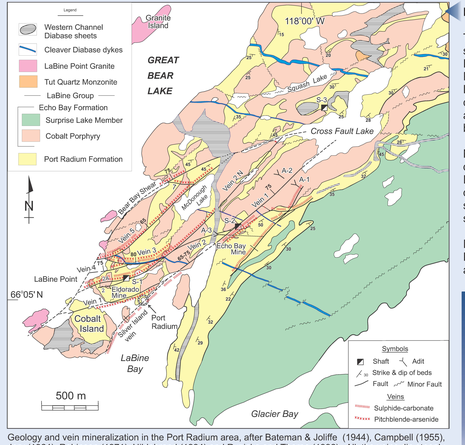
The metals were deposited along steep, NE-trending, late tectonic brittle faults in andesitic volcanics of the Great Bear magmatic zone (GBmz), a 1.87-1.84 Ga continental arc along the west margin of Wopmay Orogen.

The brittle faults were healed by quartz veins with sparse chalcopyrite and pitchblende, then cut by 1.74 Ga Cleaver diabase dykes. Fault reactivation offset the dykes and led to 5 stages of polymetallic veins.

The veins are cut by a gently dipping sheet of 1.59 Ga Western Channel diabase. The Lower Hornby Bay Group was deposited between the two diabase events, and was later eroded at Port Radium.



Geology of the northern Great Bear magmatic zone. Geochronology from Bowring & Ross (1985), LeCheminant & Heaman (1989), Park et al., (1995), Irving et al., (2004) and Hamilton & Buchan (2010).



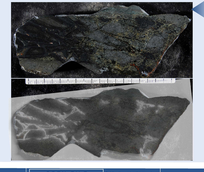
Geology and vein mineralization in the Port Radium area, after Bateman & Joliffe (1944), Campbell (1955), Jory (1964), Robinson (1971), Hildebrand (1984) and Ruzicka and Thorpe (1996). All the veins dip steeply to the N-NW (65 – 80° N; Jory, 1964)

PORT RADIUM GEOLOGY

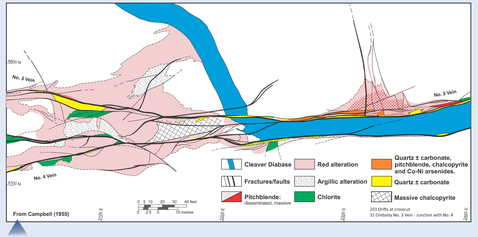
The LaBine Group complex of the GBmz comprises sandstone with a few carbonate beds of the Port Radium Formation, intruded by the hornblende-plagioclase Cobalt Porphyry, and overlain by andesite flows of the Surprise Lake Member. The Labine Group is intruded by the Tut quartz monzonite pluton and related Kiruna-type iron oxide-amphibole-apatite (IOA) veins. The complex is surrounded by granitic plutons.

NE-trending late tectonic faults host quartz veins that post-date the IOA veins, and predate the WNW trending Cleaver Diabase dykes. Fault reactivation displaced the Cleaver dykes and facilitated ingress of mineralizing solutions in 5 stages. The final stage was cross-cut by gently dipping sheets of the Western Channel Diabase.

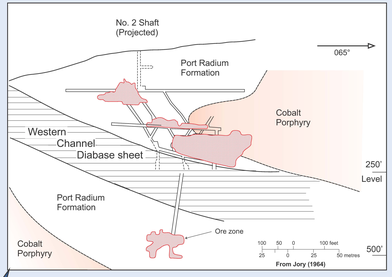
Distribution of U and Ag (the main metals produced from the Eldorado and Echo Bay veins) is indicated by red crosses and dashes on the surface map.



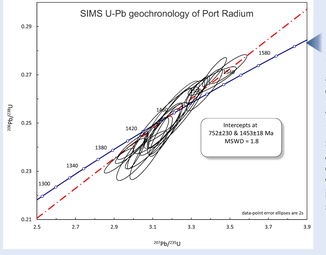
Polished sample (top) and autoradiograph (below) of uraninite (white) in altered and brecciated Cleaver diabase dyke.



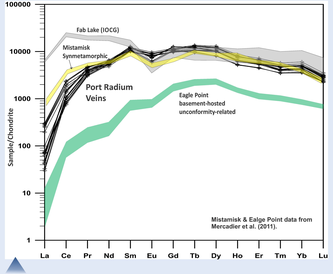
Plan view of No. 3 and No. 4 vein junction in a drift 125 m NNE of Shaft 1 and 125 m below the surface, shows a Cleaver dyke that follows the fault westward and turns to the northwest at the junction. Pitchblende-bearing polymetallic veins cut the dyke. The U-Pb baddeleyite age of 1740 +5/-4 Ma for the Cleaver dyke swarm (Irving et al., 2004) constrains the maximum age of the polymetallic veins.



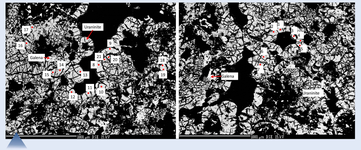
Vertical section of mine workings at Shaft 2 (Jory, 1964) shows the steep polymetallic ore zones cross-cut by a gently dipping Western Channel Diabase sheet that is barren. This relationship is also seen at a few other localities in the Eldorado and Echo Bay vein systems. Two U-Pb baddeleyite ages of 1592 ±3 and 1590 ±4 Ma are reported for separate samples of Western Channel Diabase sheets by Hamilton & Buchan (2010). They constrain the minimum age of the polymetallic veins.



Pitchblende at Port Radium is concordant at 1453 ±18 Ma, within error of the concordant 1445 ±20 Ma of Jory (1964). Isotopic re-settings at 1.4 Ga have also been reported for uranium deposits in the Athabasca Basin (ca. 1590, 1400, 1275 and 1100 Ma of Alexandre et al., 2009), Thelon Basin (ca. 1400 Ma, Fuchs and Hilger, 1989), and Lac Cinquante (1838 ±29 and 1437 ±31 Ma, Bridge et al., 2013). The Mallery Lake Au-Ag deposit also yielded 1434 ±23 Ma (Sm-Nd on fluorite, Turner et al., 2003). Clearly 1.4 Ga was a time of major isotopic resetting. Red dots in figure below left show some of the analytical spots for Port Radium.

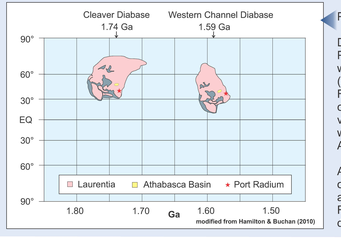


Chondrite-normalized REE signatures in pitchblende from Port Radium are similar to those from the basement-hosted, unconformity-related Eagle Point deposit in the Athabasca Basin, although the greater REE contents are more akin to the 'synmetamorphic' vein uraninite from the Mistamisk deposit in the Labrador trough (cf. Mercadier et al., 2011). Those of uraninite in ca. 1868 Ma magnetite-group iron oxide-copper-gold (IOCG) occurrences of the GBmz (e.g. Fab Lake), shown at top, are clearly distinct.



Spherulitic to botryoidal texture is characteristic of pitchblende at Port Radium.

Basement-hosted veins under the Hornby Bay Group at the Rah Prospect, 75 km north of Port Radium (Gandhi & Paktunc, 1989) also exhibit botryoidal textures.



Paleopole plots of Laurentia.

During polymetallic vein formation, the Port Radium region was sub-tropical, with rapid oxidized paleo-weathering (e.g., red beds in Hornby Bay Group). Field relationships and geochronology constrain development of the polymetallic veins between 1.74 and 1.59 Ga, coeval with filling of the Hornby Bay, Thelon and Athabasca basins.

Although mineral assemblages and forms of the ore bodies differ, the closest analogs for the uranium ore at Port Radium are the unconformity-related deposits of the Athabasca Basin.

Paragenetic sequence of Port Radium vein mineralization, modified from Kidd & Haycock (1935) and Ruzicka & Thorpe (1996)

Regional Structural, Igneous and Mineralization Events	Late Tectonic Faulting	Stage 1 : Quartz	Cleaver Diabase Dykes	Stage 2 : Pitchblende		Stage 3 : Arsenide	Narakay Islands Volcanics	Stage 4 : Sulphide		Stage 5 : Carbonate	Western Channel Diabase	Stage 6 : Native Silver
Age / Interval	~ 1.84 - 1.74 Ga		1.74 Ga	Lower Hornby Bay Group			1.66 Ga	Upper Hornby Bay Group			1.59 Ga	~ 1.59 Ga
Quartz	F			F		F	F		F			
Hematite	r			r	r		r		r			
Pitchblende	a		I	a	a		a		a		I	
Ni, Co, Fe, Ag Arsenides	c		n	c	c		c		c		n	
Ni, Co, Fe, Sb Sulpharsenides	t.		t	t.	t.		t.		t.		t	
Ni Sulphides			r								r	
Cu, Fe, Pb, Zn, Sb, Mo,	&		u	&	&		&		&		u	
As, Bi, Ag Sulphides			s								s	
Ag Tellurides	B		i	B	B		B		B		i	
Native Ag	r		o	r	r		r		r		o	
Native Bi	e		n	e	e		e		e		n	
Chlorite	c			c	c		c		c			
Fluorite	c.			c.	c.		c.		c.			
Carbonates												
Temperature (° C)		150 - 250		150 - 250	220 - 480			150 - 250		90 - 250		
$\delta^{18}O$ ‰ (n)		16.5 (1)		15.15 (2)	22.2 (12)			23.7 (7)		13.97 (13)		
$\delta^{13}C$ ‰ (n)		-73.5 (1)		-4.05 (2)	-3.64 (12)			-2.7 (7)		-4.9 (13)		

The main host fractures of Port Radium veins are part of the late tectonic, NE-trending transcurrent fault system of the GBmz, characterized by quartz veins of Stage 1 with sparse pitchblende & Cu sulphides.

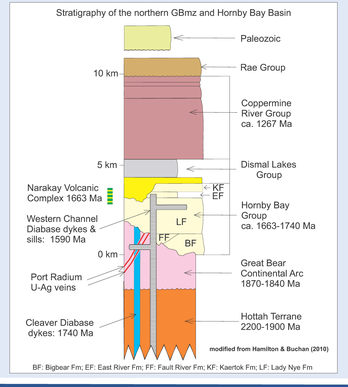
Following intrusion of the Cleaver Diabase dykes, faults at Port Radium were reactivated during stages 2 to 5. These subsidiary faults created space for deposition of economic pitchblende, Co-Ni arsenides and multiple silver phases.

The polymetallic stages 2-5 were coeval with deposition of the Hornby Bay Group including the 1.67 Ga Narakay volcanic complex.

Rare native silver-bismuth veinlets in the Western Channel Diabase represent the latest and minor stage of mineralization.

DISCUSSION

The GBmz contains excellent U-bearing source rocks, including possible pre-vein enrichment in Kiruna-type or IOA mineralization, and IOCG and affiliated systems (e.g. Terra Mine, Fab Lake and Sue Dianne).



Thorpe (1974) reported a Pb model age of 1630 ± 40 Ma for 8 galena grains, including 3 samples of Jory (1964) from the Ag + Ni-Co arsenide veins at Port Radium. This is within the age constraints of baddeleyite ages on the Cleaver and Western Channel diabase swarms.

Concordant 1.4 Ga isotopic re-setting at Port Radium is mirrored by unconformity-related U of the Athabasca, Baker Lake, Hornby Bay and Thelon basins, and by epithermal Au-Ag at Mallery Lake, NU. Possible causes of this include:

- a ~4500 km string of 'anorogenic ' volcano-plutonic complexes across central North America, including the Saint Francois mountains with associated IOCG style deposits, possibly related to a plume that was over-ridden by Nuna (Hollings et al. , 2004)
  - and/or-
- the 1.45 -1.4 Ga Berthoud orogeny (Sims & Stein, 2003; Alexandre et al., 2009).

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