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E.G. Potter

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## INTRODUCTION

Under the Northern Uranium for Canada project (GEM-Energy Program), the nature of uranium mineralization in the historic Uranium City-Beaverlodge district mining camp was examined. Despite historical production, research and on-going exploration, the genesis, age and mode of uranium mineralization in the vein systems remain contentious (e.g. Ashton, 2010, 2011; Tracey et al., 2009; Ashton *et al.,* 2013a, b, 2014; Dieng *et al.,* 2013, 2015; Liang *et al.,* 2014, 2017; Kennecott *et al.,* 2015; Chi *et al.,* 2020). The data presented in this report were collected to build upon historic data in collaboration with on-going academic, industry and provincial projects through the application of modern geochemical tools to constrain genetic models and enhance exploration vectors. Furthermore, these data were collected to examine the potential for economic concentrations of rare earth elements (REE) in the historic Beaverlodge occurrences.

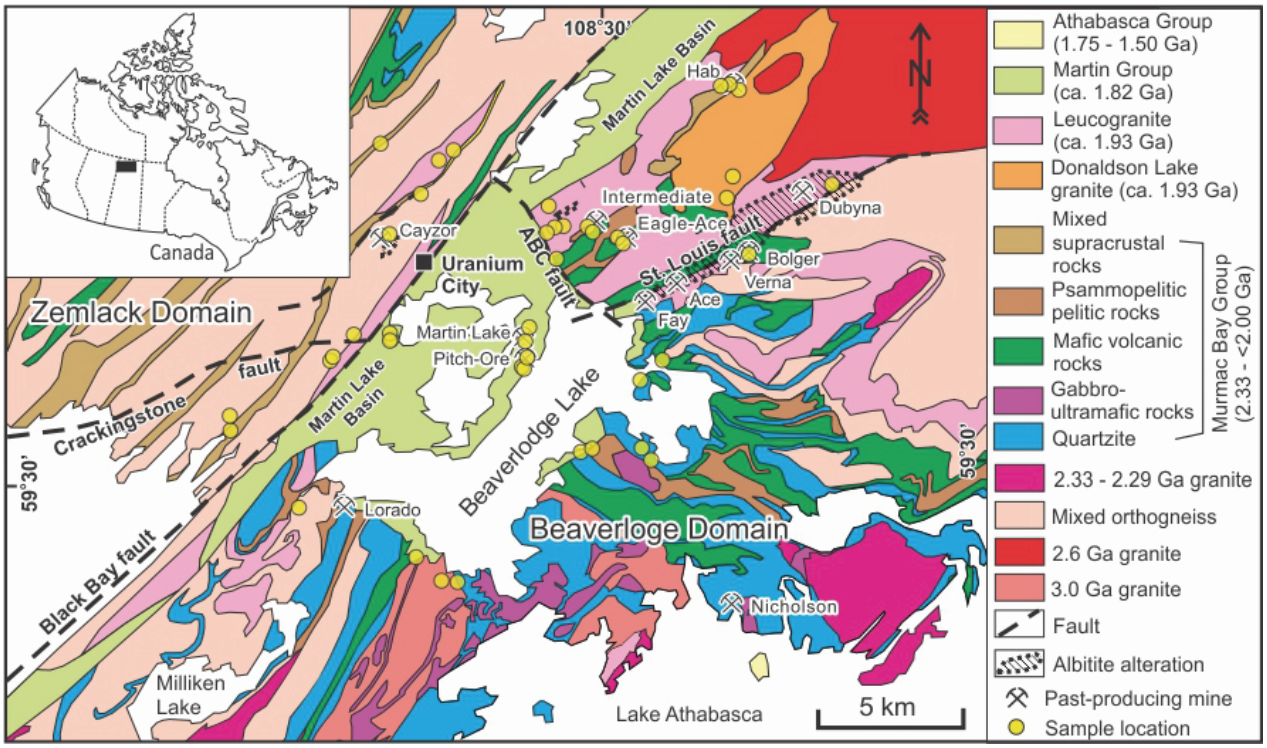


**Figure 1.** Regional geology of the Beaverlodge district, after Ashton and Hartlaub (2008), Ashton et al. (2013a) and Chi et al. (2020). Inset shows location of the study area in northern Saskatchewan. Sixty-seven samples were collected from mineralized occurrences and historic mines.

## GEOLOGICAL SETTINGS

The Beaverlodge vein systems are located on the northern shoreline of Lake Athabasca, within the Rae Subprovince of the Churchill Province. The Rae Subprovince in northern Saskatchewan is divided into the Nolan, Zemlak, Beaverlodge, Train Lake, Dodge and Tantato domains (Ashton et al., 2000). The majority of the vein occurrences examined in this study are located within the Beaverlodge Domain, with a few (e.g. Cayzor) situated in the eastern margin of the Zemlak Domain, west of the Black Bay fault that separates the domains (Fig. 1).

The Beaverlodge Domain includes Archean granitoid rocks and derived orthogneiss, as well as

younger Paleoproterozoic dominantly sedimentary rocks such as the *ca*. 2.3 to 2.1 Ga Murmac Bay Group (Ashton et al., 2013a) and the *ca.* 1.83 to 1.818 Ga Martin Group (Morelli et al., 2009). At least three distinct granitoid suites, dated between 3.0 Ga and 1.90 Ga (Koster and Baadsgaard, 1970; van Schmus et al., 1986; Hartlaub et al., 2004, 2005, 2007; Ashton et al., 2013a, b), have been recognized in the domain and were deformed and metamorphosed along with younger cover between 1940–1900 Ma (Bethune et al., 2013). The folded and faulted Martin Group consists of continental red beds and *ca.* 1818 Ma mafic volcanic rocks (Tremblay, 1972; Mazimhaka and Hendry, 1984; Morelli et al., 2009). Finally, along the southern margin of the study area, flat-lying, unmetamorphosed Athabasca Group sandstone overlies the Murmac Bay Group (Tremblay, 1978; Ramaekers et al., 2007). Bosman and Ramaekers (2015) proposed that the Martin Group sedimentary rocks filled the earliest of four stacked sub-basins that constitute the Athabasca supergroup. As such, the 1.83 to 1.54 Ga (Creaser and Stasiuk, 2007; Ashton et al., 2009) Athabasca Supergroup would be analogous to the 1.85 to 1.50 Ga Dubawnt Supergroup (Rainbird and Hadlari, 2000; Rainbird et al., 2007; Chamberlain et al., 2010) of the Baker Lake region in Nunavut (Bosman and Ramaekers, 2015).

Located west of the Black Bay fault, the Zemlak Domain is postulated to be an eastward continuation of the Taltson Domain based on Sm–Nd and U–Pb ages (Ashton et al., 2014). The Zemlak Domain consists of predominantly Archean to Paleoproterozoic orthogneiss deformed together with rare paragneiss (Card et al., 2007a, b), intruded by four suites of granite ranging in age from 2.71 to 2.33 Ga (Ashton et al., 2017). Metasedimentary rocks of the *ca.* 1.92 to 1.82 Ga Thluicho Lake Group the gneiss and granites (Card et al., 2007a, b; Bethune et al., 2010a, b).

## URANIUM DEPOSITS

Following discovery in 1946, production from the Beaverlodge vein systems from 1953 to 1982, yielded 22, 467, 229 kg of $U_3O_8$, mainly from the Fay-Ace-Verna mines (Smith, 1986). Although minor occurrences occur within the Martin Lake Basin, the majority of the deposits are hosted in the underlying basement rocks, within steeply dipping faults developed close to the present-day Martin Lake Basin. The majority of the deposits also exhibit a spatial association with granitic rocks, particularly 1.93 Ga leucogranite (Fig. 1), although the immediate host rocks of mineralization may be older rocks of the Murmac Bay Group (Chi et al., 2020).

The mineral occurrences sampled in this study have a relatively simple ore mineralogy dominated by fine-grained uraninite with minor brannerite, coffinite, pyrite, chalcopyrite and galena set in a gangue assemblage of dolomite, calcite, quartz, chlorite, hematite ± albite (Beck, 1986; Smith, 1986; Kennicott et al., 2015; Liang et al., 2017; Chi et al., 2020). The host rocks to the veins exhibit various types of alteration, including chloritization, carbonatization, hematitization, and albitization (Tremblay, 1972; Liang et al., 2017), the latter two of which include several generations that predate, are synchronous and postdate the veins and impart a distinctive red colour to the hosts (Kennecott et al., 2015). Although referred to as 'vein-type', the uranium minerals also occur in breccias, stockworks, disseminations, as well as veins associated with faults (Tremblay, 1972; Beck, 1986; Smith, 1986).

Along the south extent of the study area, several vein systems (i.e. Nicholson; Fig. 1) exhibit more complex mineralogy consisting of uraninite with Co-Ni-arsenides and sulfides, Co-Ni-Pb-Cu selenides and native Pt, Ag, Au, Cu in carbonate quartz, chlorite and hematite gangue (Beck, 1986). Further south of the study area, about 17 km southwest of the Lorado mine (Fig. 1), uranium is associated with intense albitization at the historic Gunnar mine forming albitite composed of up to

90 modal % albite and 30% carbonate-filled vugs and veins. The albitite contains minor chlorite, specular hematite and rutile and was termed 'episyenite' by Evoy (1986). Uraninite and uranophane with minor chalcopyrite, pyrite, are disseminated in the 2321 ± 3 Ma Gunnar granite with associated galena, quartz, chlorite, and kaolinite alteration (Beck, 1986; Hartlaub et al., 2007; Ashton, 2010). Although these occurrences share several characteristics with the Beaverlodge veins (cf. Chi et al., 2020 and references therein), logistic constraints prevented sampling for this study.

## SAMPLING

During the fall of 2009, several historic uranium occurrences and showings were sampled. Although efforts were made to collect samples from in-situ occurrences, at the majority of the occurrences only mine waste rock was available for sampling. At most occurrences, high-grade ore materials were discovered in the waste piles and/or within veins exposed in outcrop. Weathered surfaces of waste pile samples were removed as much as possible in the field but was not possible in all samples. Prospecting for uranium-bearing samples used a portable RS-230 spectrometer equipped with a 103 $cm^2$ bismuth germanate detector. Uranium grades of the samples collected during the current study ranged from 0.01 to 26.6 wt. % $U_3O_8$, which corresponded to approximately 1,000 to >60,000 counts per second on the gamma-ray spectrometer.

## METHODS

After cobbling away weathering material with a rock hammer in the field, samples were sent directly to Act Labs in Ancaster. Prior to analysis, samples crushed to a nominal minus 10 mesh (1.7 mm), mechanically split (riffle) to obtain a representative sample and then pulverized to at least 95% minus 150 mesh (105 microns). Processing of mineralized samples focused on the vein material, with as much host rock removed as possible prior to crushing. Mild steel mills were utilized to minimize chromium or nickel contamination. Vein samples were fused using a sodium peroxide technique followed with ICP-MS analysis at Act Laboratories in Ancaster, Ontario (Code UltraTrace 7). Non-mineralized samples were analyzed by lithium meta/tetraborate fusion followed by ICP-MS (Code 4 Litho). The fusion process was selected to ensure dissolution of metals, particularly elements such as REE that may be hosted in refractory minerals. Samples with elevated uranium contents (determined by a portable RS-230 gamma-ray spectrometry) underwent uranium assay by X-ray fluorescence (XRF; Code 8 $U_3O_8$ XRF Assay). Despite some samples exceeding the reporting standards for ICP-MS, there is a very good correlation between the ICP-MS and XRF analyses of uranium contents (Fig. 2). Blind samples of certified reference materials UTS-3 (Beaverlodge U tailings) and SY-4 (diorite gneiss) were submitted along with the samples to verify analytical results. The data including sample coordinates and host lithology are in the accompanying spreadsheet (OF7873_data.xls).

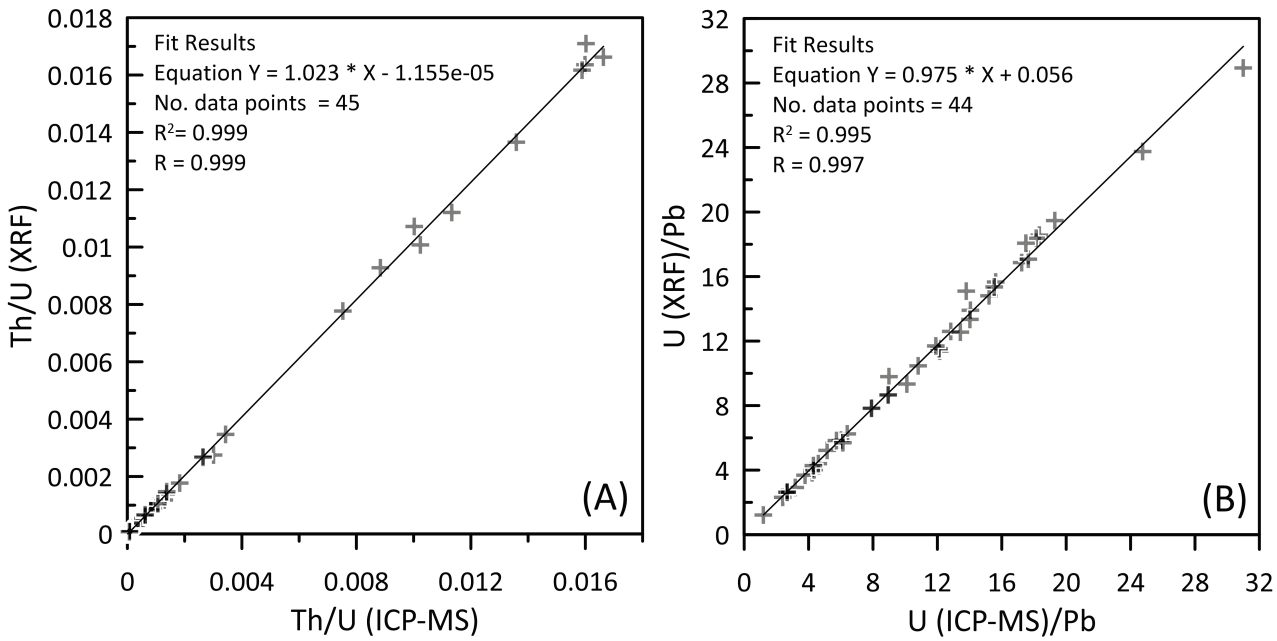


**Figure 2**. Comparison of uranium concentrations by sodium peroxide fusion followed with ICP-MS analysis and X-ray fluorescence (XRF) analyses using U/Th (**A**) and U/Pb (B) ratios. Thorium and lead concentrations by sodium peroxide fusion followed with ICP-MS analysis.

## QUALITY CONTROL

Analyses of the blind standards, certified reference materials and sample duplicates produced linear correlation trends and yielded results within analytical errors (Figs. 3, 4). The sole exception was one analysis of USGS certified reference material (W-2a diabase) for uranium contents by sodium peroxide fusion followed with ICP-MS that yielded a value of 3.1 ppm U versus the reported value of 0.53 ppm U (Figs. 3). However, all uranium analyses within the analytical range of samples of this study (e.g. 0.1 to 26 wt.% U) yielded good results.

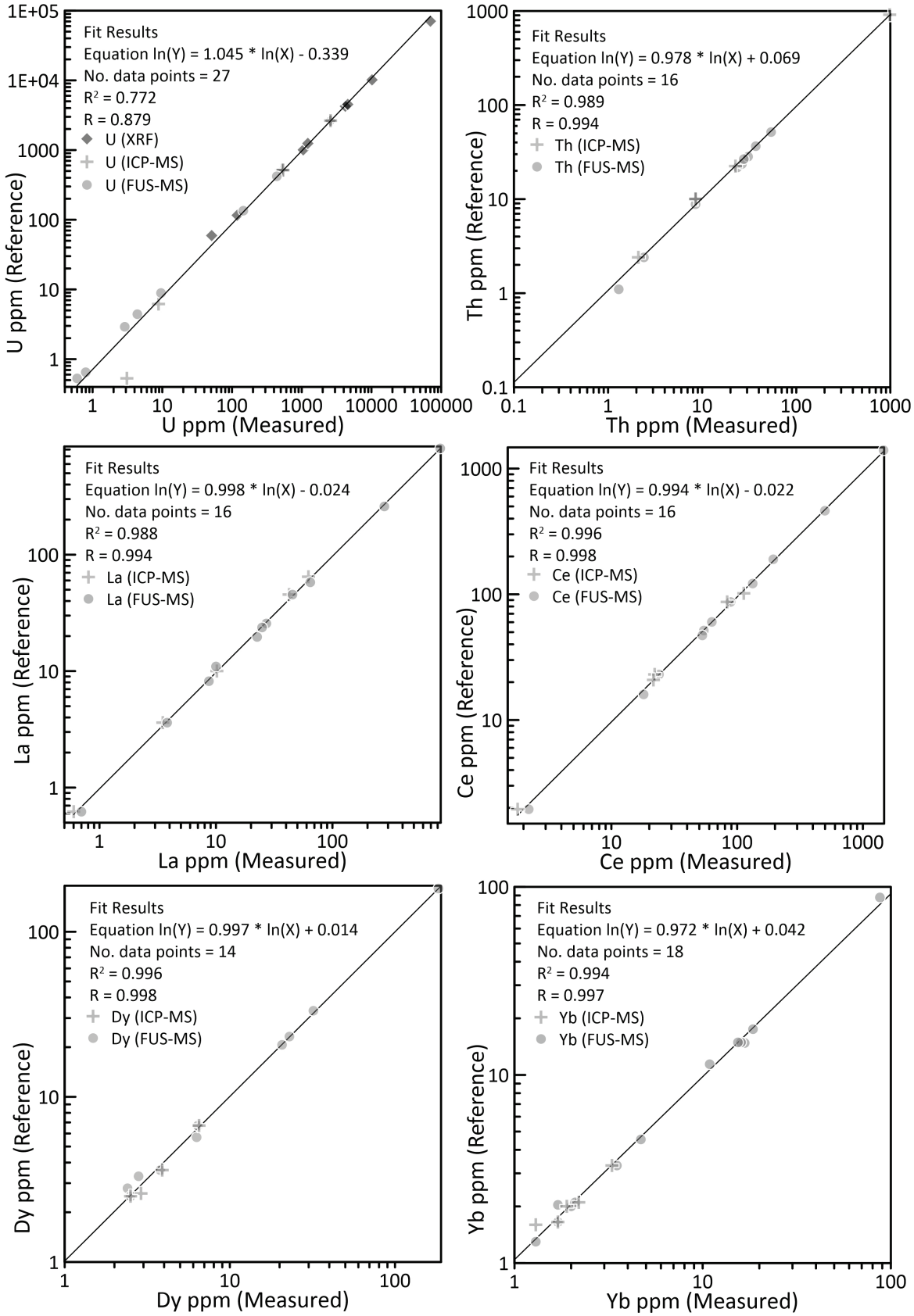


**Figure 3**. Comparison between measured and certified values for blind standards and certified reference materials for all three analytical methods used in this study (XRF= X-ray fluorescence; ICP-MS= sodium peroxide fusion and ICP-MS; FUS-MS= lithium meta/tetraborate fusion and ICP-MS).

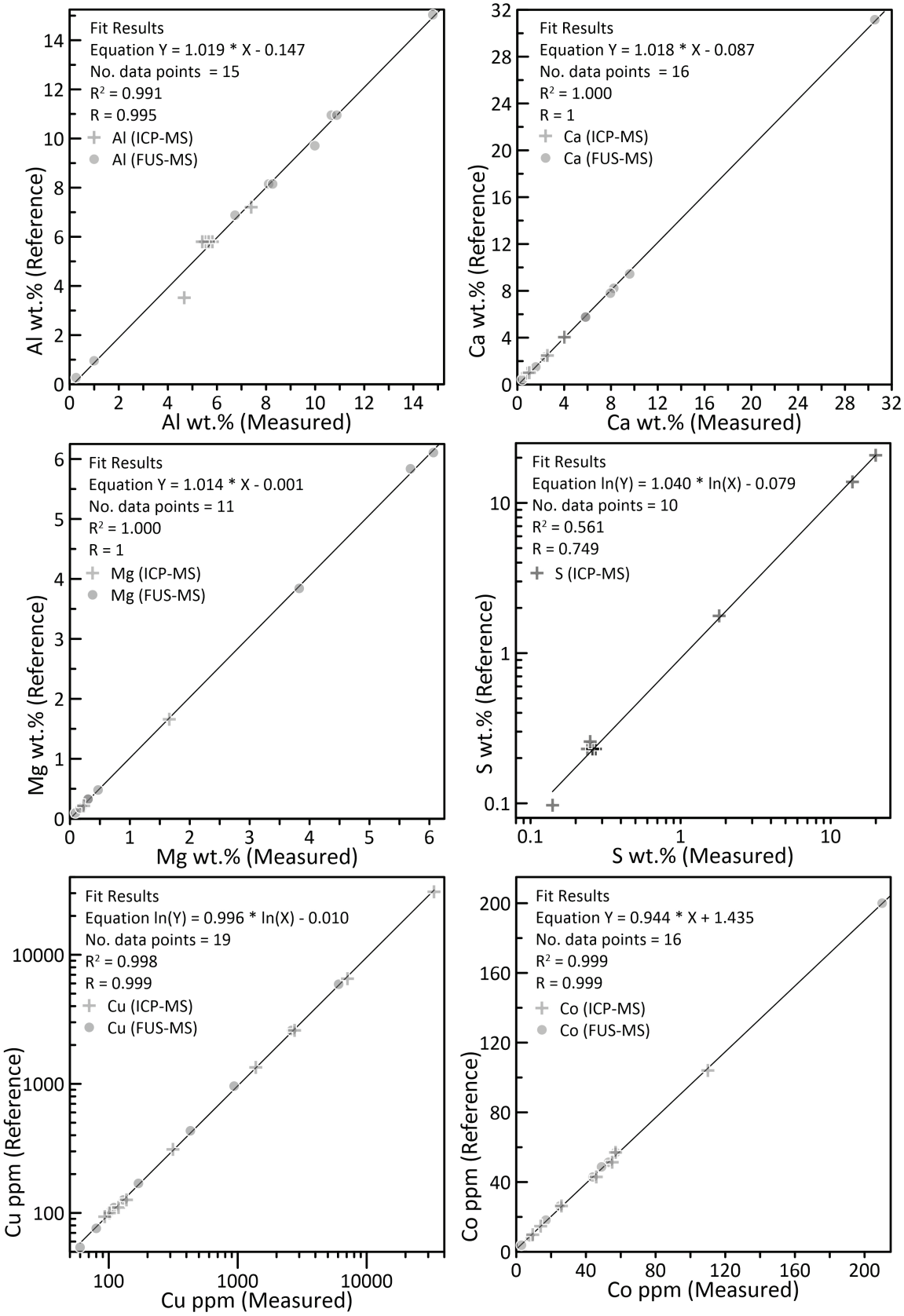


**Figure 4.** Comparison between measured and certified values for blind standards and certified reference materials for all three analytical methods used in this study (ICP-MS= sodium peroxide fusion and ICP-MS; FUS-MS= lithium meta/tetraborate fusion and ICP-MS).

## PRELIMINARY OBSERVATIONS

To simplify presentation of the data, the results were sorted based on the host lithology (i.e. leucogranite, Murmac Bay, Martin Group). Despite different host rocks, all the ore samples exhibit LREE-enriched, chondrite normalized REE patterns with negative europium anomalies (Fig. 5A–C). Overall, the REE patterns resemble patterns of the host rocks, with total REE contents ranging from 20 to 2595 ppm. As the host rocks were visually removed from the mineralized vein samples, these signatures most likely reflect the primary REE mineral hosts in the vein assemblages. The total REE contents vary within the vein samples and a weak positive correlation was observed between REE and uranium contents (Fig. 5D), indicating that uraninite is likely the dominant host of REE.

In addition to historical vein occurrences, anomalous uranium concentrations were noted within pink 1.93 Ga leucogranite dykes, such as the Emar Showing south of Schmoo Lake (near the Dubnya mine site). At this showing, medium-grained pink leucogranite dykes (Fig. 6A) trending 050° and dipping 60° to the southeast host disseminated and narrow carbonate veinlets with anomalous uranium (up to 0.548 wt. % $U_3O_8$). The uranium-bearing dykes trend toward the Dubnya open pit and were observed in outcrop for several hundred metres along strike. This poorly documented occurrence has several features in common with the Dubnya pit (Fig. 6B) and possibly the Gunnar episyenite uranium mine, highlighting the uranium prospectivity of the region.

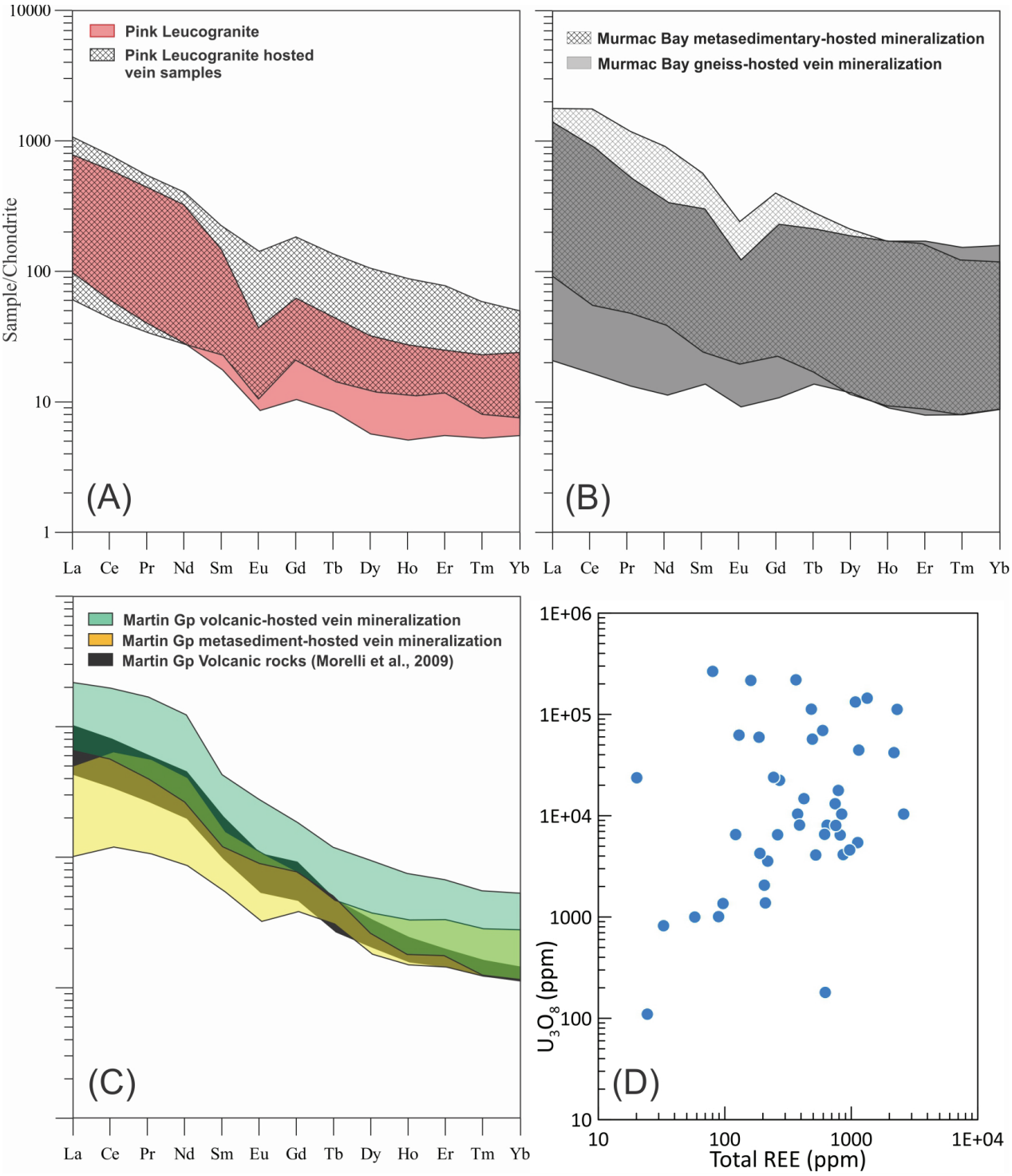


**Figure 5**. Chondrite-normalized rare earth element plots of: (A) leucogranite-, (B) Murmac Bay-, and (C) Martin Group-hosted vein samples. (D) Plot of total REE contents versus uranium (XRF). Chondrite values of McDonough and Sun (1995).

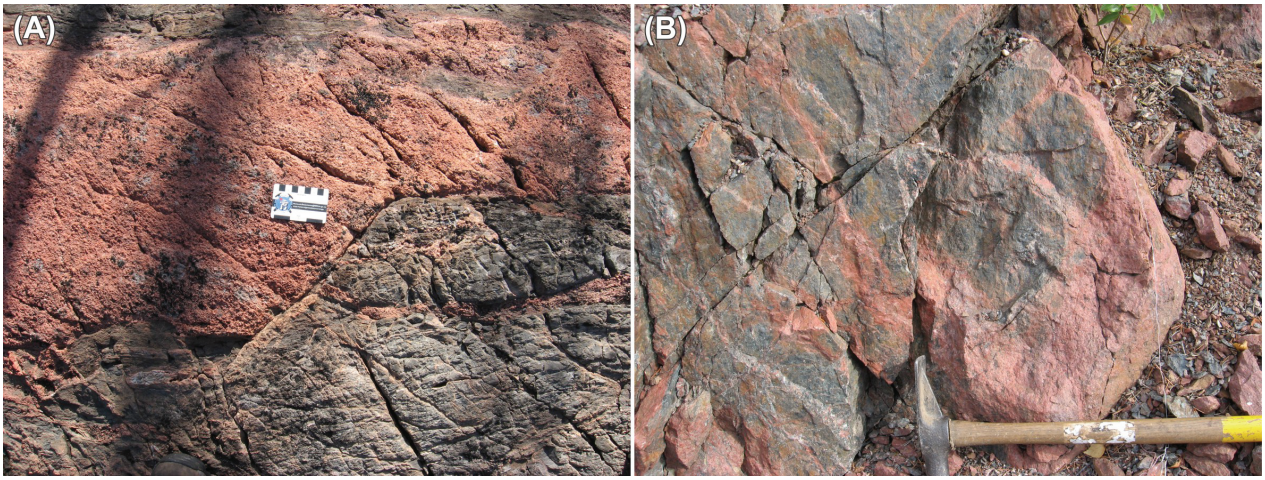


**Figure 6**. (A) Pink leucogranite dike with disseminated and fracture-hosted U-mineralization intruding orthogneiss and (B) texturally similar alteration (episyenite) propagating along fractures in gneiss at the Dubyna pit. NRCan photos 2021-232 and 2021-233.

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