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# VOLCANIC-HOSTED URANIUM MINERALIZATION IN THE EASTERN CENTRAL MINERAL BELT OF LABRADOR: BENEDICT MOUNTAINS REGION

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## ABSTRACT

*The Benedict Mountains region represents the easternmost extension of the Central Mineral Belt of Labrador. Within the western portion of the Benedict Mountains region, a north–south-trending belt of supracrustal rocks is host to several examples of volcanic-hosted uranium mineralization. This mineralization is predominantly fracture-hosted and is accompanied by the development of hematization and potassium metasomatism within the adjacent country rock, which are relatively undeformed, along with lesser mineralization developed proximal to mafic dykes that intrude the volcanic sequence. A lapilli tuff unit, which is locally host to uranium mineralization, has produced a U–Pb age of 1855.2 ± 1.4 Ma, providing a maximum age limit on the development of the uranium mineralization. This U–Pb age also provides additional supporting evidence for the inclusion of the supracrustal rocks in this region with the regionally extensive Aillik Group, located farther to west.*

## INTRODUCTION

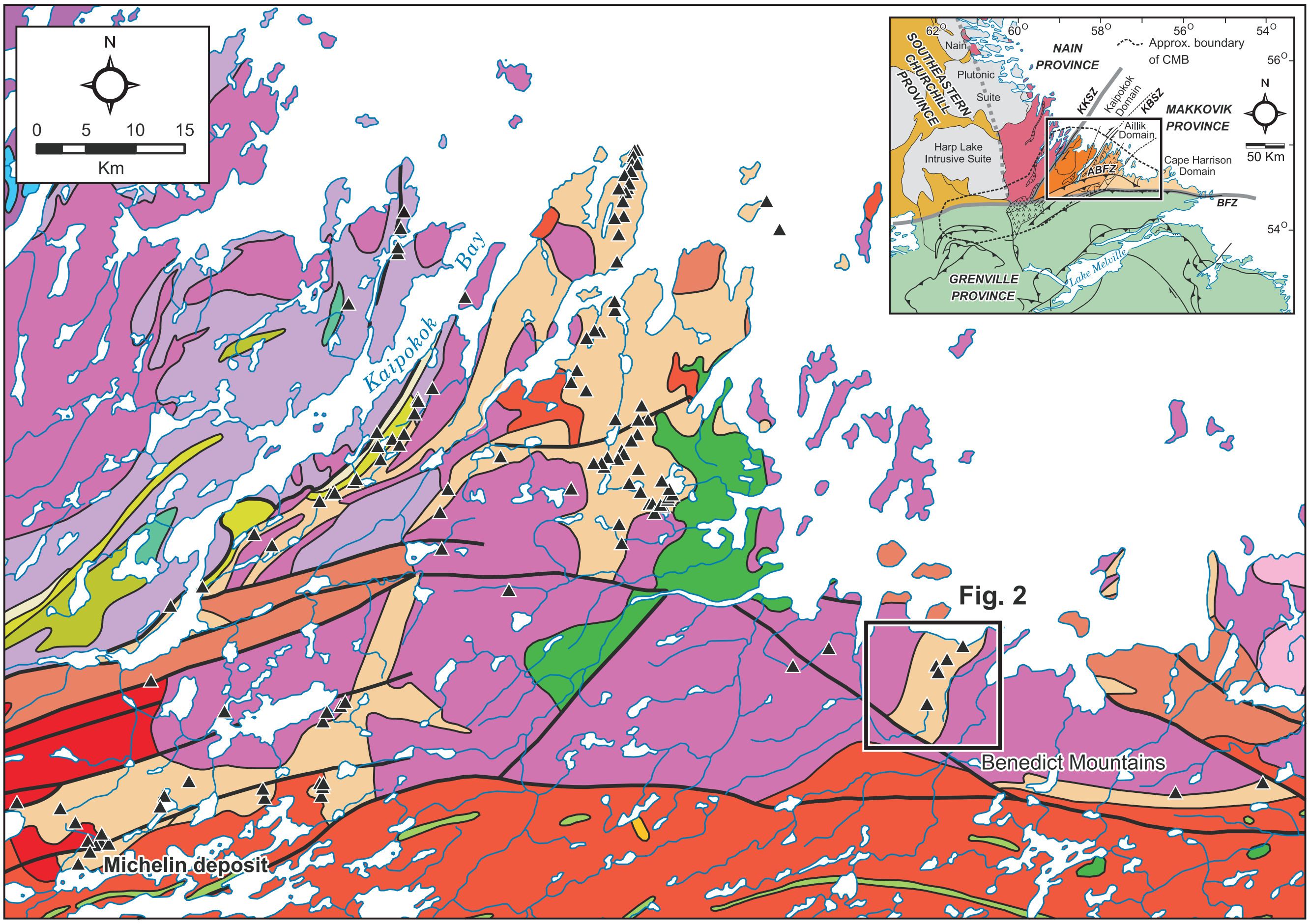
### REVIEW

The Benedict Mountains region forms the easternmost extension of the Central Mineral Belt (CMB, Figure 1), an area of Labrador that has long been of interest for its occurrences of base metals, and widespread uranium mineralization (Ryan, 1984; Wilton, 1996). Numerous styles of uranium mineralization occur throughout the CMB, and the most significant deposits are hosted within the metavolcanic rocks of the Aillik Group (*cf.,* Sparkes and Kerr, 2008, and references therein). A correlation between the volcanic rocks of the Benedict Mountains region, and those of the Aillik Group located farther to the west, was first noted by Gower (1981). Subsequent studies have also highlighted the possible correlation between these units (*e.g.,* Kerr *et al*., 1996), and limited geochronological data support this correlation (*e.g.,* Ketchum *et al*., 2002). However, despite this link, the Benedict Mountains region has received far less attention with respect to uranium exploration in comparison with the Aillik Group farther to the west. This paper compares the style of uranium mineralization observed within the western belt of supracrustal rocks in the Benedict Mountains region (Figure 2) with that developed elsewhere in the CMB. In addition, new geochronological data for a volcanic unit hosting uranium mineralization provide further supporting evidence for the correlation of these volcanic rocks with the Paleoproterozoic volcanic rocks of the Aillik Group.

### EXPLORATION HISTORY

The first systematic uranium exploration carried out in the region of the Benedict Mountains began in the late 1960s with a reconnaissance airborne gamma ray survey flown by Brinex Exploration Limited; however no follow-up work was reported. The area remained relatively inactive, aside for minor exploration related to molybdenum occurrences until the late 1970s, when uranium exploration resumed under a joint venture between Placer Development Limited and Brinex. As part of this program, an airborne survey was again conducted over the area, resulting in the discovery of the B-22 prospect, which was the first uranium occurrence identified in the Benedict Mountains region. Ground follow-up of the anomaly produced assays of up to 0.05% $U_3O_8$, in association with hematite–pyrite alteration within a felsic pyroclastic unit (Davidson and Kowalczyk, 1979); however, no further work was reported for the area.

In the mid-2000s, Monster Copper (later acquired by Mega Uranium Limited) commenced uranium exploration in the Benedict Mountains. This exploration included more




**LEGEND**

**MESOPROTEROZOIC**

- Olivine gabbro and metamorphic equivalents, including coronitic varieties (Shabogamo and Michael gabbros, *ca.* 1460 to 1425 Ma)

**PALEOPROTEROZOIC**

- Granite, quartz monzonite, granodiorite, syenite and minor quartz diorite (*ca.* 1650 Ma)
- Rhyolitic to andesitic volcanic rocks including ash-flow tuff and agglomerate (*ca.* 1650 Ma)
- Mafic intrusive suites (gabbronorite, lesser diorite), some metamorphosed as amphibolite to granulite facies
- High-level, locally flourite-bearing granites (1776 to 1719 Ma)
- Tonalite, granodiorite and monzogranite gneiss; minor amphibolite, calc-silicate and felsic (metavolcanic?) gneiss
- Granite and granodiorite (1840 to 1795 Ma)
- Gabbro and leucograbbro sills (*ca.* 1884 to 1874 Ma)
- Granite plutons (*ca.* 2134 Ma, locally 2032 Ma in the Nain Province; 1973 to 1891 Ma in the Makkovik Province)
- Rhyolite, ash-flow tuff, breccia and hypabyssal rhyolite intrusions; volcaniclastic siltstone and sandstone; minor basalt (*ca.* 1860 to 1807 Ma)
- Schistose amphibolite derived from mafic volcanic rocks (Moran Lake and Post Hill gps.)
- Pelitic schist

**ARCHEAN**

- Tonalitic and other gneisses reworked and retrograded during Makkovikian orogenisis
- Granodiorite, tonalite and minor granite (Kanairiktok Intrusive Suite, *ca.* 2850 to 2830 Ma)
- Tonalitic to granodioritic migmatitic orthognessis containing abundant mafic to ultramafic inclusions and relict mafic dykes
- Mafic volcanic and volcaniclastic rocks, lesser sedimentary and felsic volcanic rocks, and mafic-ultramafic sills; at greenschist to amphibolite facies (Florence Lake group, *ca.* 3000 Ma)

**SYMBOLS**

*Geological contact* ..................

*Fault* ........................................

*Radioactive occurrence* .......... ▲

**Figure 1.** *Regional geology map outlining the distribution of known uranium occurrences within the eastern portion of the Central Mineral Belt. Geological base map modified from Wardle* et al. *(1997). Inset map outlines the regional subdivisions of the Central Mineral Belt; modified from Hinchey and Laflamme (2009). BFZ–Benedict fault zone; KBSZ–Kaipokok Bay shear zone; KKSZ–Kanairiktok shear zone; ABFZ–Adlavik Brook fault zone.*

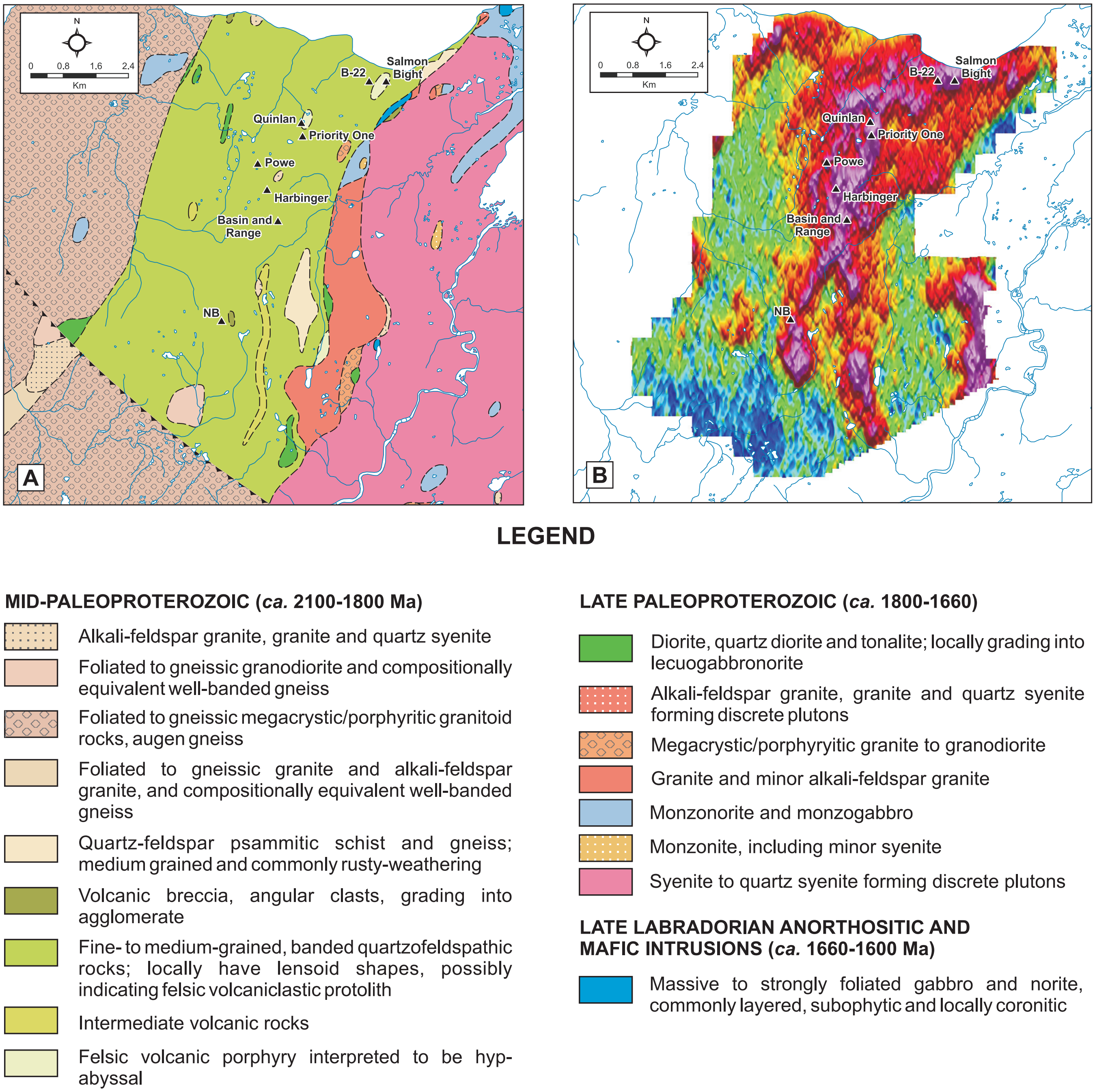



**Figure 2.** A*) Regional geology map of the western belt of suparcrustal rocks in the Benedict Mountains region; geological base map from Gower (2010). Prospects indicated by black triangles. B) Airborne radiometric data conducted by Mega Uranium Limited; bright pink to red colours denote areas of elevated radioactivity (Kruse and Tykajio, 2009).*

sophisticated airborne radiometric and geochemical surveys along with follow-up prospecting and geological mapping, resulting in the discovery of several new uranium occurrences within the area (Setterfield and Dyer, 2007; Setterfield *et al*., 2008; Kruse and Tykajio, 2009). Intensive exploration in the area continued up until the implementation of a uranium moratorium by the Nunatsiavut Government in the late 2000s, which led to a decline in uranium exploration throughout the CMB of Labrador.

## REGIONAL GEOLOGY

The CMB of Labrador is a region that encompasses portions of the Archean Nain Province, the Paleoproterozic

Makkovik and Churchill provinces, and the Mesoproterozic Grenville Province (Figure 1). A significant portion of the CMB is composed of the Makkovik Province, which is further subdivided into three domains; from west to east they are the Kaipokok, Aillik and Cape Harrison domains (Kerr *et al*., 1996; Ketchum *et al*., 2002; Hinchey, 2007). The dominant rocks within the Kaipokok domain are reworked Archean basement rocks, whereas the Aillik domain contains mostly supracrustal rocks, and the Cape Harrison domain is composed of syntectonic and posttectonic plutonic rocks, and scattered enclaves of supracrustal sequences (Kerr *et* al., 1996). The Benedict Mountains region is located in the easternmost Cape Harrison domain of the Makkovik Province. The adjacent Aillik domain to the west, is largely dominated by metasedimentary and metavolcanic supracrustal rocks of the Aillik Group (Ketchum *et al*., 2002), along with lesser Paleoproterozic intrusive suites (Kerr *et al.*, 1996; Hinchey, 2007; Hinchey and LaFlamme, 2009). Within the Aillik domain, the metavolcanic rocks of the Aillik Group are noted for hosting numerous occurrences of uranium mineralization in association with zones of pervasive sodic alteration, the most notable of which is the Michelin deposit (Gandhi, 1978; Evans, 1980; Gower *et al.*, 1982; Sparkes and Kerr, 2008 and references therein).

The Cape Harrison domain is dominated by plutonic rocks and its contact with the adjacent Aillik domain to the west is largely intrusive (Kerr *et al*., 1996). This domain also contains lesser supracrustal sequences that are dominated by felsic volcanic rocks and related volcaniclastic units, preserved as enclaves and fault-bounded blocks; these rocks are inferred to be correlatives of the Aillik Group (Gower, 1981; Gower and Ryan, 1986; Kerr *et al.*, 1996). The plutonic rocks within the Cape Harrison domain can be broadly separated into four main intrusive events at *ca.* 1840 Ma, *ca.* 1800 Ma, *ca.* 1720 Ma and *ca.* 1650 Ma (Kerr, 1989; Kerr *et al*., 1992; Kerr and Fryer, 1993, 1994). The western belt of supracrustal rocks within the Benedict Mountains region (Figure 2) is composed of felsic agglomerates, tuffs and porphyries with lesser felsic flows and volcaniclastic sediments, all of which display typical greenschist-facies metamorphic assemblages and are crosscut by numerous southeast-trending diabase and gabbroic dykes (Gower, 1981). Most of the supracrustal rocks within the Cape Harrison domain are metamorphosed and deformed, but the western belt of supracrustal rocks is noted to be relatively undeformed with primary volcanic textures locally being preserved, including ignimbrite and spherulitic rhyolite (Kerr *et al*., 1996). This western belt is bounded to the west and south by granitoid rocks of the *ca.* 1800 Ma Stag Bay granodiorite, and to the east by the *ca.* 1650 Ma Mount Benedict Intrusive Suite (Kerr, 1994).

Geochronological data from volcanic rocks exposed on an island to the northeast of the western supracrustal belt indicated an age of 1853 ± 2 Ma (Ketchum *et al*., 2002), providing supporting evidence for their correlation with the Aillik Group, which has a typical age range between 1883–1856 Ma (Schärer *et al*., 1988; Hinchey and Rayner, 2008).

## MINERALIZATION

Since the mid 2000s, uranium exploration in the Benedict Mountains region has resulted in the discovery of several new uranium occurrences, in addition to the B-22 prospect; most of these occurrences are hosted within felsic volcanic rocks that are inferred to be correlative with the Aillik Group (Table 1 and Figure 2). Within the Benedict Mountains region, uranium mineralization is predominantly fracture-hosted, and occurs without widespread metasomatism, similar to the "Type 3 - disseminated or fracture-hosted mineralization in felsic volcanic rocks without associated deformation or metasomatism" (Sparkes and Kerr, 2008). This style of mineralization differs from most of that seen elsewhere in the Aillik Group farther to the west and is more typical of mineralization observed within the younger volcanic sequences of the Bruce River Group (*cf.,* Sparkes and Kerr, 2008). The following represents a summary of the information available on the uranium mineralization within the western belt of supracrustal rocks in the Benedict Mountains region. It is drawn from assessment files, supplemented by observations from field work and other studies.

**Table 1.** Summary of the main uranium prospects within the western belt of supracrustal rocks in the Benedict Mountains region, along with the corresponding highest assay value obtained at each

| Prospect | Highest Assay Value (% $U_3O_8$) | Reference |
|---|---|---|
| B-22 | 0.50 | Setterfield *et al.* (2008) |
| Basin and Range | 0.38 | Setterfield *et al.* (2008) |
| Harbinger | 0.52 | Kruse and Tykajio (2009) |
| NB | 1.75 | Kruse and Tykajio (2009) |
| Powe | 13.8 | Setterfield *et al.* (2008) |
| Priority One | 0.70 | Setterfield *et al.* (2008) |
| Quinlan | 2.09 | Setterfield *et al.* (2008) |
| Salmon Bight | 0.23 | Kruse and Tykajio (2009) |

Within the approximately 11-km-long north–south-trending belt of supracrustal rocks in the western portion of the Benedict Mountains region, Mega Uranium Limited has identified thirteen uranium occurrences. These occurrences are generally fracture-hosted, but also include mineralization locally developed marginal to younger mafic dykes. This uranium mineralization is associated with hematization and potassium metasomatism of adjacent host rocks, as well as the local development of uranophane along fractures. In some instances, the host rocks are also crosscut by magnetite and lesser carbonate veins, such as at the B-22 prospect (Setterfield and Dyer, 2007).

The Powe prospect is host to the highest grade uranium mineralization within the area, with assays locally returning up to 13.8% $U_3O_8$ (Setterfield *et al*., 2008). The main mineralization occurs within a narrow, north–northeast-trending, moderate to steeply westerly dipping shear zone, hosted within a massive, crystal-rich lapilli tuff (Plate 1). The mineralized shear zone is between 15–30 cm wide, from which channel samples of up to 7.0% $U_3O_8$ over 1 m have been obtained; the surrounding country rock contains magnetite and hematite alteration (Kruse and Tykajio, 2009). Other mineralization within the area, such as the Priority One prospect (Figure 2), is also associated with weakly anomalous Au, Ag and Cu (Setterfield *et al*., 2008).


**Plate 1.** *Uranophane-stained fractures within lapilli tuff developed proximal to the sample site, which assayed up to 13.8% $U_3O_8$; Powe prospect.*

At the Harbinger prospect, located approximately 1 km to the southeast of the Powe prospect, primary volcanic textures, such as spherulitic rhyolite (Plate 2) are preserved within the volcanic sequence, demonstrating the relatively pristine nature of some of the volcanic rocks. Here, the volcanic rocks are associated with a 750-m-long, north-trending airborne radiometric anomaly, within which assays of up to 0.52% $U_3O_8$ have been obtained (Setterfield *et al*., 2008; Kruse and Tykajio, 2009). Areas of elevated radioactivity generally correspond with fracture zones developed within

**Plate 2.** *Spherulitic rhyolite at the Harbinger prospect, displaying well-preserved primary volcanic textures within the relatively pristine volcanic rocks of the Benedict Mountains region. Rhyolite unit is associated with anomalous high-background radioactivity and contains up to 50 ppm U.*

the felsic volcanic host rocks. These host rocks contain up to 50 ppm uranium, providing similar values to the enriched volcanic rocks noted in the area of the Michelin deposit by Evans (1980).

The Quinlan prospect is somewhat different with respect to other uranium prospects within the area in that the uranium mineralization is developed along the margins of a younger southwest-trending feldspar-phyric mafic dyke (Plate 3). This area contains uranophane-stained fractures along the margin of the mafic dyke, from which grab samples of up to 2.09% $U_3O_8$ have been obtained (Setterfield *et al*., 2008). The fine-grained chilled margin of the dyke also contains anomalous uranium values, locally assaying up to 0.04% $U_3O_8$.

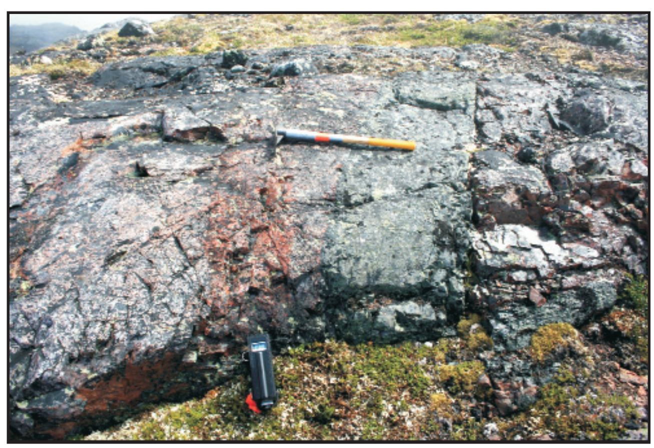


**Plate 3.** *Fine-grained mafic dyke intruding felsic volcanic rocks at the Quinlan prospect. Dyke emplacement results in minor hematization of the adjacent wallrock marginal to the dyke, as well as the development of elevated radioactivity.*

## GEOCHRONOLOGY

Limited U–Pb geochronolgical data exist for the volcanic rocks in the Benedict Mountains. The only previously reported age (1853 ± 2 Ma; Ketchum *et al*., 2002), is located on an island approximately 18 km to the northeast of the western belt of supracrustal rocks. To test the age of the volcanic rocks hosting uranium mineralization within the Benedict Mountains, a sample was collected at the Powe prospect. This unit consists of a red to maroon, massive, crystal-rich lapilli tuff containing up to 5–8 mm subhedral white feldspar in a very fine-grained, aphanitic groundmass (Plate 4). In thin section, the feldspar phenocrysts consist of an intergrowth of alkali and plagioclase feldspar as indicated by staining.


**Plate 4.** *Fresh, relatively undeformed, lapilli tuff that is host to the development of uranium mineralization at the Powe prospect.*

The sample was analyzed at the Geological Survey of Canada by Isotope-Dilution Thermal Ionization Mass Spectrometry (ID-TIMS) analysis; analytical techniques used are described in Parrish *et al*. (1987). The sample produced an abundant population of euhedral, well-faceted prismatic crystals (Plate 5), from which four separate analyses were carried out; two of which consisted of single grain analyses (A1 and B1, Table 2 and Figure 3). The results are reported in Table 2 and presented in Figure 3. The four analyses yielded concordant, to slightly (1.7%) discordant points with a weighted average $^{206}Pb/^{207}Pb$ age of 1855.2 ± 1.4 Ma (MSWD = 0.49; probability of fit = 69%). Linear regression of the data yield an upper intercept age of 1855.8 ± 2.1 Ma (MSWD = 0.36) and a lower intercept of 140 ± 310 Ma indicating some recent Pb-loss. This age is interpreted to provide the crystallization age of the tuff, and represents the maximum age limit on uranium mineralization in the area.

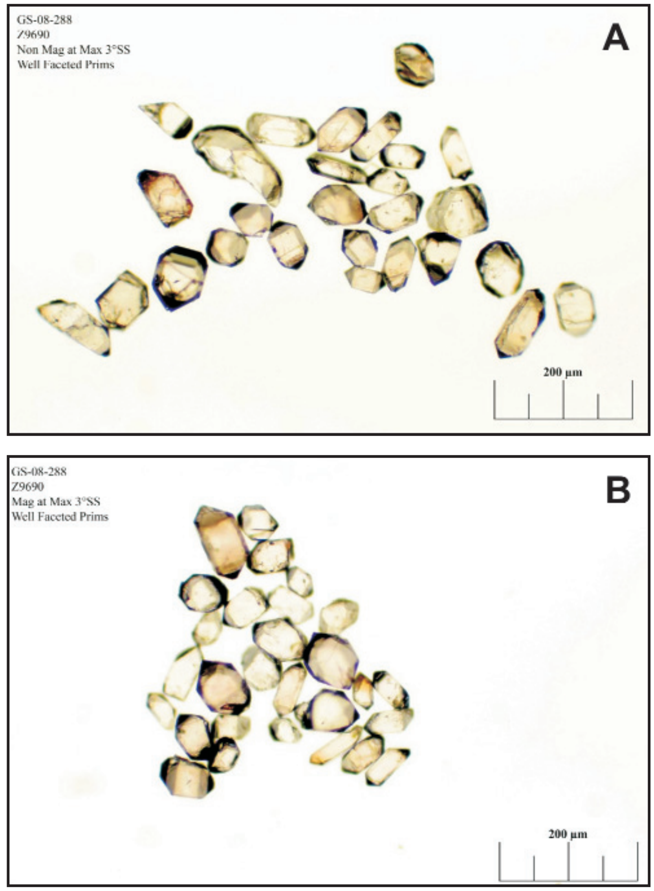



**Plate 5.** *Nonmagnetic (A) and magnetic (B) fractions of the zircon separates obtained from the lapilli tuff at the Powe prospect, respectively.*

## DISCUSSION

The rocks hosting uranium mineralization in the Benedict Mountains region fall within the typical age range of the Aillik Group farther to the west; however, the two areas display contrasting styles of uranium mineralization. Much of the uranium mineralization within the Aillik Group is typically associated with strong albitization (*i.e.,* sodium metasomatism), within discrete zones of strong deformation; these alteration zones normally contain low-grade, finely disseminated uranium mineralization throughout (Type 4 of Sparkes and Kerr, 2008). As a result of these characteristics, Sparkes and Kerr (2008) suggested that the introduction of uranium and the related metasomatism occurred prior to, or during deformation of the volcanic host rocks.

In contrast, much of the uranium mineralization within the Benedict Mountains region is associated with only minor alteration, which is generally developed in the form of hematization and potassium metasomatism. The related uranium mineralization is restricted to fracture zones, which

**Table 2.** The U–Pb data for the massive, crystal-rich lapilli tuff, Powe prospect; sample number GS-08-288

| | | | | | | | | | Atomic Ratios3 (± 1σ error absolute) | | | | | | | | Age (Ma) ± 2σ error absolute | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fraction | Description | # gr | Size | Wt.1 (µg) | U (ppm) | Pbr2 (ppm) | $^{206}$Pb/$^{204}$Pb | Pbc (pg) | $^{208}$Pb/$^{206}$Pb | $^{207}$Pb/$^{235}$U | ± | $^{206}$Pb/$^{238}$U | ± | Correlation Coefficient4 | $^{207}$Pb/$^{206}$Pb | ± | $^{207}$Pb/$^{206}$Pb | ± | Discord (%) |
| GS-08-288 Aillik Group (Z9690) | | | | | | | | | | | | | | | | | | | |
| A1 (Z) | Z,Co,Clr,fFr,Eu,Pr,Abr,NM3° | 1 | 80 | 1 | 43 | 15 | 1243 | 0.59 | 0.09 | 5.19525 | 0.00942 | 0.33195 | 0.00048 | 0.786679351 | 0.11351 | 0.00013 | 1856.4 | 4 | 0.53 |
| A2 (Z) | Z,Co,Clr,fFr,Eu,Pr,Abr,NM3° | 8 | 100 | 3.1 | 66 | 23 | 1306.9 | 3.31 | 0.1 | 5.21434 | 0.00786 | 0.33317 | 0.00035 | 0.851754224 | 0.11351 | 0.00009 | 1856.3 | 3 | 0.16 |
| B1 (Z) | Z,Co,Clr,Eu,Pr,Abr,M3° | 1 | 75 | 0.9 | 113 | 39 | 3596.1 | 0.44 | 0.11 | 5.21136 | 0.00675 | 0.33324 | 0.00037 | 0.810941717 | 0.11342 | 0.00009 | 1854.9 | 2.7 | 0.06 |
| B2 (Z) | Z,Co,Clr,Eu,Pr,Abr,M3° | 8 | 75 | 2.6 | 100 | 34 | 2800.9 | 1.9 | 0.1 | 5.12085 | 0.00643 | 0.32754 | 0.00031 | 0.889384089 | 0.11339 | 0.00007 | 1854.4 | 2.2 | 1.73 |

Description Legend: Z=Zircon, Co=Colourless, Clr=Clear, fFr=Few Fractures, nFr=Numerous Fractures, Eq=Equant, Eu=Euhedral, Fg=Fragment, Pr=Prismatic, St=Stubby Prism, Tip=Tip, Abr=Abraded

(1) Concentration uncertainty varies with sample weight: >10% for sample weights <10 µg, <10% for sample weights above 10 µg
(2) Pbr = radiogenic Pb. Pbc = total common Pb in analysis corrected for spike and fractionation
(3) Atomic ratios corrected for spike, fractionation, blank and initial common Pb, except $^{206}$Pb/$^{204}$Pb ratio corrected for spike and fractionation only. Errors are one sigma absolute. Pb blank: <1 pg for zircon; blank composition in atomic proportions = 51.966:21.356:25.288:1.3895 (208:207:206:204)
(4) Correlation coefficient of errors in isotopic ratios
(5) Discordance of the analysis
(6) UTM coordinates; NAD 27, Zone 21; 393366/6070271

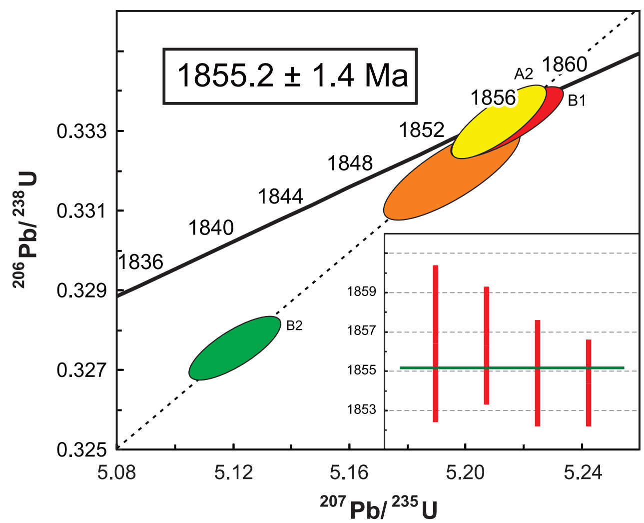



**Figure 3.** *Concordia diagram of zircon U–Pb results from sample GS-08-288, a crystal-rich lapilli tuff. Error ellipses are at the 2σ level.*

locally result in very high grades over narrow widths, as opposed to the broader low-grade mineralization more typical of uranium mineralization within the Aillik Group. This fracture-hosted style of mineralization is similar to the Type 3 (disseminated or fracture-hosted mineralization in felsic volcanic rocks without associated deformation or metasomatism) of Sparkes and Kerr (2008). This style of mineralization is locally associated with anomalous enrichment of Au, Ag, Cu in association with the development of uranium mineralization similar to that locally noted within the Benedict Mountains region (*e.g.*, Setterfield *et al.*, 2008). Uranium mineralization observed within these felsic volcanic rocks is more typical of that observed in the *ca.* 1650 Ma Bruce River Group, located in the southwestern portion of the CMB (Ryan, 1984; Sparkes and Kerr, 2008). It should also be noted that much of the uranium mineralization within the CMB has not been dated directly, and even though uranium mineralization may be developed within similar age host rocks, the mineralization itself may be of considerable different ages.

The source of the uranium within the Benedict Mountains region, similar to the uranium mineralization hosted within the felsic volcanic rocks of the Bruce River Group, is likely the host volcanic succession. In the Benedict Mountains region, the volcanic rocks locally contain up to 50 ppm U, and therefore represent a plausible source for uranium. Many studies also attribute much of the uranium mineralization observed within the Aillik Group to be derived from the host metavolcanic rocks (*e.g.,* Marten, 1977; Gandhi, 1978; Gower *et al.*, 1982; Kerr, 1994; Wilton, 1996); however, the deformation within these units makes recognizing potential primary volcanic-hosted styles of uranium mineralization somewhat problematic. The locally uranium-enriched, relatively undeformed, volcanic rocks of the Benedict Mountains region may provide some insight as to an initial style of uranium mineralization in the Aillik Group prior to subsequent deformation and remobilization.

## CONCLUSIONS

The volcanic rocks within the western belt of supracrustal rocks in the Benedict Mountains region are similar in age to the regionally extensive Aillik Group. The U–Pb data presented herein provide supporting evidence for the correlation of the volcanic rocks in this area with those of the Aillik Group, located farther to the west. Examples of volcanic-hosted uranium mineralization in the Benedict Mountains contain uranium within discrete fracture networks within the volcanic sequence. This mineralization is interpreted to represent remobilization of uranium from the surrounding volcanic rocks by broadly synvolcanic hydrothermal and/or meteroric fluids circulating within the volcanic pile. Uranium was deposited in more permeable zones and along the margins of mafic dykes during their emplacement. The lack of strongly deformed host rocks hosting pervasive sodium metasomatism in relation to the uranium mineralization within the Benedict Mountains region indicates a different style of mineralization compared to that within the Aillik Group. Nevertheless, there might be a connection between these types of deposits if primary volcanic-hosted uranium mineralization represents the first step in a multistage process.

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