

## APPENDIX A

### Study Sites

A brief description of each study site where samples were collected is provided (see Fig. 2 for locations). Table A1 summarizes the possible minerals that can be found at each of the sites visited during the 2010-2013 field campaigns.

#### Study Sites

##### *Bicroft Mine*

In 1955, Bicroft Uranium Mines, Limited formed due to the amalgamation of Centre Lake Uranium Mines, Limited, and Croft Uranium Mines, Limited (Satterly, 1957). Uraniferous granitic pegmatites occur in a zone of syenitized paragneiss and amphibolite which is overlain by marble to the east and underlain by leucogranite (alaskite) of the Cardiff batholith (Satterly, 1957; Gordon *et al.*, 1981). The metasediments are comprised of biotite paragneiss, amphibolite, scapolite-biotite gneiss, garnet-sillimanite-biotite paragneiss and a band of silicified marble. The metasediments were intruded and replaced by grey albite syenite, yellow-brown sodic syenite and granite containing alkaline hornblende or pyroxene and titanite and pink potassic syenite and granite. Radioactive minerals such as uranothorite, uraninite, allanite, thorite, pyrochlore and betafite generally occur in the yellow-brown or red sodic granite and syenite pegmatites (Satterly, 1957). Satterly (1957) provides detailed descriptions of the various lithologies, wall-rock alteration and the ore and Sabina (1986) provides a synopsis of the primary and accessory minerals associated with this U and Th deposit. Exploration was conducted through trenching, development of a 53.4 m adit and two shafts (71.4 m and 562 m) (Sabina, 1986). Exploration by Kerr-Addison continued until about 1975 through diamond drilling. However, production ceased by 1963; over 2 million kg of U<sub>3</sub>O<sub>8</sub> were extracted from 2,233,067 t of ore (see Table 2) (Gordon *et al.*, 1981; Sabina, 1986).

##### *Canadian Dyno Mine*

This deposit occurs between the Cheddar granite on the west and the Centre Lake granite of the Cardiff pluton on the east. It is underlain by amphibolite, pyroxene amphibolite, biotite-diopside-scapolite granulite, garnet-sillimanite paragneiss and marble. The metasediments are intruded and replaced by syenite gneiss and country rocks intruded by N-trending pegmatitic leucogranite dykes (Satterly, 1957; Gordon *et al.*, 1981). It was mined for uranium and thorium between 1954 and 1960 with a total production of 599,523 t of ore with 453,592 t in reserve (see Table 2). In all, 360,524 kg of U<sub>3</sub>O<sub>8</sub> were produced (Gordon *et al.*, 1981; Griffith, 1986; Sabina, 1986). Ore minerals include uraninite and uranothorite associated with allanite, uranophane, crytolite (zircon) and thorite from magnetite-rich zones in the pegmatites. Sabina (1986) reported that the U-bearing minerals occur in deep red to purplish zones due to intense hematization. Accessory minerals include titanite, apatite, pyrite and molybdenite. Pegmatites also contain albite (peristerite), microcline, smoky quartz, pyroxene and amphibole (Sabina, 1986).

### ***Cardiff Mine (Prospect)***

The Cardiff prospect was initially explored for fluorite in 1943 by the Cardiff Fluorite Mines Limited and exploration for uranium and thorium began in 1953 by Cardiff Uranium Mines Limited (Satterly, 1957; Sabina, 1986). Both the uraninite and fluorite occur in calcite veins within a band of calcareous paragneiss and amphibolite near the contact with crystalline limestone (Satterly, 1957). The limestone (marble) underlies the western part of the prospect and is overlain by scapolitic amphibolite, calcareous paragneiss and biotite amphibolite. The gneisses are syenitized and intruded by syenite and granite pegmatites. Veins tend to be lenticular, pod-shaped or irregular in shape but strike conformably with the country rock (Satterly, 1957). No production occurred although two adits and a shaft (83.8 m) were developed in the south zone. Minerals associated with the calcite veins include apatite, biotite, pyroxene, scapolite, titanite, molybdenite and quartz. The shaft of this mine, sealed using waste rock from the original site, is shown in Fig. A1-B.

### ***Croft Mine (Prospect)***

The Croft deposit occurs in the same belt of syenitized paragneiss and amphibolite which hosts the Bicroft Mine. The metasediments include hornblende gneiss, amphibolite, biotite paragneiss, biotite-garnet-sillimanite gneiss (augen gneiss) cut and replaced by syenite and granite dykes (Satterly, 1957; Gordon *et al.*, 1981). Development of this deposit included surface trenches, extensive diamond-drilling and an adit. Exploration of the adit level revealed four lenticular *en échelon* pegmatite bodies, along the contacts of pods of biotite-garnet-sillimanite gneiss. The dykes are biotite granite pegmatite with porphyroblastic textured feldspar (Gordon *et al.*, 1981). The main mineral is uranothorite in association with secondary uranium minerals (*e.g.*, allanite, betafite, uranophane, pyrochlore), zircon (cyrtolite), pyrite and molybdenite. Kerr-Addison Mines Limited carried out further exploration in the 1970s and estimated reserves at 888,867 tonnes (see Table 2) grading at 0.6 kg/tonne (Gordon *et al.*, 1981). Figure A1-C shows the adit where water was sampled for the groundwater part of this study and Fig. A1-D shows AD downloading data from the submersed data-logger placed in an artesian borehole for the duration of the study.

### ***Desmont Mine***

This prospect is underlain by marble with inter-bands of diopside-bearing rock, calc-silicate rock and rusty mica-bearing gneisses (Satterly, 1957). The surface workings of pits, trenches and strippings are extensive over a distance of 1150 m (Sabina, 1986). The minerals uranothorite occurs in diopside or diopside-calcite rock within marble and uraninite in calc-silicate bands in marble or mica-bearing marble. Other minerals in calcite veins include uncommon stillwellite and hydroxybastnäsite. Sabina (1986) reported a long list of minerals that can be found at this site for mineral collectors (Table A1, Appendix A). Assays indicated 0.004% U<sub>3</sub>O<sub>8</sub> and 0.016-0.44% MoS<sub>2</sub> (Gordon *et al.*, 1981). The most recent exploration between 1976 and 1977 was carried out by Highland Mercury Mines, Limited (Gordon *et al.*, 1981).

### ***Dwyer Fluorite Mine***

This deposit was developed for fluorite in 1918 by P.J. Dwyer with production listed as 33.5 t (see Table 2). The fluorite is in calcite veins that cut granite. Accessory minerals include apatite, hornblende and clinopyroxene (Sabina, 1986).

### ***Halo Mine***

This deposit occurs along the western side of the Cardiff dome in a curving belt of amphibolite and paragneiss with interbedded marble and metamorphic pyroxenite (Satterly, 1957; Gordon *et al.*, 1981). Uranium mineralization occurs in pegmatite, syenite, metamorphic pyroxenite and calcite-fluorite veins and consists of uraninite, uranothorite, thorite and betafite. Accessory minerals include chlorite, tourmaline, titanite, amphibole, molybdenite, pyrite and pyrrhotite (Sabina, 1986). Several prospects were explored and developed: Northwest zone, Lake zone, Pyroxenite zone and South zone. Adits were developed in the Northwest and Lake zones only. The Northwest zone is comprised of west- to northwest-striking biotite paragneiss or biotite-garnet paragneiss with uraninite occurring in granite or syenite pegmatite bodies that strike north or northwest. The Lake zone consists of paragneiss and garnet-biotite paragneiss with a narrow band of metamorphic pyroxenite and interbedded marble. Uranothorite occurs in irregular-shaped lenticular bodies within a leucogranite pegmatite (Satterly, 1957; Gordon *et al.*, 1981). Including other prospects at this site, reserves were estimated at 428,191 tonnes grading 0.112% U<sub>3</sub>O<sub>8</sub> (see Table 2; Gordon *et al.*, 1981). The adit and remains of an exploration trench found at this site are shown in Figs. A1-E and -F, respectively.

### ***Kenmac-Chibougamou Mine***

Uranium-bearing minerals uranothorite and allanite occur with magnetite in numerous pegmatite dykes that cut amphibolite, biotite-rich paragneiss and marble (Satterly, 1957; Gordon *et al.*, 1981). Accessory minerals include zircon, apatite, scapolite, calcite and biotite (Sabina, 1986). Reserves in 1957 were estimated at 181,436 tonnes at 0.20% U<sub>3</sub>O<sub>8</sub> (see Table 2). Development included trenching, surface stripping, diamond-drilling and an 84-m long adit (Gordon *et al.*, 1981).

### ***Millar's Mine***

This deposit was opened in about 1900 as a radioactive (thorite, thorianite, uranophane) and phosphate (apatite) prospect. The minerals occur in calcite veins cutting graphic granite pegmatite. Development included trenching and a 9 m long adit driven into a ridge (Sabina, 1986).

### ***OTC Highway 118***

In 1979 the GSC drilled two holes (60 mm diameter; BN-79-4 and BN-79-5) along Highway 118, southwest of Bancroft (near Monck Road) in a Kerr-Addison property. These boreholes were drilled to intersect uranium- and thorium-bearing mineralized zones to test and develop new logging systems, starting with gamma ray spectral logging. In 1981 two 100 mm holes (HQ; BN-81-1 and BN-81-2) were drilled 60 m apart in the same location to test and evaluate a new borehole

XRF probe (Killeen, 1986). In addition, magnetic susceptibility, IP and resistivity were tested as well as an assessment of the volume of rock between holes. The logs of these boreholes show numerous narrow pegmatite intersections within strongly banded biotite gneiss and hornblende biotite gneiss lithologies. Based on the tests, the pegmatite intersections show high counts for U and Th using both the gamma ray spectral logging tool as well as the downhole XRF probe (Killeen, 1986). Magnetic susceptibility tended to be negligible for the pegmatites in comparison with the gneisses (Bristow and Bernius, 1984).

### ***Rare Earth Mine 2***

The deposit is underlain by amphibolite and marble bands that were intruded by metagabbro and granite or granite pegmatite. Uranothorite, uraninite and uranophane occur in the granite or granite pegmatite in lenticular bodies which parallel the gneissic fabric of the metagabbro. Accessory minerals include fergusonite, zircon, allanite, with minor titanite, pyroxene, smoky quartz, hematized feldspar and peristerite (Satterly, 1957; Sabina, 1986). This deposit was developed by shaft, adit and several trenches. Reserves in 1957 were estimated at 265,305 tonnes with a grade of between 0.095 and 0.12% U<sub>3</sub>O<sub>8</sub> (see Table 2; Gordon *et al.*, 1981). There was no production from this mine.

### ***Richardson Fission Mine (Prospect)***

Uraninite was discovered on this property by W.M. Richardson in 1922, the first discovery in the Wilberforce area. The uranium minerals occur in calcite-fluorite-apatite veins or pegmatite bodies. The deposit is found on the northwest side of the Cardiff plutonic complex. Country rocks are syenitized metasediments comprised of amphibolite, biotite-scapolite granulite and syenitized gneiss striking northeast, cut and replaced by granite and syenite pegmatites rich in fluorite and calcite. In this deposit, uraninite is found in the calcite-fluorite veins whereas uraninite plus uranothorite occur in pyroxene-fluorite syenite pegmatite dykes (Satterly, 1957; Gordon *et al.*, 1981). Sabina (1986) noted that deep purple fluorite associated with uraninite gives off a foul odour when crushed and that the emerald green clinoamphibole is suitable for lapidary purposes. Other accessory minerals include magnetite, allanite, zircon, titanite, molybdenite, pyrite, pyrrhotite, thorite and melanocerite. In addition, Sabina (1986) reports uranophane, betafite and euxenite in the deposit. Reserves were estimated as 272,155 tonnes of 26% fluorite and some zones containing up to 0.07% U<sub>3</sub>O<sub>8</sub> (see Table 2; Gordon *et al.*, 1981).

### ***Silver Crater Mine***

The Silver Crater deposit, also known as the Basin property, was originally mined for black mica (lepidomelane) in the 1920s by the Bancroft Mining Company for use in the roofing industry (Sabina, 1986). Between 1947 and 1951, 426 tonnes of mica were produced from an open pit. Exploration for radioactive minerals occurred between 1953 and 1955 by Silver Crater Mines Limited through trenching and a development of a 70 m long adit south of the original mica pit. The main uranium mineral discovered was betafite in association with zircon, fluorite, titanite, molybdenite, pyrrhotite and pyrochlore. The deposit is found within a carbonate lens, surrounded by a band of amphibolite in a trough of syenitic and nepheline syenite gneisses (Satterly, 1957;

Gordon *et al.*, 1981). Satterly (1957) provides very detailed descriptions of the adit and cross-cuts at this site.

### ***Tripp (Nu-Age) Mine***

This deposit containing uraninite, uranothorite, allanite and thorite is located in an amphibolite and syenitized gneiss belt, northwest of the Cardiff plutonic complex (Satterly, 1957, Gordon *et al.*, 1981). Originally worked for fluorite by Industrial Minerals Corporation and then later explored for radioactive minerals by Nu-Age Uranium Mines, Limited (Sabina, 1986). The former company hand-picked 1.8 tonnes of fluorspar grading 98% CaF<sub>2</sub>, which sold for \$32 in 1924 (Satterly, 1957). Satterly (1957) reported that the radioactive anomalies were produced by uraninite in red syenitized gneiss, uranothorite in pegmatite and both minerals in calcite-fluorite-apatite veins.



Figure A1: (A) typical drill core dump, Tripp (Nu-AGE) mine (NRCan Photo 2023-689); (B) rehabilitated shaft, Cardiff Mine (NRcan Photo 2023-690); (C) adit, Croft mine (NRCan Photo 2023-691); (D) AD downloading data from borehole-submersed data-logger, Croft mine (NRCan Photo 2023-692); (E) AD in front of adit, Halo mine (NRCan Photo 2023-693); (F) remains of an exploration trench, Halo mine (NRCan Photo 2023-694). All photos by J.B. Percival

Table A1. Possible mineral phases found at each mine site and prospect visited in the Bancroft area (after Sabina, 1986).

Mine Site	Radioactive Minerals (U/Th)	Silicates	Carbonates	Phosphates/ Sulphates/ Borates	Oxides/ Selinides	Sulphides	Other
Bicroft Mine	allanite, betafite, euxenite, pyrochlore, uraninite, uranothorite	amphibole, scapolite, garnet, microcline, peristerite, pyroxene, quartz, sillimanite, titanite, tourmaline, zircon	bastnäsite, calcite	apatite	anatase, magnetite, umangite	molybdenite, pyrite, pyrrhotite	fluorite, graphite
Canadian Dyno Mine	allanite, kasolite, uraninite, uranophane, uranothorite	amphibole, microcline, peristerite, pyroxene, quartz, titanite, zircon		apatite	magnetite	molybdenite, pyrite	
Cardiff Mine (prospect)	allanite, betafite, euxenite, pyrochlore, uraninite, uranothorite	nordbergite, phlogopite, pyroxene, scapolite, sepiolite, serpentine, talc, titanite, tourmaline	calcite	apatite, fluoborite		molybdenite, pyrite, pyrrhotite	fluorite, graphite
Croft Mine (prospect)	allanite, betafite, pyrochlore, uraninite, uranothorite	chlorite, clinopyroxene, garnet, sillimanite, titanite, tourmaline, zircon	calcite	apatite, monazite		molybdenite, pyrite, pyrrhotite	sulphur
Desmont Mine	allanite, thorianite, uranothorite	chondrodite, clinoamphibole, clinopyroxene, garnet, K-feldspar, perrierite, plagioclase, quartz, scapolite, serpentine, stillwellite, titanite, tourmaline	ancylite, calcite, hydroxylbastnäsite	apatite, monazite, gypsum	goethite, magnetite	marcasite, molybdenite, pyrite, pyrrhotite, sphalerite	graphite, sulphur

Table A1 continued

Mine Site	Radioactive Minerals (U/Th)	Silicates	Carbonates	Phosphates/ Sulphates/ Borates	Oxides/ Selinides	Sulphides	Other
Dwyer Fluorite Mine	—	clinoamphibole, clinopyroxene	calcite	apatite			fluorite, graphite
Halo Mine (prospect)	betafite, thorite, thorigummite, uraninite, uranothorite	amphibole, chlorite, pyroxene, titanite, tourmailine, zircon	calcite			molybdenite, pyrite, pyrrhotite	fluorite
Kenmac Chibougamou	allanite, uranothorite	biotite, pyroxene, scapolite, zircon	calcite	apatite	magnetite		
Millar's Mine	thorianite, thorite, uranophane	biotite, chondrodite, clinoamphibole, clinopyroxene, orthoclase, quartz, serpentine, talc, titanite	calcite			pyrite	
Blue Rock Rare Earth Mine 2	allanite, uraninite, uranophane, uranothorite	amphibole, clinopyroxene, corundum, garnet, peristerite, scapolite, talc, titanite, vesuvianite, zircon	calcite, bastnäsite		fergusonite	galena, molybdenite, pyrite, pyrrhotite	graphite
Richardson Fission Mine (prospect)	allanite, betafite, euxenite, uraninite, uranophane, uranothorite	biotite, chlorite, clinoamphibole, clinopyroxene, feldspar, melanocerite, titanite, zircon	calcite	apatite	hematite, magnetite	chalcopyrite, molybdenite, pyrite, pyrrhotite	fluorite

Table A1 continued

<b>Mine Site</b>	<b>Radioactive Minerals (U/Th)</b>	<b>Silicates</b>	<b>Carbonates</b>	<b>Phosphates/ Sulphates/ Borates</b>	<b>Oxides/ Selenides</b>	<b>Sulphides</b>	<b>Other</b>
Silver Crater Mine	betafite, euxenite	albite, amphibole, lepidomelane, titanite, tourmaline, zircon	calcite	apatite	magnetite	molybdenite, pyrite, pyrrhotite	fluorite
Tripp (Nu-Age) Mine	allanite, thorite, uraninite, uranothorite	biotite, clinoamphibole, clinopyroxene, feldspar, peristerite, scapolite, zircon	calcite	apatite	magnetite	chalcopyrite, pyrite	fluorite