ERCB/AGS Open File Report 2010-08

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Energy Resources Conservation Board

Alberta Geological Survey

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Abstract

The Andrew Lake–Waugh Lake area in the northeastern corner of the Alberta shield has been identified as an area of mineral exploration interest, particularly for uranium, since the 1950s, and was actively explored in the 1960s and again in recent years. In the summer of 2006, Alberta Geological Survey performed geological mapping and sampling near Andrew and Waugh lakes to understand better the geological context, with direct metallogenic implications for the Alberta portion of the Canadian Shield.

This project re-examined and sampled previously identified mineral occurrences on the west side of Pythagoras and Lindgren lakes, as well as several clusters of radioactive sites south of Andrew Lake. Elevated radioactivity values have been confirmed south of the elbow of the west arm of Andrew Lake, on the prominent peninsula at the north end of Spider Lake and at a few sites north of Cherry Lake. Observations suggest that uranium enrichment was related to pegmatite veining during ductile deformation within the migmatitic Rutledge River Complex, and to minor shear zones and brittle faults. Granitoid bodies show only slightly elevated radioactivity at apparently randomly distributed spots, and mylonitic gneiss within the Taltson basement complex appears essentially barren of anomalous radioactivity.

1 Introduction

1.1 Scope of Work

To better assess the mineral potential of the Canadian Shield in northeastern Alberta (Alberta shield), Alberta Geological Survey (AGS) has re-examined, during the past five years, selected outcrops and previous exploration sites of the 1960s and 1970s. One of the areas with economic potential, identified both by the exploration industry and by AGS (Godfrey, 1986b; Langenberg and Eccles, 1996; Pană et al., 2006), was the Andrew Lake–Waugh Lake area in the northeasternmost corner of Alberta. Between July 14 and 28 of 2006, a crew varying in size from two to five AGS staff members did float-plane– and motorboat-supported geological mapping and sampling near Andrew and Waugh lakes. The objective of the work was to examine the geological setting of uranium mineralization, with direct metallogenic significance for the Alberta shield.

An overview of the general geology of the Andrew Lake area, based on the original geological reports of J.D. Godfrey (Godfrey, 1958, 1961, 1963), the updated Geological Survey of Canada Map 1953A (McDonough et al., 2000a), related publications and the senior author's own work, was presented by Pană (2010a). The present report includes a concise presentation of the geological context and main map units in the Andrew Lake–Waugh Lake area, and descriptions of the examined outcrops with summary tables of new geochemical data.

1.2 Location, Access and Physiography

The Andrew Lake map area (NTS 74M/16) is about 60 km north of Lake Athabasca in the extreme northeastern corner of Alberta, adjoining Saskatchewan and the Northwest Territories (Figure 1). The area of interest lies between latitudes 59°45′ and 60°N, and longitudes 110° and 110°30′W.

Float planes can be chartered from Fort Chipewyan in Alberta, Fort Smith in the Northwest Territories and Uranium City in Saskatchewan to access the map area. Many scattered lakes are suitable for landing. An airstrip at the south end of Andrew Lake allows access to the area by small wheel-equipped planes.

The general elevation varies from 330 to 470 m above sea level. Pleistocene glacial scouring has left numerous rocky-basin lakes and a locally rugged surface, with a maximum relief of about 115 m. At some localities, clean, fresh bedrock surfaces occur in the form of low wide aprons bordering lakes. Glacially smoothed outcrops, highly polished striated rock surfaces, sand plains, drumlins, eskers and glacial erratics provide evidence of Pleistocene glaciation. The lakes are either poorly connected, with drainage westward to Charles Lake, or disconnected, thus necessitating portages when travelling cross-country by water.

1.3 Previous Work

The first geological information on the Alberta shield came from J.B. Tyrrell and F.J. Alcock, who made the first canoe traverses along the north shore of Lake Athabasca, and from A.E. Cameron and H.S. Hicks, who conducted reconnaissance surveys north of Lake Athabasca (Tyrrell, 1896; Alcock, 1915, 1917; Cameron, 1930; Cameron and Hicks, 1931; Hicks, 1930, 1932). The area adjoining Andrew Lake to the east (in Saskatchewan) was mapped at a scale of 1:253 440 (1 inch to 4 miles) after gold was discovered at Goldfields (Alcock, 1936). North of the Alberta border, Wilson (1941) published the geology of the Fort Smith map area at a scale of 1:253 440.

In 1959, the Geological Survey of Canada carried out a reconnaissance survey of the Alberta shield and published a map at 1:253 440 scale, with marginal notes (Riley, 1960). Between 1957 and 1975, the Alberta shield was systematically mapped at a scale of 1:31 680 by J. Godfrey of the Alberta Research

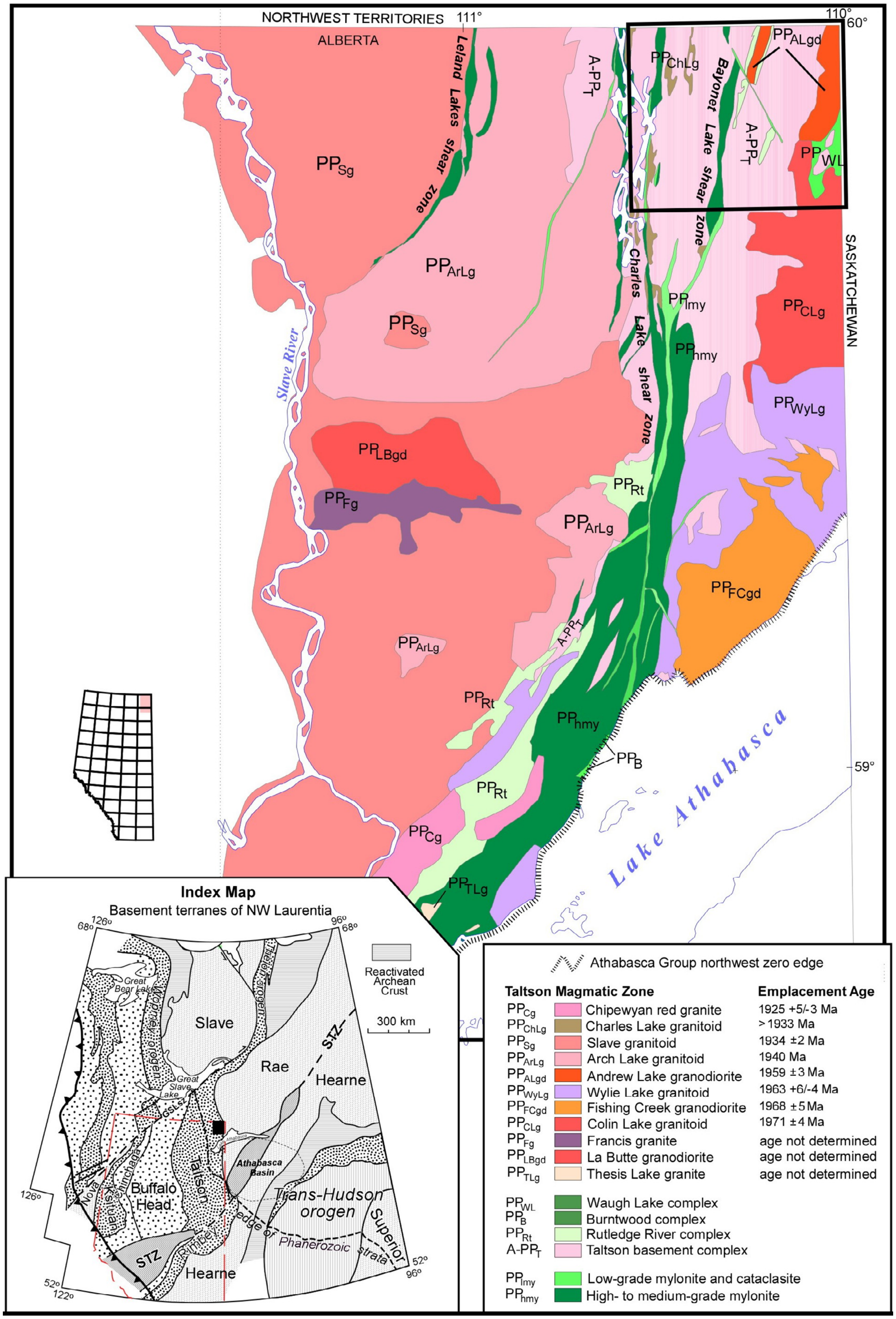

Figure 1. Simplified geology of the Alberta shield (after Godfrey, 1986a); index map compiled from Hoffman (1988) and Ross et al. (1994); black rectangle is area under investigation. See Pană (2010b) for an updated map of the Alberta shield at a scale of 1:250 000. Abbreviations: GSLsz, Great Slave Lake Shear Zone; STZ, Snowbird Tectonic Zone.

Council. In the 1990s, large portions of the Alberta shield were selectively remapped at a scale of 1:50 000 by the Geological Survey of Canada, aided by radiometric age determination (McDonough et al., 2000b; McNicoll et al., 2000), thermobarometry (Grover et al., 1997) and satellite-imagery interpretation (Schetselaar, 2000). See Pană and Olson (2009) for the location of each map produced by AGS and the Geological Survey of Canada. Bednarsky (1999) has published the results of surficial mapping of the Alberta shield. Sprenke et al. (1986), Charbonneau et al. (1994), and Lyatsky and Pană (2003) have published regional geophysical data for the Alberta shield.

The geology of the Alberta shield and its mineral occurrences have been previously compiled on a 1:250 000 scale map (Godfrey, 1986a, b). Alberta Geological Survey has recently digitally compiled these mineral occurrences and others reported by Langenberg and Eccles (1996), as well as uranium boulders reported along the north shore of Lake Athabasca (Pană and Olson, 2009). An updated version of the geology of the Alberta shield is included in the recent 1:250 000 scale geological compilation map (Pană, 2010b).

The first geological reporting specific to the Andrew Lake area is credited to Cameron and Hicks (1931), who started one of their canoe traverses of the Canadian Shield from Andrew Lake. Low-grade uranium mineralization was found in the Andrew Lake area in the course of uranium prospecting and exploration during the 1950s (e.g., Ferguson, 1953), which led to a small uranium prospecting program of the Alberta shield by the Alberta Research Council (Collins and Swan, 1954). J. Godfrey started his systematic mapping of the Alberta shield with the Andrew Lake area (1957–1959). Publication of the report by Godfrey (1958) on mineral showings in the area, and of his subsequent reports accompanied by detailed geological maps (Godfrey, 1961, 1963), led to intense staking activity and filing of about 150 mineral claims. A geological map at a scale of 1:15 840, credited to R. Watanabe and J. Godfrey (1960) and included in Watanabe's M.Sc. thesis (Watanabe, 1965), covers the Waugh Lake area and extends a few kilometres into Saskatchewan. Godfrey incorporated the Alberta portion of this map, with more detail, into the 'Andrew Lake North District' and 'Andrew Lake South District' map areas at 1:31 680 scale, published in 1960 and 1961, respectively, and included in his geological reports on the area (Godfrey, 1961, 1963).

In 1963, Aero Survey Ltd. flew an aeromagnetic survey of the area on behalf of the federal government (Geological Survey of Canada, 1964a, b). In 1969 and the early 1970s, Hudson's Bay Oil and Gas Co. Ltd. carried out an airborne survey over the area, conducted limited ground geophysics and completed four small trenches across an electromagnetic conductor discovered on the eastern shore of Waugh Lake (Burgan, 1971). Exploration (including blasting, trenching and drilling) for uranium was carried out in the 1970s near Andrew Lake, including the area west of Carrot Lake and near the north end of Spider Lake. No significant volume of economic mineralization was found and no further exploration was carried out at the time.

Under the Canada-Alberta Partnership Agreement on Mineral Development, Alberta Geological Survey examined the Andrew Lake area and the previously reported mineralized zones (Langenberg et al., 1993). In 1993, map units and mineral occurrences were outlined in an area of approximately 24 km^2 near Waugh Lake that was remapped at a scale of 1:10 000 (Salat et al., 1994). The revision of this work in 1994 resulted in a very different map and a formal stratigraphic nomenclature for the low-grade metamorphic rocks, now assigned to the 'Waugh Lake Group' (Iannelli et al., 1995). Selective remapping and reinterpretation of the local geology, aided by isotope dating, is included in the 1:50 000 scale map by McDonough et al. (2000a). More recently, AGS conducted reconnaissance geological field programs in the northeastern corner of the Alberta shield (Pană et al., 2006; Pană, 2010a) and along the northern shore of Lake Athabasca (Pană and Olson, 2009).

2 Tectonic Setting

The Andrew Lake area is part of the Taltson magmatic zone (TMZ), which makes up the southern segment of the approximately 3000 km long, Paleoproterozoic (2.0–1.9 Ga), Thelon-Taltson orogenic belt (McNicoll et al., 2000; see index map in Figure 1). The TMZ includes numerous ca. 1.99–1.92 Ga granitoid bodies that intrude and rework Archean to Paleoproterozoic crust at the western margin of the Rae Terrane (Figure 1; e.g., Berman and Bostock, 1997; McNicoll et al., 2000; McDonough et al., 2000a, b).

In Alberta, the exposed TMZ includes a curving, linear body of high- to medium-grade metamorphic tectonite referred to as the Taltson basement complex (TBC), which is considered the westernmost expression of the Churchill crust (Rae Terrane). The TBC is flanked by several distinct, moderately to strongly foliated granitoid plutons with minor TBC roof pendants (Figure 1; Godfrey, 1986a; McDonough et al., 2000b). The TBC consists of a composite succession of Archean (ca. 3.2, 3.1 and 2.6 Ga) and Paleoproterozoic (ca. 2.4–2.1 Ga) metaplutonic gneisses (Goff et al., 1986; McNicoll et al., 2000). Subordinate biotite±aluminosilicate gneiss was inferred to be derived from clastic sedimentary rocks of the 2.13–2.09 Ga Rutledge River basin (e.g., Bostock and van Breemen, 1994; McDonough et al., 2000b). Minor but widespread amphibolite and hornblendite, and rare metagabbro within the Taltson basement complex, have been interpreted as possible metamorphosed ophiolite remnants from the initial phase of rifting that subsequently formed the Rutledge River basin (McNicoll et al., 2000).

The origin and tectonic setting of the TMZ granitoid plutons is controversial. Based on initial petrological data, age and position relative to the TBC, the granitoid bodies in Alberta have been assigned to two groups (e.g., Bostock et al., 1991; McDonough et al., 2000b; McNicoll et al., 2000): 1) an earlier, 1.99–1.96 Ga, subduction-related, weakly peraluminous to metaluminous suite (I-type) east of the TBC; and 2) a later, ca. 1.96–1.93 Ga, collision-related peraluminous suite (S-type) west of the TBC (Figure 1).

The early TMZ plutons include

- the ca. 1971 Ma Colin Lake granodiorite to quartz diorite;
- the ca. 1963 Ma Wylie Lake suite of granodiorite, quartz diorite and quartz monzonite; and
- the ca. 1962–1959 Ma Andrew Lake suite of granodiorite to diorite.

The late S-type plutons, characterized by abundant mafic clots of biotite, garnet, andalusite, hercynite and cordierite, include

- the ca. 1960–1934 Ma, polyphase Slave monzogranite; and
- the ca. 1938 Ma Arch Lake quartz monzo- to syenogranite.

Several smaller, variously foliated plutons of uncertain geochemical affiliation are enclosed in the TBC:

- the Charles Lake granite suite with monazite metamorphic ages of ca. 1933–1919 Ma
- the ca. 1925 Ma Chipewyan syenogranite to quartz monzonite suite

Subsequent petrological data, including chemical and isotope analyses, indicate that the entire TMZ plutonic suite may be derived from the recycling (remelting) of the essentially igneous TBC crust (Chacko et al., 2000; De et al., 2000; Pană et al., 2007).

From west to east, the following major, northerly trending, high- to low-grade shear zones cross the Alberta–Northwest Territories border: Leland Lakes Shear Zone (LLSZ), Charles Lake Shear Zone (CLSZ) and Bayonet Lake Shear Zone (BLSZ; Figure 1; Godfrey, 1986a; McDonough et al., 2000b). The crosscutting relationships between shear zones and granitoid bodies are very complex, indicating concurrent deformation and granitoid intrusion during the ca. 2.0–1.9 Ga Taltson tectonothermal event (e.g., McDonough et al., 2000b; Pană, 2010a).

3 Main Map Units in the Andrew Lake Area

The dominant geological feature of the Andrew Lake area (Figure 2) is the alternation of northerly trending units, ranging from several metres to 5 km in width, that consist, in chronological order, of the following four principal rock groups (Godfrey 1958, 1961, 1963; McDonough et al., 2000a, b; McNicoll et al., 2000; Pană, 2010a):

1) Taltson basement complex
2) Rutledge River Complex
3) Waugh Lake Complex
4) Taltson plutonic complex

3.1 Taltson Basement Complex

Most of the western half of the Andrew Lake map area is underlain by granitoid gneiss of the Taltson basement complex, which consists of foliated to layered to banded mylonitic, biotite-hornblende granite to granodiorite gneiss and hornblende diorite gneiss. This complex also includes minor lenses of biotite schist, quartzitic layers, amphibolite and garnetiferous layers, and is pervasively intruded by dispersed bodies of granite pegmatite; massive, medium-grained or porphyritic pink granite; and granodiorite dikes. Numerous bands of biotite amphibolite, amphibolite and hornblendite are scattered throughout the granite gneiss. Occasionally observed transitions from hornblendite to amphibolite and from hornblende granite or diorite to amphibolitic gneiss suggest the amphibolite bodies are the result of metamorphic re-equilibration of igneous and high-grade gneiss to medium-grade metamorphic conditions.

Contacts between the Taltson basement complex and the interspersed Rutledge River Complex are transitional. Local migmatitic structures and frequent granite dikes indicate partial melting of the crust. Consistent belts of well-banded mylonite with sparsely preserved subhorizontal stretching lineations, amphibolite pull-apart structures and ductilely deformed feldspar define the Charles Lake and Bayonet Lake high- to medium-grade mylonite zones, variably overprinted by low-grade mylonite (Figure 2).

Because most samples from Taltson granitoid gneiss layers yielded U-Pb zircon (emplacement) ages ranging from ca. 2.56 to 2.14 Ga and include layers dated at ca. 3.19 Ga and ca. 3.08 Ga, it is inferred that the Taltson orthogneiss complex formed through Paleoproterozoic recycling of the Archean Rae Terrane (McNicoll et al., 2000). Multisystem isotope data from the Taltson basement complex and Taltson plutons in areas adjacent to Andrew Lake and elsewhere on the Alberta shield are consistent with slow uplift and cooling of the TMZ through the hornblende (approx. 530°±40°C) and biotite (280°±30°C) closure temperatures between ca. 1.9 Ga and ca. 1.8 Ga (Pană, 2010a). The $\varepsilon_{Nd\,(2.2.\,Ga)}$ values of –1.6 to –14.3 and Sm-Nd model ages relative to depleted mantle (T_{DM}) of 3.73–2.59 Ga from rocks of the Taltson basement complex are similar to those obtained from the Buffalo Head Terrane, and overlap with values for the Archean Rae Terrane (De et al., 2000; McNicoll et al., 2000).

3.2 Rutledge River Complex

The Rutledge River Complex consists of mappable bands and minor unmappable lenses of migmatite scattered throughout the granite gneiss domain that underlies the western part of the Andrew Lake map area. The migmatitic complex consists of mainly biotite±aluminosilicate gneiss and schist interlayered with granite and pegmatite lenses or dikes, milky quartz pods, augen gneiss, and small amphibolite and mafic lenses. Larger belts of Rutledge River Complex, which commonly include up to 50% migmatite and intense quartz veining, are found

- immediately west and north of Andrew Lake,
- south of Holmes Lake,

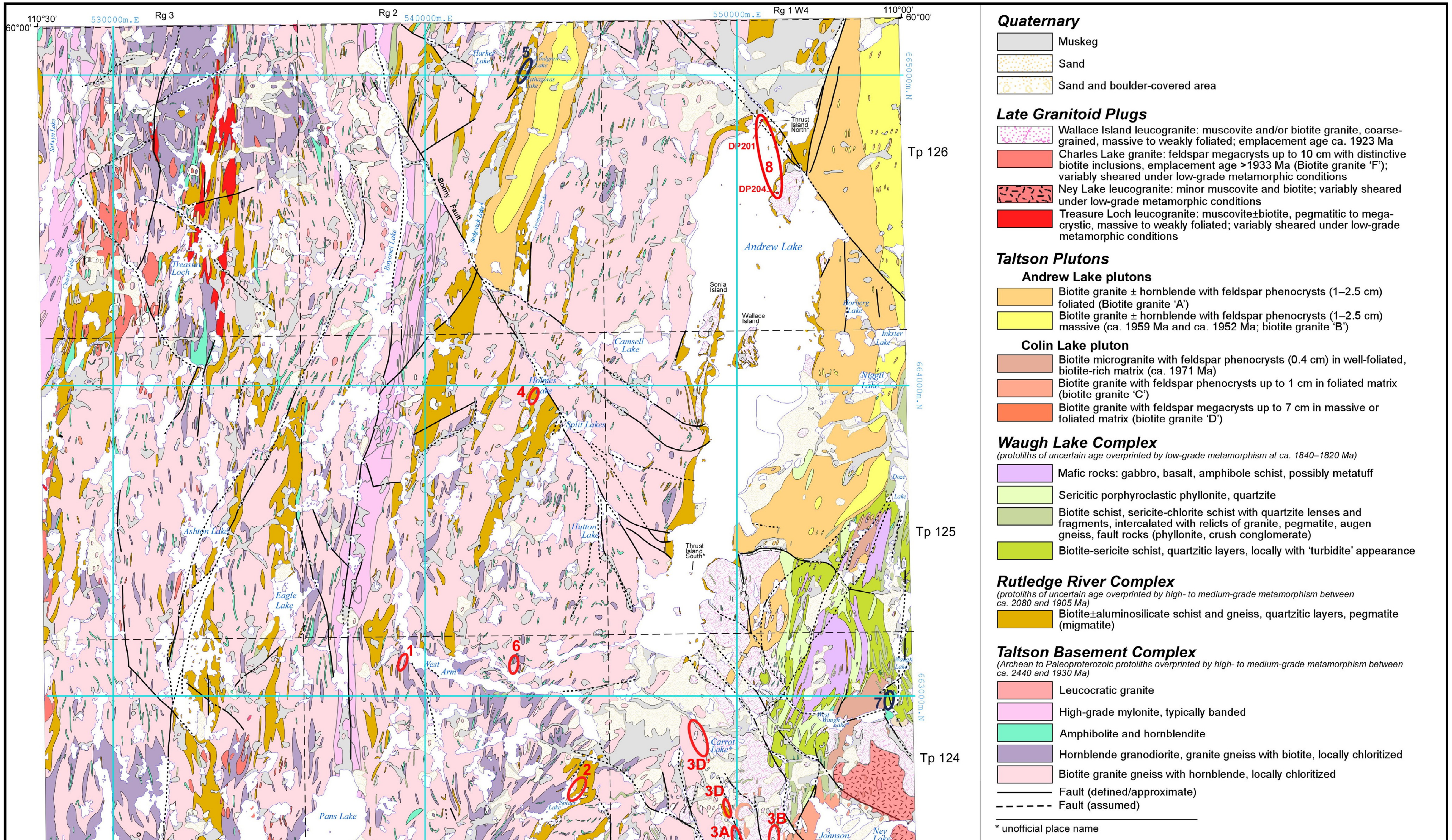

Figure 2. Compiled geological map of the Andrew Lake area (from Pană, 2010a). Labelled ellipses are high-radioactivity sites (in red) and other mineral occurrences (in black) discussed in text.

Figure 2. Geological compilation of the Andrew Lake area (from Pană, 2010a). Labelled ellipses are high-radioactivity sites (in red) and other mineral occurrences (in black) discussed in the text.

- south of Sedgwick Lake,
- north of Potts Lake, and
- near Spider Lake (Figure 2).

The biotite-rich lenses have been routinely described as pelitic and semipelitic gneiss and metaquartzite, essentially based on their well-developed layering and the frequent presence of aluminosilicate mineral phases (± pink to red garnet, graphite and tourmaline). Following Bostock and van Breemen (1994), McDonough et al. (2000a, b) interpreted these rocks as sediments deposited within the Rutledge River basin and later tectonically incorporated in the Rae crust and metamorphosed together under granulite- to amphibolite-grade metamorphic conditions. Minor amphibolite and mafic lenses were noted in these bands and are particularly conspicuous toward the north end of the Spider Lake band of Rutledge River rocks.

The common mineral assemblages in the Rutledge River Complex include quartz–potassium feldspar–biotite–garnet–aluminosilicate (sillimanite and/or andalusite) ±cordierite±graphite. Rock types consisting of various proportions of these minerals are the distinctive characteristic of the Rutledge River Complex and will be described hereinafter with the generic terms biotite±aluminosilicate schist and gneiss. Rutledge River schist and gneiss are commonly interlayered and folded with, or crosscut by, granite or pegmatite dikes, lenses, pods or stringers to form migmatite characterized by tight isoclinal or occasionally chevron folds, drag folds and other more complicated forms indicative of plastic flow.

Isolated occurrences of spinel inclusions in cordierite and garnet (Swinnerton Lake) and of zoned clinopyroxene in biotite-amphibole gneiss (Holmes Lake) suggest that the apparent amphibolite-facies Rutledge River Complex is the result of retrogression from granulite-facies rocks. The six-phase mineral assemblage of the typical Rutledge River schist and gneiss mapped in the Andrew Lake area is consistent with the retrograde reaction due to fluid access at the granulite–upper amphibolite transition (Pană, 2010a). Further retrogression of the biotite±aluminosilicate gneiss to interlayered quartz-biotite schist, chlorite-sericite schist, phyllonite and granoblastic quartz-rich layers occurs in narrow bands. Minor retrogressive shear zones are locally marked by hematite and pyrite, and highlighted by weathering as gossans and rusty zones.

Nearly concordant monazite analyses from Taltson plutons and Taltson basement complex, corroborated with concordant zircon ages and titanite ages, constrain the age of the granulite-facies metamorphism to slightly older than ca. 1932 Ma. Uranium-lead analyses of single metamorphic monazite grains from granulite-facies gneiss near the Leland Lakes shear zone have $^{207}Pb/^{206}Pb$ ages that cluster in the 1926–1923 Ma range and can be interpreted to record cooling through the 725°C isotherm following high-temperature deformation (McDonough et al., 2000b). The $^{207}Pb/^{206}Pb$ age of ca. 1925 Ma yielded by one monazite grain and two ages of ca. 1919 Ma yielded by two other monazite grains from biotite-spinel gneiss near the Charles Lake Shear Zone may indicate protracted deformation and exhumation of this more easterly shear zone until ca. 1919 Ma (McDonough et al., 2000b). Younger concordant zircon (1910 Ma), monazite (1913 Ma) and titanite (1916 Ma) ages probably represent mineral growth at or below the respective closure temperatures for these minerals (McDonough et al., 2000b).

These data from the Alberta portion of the TMZ are consistent with, and complemented by, existing data from the TMZ segment to the north in Northwest Territories, where various rock types assigned to the 'Rutledge River Group' record post–high-grade metamorphism cooling at ca. 1910–1905 Ma (Bostock and van Breemen, 1994). Igneous zircon grains from these rocks yielded ages in the ca. 2600–2000 Ma range, which overlaps the range of the most common ages obtained from zircon grains in orthogneiss of the Taltson basement complex. Zircon grains of similar igneous origin in the Rutledge River Complex and Taltson basement complex, as well as the concordant and gradational contacts of these complexes (through either migmatitic mixed-rock zones or shear zones), suggest a close genetic relationship between the two complexes. The lack of ca. 2000–1900 Ma igneous zircon in the Rutledge River Complex indicates that the medium- to high-grade metamorphic complex formed prior to Taltson plutonism.

3.3 Waugh Lake Complex

In the Waugh Lake area near the Alberta-Saskatchewan border, a distinct lithological assemblage of low-grade metamorphic and igneous rocks was originally mapped and described by Godfrey (1958, 1961, 1963) as the volcano-sedimentary 'Waugh Lake Formation.' Iannelli et al. (1995) introduced a formal nomenclature and described members and formations of the 'Waugh Lake Group.' McDonough and McNicoll (1997) described the 'Waugh Lake Group' as a small outlier of strata deposited in an intra-arc basin near the eastern periphery of the Taltson magmatic arc.

Based on detailed field and thin-section observations complemented by Sm-Nd data across selected contacts, Pană (2010a) argued that there is insufficient information to justify its designation as a formal stratigraphic unit. The low-grade metamorphic succession near Waugh Lake is unified in a general way by lithological features (structural/deformational features and metamorphic grade), mutual relations and evolution, and would therefore be more appropriately described as the 'Waugh Lake Complex' (Pană, 2010a).

Furthermore, based on reinterpretation of existing maps (Mulligan and Taylor, 1969; Koster, 1971; Bostock, 1992, Ashton, 2009), Pană (2010a) showed that, in fact, the Waugh Lake Complex is just a wider segment of a rather extensive belt of low-grade metamorphic tectonite that stretches several tens of kilometres from west of Harper Lake, Saskatchewan into the Northwest Territories. This belt appears to be part of a network of merging and diverging, steeply dipping, retrogressive shear zones with widths of 0.5–1.5 km that make up a network more than 150 km long at the eastern margin of the TMZ. The protoliths include mostly sheared and retrogressed rocks of the adjacent crust, and may incorporate sedimentary and volcanic units deposited atop the shear zone during its late evolution through shallow structural levels (Pană, 2010a).

3.3.1 Type of Metamorphism

Nilsen et al. (1981) inferred a metamorphic evolution of the Alberta shield that included a first granulite-grade metamorphic cycle of Archean age and a second metamorphic cycle that started under granulite-grade conditions and then passed through amphibolite-grade and finally greenschist-grade metamorphic conditions in the late Aphebian (1900–1790 Ma). Langenberg et al. (1993) proposed an unconformity contact between low-grade volcano-sedimentary rocks and their inferred basement, the Taltson basement complex. Salat et al. (1994) pointed out that this unconformity could not be found, so the basement of the Waugh Lake Complex is therefore unknown.

Based on selective remapping and aided by great progress in geochronology techniques, McDonough et al. (2000b) proposed a different tectonometamorphic evolution of the Alberta shield. In their interpretation, a major thrust zone developed at midcrustal levels toward the end of the Taltson tectonomagmatic event ca. 1932 Ma, allowing a thrust sheet of granulite- to upper amphibolite–facies rocks to advance northeastward and to juxtapose the hot rocks on top of the Andrew Lake pluton (ca. 1962 Ma) and the 'volcano-sedimentary Waugh Lake Group.'

Pană (2010a) argued that the structural elements, mineral paragenesis and strain distribution within the Waugh Lake Complex are consistent with tectonothermal evolution of a transcurrent shear zone at and above the brittle-ductile transition zone. Field and microscope observations suggest that at least parts of the low-grade Waugh Lake Complex may be directly derived from the adjacent crust (i.e., the Taltson magmatic zone) through shearing and metamorphic re-equilibration.

3.3.2 *Existing Isotope Data*

Initial K-Ar dates from Godfrey's 'Waugh Lake Formation' (1860–1740 Ma) partly overlapped the age range of the adjacent gneiss (1940–1620 Ma) and Taltson plutons (1930–1740 Ma), and could therefore not be used to constrain the geological history of the area (Godfrey and Baadsgaard, 1962; Baadsgaard and Godfrey, 1967, 1972). A 1760 Ma K-Ar biotite date from a 'basalt flow' and its low-grade metamorphism were interpreted to indicate that the Waugh Lake Complex is younger then the adjacent Taltson basement orthogneiss (Baadsgaard and Godfrey, 1972). More recently obtained K-Ar muscovite (1745 Ma) and biotite (1739 Ma) dates are consistent with previous K-Ar dates from the low-grade tectonite (McDonough et al., 2000a).

Re-evaluation of existing geochronological data from the Taltson basement complex and Taltson plutons shows that K-Ar dates record uplift and cooling (Pană, 2010a). However, the significance of K-Ar dates from the low-grade Waugh Lake tectonite is less clear. Quartz-albite-biotite-sericite schist of the Waugh Lake area formed in the low-grade temperature range that includes the closure temperatures of biotite, sericite and feldspar. Reported biotite and muscovite dates of 1830–1740 Ma from the foliated low-grade rocks of the Waugh Lake Complex may record syntectonic mineral growth during foliation development at temperatures of approximately 350°–300°C. Thus, foliation development in the Waugh Lake Complex appears to be quasicontemporaneous with the passage of the adjacent crust through the muscovite-biotite isotherms at ca. 1.84–1.73 Ga (i.e., approximately 120–240 Ma after the emplacement of the Andrew Lake [ca. 1.96 Ga] and Colin Lake [ca. 1.97 Ga] granitoid plutons in the Andrew Lake area).

Recently obtained $^{40}Ar/^{39}Ar$ ages on muscovite-rich schist samples in the 1840–1820 Ma age range likely date late movements along the phyllonite belt west of Waugh Lake. However, because similar sericite-bearing schist units occur throughout the Waugh Lake Complex, Pană (2010a) proposed that tectonism along the greenschist belt surrounding Waugh Lake took place or continued around 1830 Ma. These ca. 1840–1820 Ma $^{40}Ar/^{39}Ar$ dates from phyllonite samples are contemporaneous with the late phases of strike-slip displacement on major shear zones overprinting the Taltson magmatic zone (Plint and McDonough, 1995).

Uranium-lead dates on detrital zircon from a 'feldspathic wacke' layer (mostly in the range 2.3–2.01 Ga, with one grain of ca. 2.7 Ga) and an emplacement age of ca. 1971 Ga for the Colin Lake granitoid, interpreted to intrude the basal units of the volcano-sedimentary sequence, were inferred to constrain the timing of deposition of the lower part of the 'Waugh Lake Group' to between ca. 2020 and 1971 Ma (McDonough and McNicoll, 1997). There is, however, a distinct possibility that the 'feldspathic wacke' described by McDonough and McNicoll (1997) is, in fact, a ca. 2320 Ma granite gneiss of the Taltson basement complex overprinted by strain under low-grade conditions in the Waugh Lake area (Pană, 2010a). This possibility is suggested by the cluster of slightly discordant U-Pb zircon data points and a concordant zircon fraction with a $^{207}Pb/^{206}Pb$ age of 2318 ±4 Ma, which correspond to the inferred emplacement ages for some of the granitoid protoliths (e.g., ca. 2295 Ma, ca. 2330 Ma) of the Taltson orthogneiss (McNicoll et al., 2000). Similar to the 'feldspathic wacke,' some of the Taltson orthogneiss samples contain zircon grains with younger $^{207}Pb/^{206}Pb$ ages (e.g., 2.13 and 2.14 Ga) and inherited zircon grains (e.g., 2.58 and 2.93 Ga).

Furthermore, the interpretation of an intrusive contact between the ca. 1.971 Ga Colin Lake granitoid and the Waugh Lake Complex is controversial. Pană (2010a) showed that the ca 1.971 Ga Colin Lake diorite from the elbow of Waugh Lake (McDonough and McNicoll, 1997) and the ca. 1.973 Ga Martyn Lake granitoid represent undigested pods and lozenges with gradational contacts through strain and metamorphic reactions to the surrounding low-grade Waugh Lake Complex. Selected samples of mylonite from the Waugh Lake Complex yielded Sm-Nd T_{DM} model ages and ε_{Nd} values consistent with their derivation from adjacent Taltson plutons (Pană, 2010a).

3.4 Taltson Plutonic Rocks

In the Andrew Lake area, the Taltson magmatic event is represented by the emplacement of relatively voluminous Andrew Lake and Colin Lake granitoid plutons and by smaller, muscovite-bearing granite intrusions.

Two north-south–elongated plutons of Andrew Lake biotite-hornblende granodiorite have been previously mapped, one located west of Swinnerton Lake and the other east of Andrew Lake (Godfrey, 1961, 1986a). Their U-Pb zircon emplacement ages are 1959 ±3 Ma and 1962 +16/–10 Ma (McDonough et al., 2000b). The cores of the plutons are relatively massive to weakly foliated biotite granite and may include a more feldspathic and massive grey granite phase. The peripheries of the plutons are foliated, with K-feldspar megacrysts set in a foliated matrix of feldspar, biotite, quartz and minor hornblende. The strained peripheries of the Andrew Lake plutons grade into high-strain rocks and are commonly intruded by syn- to late-kinematic pegmatite, microgranite and aplite bodies that range in width from 1 cm to more than 3 m. The foliation is northerly trending, steeply dipping and typically well expressed by coarse-grained biotite and lenticular quartz matrix with aligned feldspar porphyroblasts/clasts.

The Colin Lake pluton consists of several granitoid phases that crop out over a large area along the Alberta-Saskatchewan border, from Waugh Lake in the north to Colin Lake, some 30 km to the south (Godfrey, 1986a). The dominant phase around Colin Lake is a megacrystic granodiorite, whereas the Colin Lake pluton at Waugh Lake is represented by a medium-grained, equigranular diorite. The emplacement age of the Colin Lake pluton is inferred based on an upper intercept age of 1971 ±4 Ma obtained from the diorite phase at Waugh Lake (McDonough and McNicoll, 1997).

The smaller muscovite-bearing granite plugs are associated with zones of strain concentration and may represent late-stage igneous phases emplaced at shallower structural level than the hornblende and biotite granitoid plutons (Pană, 2010a). From west to east, these are as follows:

- The Charles Lake granite consists of a series of sub-kilometre–size bodies of massive to foliated, occasionally megacrystic granite, spatially associated with the Charles Lake and Bayonet Lake high-grade mylonite belts and their peripheries of Rutledge River rocks (Figure 2). This granitoid rock, which contains zircon of ca. 2.1 Ga age, has been variably deformed to amphibolite-grade metamorphic conditions prior to ca. 1919 ±2 Ma (youngest monazite age) and later to greenschist-grade, strike-lineated protomylonite and mylonite. The best estimate of the minimum emplacement age is ca. 1933 Ma (McDonough et al., 2000b).

- The Treasure Loch granite in the same setting, between the CLSZ and the BLSZ, consists of several bodies of white or light grey to pink, muscovite-bearing (with rare biotite), coarse-grained to megacrystic granite (Godfrey, 1966; Pană, 2010a; Figure 2). Its age has not yet been determined.

- The Wallace Island granite is represented by several bodies of massive biotite±muscovite granite that plug the belt of highly deformed migmatite (Rutledge River Complex) in the Andrew Lake–Cherry Lake area (Godfrey, 1961). The inferred emplacement age is 1923–1921 Ma, with monazite growth during cooling between 1921 and 1913 Ma (McDonough et al., 2000b).

- The Ney Lake granite, south of Waugh Lake and on strike with the main body of phyllonite of the Waugh Lake Complex, contains minor muscovite and biotite, and is overprinted by small shear zones parallel to an incipient northerly trending foliation marked by sericite and chlorite. This foliation is concordant with, and at the same metamorphic grade as, the foliation of the Waugh Lake tectonite, indicating that the Ney Lake granite was overprinted by the same tectonometamorphic event as the Waugh Lake tectonite.

The muscovite-bearing granite bodies intrude and crosscut ductile shear fabrics and are massive to weakly foliated. They are likely late to post kinematic relative to the ductile strain recorded by the belts of Rutledge River Complex, and may have been emplaced independently of the larger Taltson plutons. Field relationships suggest a decompression melting origin for the muscovite-bearing granite bodies within zones of ductile shearing during late phases of tectonomagmatic evolution of the TMZ, accompanied by progressive exhumation of the crust and concentration of strain in major shear zones (Pană et al., 2007).

The late muscovite-bearing granites are cut by pink granitic, muscovite and/or feldspar pegmatite dikes. These dikes are typically associated with contacts between bands of Rutledge River Complex and either the Taltson basement complex or the Taltson plutons.

4 Mineral Occurrences

Godfrey (1958, 1961, 1963) reported on previously discovered and new mineral occurrences and high-radioactivity localities identified during his systematic mapping of the Andrew Lake area. Limited exploration work followed in the early 1960s and 1970s. Langenberg and Eccles (1996) re-examined and described some of these known mineral occurrences. With the steep rise in the price of uranium, most of the Andrew Lake area has been restaked. Some of the known mineral occurrences were revisited and sampled in the summer of 2005 (Pană et al., 2006). Particular attention was given to known areas of high radioactivity along the Bonny Fault.

This report includes the results of a short follow-up program undertaken by AGS in the summer of 2006, aimed at updating geological knowledge of the area in light of new analytical work, and assessing the metallogenic potential of the region. Several known high-radioactivity locales south of Andrew Lake and near the west arm of Andrew Lake, and the mineral occurrences at Pythagoras and Lindgren lakes near the Alberta–Northwest Territories border, were examined and sampled (Figure 2).

The following localities and clusters of high-radioactivity sites south of Andrew Lake have been examined:

1) Godfrey's (1958) 'location 1,' near the elbow of the west arm of Andrew Lake
2) Godfrey's 'location 2,' a cluster of high-radioactivity sites near Spider Lake
3) Godfrey's 'location 3,' a cluster of radioactivity spots north of Cherry Lake and along the ridge west of Carrot Lake (labelled 3A, 3B and 3D' in Figure 2)

For completeness, this report also includes a brief review of the field and analytical data from Godfrey's high-radioactivity 'location 4,' re-examined by AGS in 2005 (Pană et al., 2006), as well as a site within an airborne radioactivity anomaly on the north shore of the west arm of Andrew Lake (highlighted area 6 in Figure 2). In addition, brief notes are included on the sulphide occurrence at Godfrey's 'location 5' and on the tourmaline veins occurrence near Waugh Lake.

4.1 Location 1

Approximately 500 m south of the elbow of the west arm of Andrew Lake, Godfrey (1958) described, at his 'location 1,' vertical layers of quartzite, biotite schist, feldspathic quartzite, porphyroblastic feldspar schist and pegmatite that record high strain (Figure 2). A 0.15 m by 20 m iron-stained band in biotite schist, with lenses, pods and veins of quartz, was reported to contain pyrite, molybdenite and yellow uranium stain (carnotite?) associated with anomalous radioactivity more than six times local background.

Godfrey (1958) reported that three assayed grab samples from the radioactive zone had relatively high concentrations of U_3O_8 and MoO. This was partly confirmed for two of his three samples by semiquantitative spectrographic analysis (values in parentheses): 1.03% (1.0%), 3.29% and 3.93% (2.5%) U_3O_8 and 0.69% (1%), 1.03% and 1.40% (2%) MoO.

The site is in the Taltson orthogneiss within a 20–30 cm wide, northwesterly trending zone of high strain and partial retrogression, with chloritization and limonite alteration (Figure 3a, b). To the west, the exposure is poor and, to the east, the high-radioactivity zone is bounded by an approximately 5 m wide layer of high-grade, plane-parallel mylonitic gneiss (banded gneiss), intruded by a metre-size white pegmatite body.

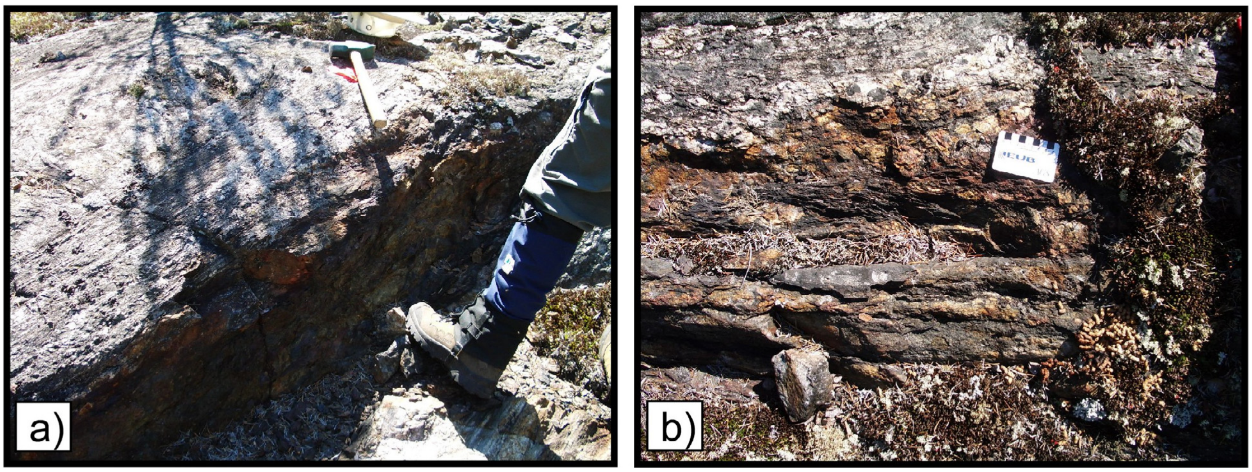

Figure 3. Zone of increased radioactivity south of the elbow of the west arm of Andrew Lake ('location 1' of Godfrey [1958] near UTM Zone 12, 538982E, 6630801N, NAD 83,): a) 10–30 cm wide shear zone overprinting biotite gneiss of the Taltson basement complex; the shear zone is exposed for approximately 20 m; b) sample site (6701 and 6702; see Tables 1–3) along the shear zone, containing minor sulphide minerals and high radioactivity values.

Samples of schistose material from the radioactive zone (6701 and 6702) show very low SiO_2, high Fe_2O_3, MnO, MgO and TiO_2, and elevated U, Th, Mo, V, Ni, Cr and Co, similar to Athabasca-type polymetallic uranium deposits. In addition, concentrations of Cu, Pb, Zn, Nb, Ta, Tl, W, Ag, Y, Zr and Hf are also elevated (Tables 1 and 2). Sample 6701 yielded 0.332% Mo and 0.07% U, and sample 6702 yielded 0.411% U. Elevated S contents indicate that many of the base metals may occur dominantly as sulphides. However, the small proportion of S (1.32% and 1.34%) relative to total Fe (20.12% and 22.92%, expressed as Fe_2O_3) indicates that most of the iron exists in one or more silicate (±oxide) minerals. Scintillometer traverses around this site showed that the high-radioactivity zone does not extend along trend and no other high-radioactivity sites could be found nearby.

4.2 Location 2

Godfrey's (1958) 'location 2' at Spider Lake has been described as an 800 m long zone of strain (inferred to extend for possibly 3.6 km) marked by biotite schist, garnetiferous quartzite and feldspathic quartzite with molybdenite, yellow uranium stain (carnotite?) and anomalous radioactive occurrences (three to five times background), associated with variably strained pink-feldspar pegmatite. Exploration in the area, including drilling and trenching, returned up to 0.17% U_3O_8 (Thorpe, 1969).

Field relationships and radioactivity measurements using a GR-135 spectrometer indicated that elevated radioactivity is consistently associated with pegmatite veining within biotite±aluminosilicate gneiss and schist (Figure 4). Although background radioactivity was found to be around 150 c/s (counts per second), pegmatite bodies at several blast locations and trenches north of the prominent peninsula in Spider Lake

Table 1. Major-elements (in %) in samples from the Andrew Lake area. Analyses by fusion inductively coupled plasma–optical emission spectrometry (FUS-ICP).

Area	UTM[1]		SiO_2	Al_2O_3	$Fe_2O_3^T$	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total
	East	North	*0.01*[2]	*0.01*	*0.01*	*0.001*	*0.01*	*0.01*	*0.01*	*0.01*	*0.001*	*0.01*	*0.01*	*0.01*
Andrew Lake (north end)	550873	6648447	63.90	20.01	0.56	0.012	0.17	0.91	6.71	5.65	0.074	0.10	1.11	99.20
Andrew Lake (north end)	551598	6646385	73.06	13.22	3.10	0.031	0.75	1.01	2.31	5.49	0.388	0.02	0.75	100.10
South Twin Lake[3] (south shore), north-northwest of Cherry Lake	550276	6625268	75.60	13.45	1.57	0.027	0.56	1.78	3.86	2.69	0.189	0.02	0.84	100.60
South Twin Lake (southeast shore), north-northwest of Cherry Lake	550285	6625312	64.40	18.13	3.59	0.055	1.17	2.87	5.36	2.16	0.464	0.02	1.13	99.33
Cherry Lake (north shore)	551025	6624884	75.22	13.09	1.30	0.016	0.36	0.35	3.36	5.23	0.042	0.02	0.75	99.73
Andrew Lake (south of)	548496	6628643	72.16	15.34	1.73	0.013	1.10	0.41	7.18	0.80	0.261	0.12	0.98	100.10
Andrew Lake, north of West Arm[3]	542833	6630862	58.50	20.20	4.58	0.044	1.94	2.52	3.99	6.11	0.716	0.27	1.66	100.50
Andrew Lake, north of West Arm	542825	6630830	58.46	15.20	12.84	0.062	1.01	1.60	3.13	4.07	1.613	0.05	1.44	99.46
Spider Lake Penninsula	544930	6626783	90.94	3.04	2.62	0.011	0.64	0.11	0.27	1.47	0.446	0.02	0.52	100.10
Andrew Lake, south of West Arm	539156	6630857	41.09	15.44	20.12	0.233	6.99	0.89	0.87	6.26	2.060	< 0.01	5.04	99.00
Andrew Lake, south of West Arm	539156	6630857	36.45	16.00	22.92	0.326	8.55	0.30	0.67	4.23	2.513	0.01	7.05	99.02
Cherry Lake (north shore)	551213	6624981	71.41	14.33	1.34	0.022	0.40	0.26	2.94	7.57	0.090	0.04	0.80	99.20
Pythagoras Lake (west shore)	543533	6650415	52.97	25.02	9.02	0.029	2.66	0.09	0.65	4.47	1.098	0.04	4.20	100.30
Pythagoras Lake (west shore)	543284	6649820	54.98	20.56	10.57	0.081	3.11	0.20	0.39	4.88	0.985	0.05	4.44	100.20
Pythagoras Lake (west shore)	543598	6650405	61.76	17.92	8.55	0.058	2.21	0.51	1.14	4.97	0.839	0.05	2.08	100.10
Carrot Lake (ridge west of lake)	548553	6629199	42.32	26.75	10.89	0.099	4.46	0.25	0.62	7.16	1.140	0.07	5.56	99.32
	-	-	49.59	20.41	6.24	0.107	0.51	8.14	7.07	1.68	0.289	0.14	4.92	99.09

yielded 2000–3100 c/s. Higher radioactivity values of up to 8000 c/s were measured in quartzofeldspathic layers and pegmatite bodies exposed by trenches on the peninsula. Most trenches are approximately perpendicular to the local metamorphic layering, which dips steeply to the west (85°) and trends 060°, approximately parallel to the long axis of the northern Spider Lake peninsula.

Striations occasionally show late thrust displacement on east-trending (087°/60°N) slip surfaces or dextral shear along fracture cleavages perpendicular to layering (147°/87°W). In general, the rocks exposed by trenching on this peninsula appear somewhat more retrogressed than outcrops north of the lake. Observations in the Spider Lake area suggest that ductile deformation and pegmatite segregation-intrusion in the Rutledge River Complex were accompanied by concentration of radioactive elements in pegmatite, with further concentration of radioactivity through subsequent retrogression and brittle faulting.

One of the larger trenches on the Spider Lake peninsula is 0.5 to 1.5 m deep and 8 m long, with the long axis trending 340° (UTM Zone 12, 544930E, 6626780N, NAD 83). The trench exposes quartz-feldspar-biotite gneiss, with a strong foliation striking 065° and dipping 80°W, and sheared quartz-feldspar-(biotite) pegmatite. Sample 6609 was collected near the west end of the trench in a 120 cm wide pegmatite lying parallel to the gneissic foliation. Readings of up to 8300 c/s were obtained with the GR-135 spectrometer. The pegmatite is white to pink on fresh surfaces, white weathering and nonmagnetic, and contains approximately equal amounts of light grey, anhedral quartz up to 5 mm across and white to pink (hematized) feldspar. The feldspar is subhedral and up to 2 cm long, with crystals up to 1 cm in length common. The pegmatite also contains approximately 5% biotite in irregular veinlets up to 3 mm wide. Minor amounts of yellow stain on fractures (present in sample 6609) may be a uranium oxidation product. Sample 6609 returned 138 ppm Th, 1320 ppm U, 15 ppm Ag, 703 ppm Pb and 1635 ppm Zr (Table 2).

Table 2. Trace-elements (in ppm, except for S [in %], and Au and Ir [in ppb]) in samples from the Andrew Lake area. Analytical method as indicated in the footnotes.

Sample No.	Au	Ag	Cu	Pb	Zn	Mo(1)		V	Ni	Cr	Co	As	Ba	S	Cd	Sc	Be	Zr
Detection:	*2*	*0.3*	*1*	*5*	*1*	*2*	*10*	*5*	*1*	*5*	*1*	*0.5*	*3*	*0.001*	*0.5*	*0.1*	*1*	*4*
Method:	INAA	TD-ICP	TD-ICP	TD-ICP	TD-ICP	FUS-MS	ICP-OES	FUS-ICP	TD-ICP	INAA	FUS-MS	INAA	FUS-ICP	TD-ICP	TD-ICP	INAA	FUS-ICP	FUS-ICP
6601	-2	<0.3	24	67	17	<2		8	2	9	<1	5.1	736	0.030	0.6	3.0	3	38
6602	-2	1.8	13	103	43	14		27	8	27	3	-0.5	999	0.034	<0.5	6.3	1	210
6603	-2	2.9	6	146	31	21		21	10	24	2	2.0	359	0.009	<0.5	5.3	3	335
6604	-3	1.7	5	81	63	82		40	7	18	4	1.8	294	0.015	<0.5	10.5	5	231
6605	-2	0.8	7	31	14	<2		<5	4	17	<1	2.2	572	0.002	0.5	1.2	3	124
6606	-3	1.7	10	11	13	<2		14	1	15	2	-0.5	96	0.003	<0.5	4.3	1	276
6607(2)	-5	<0.3	20	171	70	<2		29	4	-5	9	-1.0	2791	0.019	<0.5	2.6	3	142
6608	-3	0.4	39	41	81	5		138	7	-5	13	2.0	1705	0.255	<0.5	3.7	2	101
6609	-2	14.7	8	703	33	60		39	10	71	4	4.2	249	0.014	<0.5	3.4	<1	1635
6701	-2	4.5	174	1670	173	>100	3320	239	73	188	37	-0.5	1257	1.320	<0.5	30.7	3	670
6702(2)	-10	10.1	283	3790	350	>100	7340	232	92	131	49	-1.5	1099	1.340	<0.5	40.4	1	1048
6703	-2	0.9	10	95	20	37		<5	5	-5	1	4.3	1210	0.008	<0.5	2.2	3	55
6713	-2	1.1	92	48	138	6		244	30	149	5	322.0	1010	0.535	0.6	17.0	2	175
6714	25	0.9	76	38	77	2		165	28	85	13	615.0	1016	0.518	0.5	24.1	3	156
6715	-2	0.8	62	41	150	2		142	53	102	14	180.0	1064	1.010	0.8	22.4	1	194
6716	-2	2.0	214	575	458	3		205	84	116	17	15.2	1526	0.536	1.5	22.6	5	184
6717	-2	<0.3	6	9	104	<2		6	8	15	2	16.4	356	0.017	<0.5	1.1	3	560

Sample No.	Rb	Sr	Y	Sn	Sb	Nb	Ta	W	Tl	Bi	Br	Ga	Ge	In	Ir	Se	Hf	Cs	Th	U(1)		B
Detection:	*2*	*2*	*2*	*1*	*0.5*	*1*	*0.1*	*1*	*0.1*	*0.4*	*0.5*	*1*	*1*	*0.2*	*5*	*3*	*0.2*	*0.5*	*0.1*	*0.1*		*2*
Method:	FUS-MS	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	INAA	FUS-MS	FUS-MS	FUS-MS	INAA	INAA	FUS-MS	FUS-MS	FUS-MS	FUS-MS	DNC	PGNAA
6601	164	302	8	2	0.5	3	0.3	<1	1.0	1.2	578	14	<1	<0.2	-5	-3	1.6	0.6	1.9	1.8		11
6602	210	177	3	2	0.9	16	1.0	<1	1.3	<0.4	825	18	1	<0.2	-5	-3	6.6	1.7	47.3	44.2		11
6603	137	190	8	<1	1.7	13	0.9	<1	0.9	<0.4	400	18	1	<0.2	-5	-3	10.8	2.5	229.0	134.0		18
6604	144	238	8	2	2.1	30	1.7	<1	1.1	<0.4	-50	28	2	<0.2	-5	-3	7.5	4.1	107.0	64.2		26
6605	164	163	8	2	1.5	4	0.2	<1	1.5	<0.4	468	14	1	<0.2	-5	-3	3.9	5.0	31.3	9.9		30
6606	18	80	27	2	2.0	16	0.9	<1	0.1	<0.4	-50	23	1	<0.2	-5	-3	7.0	<0.5	43.1	5.1		11
6607(2)	234	558	32	3	2.4	19	0.8	<1	1.3	<0.4	-100	39	3	<0.2	-5	-3	3.7	1.1	1260.0	13.4		37
6608	148	373	6	5	2.7	16	0.7	3	1.0	<0.4	1360	34	2	<0.2	-5	-3	2.7	1.1	212.0	3.1		18
6609	84	26	27	1	2.4	15	0.6	<1	0.6	<0.4	6800	7	1	<0.2	-5	-3	47.6	0.9	138.0	>1000	1320	8
6701	403	84	52	4	1.2	92	4.6	4	4.2	1.3	960	34	2	<0.2	-5	-3	20.0	3.5	264.0	701.0		6
6702(2)	245	51	166	4	0.7	125	5.8	9	3.6	1.4	-100	40	2	<0.2	-5	-3	31.9	2.0	728.0	>1000	4110	11
6703	232	218	13	3	3.6	9	1.4	<1	1.5	5.5	800	14	1	<0.2	-5	-3	2.0	1.8	24.0	548.0		18
6713	198	88	15	<1	2.3	17	0.8	<1	1.2	2.0	752	38	1	<0.2	-5	-3	5.0	3.3	19.8	3.0		17
6714	220	46	47	<1	1.6	18	0.9	<1	1.5	0.7	880	28	2	<0.2	-5	-3	4.6	2.4	25.8	3.1		6
6715	214	128	47	<1	1.9	15	0.8	<1	1.2	4.6	800	24	2	<0.2	-5	-3	5.6	2.6	18.1	3.1		12
6716	250	38	67	3	0.9	22	1.5	<1	1.3	5.9	960	46	1	<0.2	-5	-3	5.6	1.2	33.8	792.0		21
6717	54	1193	119	7	2.1	13	0.6	<1	0.3	<0.4	-100	35	1	<0.2	-5	-3	11.0	1.7	1.2	1.4		27

(1) high values of Mo (samples 6701 and 6702) and U (samples 6609 and 6702) obtained through FUS-MS reanalyzed by ICP-OES and DNC, respectively

(2) detection limit by INAA higher than usual due to high U and/or Th content in the sample

Analytical methods: DNC, delayed neutron counting; **FUS-ICP**, fusion inductively coupled plasma–optical emission spectrometry; **FUS-MS**, fusion inductively coupled plasma–mass spectrometry; **ICP-OES**, inductively coupled plasma–optical emission spectrometry; **INAA**, instrumental neutron activation analysis; **PGN AA**, prompt gamma neutron activation analysis; **TD-ICP**, total-digestion inductively coupled plasma–optical emission spectrometry.

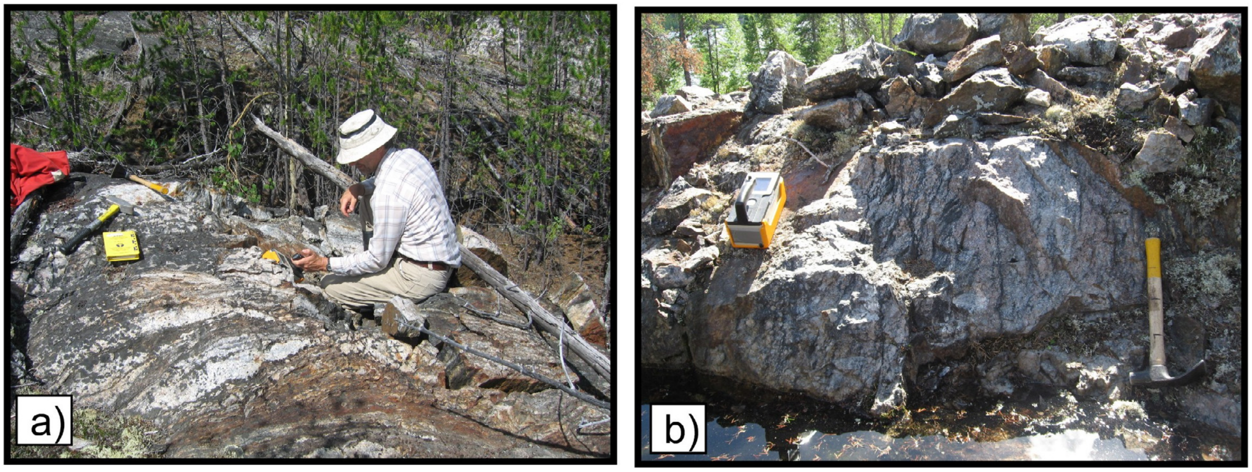

Figure 4. Old uranium exploration workings at the north end of Spider Lake within a) quasi-concordant decimetre- to metre-size metamorphic pegmatite bodies in biotite gneiss on the ridge north of the lake, and b) sheared pegmatite with biotite veinlets along irregular fractures on the prominent peninsula at the north end of the lake.

4.3 Location 3

4.3.1 Location 3A

Two zones of anomalous radioactivity were examined near the south end of South Twin Lake[1], north of Cherry Lake and near the northern end of Godfrey's (1958) radioactive trend '3A.' One zone is immediately south of this small lake and the other is along the eastern shore. Both zones occur along a north-northwest-trending fault within the Colin Lake granite (Godfrey, 1961). Previous sampling in this area has returned values of up to 0.14% U_3O_8 (Hart, 1967).

One small trench, approximately 1 m long and 0.4 m deep, was located a short distance south of South Twin Lake at UTM Zone 12, 550280E, 6625270N (NAD 83). Outcrops in the vicinity consist of pegmatite-bearing granitic mylonite with foliation striking 350° and dipping 75°E. The trench occurs within leucocratic quartz-feldspar-(biotite) pegmatite containing subhedral feldspar phenocrysts up to 1 cm long. The location of the trench corresponds to the highest radioactivity detected in the area with a hand-held spectrometer (up to 3400 c/s on the GR-135 spectrometer), and this is where sample 6603 was collected. The elevated radioactivity is associated with fracture-controlled biotite within the pegmatite. The biotite-rich fractures and veins strike 355°, dip 70°W, are up to 1 cm wide and locally form up to 5% of the rock. The fracture-controlled biotite is fine to medium grained and is accompanied by approximately 2% muscovite. Centimetre-scale, elongate quartz 'rods' within granitic mylonite near the trench plunge 65° toward 205°. Sample 6603 returned 229 ppm Th and 134 ppm U (Table 2).

The highest radioactivity detected (up to 3300 c/s on the GR-135) on the southeastern shore of South Twin Lake (UTM Zone 12, 550290E, 6625310N, NAD 83) occurs within a 40 cm wide, coarse-grained pegmatite dominated by 1–3 cm long, white subhedral feldspar with 5%–10% quartz and 5%–15% fracture-controlled biotite (Figure 5). This pegmatite, which was sampled (sample 6604), strikes 355° and dips 85°W. Spotty hematite staining of moderate intensity occurs on the surface of the pegmatite. Outcrop in the area consists mainly of strongly foliated (sheared) granitic rocks, locally containing lenses of quartz-feldspar-biotite schist and pegmatite (Figure 6). The foliation, which locally has the character of

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[1] unofficial place name

Figure 5. Pegmatite on the east shore of South Twin Lake from which sample 6604 was collected. Irregular black stringers consist mainly of biotite. The notebook is about 18 cm in height.

Figure 6. Outcrop of sheared granite containing irregular lenses of pegmatite on the east shore of South Twin Lake near sample site 6604.

gneissic layering, strikes 010° and dips 85°E. Small-scale fold axes in the schist plunge 70° toward 175°. Sample 6604 returned 107 ppm Th and 64 ppm U (Table 2).

4.3.2 Location 3B

Spots of radioactivity up to three times background are scattered throughout biotite granite at Godfrey's (1958) radioactive trend '3B,' at the northeastern end of Cherry Lake (Figure 2). On the north shore of Cherry Lake, a minor northerly trending shear zone, which could not be followed in outcrop for more than a few metres, shows local high radioactivity. On the GR-135 spectrometer, a 10–15 cm wide banded quartzitic ultramylonite in the centre of the zone yielded 6700 c/s. The radioactivity decreases abruptly outside the zone, to about 5000 c/s in the adjacent 20 cm wide band of sheared granite and to background values within a metre from the ultramylonite (Figure 7a, b). The ultramylonite in the centre of the zone returned an anomalous U value of 548 ppm (0.055%) but no enrichment in other metals (sample 6703, Table 2).

Approximately 1 km north, several large biotite-bearing pegmatite bodies, which have been previously trenched and drilled, show radioactivity up to three times background and yellow stain. Once again, the higher radioactivity values, up to 2200 c/s (scintillometer), were associated with minor shear planes (Figure 7c, d).

4.3.3 Location 3D'

Approximately midway between Andrew and Cherry lakes, west of a small lake informally named Carrot Lake (Figure 2), old trenches and blasting zones have exposed several high-radioactivity locations associated with small pegmatite bodies and narrow shear zones (Figure 8). High radioactivity, ranging from 3 000 to 14 000 c/s, occurs in boulders previously gathered in a pile near the northernmost blasting zones and trenches (Figure 8a). Spot radioactivity values up to 6000 c/s (scintillometer) have been found in one of the adjacent trenches that exposes slightly retrogressed biotite gneiss with small pegmatite and quartz pods, and a 20 cm wide, horizontally striated shear zone (180°/87°W; Figure 8b, c). Blast zones 20 m to the west uncovered pegmatite pods with radioactivity two to four times background and higher values in the surrounding biotite gneiss/schist, which is partly retrogressed to chlorite-sericite schist (Figure 8d, e). Exploration industry sampling of the trenches west of Carrot Lake returned values of up to 0.18% U_3O_8 (Burgan, 1971), and subsequent government sampling of a gouge zone exposed in one of the trenches yielded 17 957 ppm U (Langenberg et al., 1993).

4.4 Location 4

In the summer of 2005, AGS re-examined and sampled a number of anomalous radioactive spots along the Bonny Fault, identified by Godfrey (1958) as 'location 4' (Pană et al., 2006). The Bonny Fault is marked by a topographic low between Hutton and Andrew lakes, where a spectacular quartz stockwork and a hematite-cemented breccia with granite gneiss and vein-quartz fragments are locally exposed (Figure 9). The wallrock consists mainly of pink granitoid gneiss and pegmatite of the Taltson granitoid gneiss complex and locally of the migmatitic Rutledge River Complex (Figure 2).

The Bonny Fault, where brecciation and shearing are associated with hematization, feldspathization and chloritization, has the typical appearance of uraniferous zones in the Beaverlodge district of Saskatchewan, some 70 km to the east (Godfrey, 1958, 1961). Fluid-inclusion homogenization temperatures between 150°C and 250°C (Byron, 2006) are similar to those reported from uranium deposits in the Beaverlodge district (Sassano et al., 1972) and may indicate that portions of the Bonny Fault and adjacent wallrock are favourable for Beaverlodge-style vein-type uranium deposits. However, the intense carbonate metasomatism typical of the Beaverlodge and Athabasca vein-type uraniferous zones has not been observed along the Bonny Fault (Pană et al., 2006).

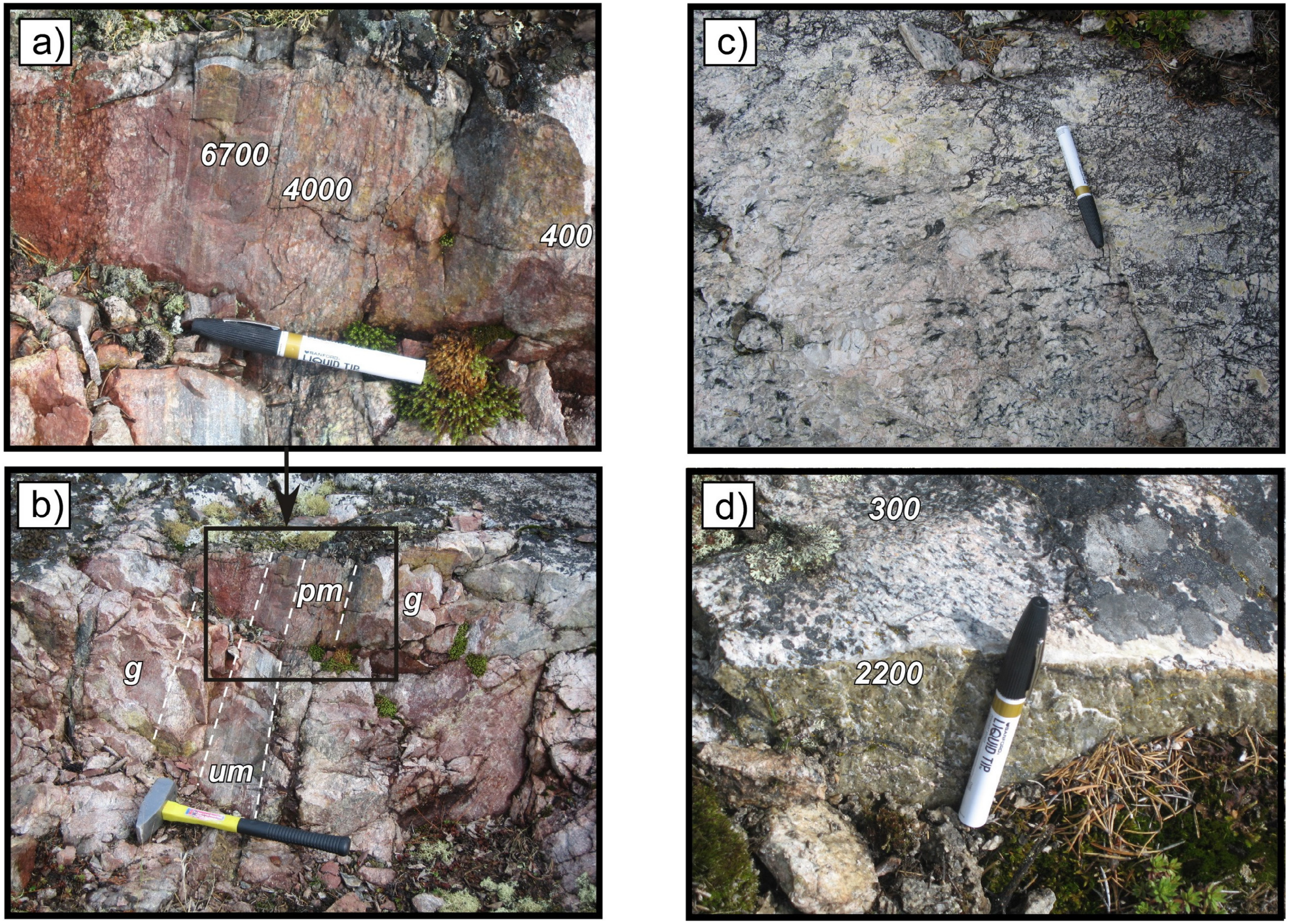

Figure 7. Zones of increased radioactivity near the north shore of Cherry Lake: a) and b) distribution of radioactivity around a minor shear zone within the Cherry Lake biotite granite near the north shore of Cherry Lake (UTM Zone 12, 551213E, 6624981N, NAD 83); c) yellow-stained, coarse biotite pegmatite; and d) higher radioactivity associated with minor reverse fault, approximately 1 km north of Cherry Lake (UTM Zone 12, 551105E, 6625030N, NAD 83). Numbers are counts per second (c/s) determined with a GR-135 spectrometer in (a) and an SPP2 scintillometer in (d). Abbreviations: um, ultramylonite; pm, granite protomylonite; g, granite country rock.

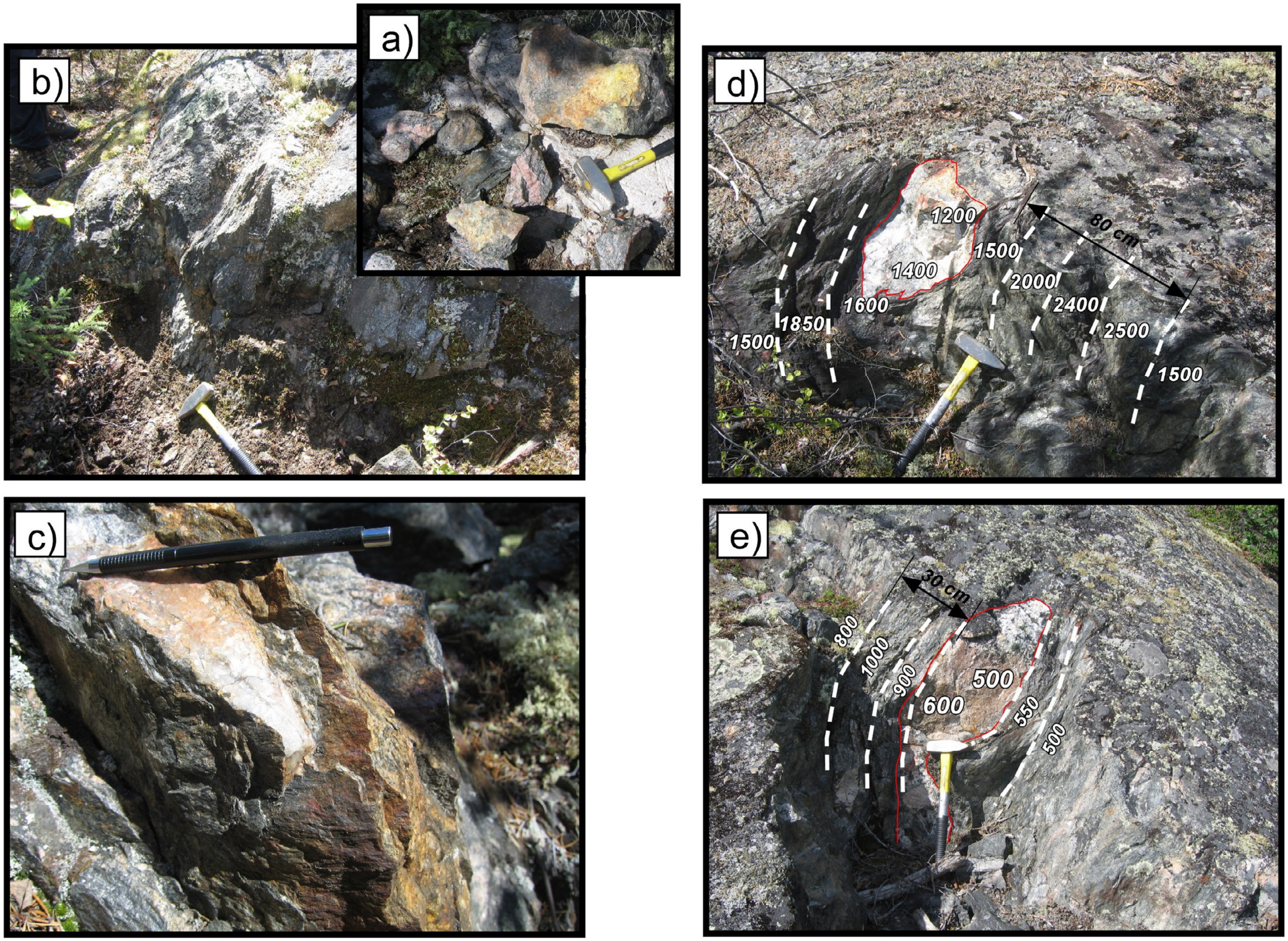

Figure 8. Zones of increased radioactivity northwest of Carrot Lake (informal name; UTM Zone 12, 548527E, 6628987N, NAD 83): a) rock fragments from an adjacent blast have radioactivity as high as 14 000 c/s; b) old trench northwest of Carrot Lake exposes biotite gneiss with pegmatite, quartz veins and a 30 cm wide subvertical shear zone associated with minor sulphide minerals and radioactivity one order of magnitude higher (7500 c/s) than background (220 c/s for biotite gneiss and 370 c/s for pegmatite); c) strike-parallel striations within the shear zone; d) and e) distribution of radioactivity, measured in old blasting zones, around pegmatite bodies (highlighted in red) within partly retrogressed biotite gneiss; numbers are counts per second (c/s) measured with a GR-135 spectrometer.

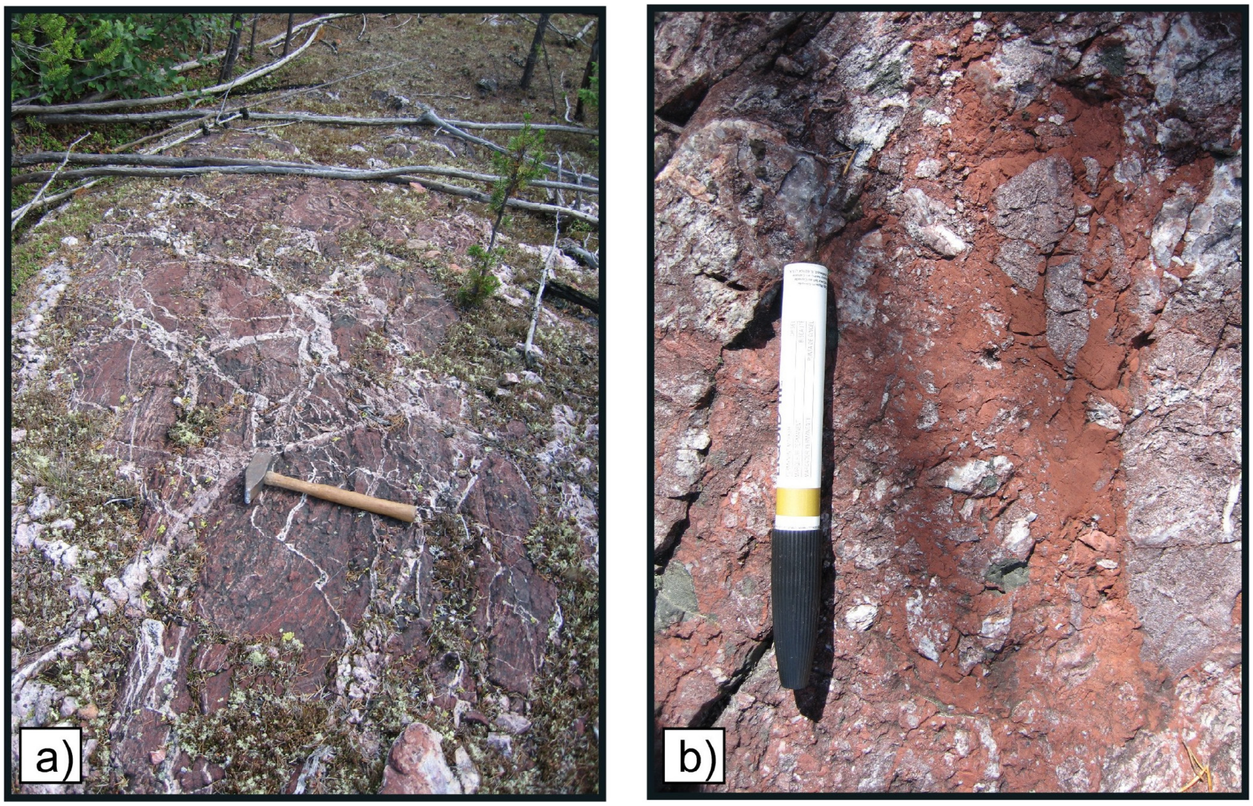

Figure 9. Fault rocks along the Bonny Fault: a) quartz stockwork in brecciated granite gneiss; b) tectonic breccia with angular fragments of shattered and altered granitoid gneiss and vein quartz cemented by hematitic gouge.

Scintillometer traverses indicate the highest radioactivity occurs in spotty locales in less tectonized granite gneiss wallrock and undigested pods within the Bonny Fault with very low radioactivity in the hematitic breccia. For example, radioactivity five times background (900 c/s, using the GR-130 spectrometer) was reported from a K-feldspar hornblende granitoid pod with high Ba (2017 ppm) and U (24.6 ppm) concentrations, in contrast to adjacent, highly tectonized and strongly hematitic zones of the same rock type that returned low Ba (38–105 ppm) and U (<3 ppm) values (Pană et al., 2006). These geochemical data suggest that the granitoid may have released Ba and U during metasomatism related to brecciation and hematization within the Bonny Fault. The apparent U depletion in the hematite-cemented breccia and quartz stockwork within the examined segments of Bonny Fault suggests that active vertical hydrodynamic cells, responsible for the extensive rock alteration, may have effectively removed the uranium (Pană, 2007).

Several radioactive zones (spots with >5000 c/s on the GR-130 spectrometer) have been found along a 50 m wide ‘trend’ that strikes southwesterly between Holmes Lake and the small pond 300 m southwest of it (Figure 2). Three old, partly overgrown trenches were excavated in the 1970s across the structural trend in hostrocks, consisting of biotite schist/gneiss, biotite pegmatite and plagioclase pegmatite with gabbro-diorite and amphibolite lenses, that are part of a 1 km by 6 km band of the Rutledge River Complex (Figure 10). Exceptionally high radioactivity readings for the area under consideration, up to 11 300 c/s on the GR-130 spectrometer, were found about 25 m inland from the southwestern shore of Holmes Lake, immediately south of the Bonny Fault (Figure 2). Samples from the most ‘radioactive’ outcrop yielded elevated concentrations of U (395 ppm), Th (210 ppm) and Pb (215 ppm). These samples also had minor amounts of S (0.12%–0.15%) and slightly elevated Mo, V, Zn, As (11–12 ppm) and Au (16 ppb). Uranium oxides and molybdenite were identified in a number of thin sections from this location (Pană et al., 2006).

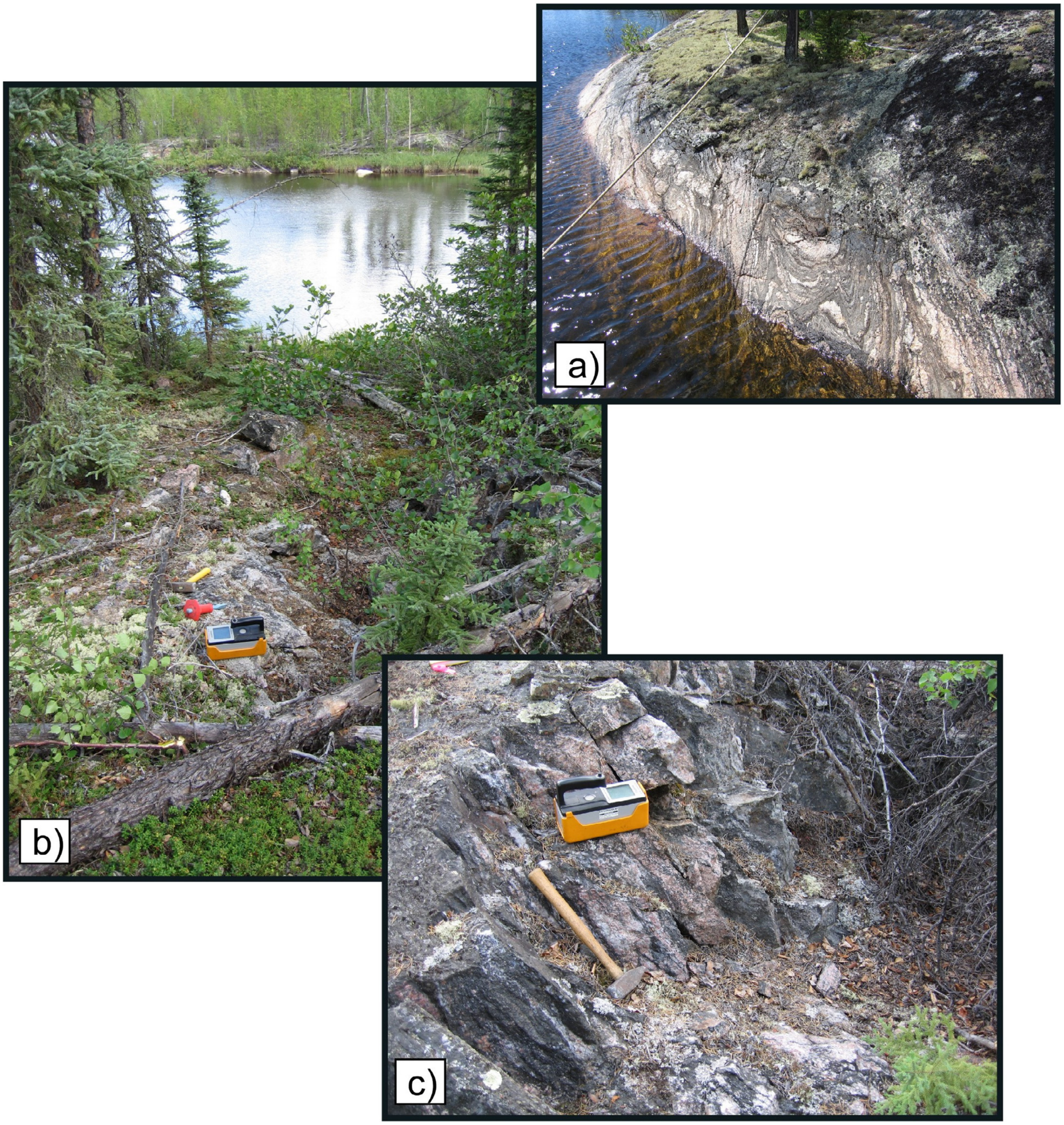

Figure 10. Cluster of radioactive sites south of Holmes Lake ('location 4' of Godfrey, 1958): a) rocks of the migmatitic Rutledge River Complex exposed on the south shore of Holmes Lake; b) old exploration trench; c) biotite±aluminosilicate gneiss and pink granite pegmatite exposed by old trench in the Rutledge River Complex.

Table 3. Lanthanide group elements (in ppm) in samples from the Andrew Lake area. Analyses by fusion inductively coupled plasma–mass spectrometry (FUS-MS).

Sample No.	La *0.1* [(1)]	Ce *0.1*	Pr *0.05*	Nd *0.1*	Sm *0.1*	Eu *0.05*	Gd *0.1*	Tb *0.1*	Dy *0.1*	Ho *0.1*	Er *0.1*	Tm *0.05*	Yb *0.1*	Lu *0.04*
6601	9.8	16.6	1.75	5.9	1.2	0.84	1.0	0.2	1.3	0.3	0.9	0.20	1.7	0.32
6602	6.7	10.7	1.04	3.5	0.7	1.44	0.6	0.1	0.7	0.1	0.4	0.07	0.5	0.10
6603	21.1	33.1	3.27	10.8	1.8	1.37	1.4	0.2	1.4	0.3	1.0	0.16	1.2	0.24
6604	21.9	35.2	3.43	10.9	1.5	1.64	1.0	0.2	1.1	0.2	0.7	0.12	0.9	0.18
6605	20.4	36.3	3.90	13.6	2.3	0.68	1.6	0.3	1.7	0.3	1.0	0.15	1.0	0.15
6606	136.0	261.0	26.50	84.5	11.9	1.13	6.9	1.1	5.7	1.0	2.8	0.39	2.2	0.32
6607	1010.0	1850.0	205.00	679.0	77.3	4.08	39.5	3.3	10.3	1.5	3.1	0.26	0.9	<0.04
6608	200.0	340.0	34.50	112.0	12.0	1.47	5.8	0.5	1.8	0.2	0.6	<0.05	0.3	<0.04
6609	4.2	7.7	0.98	5.7	2.4	0.32	3.2	0.9	6.0	1.3	4.2	0.68	4.8	0.88
6701	16.3	37.2	4.90	23.4	6.7	0.93	6.4	1.5	10.6	2.3	8.1	1.34	8.6	1.16
6702	37.3	92.8	12.60	64.9	21.3	1.81	21.6	5.6	39.0	8.5	27.4	4.21	25.1	3.20
6703	7.0	15.1	2.72	10.0	2.3	1.20	2.0	0.4	2.3	0.4	1.3	0.23	1.6	0.24
6713	52.0	97.6	11.10	40.1	6.7	1.36	4.8	0.7	3.3	0.6	1.7	0.24	1.6	0.24
6714	73.9	139.0	16.00	58.0	10.2	1.24	7.9	1.4	8.6	1.7	5.4	0.83	5.3	0.78
6715	46.4	87.5	9.89	35.5	6.5	1.66	5.9	1.2	8.0	1.8	5.9	0.95	6.2	0.92
6716	85.5	165.0	18.50	67.1	13.3	2.07	11.6	2.0	11.2	2.1	6.3	0.92	5.6	0.86
6717	63.7	128.0	15.60	60.1	13.0	2.20	14.0	3.1	20.4	4.5	15.3	2.48	15.9	2.29

[(1)] detection limit

4.5 Location 6

A thorium-bearing pegmatite dike north of the west arm of Andrew Lake (area 6 in Figure 2), corresponding to a 600 m long north-northeast trend of radiometric anomalies detected by airborne surveying (Allan, 1976), was examined and samples were collected from two trenches (samples 6607 and 6608, Tables 1–3).

The more northerly trench (UTM Zone 12, 542830E, 6630860N, NAD 83) exposes a very coarse grained pegmatite dike with a 140 cm apparent width, striking 030° and dipping 80°E, parallel to nearby wallrock foliation. Measurements of up to 4100 c/s were obtained near the centre of the trench with a GR-135 spectrometer. The pegmatite at this location is white to light pink and nonmagnetic, and contains mainly feldspar with 5% to 10% quartz and about 5% biotite concentrated along irregular fractures. Sample 6607, collected in the trench near the centre of the pegmatite dike, returned 1260 ppm Th, 13 ppm U, 1010 ppm La and 1850 ppm Ce (Tables 2 and 3).

The more southerly trench (UTM Zone 12, 542830E, 6630830N, NAD 83) exposes a pinkish, coarse-grained pegmatite dike believed to be the same dike exposed in the northern trench. The dike is at least 140 cm wide with a generally northerly trend and steep dip (the dike margins are not well exposed). The pegmatite is composed mainly of pink feldspar phenocrysts up to 2 cm long with 5%–10% quartz and about 5% very fine to fine-grained biotite in multidirectional veinlets up to 2 mm wide. At this location, the pegmatite is weakly to moderately magnetic. Measurements of up to 4000 c/s were obtained near the centre of the trench with the GR-135, and sample 6608 (212 ppm Th, 3 ppm U, 200 ppm La and 340 ppm Ce; Tables 2 and 3) was collected from the most radioactive material.

4.6 Sulphide and Tourmaline Sites

Small, strike-parallel gossan and rusty zones are common in the biotite±aluminosilicate gneiss bands of the Rutledge River Complex. Whereas pyritization is a common feature of most biotite±aluminosilicate bands, other sulphide minerals have been reported on the west side of the Sedgwick[2]-Lindgren string of lakes. At his 'location 5' on the southwest shore of Lindgren Lake, Godfrey (1958) described a 1 m by 7 m gossan, formed on feldspathic quartzite and biotite schist, with massive arsenopyrite and pyrite along with smaller amounts of pyrrhotite and smaltite. A grab sample from this location containing 25% sulphide minerals assayed 0.39% Ni and 0.3 oz./ton Ag (Godfrey, 1958).

Approximately 700 m north, small amounts of smaltite were reported in a band of amphibolite and biotite schist (Godfrey, 1958). In this area, outcrops of rusty, sulphide-bearing, slightly retrogressed migmatized biotite schist were grab-sampled approximately 150 m inland from the west shore of Pythagoras Lake (samples 6714 and 6715) and 10 m from the west shore of Lindgren Lake (sample 6713). The massive sulphide lens with elevated Ni and Ag values reported by Godfrey on the west shore of Lindgren Lake could not be confirmed. Analysis of the 2006 samples from gossan in this area showed significantly elevated As (up to 615 ppm) accompanied by modest increases in S, Ba, Sc, Cu, Pb, Zn, V, Ni and Cr (Table 2). A 25 ppb Au value was found in sample 6714, collected near Pythagoras Lake.

Elevated values of sulphide minerals and metals within the Rutledge River Complex are generally related to the bands of strained and migmatized biotite±aluminosilicate gneiss, with no occurrences in the orthogneiss of the Taltson basement complex. The distribution of the mineral showings within these belts suggests that the sulphide occurrences are confined to high-strain biotite-rich zones (e.g., in the Lindgren-Sedgwick lakes band or in the Spider Lake band).

Godfrey (1958, 1963) reported small amounts of arsenopyrite, pyrrhotite, galena, molybdenite and chalcopyrite in the Waugh Lake Complex. Unique to this complex is the widespread presence of tourmaline-quartz composite veins (Figure 11), which are concentrated near the north shore of the elbow of Waugh Lake (Figure 2). A sample from a composite tourmaline-quartz-arsenopyrite veins, taken just east of the fourth meridian and north of Waugh Lake, yielded small amounts of Au, Ag and Ni (Godfrey, 1958).

5 Rare-Earth Element Geochemistry

The uranium-rich Spider Lake pegmatite sample (location 2; sample 6609) has modest rare-earth element (REE) contents with a slightly positive slope on a chondrite-normalized diagram (Ce/Yb value of 1.6; Table 3; Figures 12 and 13). The high U content of this sample (1320 ppm) relative to Th (138 ppm) results in a low Th/U ratio of 0.1. Figure 13 demonstrates a positive correlation between the Th/U and Ce/Yb ratios in pegmatite samples collected in the Andrew Lake area. The Spider Lake pegmatite sample returned the highest SiO_2 (90.94%), Br (6800 ppm), Zr (1635 ppm) and Hf (47.6 ppm) values of the analyzed samples (Tables 1 and 2).

The geochemical results from the pegmatite north of the west arm of Andrew Lake (location 6) contrast sharply with those obtained from the Spider Lake pegmatite. The Th-rich west arm pegmatite exhibits extreme enrichment of light REE and depletion of heavy REE, and Ce/Yb values of greater than 1000 (samples 6607 and 6608; Table 3; Figure 13). The high Th contents (1260 and 212 ppm), coupled with low U contents (13.4 and 3.1 ppm), result in strongly elevated Th/U ratios 68 and 94 (Figure 13).

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[2] unofficial place name

Figure 11. Multiple phases of tourmaline veining in the Waugh Lake Complex north of the Waugh Lake elbow (location 7 in Figure 2): a) pre- or interkinematic, folded quartz-tourmaline vein; b) post-kinematic, crosscutting quartz-tourmaline vein.

Two samples of limonitic, chloritic biotite schist from location 1 are characterized by relatively flat REE patterns with pronounced negative Eu anomalies (samples 6701 and 6702; Table 3; Figure 14). The variation in overall REE abundances between the samples may reflect metasomatic gain or loss of other elements during hydrothermal alteration (i.e., residual REE enrichment or depletion). In addition to

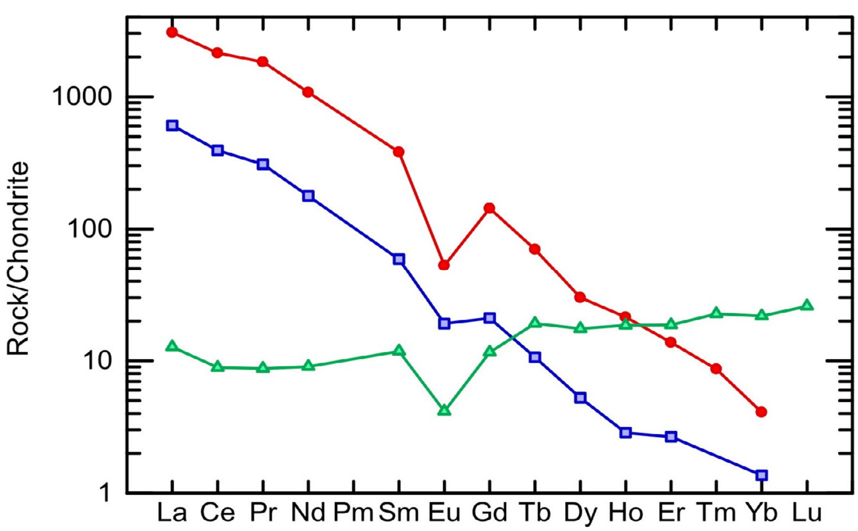

Figure 12. Spider diagram showing rare-earth element (REE) results for samples from location 6 (west arm of Andrew Lake area, samples 6607 [circles] and 6608 [squares]) and from location 2 (Spider Lake area, sample 6609 [triangles]). Data normalized to chondrite REE values of Nakamura (1974).

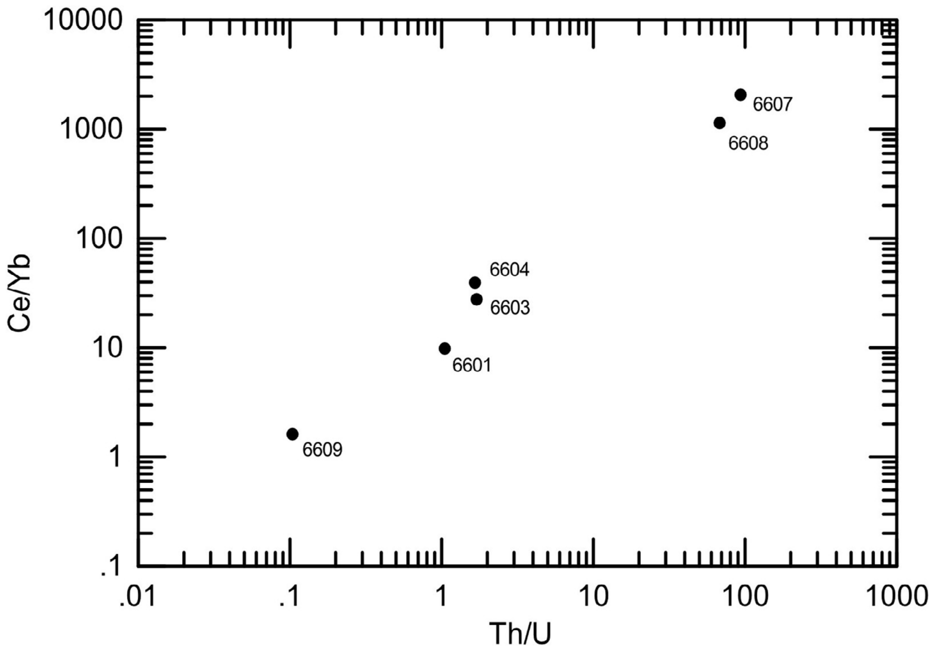

Figure 13. Th/U versus Ce/Yb diagram showing data for pegmatite samples from location 2 (Spider Lake area, sample 6609), location 3A (Twin Lakes area, samples 6603 and 6604), location 6 (west arm of Andrew Lake area, samples 6607 and 6608) and location 8 (northern Andrew Lake area, sample 6601).

strongly anomalous U concentrations (701 and 4110 ppm U), these samples contain significantly elevated contents of total iron as Fe_2O_3 (20.12% and 22.92%), Mo (3320 and 7340 ppm), Zr (670 and 1048 ppm) and Hf (20.0 and 31.9 ppm; Tables 1 and 2).

Samples from location 3A (pegmatite samples 6603 and 6604; Twin Lakes area) and location 8 (a pegmatite [sample 6601] and a pegmatitic granite [sample 6602]; northern Andrew Lake area) have similar REE patterns with distinctive positive Eu anomalies (Table 3; Figure 15). The granite sample was collected from the Wallace Island leucogranite. The similarity in REE patterns suggests, but does not

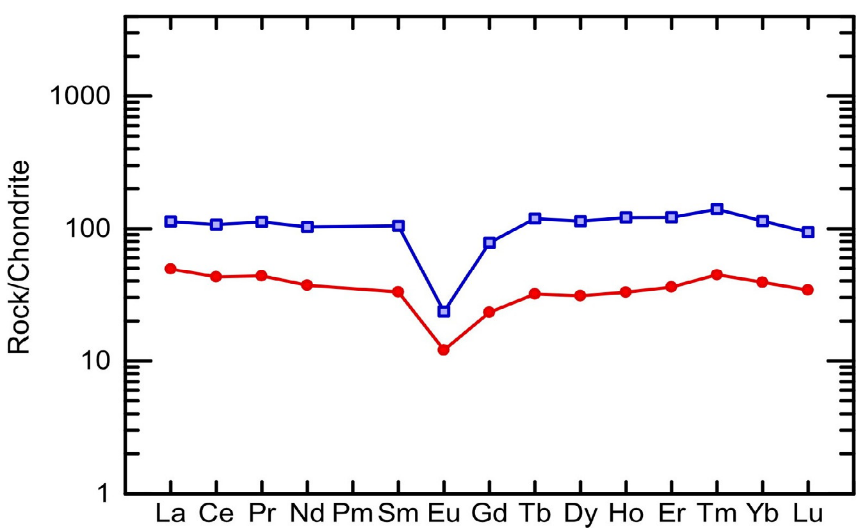

Figure 14. Spider diagram showing rare-earth element (REE) results for samples from location 1 (southwest of west arm of Andrew Lake, samples 6701 [circles] and 6702 [squares]). Data normalized to chondrite REE values of Nakamura (1974).

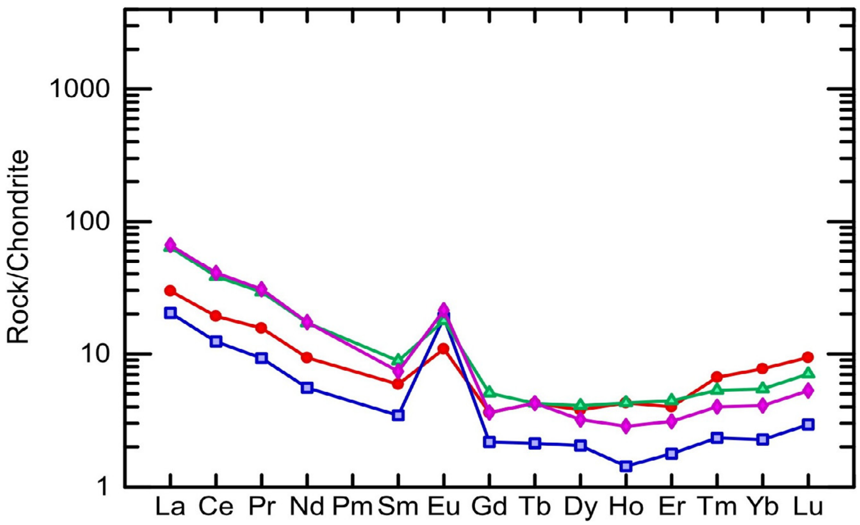

Figure 15. Spider diagram showing rare-earth element (REE) results for samples from location 3A (Twin Lakes area, samples 6703 [triangles] and 6704 [diamonds]) and location 8 (northern Andrew Lake area, samples 6601 [circles] and 6602 [squares]). Data normalized to chondrite REE values of Nakamura (1974).

confirm, a genetic relationship between the pegmatites and the Wallace Island leucogranite. The highest Th and U values from these samples (229 ppm Th and 134 ppm U) were from one of the Twin Lakes pegmatite samples (6603).

6 Conclusions and Recommendations

The AGS reconnaissance field program in the Andrew Lake area re-examined some of the previously identified radioactive sites with the aid of a GR-135 spectrometer and a preliminary petrographic study supported by geochemical analyses.

In addition to the southerly trending anomalous radioactivity zone, defined near Godfrey’s (1958) ‘location 4’ south of Holmes Lake (with radioactive ‘spots’ that locally produce 5 000–11 000 c/s; see Pană et al., 2006), other high-radioactivity sites have been confirmed during the fieldwork reported here. Selected sites of elevated radioactivity were examined and confirmed south of the elbow of the west arm of Andrew Lake, north of west arm, on the prominent peninsula at the north end of Spider Lake and at several sites north of Cherry Lake. Field observations suggest that uranium enrichment was related to pegmatite veining (metamorphic pegmatites) and to minor shear zones and brittle faults. However, the extent of individual sites is limited and the intense carbonate metasomatism that typically affects basement rocks in the Beaverlodge vein-type and Athabasca unconformity-type uraniferous zones has not been observed in the Andrew Lake area.

Limited ground surveying with a hand-held GR-135 spectrometer indicates that

- pegmatite bodies are characterized by significant radioactivity and highly variable U/Th ratios;
- granitic bodies show only slightly elevated radioactivity at apparently randomly distributed spots; and
- the Taltson orthogneiss appears essentially barren of radioactive mineralization.

A regional airborne-geophysical survey by the Geological Survey of Canada shows that the Andrew Lake granodiorite and the Colin Lake granite have high background uranium contents, and high uranium/thorium and uranium/potassium ratios, relative to the Taltson basement complex (Charbonneau et al., 1994).

Migmatization appears to be the first phase of uranium enrichment, as many of the pegmatitic dikes and veins yield radioactivity measurements several times higher than background levels (e.g., at Spider Lake).

Subsequent development of zones of strain and fluid-flow concentration within bands of biotite±aluminosilicate gneiss resulted in greenschist-facies tectonite, often associated with higher concentrations of uranium, sulphur and arsenic (e.g., the uraniferous zone southwest of Holmes Lake). Pegmatite bodies and clusters, particularly within the belts of migmatitic biotite±aluminosilicate gneiss, represent uranium and possibly rare-earth element (REE) and/or thorium targets in the Andrew Lake area. Future exploration for uranium, precious metals and base metals should focus on the belts of strain and fluid-flow concentration marked by chlorite-zone retrogression. These belts allow for meteoric water infiltration due to their high porosity, and development of active vertical hydrodynamic cells that may have effectively mobilized uranium (Pană, 2007). In the absence of a sedimentary cover (Athabasca type), the most promising sites for mineralization occur within retrogressed and relatively porous portions the belts of biotite± aluminosilicate gneiss and schist.

7 References

Alcock, F.J. (1915): Geology of the north shore of Lake Athabasca, Alberta and Saskatchewan; Geological Survey of Canada, Summary Report, 1914, p. 60–61.

Alcock, F.J. (1917): Black Bay and Beaverlodge Lake areas, Saskatchewan; Geological Survey of Canada, Summary Report, 1916, p. 152–156.

Alcock, F.J. (1936): Geology of Lake Athabasca region, Saskatchewan; Geological Survey of Canada, Memoir 196, 41 p.

Allan, J.R. (1976): Assessment report, geological and exploration report, Andrew Lake Project, northeastern Alberta, Tachyon Venture Management Ltd.; Alberta Research Council, Alberta Geological Survey, Mineral Assessment Report 19760004, 41 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/MIN_19760004.html> [April 12, 2010].

Ashton, K. (2009): Compilation bedrock geology, Tazin Lake, NTS 74N; Saskatchewan Industry and Resources, Map 246A, scale 1:250 000, URL <http://www.publications.gov.sk.ca/details.cfm?p=29587> [April 12, 2010].

Baadsgaard, H. and Godfrey, J.D. (1967): Geochronology of the Canadian Shield in northeastern Alberta: I, Andrew Lake area; Canadian Journal of Earth Sciences, v. 4, p. 541–563.

Baadsgaard, H. and Godfrey, J.D. (1972): Geochronology of the Canadian Shield in northeastern Alberta II, Charles-Andrew-Colin lakes area; Canadian Journal of Earth Sciences, v. 9, p. 863–881.

Bednarsky, J.M. (1999): Quaternary geology of northeastern Alberta; Geological Survey of Canada, Bulletin 535, 29 p.

Berman, R.G. and Bostock, H.H. (1997): Metamorphism in the northern Taltson magmatic zone, Northwest Territories; Canadian Mineralogist, v. 35, p. 1069–1091.

Bostock, H.H. (1992): Geology of the Fort Smith map area, District of Mackenzie, Northwest Territories (NTS 75D); Geological Survey of Canada, Open File 859, 52 p.

Bostock, H.H. and van Breemen, O. (1994): Ages of detrital and metamorphic zircon from a pre-Taltson magmatic zone basin at the western margin of Churchill Province; Canadian Journal of Earth Sciences, v. 31, p. 73–80.

Bostock, H.H., van Breemen, O. and Loveridge, W.D. (1991): Further geochronology of plutonic rocks in northern Taltson magmatic zone, District of Mackenzie, NWT; Geological Survey of Canada, Paper 90-2, p. 67–78.

Burgan, E.C. (1971): Assessment report, Andrew Lake Project, review of work completed during 3 year permit period, Hudson's Bay Oil and Gas Company Limited; Alberta Research Council, Alberta Geological Survey, Mineral Assessment Report 19710001, 18 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/MIN_19710001.html> [April 12, 2010].

Byron, S. (2006): Petrography and fluid inclusion study of quartz veins along the Bonny Fault in northeastern Alberta; M.Sc. thesis, University of Alberta, 60 p.

Cameron, A.E. (1930): Report of progress on mineral explorations in the Precambrian; Scientific and Industrial Research Council of Alberta, Tenth Annual Report, p. 34–39.

Cameron, A.E. and Hicks, H.S. (1931): The Precambrian area of northeastern Alberta; Research Council of Alberta, Eleventh Annual Report, p. 32–40.

Chacko, T., De, K.S., Creaser, R.A. and Muehlenbachs, K. (2000): Tectonic setting of the Taltson magmatic zone at 1.9–2.0 Ga: a granitoid-based perspective; Canadian Journal of Earth Sciences, v. 37, p. 1597–1609.

Charbonneau, B.W., Holman, P.B and Hetu, R.J. (1994): Airborne geophysical survey, northeast Alberta; Geological Survey of Canada, Open File 2807, 13 maps at 1:250 000 scale.

Collins, G.A. and Swan, A.G. (1954): Preliminary report of geological field work, northeastern Alberta; Research Council of Alberta, Information Series 18, 8 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/INF_018.html> [April 12, 2010].

De, K.S., Chacko, T., Creaser, R.A. and Muehlenbachs, K. (2000): Geochemical and Nd-Pb-O isotope systematics of granites from the Taltson Magmatic Zone, NE Alberta: implications for Early Proterozoic tectonics in western Laurentia; Precambrian Research, v. 102, p. 221–249.

Ferguson, A.B. (1953): First Alberta uranium discovery; Western Miner Oil Review, v. 26, p. 43.

Geological Survey of Canada (1964a): Andrew Lake, Alberta (NTS 74M/16); Geological Survey of Canada, Geophysical Series Map 2903G, scale 1:63 360.

Geological Survey of Canada (1964b): Colin Lake, Alberta (NTS 74M/9); Geological Survey of Canada, Geophysical Series Map 2892G, scale 1:63 360.

Godfrey, J.D. (1958): Mineralization in the Andrew, Waugh and Johnson lakes area, northeastern Alberta; Research Council of Alberta, Alberta Geological Survey, Earth Sciences Report 1958-04, 17 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_1958_04.html> [April 12, 2010].

Godfrey, J.D. (1961): Geology of the Andrew Lake, north district, Alberta; Research Council of Alberta, Alberta Geological Survey, Earth Sciences Report 1958-03, 32 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_1958_03.html> [April 12, 2010].

Godfrey, J.D. (1963): Geology of the Andrew Lake, south district, Alberta; Research Council of Alberta, Alberta Geological Survey, Earth Sciences Report 1961-02, 30 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_1961_02.html> [April 12, 2010].

Godfrey, J.D. (1966): Geology of the Bayonet, Ashton, Potts and Charles Lake districts, Alberta; Research Council of Alberta, Alberta Geological Survey, Earth Sciences Report 1965-06, 45 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_1965_06.html> [April 12, 2010].

Godfrey, J.D. (1986a): Geology of the Precambrian Shield in northeastern Alberta (NTS 74M and 74L N½); Alberta Research Council, Alberta Geological Survey, Map 180, scale 1:250 000, URL <http://www.ags.gov.ab.ca/publications/abstracts/MAP_180.html> [April 12, 2010].

Godfrey, J.D. (1986b): Mineral showings of the Precambrian Shield in northeastern Alberta (NTS 74M and 74L N½); Alberta Research Council, Alberta Geological Survey, Map 182, scale 1:250 000, URL <http://www.ags.gov.ab.ca/publications/abstracts/MAP_182.html> [April 12, 2010].

Godfrey, J.D. and Baadsgaard, H. (1962); Structural pattern of the Precambrian shield in northeastern Alberta and mica age-dates from the Andrew Lake district; Royal Society of Canada, Special Publication 3, p. 30–39.

Goff, S.P., Godfrey, J.D. and Holland, J.G. (1986): Petrology and geochemistry of the Canadian Shield of northeastern Alberta; Alberta Research Council, Alberta Geological Survey, Bulletin 51, 60 p.

Grover, T.W., Pattison, D.R.M., McDonough, M.R. and McNicoll, V. (1997): Tectonometamorphic evolution of the southern Taltson magmatic zone and associated shear zones, northeastern Alberta; Canadian Mineralogist, v. 35, p. 1051–1067.

Hart, E.A. (1967): Report on Alberta concessions for 1967, New Senator–Rouyn Limited; Alberta Research Council, Alberta Geological Survey, Mineral Assessment Report 19670002, 41 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/MIN_19670002.html> [April 12, 2010].

Hicks, H.S. (1930): A petrographic study of Precambrian rocks in northeastern Alberta; M.Sc. thesis, University of Alberta, 47 p.

Hicks, H.S. (1932): The geology of the Fitzgerald and northern portion of the Chipewyan map areas, northern Alberta, Canada; Ph.D. thesis, University of Minnesota, 82 p.

Hoffman, P.F. (1988): United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annual Review of Earth and Planetary Science, v. 16, p. 543–603.

Iannelli, T.R., Langenberg, C.W. and Eccles D.R. (1995): Stratigraphy, structure and mineral occurrences of the Aphebian Waugh Lake Group, northeastern Alberta, Canada-Alberta Mineral Development Agreement (MDA) project M92-04-007; Alberta Energy, Alberta Geological Survey, Open File Report 1995-05, 52 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/OFR_1995_05.html> [April 12, 2010].

Koster, F. (1971): Geological investigation in the Tazin Lake region, northwest Saskatchewan, Canada; Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, Series B, v. 74, no. 1, p. 1–42.

Langenberg, C.W. and Eccles, D.R. (1996): Metallic mineral occurrences of the exposed Precambrian shield in northeastern Alberta; Alberta Energy and Utilities Board, EUB/AGS Bulletin 64, 71 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/BUL_064.html> [April 12, 2010].

Langenberg, C.W., Salat, H., Turner, A. and Eccles, D.R. (1993): Evaluation of economic mineral potential in the Andrew Lake–Charles Lake area of northeast Alberta; Alberta Research Council, Alberta Geological Survey, Open File Report 1993-08, 73 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/OFR_1993_08.html> [April 12, 2010].

Lyatsky, H.V. and Pană, D.I. (2003): Catalogue of selected regional gravity and magnetic maps of northern Alberta; Alberta Energy and Utilities Board, EUB/AGS Special Report 56, 40 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/SPE_056.html> [April 12, 2010].

McDonough, M.R. and McNicoll, V.J. (1997): U-Pb age constraints on the timing of deposition of Waugh Lake and Burntwood (Athabasca) groups, southern Taltson magmatic zone, northeastern Alberta; *in* Radiogenic Age and Isotopic Studies: Report 10, Geological Survey of Canada, Current Research 1997-F, p. 101–111.

McDonough, M.R., Grover, T.W., McNicoll, V.J., Lindsay, D.D., Kelly, K.L., Guerstein, P.G. and Bednarski, J.M. (2000a): Geology, Andrew Lake, Alberta–Saskatchewan–Northwest Territories; Geological Survey of Canada, Map 1953A, scale 1:50 000.

McDonough, M.R., McNicoll, V.J., Schetselaar, E.M. and Grover, T.W. (2000b): Geochronological and kinematic constraints on crustal shortening and escape in a two-sided oblique-slip collisional and magmatic orogen, Paleoproterozoic Taltson magmatic zone, northeastern Alberta; Canadian Journal of Earth Sciences, v. 37, no. 11, p. 1549–1573.

McNicoll, V.J., Thériault, R.J. and McDonough, M.R. (2000): Taltson basement gneissic rocks: U-Pb and Nd isotopic constraints on the basement to the Paleoproterozoic Taltson magmatic zone, northeastern Alberta; Canadian Journal of Earth Sciences, v. 37, no. 11, p. 1575–1596.

Mulligan, R. and Taylor, F.C. (1969): Geology, Hill Island Lake, Northwest Territories; Geological Survey of Canada, Map 1203A, scale 1:253 440.

Nakamura, N. (1974): Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites; Geochimica et Cosmochimica Acta, v. 38, p. 757–775.

Nilsen, P.A., Langenberg, C.W., Baadsgaard, H. and Godfrey, J.D. (1981): Precambrian metamorphic conditions and crustal evolution, northeastern Alberta, Canada; Precambrian Research, v. 16, p. 171–193.

Pană, D.I. (2007): A two-stage thermotectonic model for the Athabasca unconformity-type uranium deposits; Proceedings of the Ninth Biennial Society for Geology Applied to Mineral Deposits, Dublin, 2007, v. 2, p. 1133–1136.

Pană, D.I. (2010a): Overview of the geological evolution of the Canadian Shield in the Andrew Lake area based on new field and isotope data, northeastern Alberta (NTS 74M/16); Energy Resources Conservation Board, ERCB/AGS, Open File Report 2009-22, 76 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/OFR_2009_22.html> [April 12, 2010].

Pană, D.I. (2010b): Precambrian geology of northeastern Alberta (NTS 74M, 74L and 74E); Energy Resources Conservation Board, ERCB/AGS Map 537, scale 1:250 000, URL <http://www.ags.gov.ab.ca/publications/abstracts/MAP_537.html> [April 12, 2010].

Pană, D.I. and Olson, R.A. (2009): Overview of uranium exploration work along the northern rim of the Athabasca Basin, northeastern Alberta; Energy Resources Conservation Board, ERCB/AGS Open File Report 2009-19, 50 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/OFR_2009_19.html> [April 12, 2010].

Pană, D.I., Creaser, R.A., Muehlenbachs, K. and Wheatley, K. (2007): Basement geology in the Alberta portion of the Athabasca Basin, context for the Maybelle River area; *in* EXTECH IV: Geology and Uranium EXploration TECHnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta, C.W. Jefferson and G. Delaney (ed.), Geological Survey of Canada, Bulletin 588 (*also* Saskatchewan Geological Society, Special Publication 17; Geological Association of Canada, Mineral Deposits Division, Special Publication 4), p. 135–153.

Pană, D.I., Olson, R.A. and Byron, S. (2006): Geological reconnaissance work in the Andrew Lake area of northeastern Alberta; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2006-02, 22 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_2006_02.html> [April 12, 2010].

Plint, H.E. and McDonough, M.R. (1995): ^{40}Ar/^{39}Ar and K-Ar age constraints on shear zone evolution, southern Taltson magmatic zone, northeastern Alberta, Canadian Journal of Earth Sciences, v. 32, p. 281–291.

Riley, G.C. (1960): Geology, Fort Fitzgerald, west of Fourth Meridian, Alberta; Geological Survey of Canada, Map 12-1960, scale 1:253 440.

Ross, G.M., Broome, J. and Miles, W. (1994): Potential fields and basement structure – Western Canada Sedimentary Basin; Chapter 4 *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, Special Report 4, p 41–47., URL <http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html> [April 12, 2010].

Salat, H.P., Eccles, D.R. and Langenberg C.W. (1994): Geology and mineral occurrences of the Aphebian Waugh Lake Group; Alberta Research Council, Alberta Geological Survey, Open File Report 1994-4, 36 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/OFR_1994_04.html> [April 12, 2010].

Sassano, G.P., Fritz, P. and Morton, R.D. (1972): Paragenesis and isotopic composition of some gangue minerals from the uranium deposits of Eldorado, Saskatchewan; Canadian Journal of Earth Sciences, v. 9, p. 141–157.

Schetselaar, E. (2000): Integrated analysis of granite-gneiss terrain from field and multisource remotely sensed data: a case study from the Canadian Shield; Ph.D. thesis, University of Delft, 267 p.

Sprenke, K.F., Wavra, C.S. and Godfrey, J.D. (1986): The geophysical expression of the Canadian Shield of northeastern Alberta; Alberta Research Council, Bulletin 52, 54 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/BUL_052.html> [April 12, 2010].

Thorpe, W.H. (1969): Assessment report, New Senator–Rouyn option, N.E. Alberta, McIntyre Porcupine Mines Limited; Alberta Research Council, Alberta Geological Survey, Mineral Assessment Report 19690002, 12 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/MIN_19690002.html> [April 12, 2010].

Tyrrell, J.B. (1896): Report on country between Athabasca Lake and Churchill River, NWT; Geological Survey of Canada, Annual Report, v. VIII, pt. D, 1895, 117 p.

Watanabe, R.Y. (1965): Geology of the Waugh Lake metasedimentary complex, northeastern Alberta; M.Sc. thesis, University of Alberta, 90 p.

Wilson, J.T. (1941): Fort Smith, District of Mackenzie; Geological Survey of Canada, Map 607A, scale 1:253 440.