Current Research (2008) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 08-1, pages 193-227

DIVERSE STYLES OF URANIUM MINERALIZATION IN THE CENTRAL MINERAL BELT OF LABRADOR: AN OVERVIEW AND PRELIMINARY DISCUSSION

G.W. Sparkes and A. Kerr
Mineral Deposits Section

ABSTRACT

The Central Mineral Belt (CMB) of Labrador is well known for its widespread and diverse uranium mineralization, but there are few integrated overviews of these deposits. Exploration since 2005 has expanded the resources at previously known deposits, and new prospects have been discovered in areas not previously considered prospective. This report provides an overview of the diverse uranium mineralization across the CMB, emphasizing the styles of mineralization in the context of current deposit classifications. From this perspective, uranium mineralization in the CMB is tentatively placed in three broad categories considered to have developed in broadly magmatic, metamorphic–metasomatic and sedimentary environments.

*Magmatic mineralization of syngenetic affinity is represented by uraniferous pegmatites and aplites, and also by some mineralization hosted by undeformed or little-deformed felsic volcanic rocks. Magmatic–hydrothermal mineralization of epigenetic affinity is represented by unusual breccia-hosted mineralization associated with iron metasomatism, and V, Cu and Ag enrichment. This style may be akin to so-called iron-oxide–copper–gold (IOCG) environments, although more work is required to confirm such a link. Uranium-enriched veins in the eastern CMB are likely also of magmatic–hydrothermal origin. Mineralization of possible metamorphic–metasomatic origins is hosted by felsic metavolcanic and pelitic metasedimentary rocks that have experienced strong deformation. Several significant uranium deposits in the CMB (*e.g.*, Michelin, Jacques Lake and Kitts) are tentatively placed in this group, and some mineralization in deformed granitoid rocks may also belong to this family. These deposits are characterized by pre- or syndeformational timing, location in shear zones, and associated Na-metasomatism. Possible analogues for such deposits are provided by so-called "metasomatite" or "albitite" deposits described mostly from the Baltic Shield. Their exact origins remain obscure, but hydrothermal transport and deposition of uranium during regional deformation and metamorphism may be important processes in Labrador. Mineralization in sedimentary environments is hosted mostly by terrestrial sedimentary rocks, within which uranium appears to be linked to localized reduction of oxidized sequences. This mineralization may have affinities to sandstone-hosted mineralization known mostly from Phanerozoic sequences, or to some mineralization associated with Proterozoic unconformity-style deposits.*

The diversity of uranium mineralization in the CMB is bewildering, and the ideas outlined in this report represent initial steps in establishing better descriptive classifications, that may, in turn, refine exploration models. Further steps in this process require more systematic petrological, geochemical and (particularly) geochronological data that can constrain such models and allow wider application.

INTRODUCTION

OVERVIEW

The first indications of uranium in Labrador were discovered south of Makkovik in 1954, at a locality now known as the Pitch Lake showing. The region, now known as the Central Mineral Belt (CMB; Figure 1) became the focus of intensive exploration for over 25 years, which led to the discovery of the Kitts, Michelin and Moran Lake uranium deposits, and many smaller prospects and showings. In the late 1970s, the Kitts and Michelin deposits approached commercial development, but this effort was stalled by a decline in global uranium prices, and there was little exploration for uranium between 1980 and 2005. The recent increase in uranium prices has led to renewed exploration throughout the CMB, which now ranks as one of the most important uranium exploration areas in Canada, second only to the Athabasca basin of Saskatchewan. This second wave of exploration mostly consists of reappraisal and resource expansion at previously known deposits such as Michelin and Moran Lake, but it has also led to the discovery of sig-

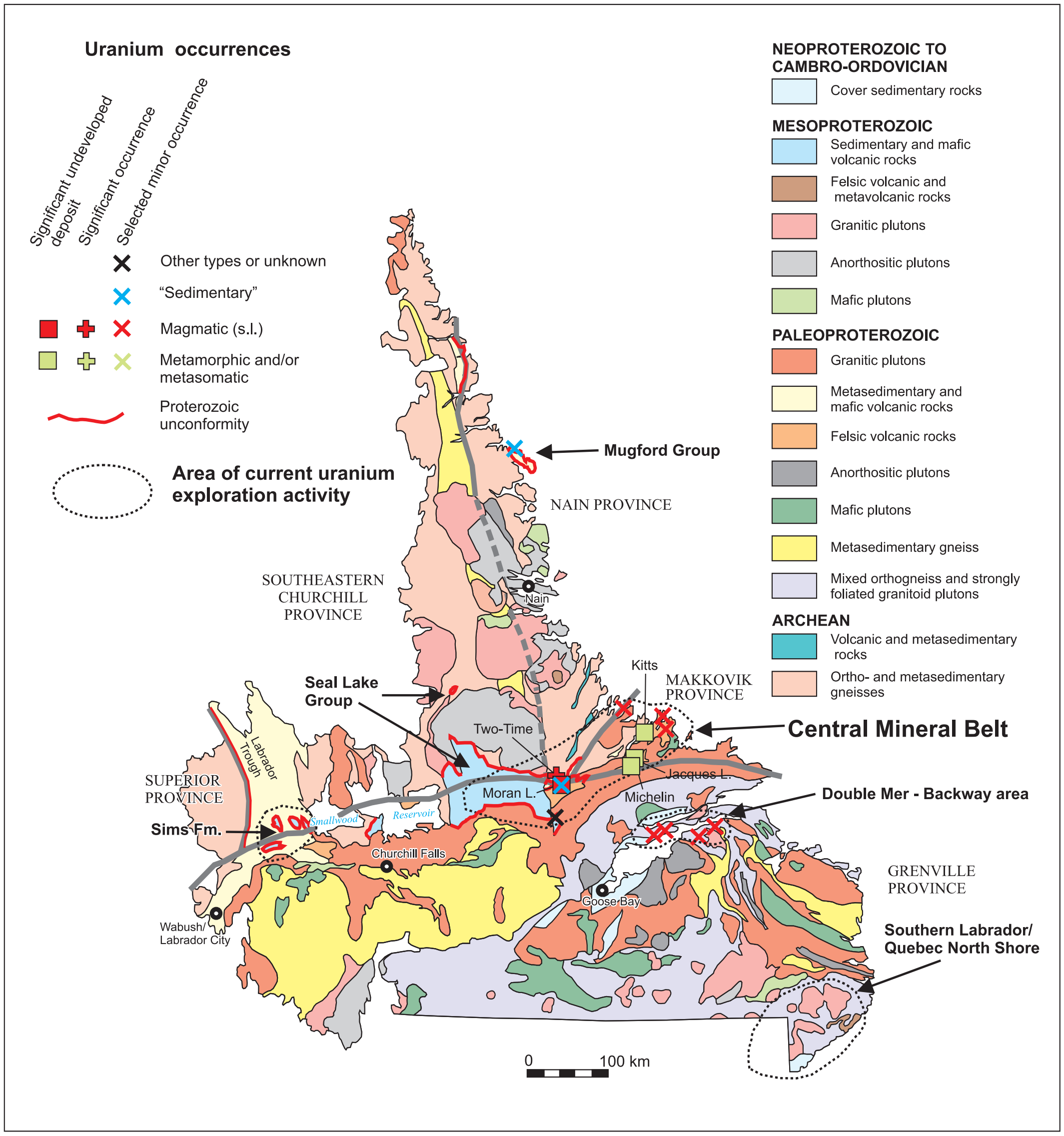

Figure 1. *Regional distribution of areas containing known uranium mineralization in Labrador that are current exploration targets, modified after Wardle (2005). For the sake of clarity, only selected larger uranium deposits in the CMB are indicated; for the locations of all sites discussed, see Figure 2. For information on areas located outside the CMB,* see *Wardle (2005) and references therein.*

nificant new areas of uranium mineralization including the Jacques Lake deposit, the Two-Time Zone and several other showings (Figure 2). The historic exploration and the newer discoveries underline the great diversity in the styles of uranium mineralization within the CMB and the surrounding region. The host rocks to such mineralization include granites, pegmatites, felsic volcanic rocks, argillaceous and clastic sedimentary rocks, conglomerates and mafic volcanic rocks. An equally wide variety of genetic models, ranging from synsedimentary precipitation in black shales to late-stage, epigenetic introduction by magmatic fluids, has been proposed over the years.

The first regional discussion of uranium mineralization in this area was by Beavan (1958), who stated that "*the distribution and variety of radioactive occurrences marks the area as a uranium metallogenic province*". Considering the potential importance of this uranium metallogenic province, there are relatively few widely available, published descriptions of this diverse mineralization; the principal sources are survey reports (*e.g.*, Gower *et al.*, 1982; Ryan, 1984; Wilton, 1996) and papers by Gandhi (1978, 1984). Postgraduate theses, notably those of Marten (1977), Evans (1980) and Kontak (1980) also provide some important information, but little of this work was published. Large amounts of data are also available in exploration-company assessment reports from the 1970s and 1980s, and information from the second phase of exploration is now gradually entering the public domain through press releases, company websites and NI 43-101 reports filed as part of securities regulation.

Rocks hosting uranium mineralization in the CMB region range in age from Archean (ca. 2800 Ma) to Mesoproterozoic (ca. 1270 Ma). The oldest host rocks known to date are the late Archean granites of the southern Nain Province, and the youngest host rocks are the terrestrial sedimentary sequences of the Seal Lake Group (Figure 1). However, most of this mineralization (including the most important examples) is hosted by supracrustal sequences of Paleoproterozoic age (between 2170 Ma and 1650 Ma), most of which are located in the Makkovik Province and adjacent parts of the Grenville Province (Figure 1). Several episodes of regional deformation, including the ca. 1800 Ma Makkovikian Orogeny and the ca. 1000 Ma Grenvillian Orogeny, have affected the CMB, and these may have led to remobilization and redistribution of uranium from primary deposits. At least some of the mineralization in older supracrustal sequences was affected by ca. 1800 Ma deformation, but uranium is also present in younger rocks that did not form until ca. 1650 Ma. At face value, such patterns indicate the presence of at least two "mineralizing episodes", and there could well be more. Direct geochronological information on the timing of uranium deposition is sparse and, because it may reflect partial resetting by subsequent events, is difficult to interpret (see later discussion, page 216).

This report reviews and evaluates some of the styles of uranium mineralization identified within the CMB, and is intended to provide a more detailed descriptive framework than recent abbreviated summaries by Wardle (2005) and Kerr *et al.* (2007). The key geological aspects of various styles of uranium mineralization are summarized, and then assessed in the context of modern classifications of uranium deposits, such as those outlined by Dahlkamp (1993). Post-mineralization deformation complicates the application of such criteria because it obscures primary geological relationships in some important examples. Consequently, some of the CMB examples could fit into more than one specific model, and some suggestions are of a preliminary nature. In a report such as this, it is impossible to describe every occurrence, and thus most attention is paid to selected deposits, or "type examples", that exemplify the characteristic features. It should also be noted that some of the uranium deposits in the CMB do not readily fit into the existing classifications, which may thus require some revision and expansion. This report is, to a large extent, based upon previous descriptions from published and unpublished sources, coupled with observations from field work and drill-core examination in 2007, and some public-domain information from recent exploration work.

The CMB contains both syngenetic and epigenetic styles of uranium mineralization, but the latter is more widespread. The syngenetic style of mineralization is essentially magmatic and includes deposits in pegmatites and related evolved granites, and also probable synvolcanic concentrations in felsic volcanic rocks. The epigenetic styles of mineralization are much more varied, and include breccia-hosted deposits with possible IOCG affinities, and possible examples of "albitite" deposits (also known as "metasomatites") in deformed felsic volcanic rocks. Also, there are examples of sandstone-hosted deposits that may have affinities to those more typically found in Phanerozoic rocks. Unconformity-style uranium deposits, like those of the Athabasca basin, are not clearly documented in the CMB, although potential may exist for these in several areas. Important mineralization hosted in pelitic metasedimentary rocks does not readily fit into existing classifications, although it may have affinities to the "albitite–metasomatite" types.

REGIONAL GEOLOGY

The CMB of Labrador includes portions of the Archean Nain Province, the Paleoproterozoic Makkovik and Churchill provinces, and the Mesoproterozoic Grenville Province (Figure 1). It is defined largely by mineralization and geography, rather than by specific aspects of its geology, which is extremely varied (Figure 2). The CMB hosts most of the uranium mineralization known within Labrador, and is also well known for Cu, Mo and rare-metal (Zr, Be, Nb, REE) mineralization. Most of the uranium occurrences are hosted by supracrustal rocks of the Makkovik Province and their equivalents in the northernmost Grenville Province, but recent exploration suggests that older plutonic rocks in the Nain Province may also have potential. The regional geology of the CMB (and parts thereof) is summarized by Gower *et al.* (1982), Ryan (1984), Ermanovics (1993), Kerr (1994), Kerr *et al.* (1996), and Wilton (1996); the following overview is largely derived from these sources. The stratigraphy of the CMB is illustrated schematically in Figure 3, which shows the temporal context of the main examples of uranium mineralization discussed in this report. It should be noted that this chart illustrates only the ages of the host rocks to specific deposits, and that the actual ages of mineralization may be significantly younger in some cases.

The oldest rocks within the CMB occur within the Archean Nain Province (Figure 2), and were unaffected by Proterozoic orogenic events. However, equivalent Archean rocks also occur in the northwestern Makkovik Province,

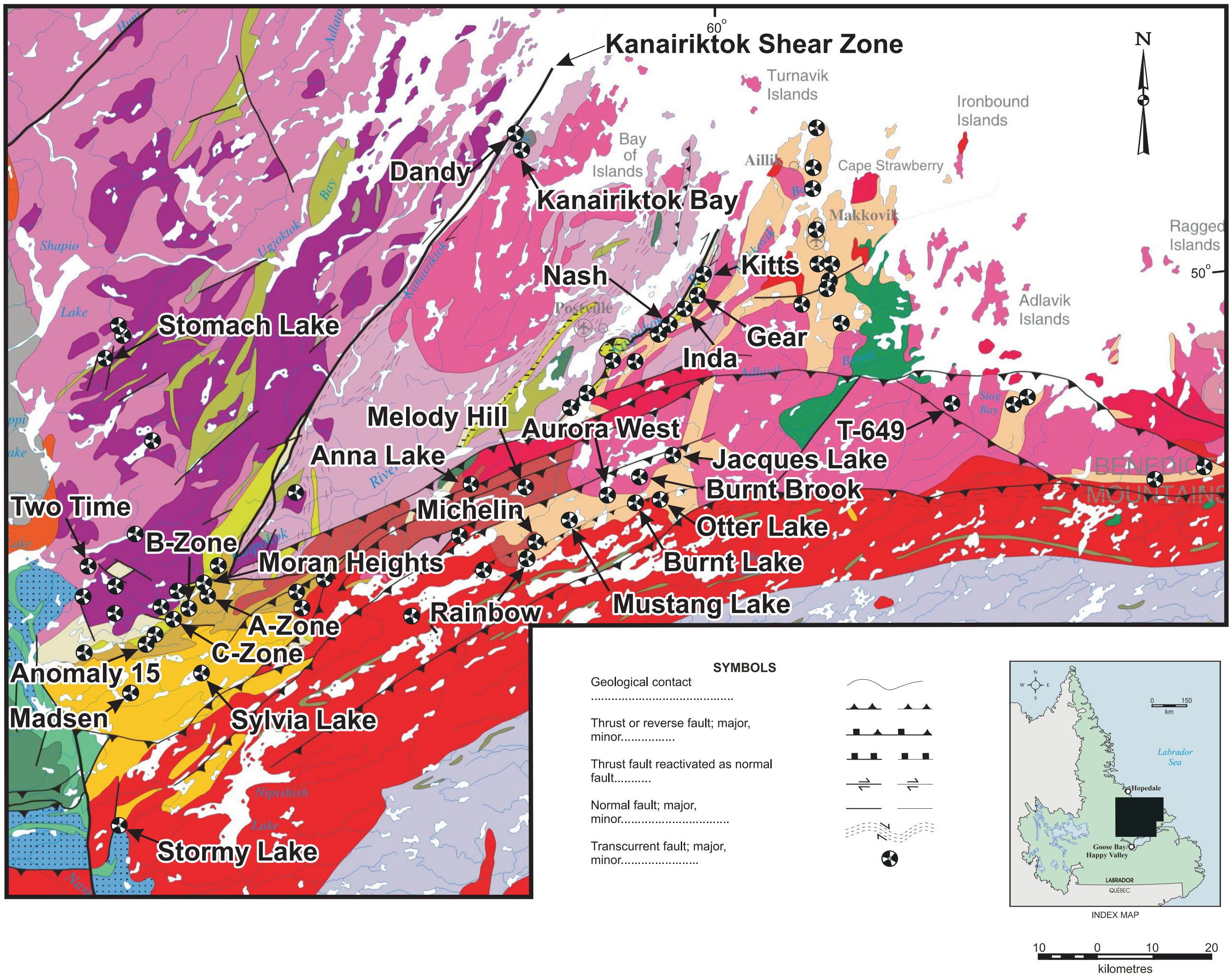

Figure 2. *Uranium occurrences of the Central Mineral Belt and surrounding region, highlighting examples discussed in this report. Geological base map modified from Wardle* et al. *(1997).*

where they were reworked by Paleoproterozoic deformation and metamorphism. These reworked Archean rocks likely form the basement to much of the Makkovik Province and the eastern CMB (Kerr *et al.*, 1996).

In the Nain Province, the Archean rocks include ancient polyphase orthogneisses, and even older remnants of supracrustal rocks. These ancient rocks may be as old as ca. 3250 Ma (Loveridge *et al.*, 1987). The gneisses are interleaved with more extensive metavolcanic and metasedimentary rocks of the Florence Lake greenstone belt, considered to represent a younger cover sequence. The youngest Archean rocks are those of the Kanairiktok intrusive suite, which consist of massive to intensely foliated tonalite, granodiorite and granite. These intrude all of the older Archean units, and are, in part, posttectonic; they were dated at ca. 2838 Ma by Loveridge *et al.* (1987). The Kanairiktok intrusive suite, and older units, are in turn cut by fresh diabase dykes known as Kikkertavak dykes, which are dated precisely at ca. 2230 Ma (Cadman *et al.*, 1993).

The boundary between the Nain and Makkovik provinces is marked by a prominent NE-trending shear zone known as the Kanairiktok shear zone (Figure 2). This has a long and complex history of deformation and syntectonic magmatism and contains multiple sheets of leucocratic and pegmatitic granite, dated at 1870 ± 2 Ma (Ketchum *et al.*, 2001a; Culshaw *et al.*, 2000). The northwestern Makkovik Province contains the same rock units as the Nain Province, but they are affected by Paleoproterozoic deformation and metamorphism, and are intruded by complex plutonic rocks ranging in age from ca. 1900 Ma to ca. 1720 Ma (Ermanovics, 1993; Ketchum *et al.*, 2001a). The ca. 2230 Ma Kikkertavak dykes are transformed into folded amphi-

Legend for Figure 2

MESOPROTEROZOIC

- Gabbro sills (ca. 1250 to 1224)
- Subaerial basalt flows
- Arkose, grading south into quartzite
- Olivine gabbro and metamorphic equivalents, including coronitic varieties (Shabogamo and Michael gabbros, ca. 1460 to 1425 Ma)
- Granitoid rocks (1500 to 1420 Ma)
- Anorthosite and other, locally layered, mafic rocks

PALEOPROTEROZOIC

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

ARCHEAN AND/OR PALEOPROTEROZOIC

- Anorthosite, leucogabbro, leuconorite and derived gneiss

ARCHEAN

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

bolites within the Makkovik Province, but locally retain their original discordance with Archean host rocks (Ryan *et al.*, 1983). Deformed and metamorphosed supracrustal rocks, likely equivalent to the Post Hill Group also occur within this region (Marten, 1977; Ryan *et al.*, 1983).

The oldest supracrustal sequences in the Makkovik Province are the Moran Lake and Post Hill groups (Figure 2). Note that the Post Hill group was for many years known as the Lower Aillik Group, prior to redefinition of the terminology by Ketchum *et al.* (2002). The Moran Lake and Post Hill groups have long been correlated on the basis of their similar stratigraphy and lithology (*e.g.*, Marten, 1977; Wardle and Bailey, 1981). Uranium–lead geochronological data from the Post Hill group demonstrate that mafic metavolcanic rocks in its lowermost part were deposited ca. 2178 Ma ago, but that sedimentary rocks higher in the sequence were deposited after ca. 2013 Ma, suggesting that there are some unresolved stratigraphic complexities (Ketchum *et al.*, 2001b). The Moran Lake Group remains undated. Both sequences consist of siliciclastic sedimentary rocks and mafic volcanic rocks; the Moran Lake Group contains carbonate rocks in its lower section and is generally interpreted to be the shallow-water equivalent of the higher (younger ?) parts of the Post Hill group. The Moran Lake Group sits unconformably upon Archean basement rocks, but the more strongly deformed and metamorphosed Post Hill group is in tectonic contact with these older rocks. The Post Hill group is strongly deformed and disrupted by shear zones, and it experienced amphibolite-facies metamorphism, which locally led to partial melting. In contrast, the Moran Lake Group displays only greenschist-facies metamorphism. However, regional relationships and the presence of deformed clasts of typical Moran Lake Group rock types in the basal part of the ca. 1650 Ma Bruce River Group (Ryan, 1984), indicate pre-1650 Ma deformation of the Moran Lake Group.

Younger supracrustal sequences in the eastern part of the CMB are very different in character from the Moran Lake and Post Hill groups, as they are dominated by shallow-water to terrestrial sedimentary rocks and subaerial felsic volcanic rocks. The Aillik Group dominates the central part of the Makkovik Province (Figure 2). Note that these rocks were for many years known as the Upper Aillik Group, prior to the redefinition of terminology by Ketchum *et al.* (2002). The Aillik Group includes a lower sequence of mixed sedimentary rocks and volcanic rocks of both mafic and felsic composition, which is overlain by a thick sequence of felsic volcanic, pyroclastic and volcaniclastic

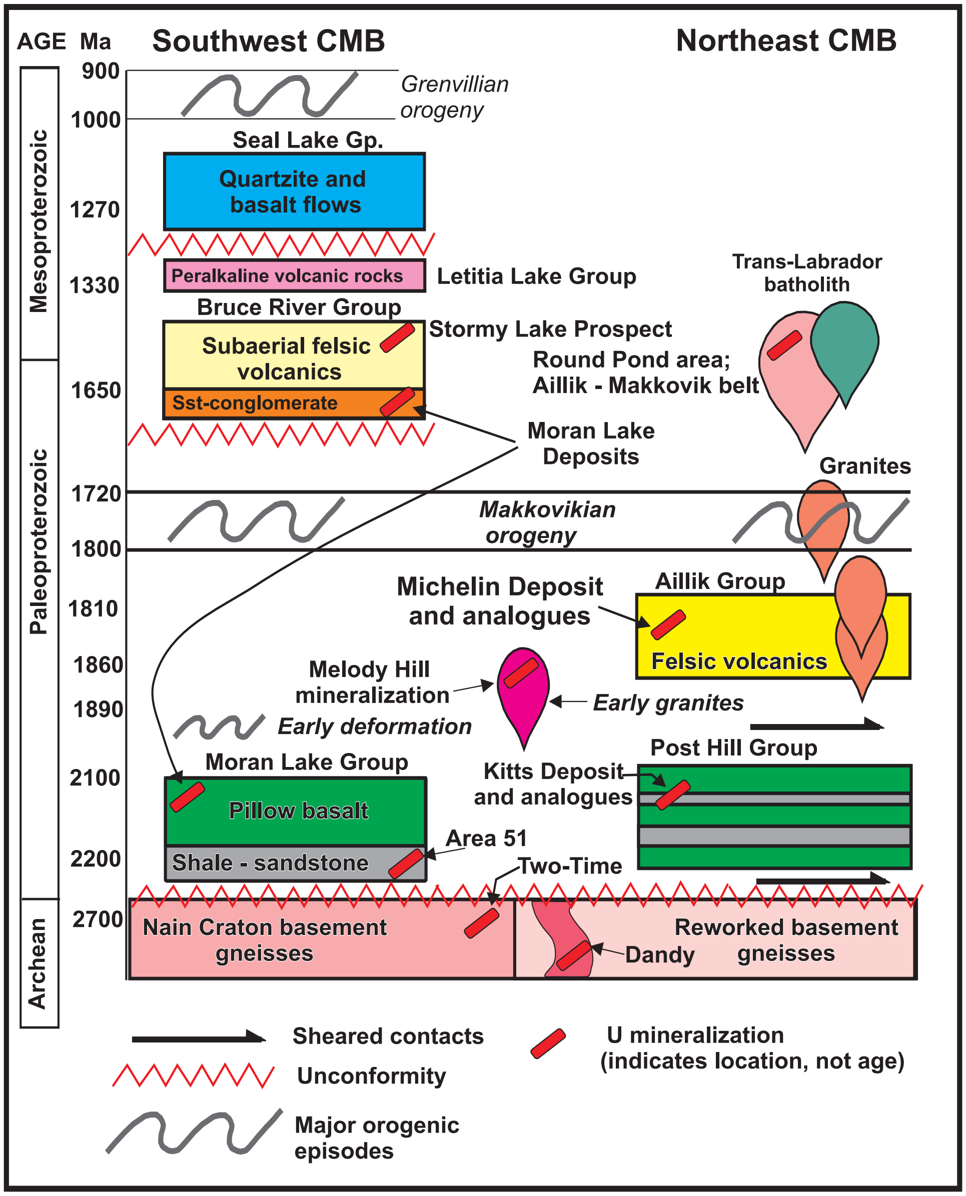

Figure 3. *Schematic chart showing the stratigraphic setting of uranium mineralization in the Central Mineral Belt of Labrador. Note that the uranium deposits are indicated with reference to their host rocks, and that in many cases the mineralization is suspected to be younger; modified after Wardle (2005).*

rocks. The volcanic rocks formed ca. 1860-1850 Ma ago (Schärer *et al.*, 1988; Ketchum *et al.*, 2002), but their primary features are obscured by metamorphism, recrystallization and locally intense deformation. The contact between the Aillik Group and the older Post Hill group is generally interpreted as tectonic (Marten, 1977; Gower *et al.*, 1982; Kerr *et al.*, 1996; Ketchum *et al.*, 2002). The Aillik Group is probably the single most important host to uranium mineralization within the CMB (Figures 1 and 2).

In the southwestern portion of the Makkovik Province and adjacent Grenville Province, the Bruce River Group sits unconformably upon the Moran Lake Group. The Bruce River Group, described in detail by Ryan (1984), consists of a lower terrestrial sedimentary sequence dominated by conglomerates, arkoses and sandstones, overlain by a thick sequence of mostly felsic volcanic rocks, which were dated at ca. 1650 Ma (Schärer *et al.*, 1988).

Large areas of the CMB are underlain by plutonic rocks of broadly granitoid composition, particularly in the south and east. These plutonic rocks were formed in at least four main episodes at 1895 to 1870 Ma, 1815 to 1790 Ma, 1720 to 1715 Ma and 1650 to 1640 Ma (Kerr *et al.*, 1992; Kerr, 1994; Ketchum *et al.*, 2000, 2002). Thus, they both predate and postdate development of the supracrustal sequences of the Aillik and Bruce River groups. The oldest plutonic rocks display locally intense deformation, and the 1815-1790 Ma suites include both syntectonic and posttectonic suites; both are temporally linked to the Makkovikian Orogeny, considered to have taken place ca. 1800 Ma ago. However, there were earlier deformational events within the northwestern part of the Makkovik Province at ca. 1890 Ma that are more difficult to resolve accurately (Schärer *et al.*, 1988; Kerr *et al.*, 1992; Ketchum *et al.*, 1997). The younger (ca. 1650 Ma) plutonic suites are undeformed within the Makkovik Province, but are affected by the ca. 1000 Ma Grenvillian Orogeny in the south of the CMB. In the central part of the Makkovik Province, plutonic suites of ca. 1720 Ma and ca. 1650 Ma age form small, isolated plutons cutting the Aillik Group, suggesting that the erosion surface coincides with the roof zone(s) of larger batholiths at depth (Kerr, 1994). Some of these plutonic suites are associated with hydrothermal mineralization of granophile character, which locally includes uranium, in addition to Cu, Mo and F (Wilton and Wardle, 1987; Kerr, 1994; Wilton, 1996).

The youngest supracrustal sequences in the CMB are the Letitia Lake Group and the Seal Lake Group. The Letitia Lake Group, dated at ca. 1330 Ma (Thomas, 1981; Gandhi *et al.*, 1988), is dominated by alkaline volcanic rocks and is not represented in Figure 2. It is known primarily for its rare-metal occurrences, and is not discussed further here. The Seal Lake Group consists of terrestrial sedimentary rocks and minor mafic volcanic rocks, both of which are intruded by mafic sills (Brummer and Mann, 1961; Ryan, 1984). The sedimentary rocks are undated, but unconformably overlie the Letitia Lake Group, indicating deposition after ca. 1330 Ma; U-Pb ages from the mafic sills of ca. 1250 and ca. 1225 Ma (Romer *et al.*, 1995) provide a minimum age for deposition of the sequence. The Seal Lake Group occurs on the western edge of the area in Figure 2, where it sits unconformably upon all of the units discussed above, including several plutonic units and the felsic volcanic rocks of the Bruce River Group. The Seal Lake Group is best known for copper mineralization (Gandhi and Brown, 1975; Wilton, 1996) but minor uranium is reported to occur in its basal sequence in one area (see later discussion, page 205 and page 212).

SIGNIFICANT RESULTS FROM RECENT EXPLORATION

The first phase of uranium exploration in the CMB occurred between 1954 and the early 1980s, and many of the deposits were discovered and partly evaluated during that period. Summaries and discussions of uranium mineralization, based in large part upon the results from this exploration, were presented by Beavan (1958), Gandhi (1978, 1984), Gower *et al.* (1982), Ryan (1984), Kerr (1994) and Wilton (1996). Post-2005 exploration across the CMB now provides much new information, and this section provides a brief summary of developments that are particularly relevant in the context of this report. It is drawn from press releases, and also information in reports submitted under NI 43-101 requirements, notably Cunningham-Dunlop (2007) for Aurora Energy Resources and LaCroix and Cook (2007) for Crosshair Exploration and Mining.

The most important deposits discovered in the first phase of exploration were the Kitts and Michelin deposits. Resource calculations in the late 1970s indicated that Kitts contained some 185 000 tonnes at 0.73% U_3O_8, whereas Michelin contained a larger, lower grade resource of some 6.4 million tonnes at 0.13% U_3O_8. Expressed in terms of contained U_3O_8, these correspond to about 3 million pounds and 18.4 million pounds, respectively. Several smaller zones (*i.e.*, Rainbow, Burnt Lake, Inda, Gear and Nash) were estimated to contain an additional 4 million pounds of U_3O_8. Note that these are all historical estimates summarized by Gower *et al.* (1982) and do not conform to present NI 43-101 standards for resource or reserve calculations. The Kitts–Michelin development proposal of the late 1970s was predicated on the idea that the small, high-grade Kitts deposit could improve the overall grade of the larger Michelin resource to economic levels. The deposits at Moran Lake were also discovered in the late 1950s and early 1960s, but were not evaluated in detail until the late 1970s, and consequently did not reach the stage of formal resource assessment.

The mineral rights to the Michelin deposit and the deposits at Moran Lake eventually lapsed, but both areas were eventually re-staked as part of exploration projects aimed largely at iron-oxide–copper–gold (IOCG) targets, rather than uranium. Both areas now form advanced uranium exploration projects in which additional uranium resources are documented to NI 43-101 standards. The Kitts deposit has not undergone further exploration, as it was declared to be exempt mineral land (EML) during land-claims negotiations with the Inuit of Labrador. Although some other EML areas established during this process were subsequently opened to exploration following ratification of land claims agreements, Kitts was retained as EML by the Nunatsiavut Government pending development of a land-use plan for Labrador Inuit Lands.

Exploration at the Michelin deposit, conducted by Aurora Energy Resources, focused on expanding the resource by drilling to greater depths, along strike and in a downplunge direction. The zone of mineralization has been significantly extended, and the most recent resource calculations indicate some 40 million tones at 0.10% U_3O_8, which is equivalent to some 86 million pounds of U_3O_8 (Aurora

Energy Resources, Press Release, February 13, 2007). This figure includes all categories of the resource, and represents a nearly fivefold increase in contained uranium, albeit at a lower average grade. Recent exploration by Crosshair Exploration and Mining at Moran Lake also focused on drilling to greater depths and along strike, and recent resource estimates suggest some 8 million pounds of U_3O_8 and some 14 million pounds of V_2O_5 (Crosshair Exploration and Mining, Press Release, July 31, 2007). As discussed subsequently, the Moran Lake project may include deposits of more than one type and/or age.

The encouraging results from Michelin and Moran Lake, coupled with buoyant prices for U_3O_8, led to land acquisition and exploration by other junior mining companies. Some of these exploration programs are focused upon smaller prospects identified during earlier exploration, with the hope of similarly expanding total resources through additional drilling, but others are true grassroots exploration programs in areas where uranium mineralization was previously unknown. The initial stages of evaluation in both types of projects involved airborne radiometric surveys, using instrumentation that is much more sensitive than that employed in earlier periods of exploration. These regional exploration programs led to the discovery of new zones of uranium mineralization in several areas. Perhaps the most significant of these is the Jacques Lake deposit, which was unearthed by Aurora Energy Resources about 25 km east of the Michelin deposit. Minor uranium mineralization was previously known in this area, but new airborne surveys indicate a large radiometric anomaly suggesting wider potential. Drilling now suggests a total resource of some 6 million tones at 0.08% U_3O_8, representing some 10 million pounds of U_3O_8, which compares favourably with the 1970s estimates for Michelin (Aurora Energy, Press Release, February 13, 2007). The Jacques Lake deposit remains open at depth and along strike as of writing, and is the subject of an intensive exploration effort. From a geological perspective (see later discussion, page 208) it has some features in common with the Michelin deposit, but differs in other respects.

The Two-Time Zone, discovered by Silver Spruce Resources in an area with few previously known uranium showings, is an interesting deposit that suggests wider potential in the late Archean Kanairiktok intrusive suite. This widespread mineralization is hosted by granitoid rocks, and includes some wide intersections of low-grade material, *e.g.*, 199 m of 0.026% U_3O_8 (Silver Spruce Resources, Press Release, August 30, 2007). No formal resource estimates have been announced for this area, but these are expected in early 2008.

Exploration by Bayswater Uranium Corporation, largely within the Nain Province, discovered uranium mineralization in granitic and pegmatitic rocks, which is locally high-grade. In the Anna Lake area, located within the Makkovik Province (Figure 1) this company recently announced a new discovery of U–Mo mineralization, including intersections of 0.07% U_3O_8 and 0.022% Mo over 40 m (Bayswater Uranium, Press Release, October 29, 2007). The most recent drilling at Anna Lake intersected mineralization over a 600-m-strike length and up to a vertical depth of 230 m. The mineralization appears to have no surface expression, although exploration in the area was initially prompted by the existence of radioactive boulders. At the present time, little is known concerning the geological environment of the Anna Lake discovery, although mineralization is reportedly hosted within sulphidic, biotite- and garnet-bearing schist adjacent to a possible structural contact with quartz-sericite schist (Bayswater Uranium, Press Release, October 29, 2007).

Several other new uranium showings have been discovered in the CMB since uranium exploration resumed at an intense level in 2005. Several of these appear to be hosted by felsic volcanic and/or intrusive rocks, such as the T-649 zone (Silver Spruce Resources), the Fish Hawk Lake prospect (Santoy Resources) and the Quinlan showing (Mega Uranium). As in the case of the Anna Lake discovery, geological information on these occurrences is presently limited. However, such results certainly underline the potential of the CMB for new discoveries in previously untested environments.

SETTINGS AND CHARACTERISTICS OF URANIUM MINERALIZATION IN THE CENTRAL MINERAL BELT

This section of the report provides a summary of the most important characteristics of several subtypes of uranium mineralization defined largely on the basis of their host rock-types and environments, without specific reference to genetic concepts. The information upon which this is based comes, in large part, from published sources such as papers and survey reports, and unpublished sources such as assessment reports and theses. Some information from recent exploration is derived from exploration-company press releases and websites. These sources are supplemented by field work and examination of diamond-drill core completed during the 2007 field season. At the present time, there are no petrographic, geochemical or isotopic data available from this project, but systematic sampling of outcrops and drill core during 2007 provides material for such studies, which are ongoing. Some of the observations in this section are by their very nature preliminary, and may be subject to revision in the light of future laboratory studies. For the sake of simplicity, the types of mineralization are denoted by numbers in this section, and each of these is then discussed in terms of classification and origin in the final section of the report.

URANIUM MINERALIZATION HOSTED BY PLUTONIC ROCKS

Plutonic igneous rocks are not widespread hosts to uranium in the CMB, but they have received far less exploration attention than other environments, and may have wider potential. From a descriptive point of view, mineralization hosted by plutonic rocks falls into two contrasting types.

Type 1: Disseminated Mineralization without Associated Alteration in Granites, Pegmatites and Aplites

Uranium occurrences known in the granitoid rocks of the CMB prior to 2005 are associated with shearing and/or alteration, suggesting that they are likely of hydrothermal origin (*i.e.*, Type 2). However, minor radioactivity was reported to be associated with pegmatite veins containing molybdenite in the Jacques Lake area by Wilton (1996); note that this is unconnected to the Jacques Lake deposit later defined by Aurora Energy Resources. Radioactive pegmatites are also known in the eastern CMB, where they are associated with hydrothermal veins (*i.e.*, Type 9 below).

In the area southeast of the Kanairiktok shear zone, Bayswater Uranium Corporation discovered an extensive zone of radioactive pegmatites and leucogranites, which they named the Dandy prospect (Figure 2). The Dandy prospect consists of numerous, 1- to 3-m-wide, feldspar-rich leucocratic granite to pegmatite sheets that intrude reworked quartzofeldspathic orthogneisses, of presumed Archean age. Typical features of the mineralization are illustrated in Plate 1. These granitic sheets contain a variably developed foliation that parallels the stronger fabric within the Kanairiktok shear zone, located to the immediate northwest. The strongest radioactivity is along foliation planes enriched in biotite, and a pervasive pale-yellow staining is developed in local areas of strong radioactivity. The association between the yellow staining and elevated radioactivity suggests that the stain represents secondary alteration of a uranium-bearing mineral. Several generations of pegmatite can be discerned in the prospect area, including late crosscutting pegmatites with pink-weathering colours, but not all these exhibit radioactivity, and the later generations appear to be barren. Surface samples from the Dandy prospect contained up to 0.18% U_3O_8 (Bayswater Uranium, Press Release, November 8, 2006) and the zone was tested by drilling in the fall of 2007. Drillholes intersected numerous pegmatitic intervals, but mineralization within these appears to be sporadic, with the best intersection assaying 0.04% U_3O_8 over 5.0 m (Bayswater Uranium, Press Release, October 29, 2007). There is no indication of hydrothermal alteration associated with the radioactivity, and the uranium mineralization here thus appears to be of primary magmatic origin. There is presently no information on the uranium-bearing mineral(s) within the pegmatites. The pegmatitic sheets at the Dandy prospect have not been dated, but similar pegmatitic leucogranites from a nearby locality within the Kanairiktok shear zone were dated by Ketchum *et al.* (2001a) where they yielded a U-Pb age of 1870 ± 2 Ma.

At the nearby Kanairiktok Bay showing (Figure 2), a complex assemblage of deformed plutonic rocks, of unknown age, is cut by pink to grey pegmatites and aplites that are locally radioactive. Intense radioactivity is associated with biotite-rich material developed at the margins (?) of the pegmatite sheets, and discrete biotite-rich shear zones that crosscut the plutonic rocks locally host up to 6.9% U_3O_8 in grab samples (Bayswater Uranium, Press Release, January 18, 2007). The uraniferous pegmatites are cut by metamorphosed mafic dykes; the latter could be meta-Kikkertavak dykes, which would suggest that both the pegmatites and associated mineralization here are older than ca. 2230 Ma, and perhaps of Archean age.

A similar style of mineralization is present at the Stomach Lake showing in the southwestern Nain Province (Figure 2), which was also discovered by Bayswater Uranium Corporation. At this locality, late crosscutting pegmatites invade gneisses of broadly mafic, amphibolitic composition. As at the Dandy prospect, sporadic yellow staining is associated with zones of elevated radioactivity. Grab samples of mineralized pegmatite at Stomach Lake contained up to 0.45% U_3O_8 (Bayswater Uranium, Press Release, January 18, 2007; Figure 2), but material of such grade is developed only on a local scale. The pegmatites at Stomach Lake were not observed to be cut by diabase dykes, and their age is unconstrained, other than that they are younger than their Archean gneissic country rocks.

Type 2: Disseminated Mineralization Associated with Shearing and/or Alteration in Granitoid Rocks

In contrast to Type 1, this style of uranium mineralization is associated with localized shearing and/or variable alteration of the plutonic host rocks, suggesting that uranium was introduced from elsewhere, rather than crystallizing in minerals that formed part of the original igneous assemblage.

The most prominent example of this style of mineralization is the Melody Hill prospect, originally discovered in the 1970s. In some respects, "prospect" is a misnomer, because the site is best-known for mineralized boulders of strongly deformed granite displaying intense hematitic alteration. Some of these boulders yielded extremely high grades, up to 28.2% U_3O_8, and an average of some 27 min-

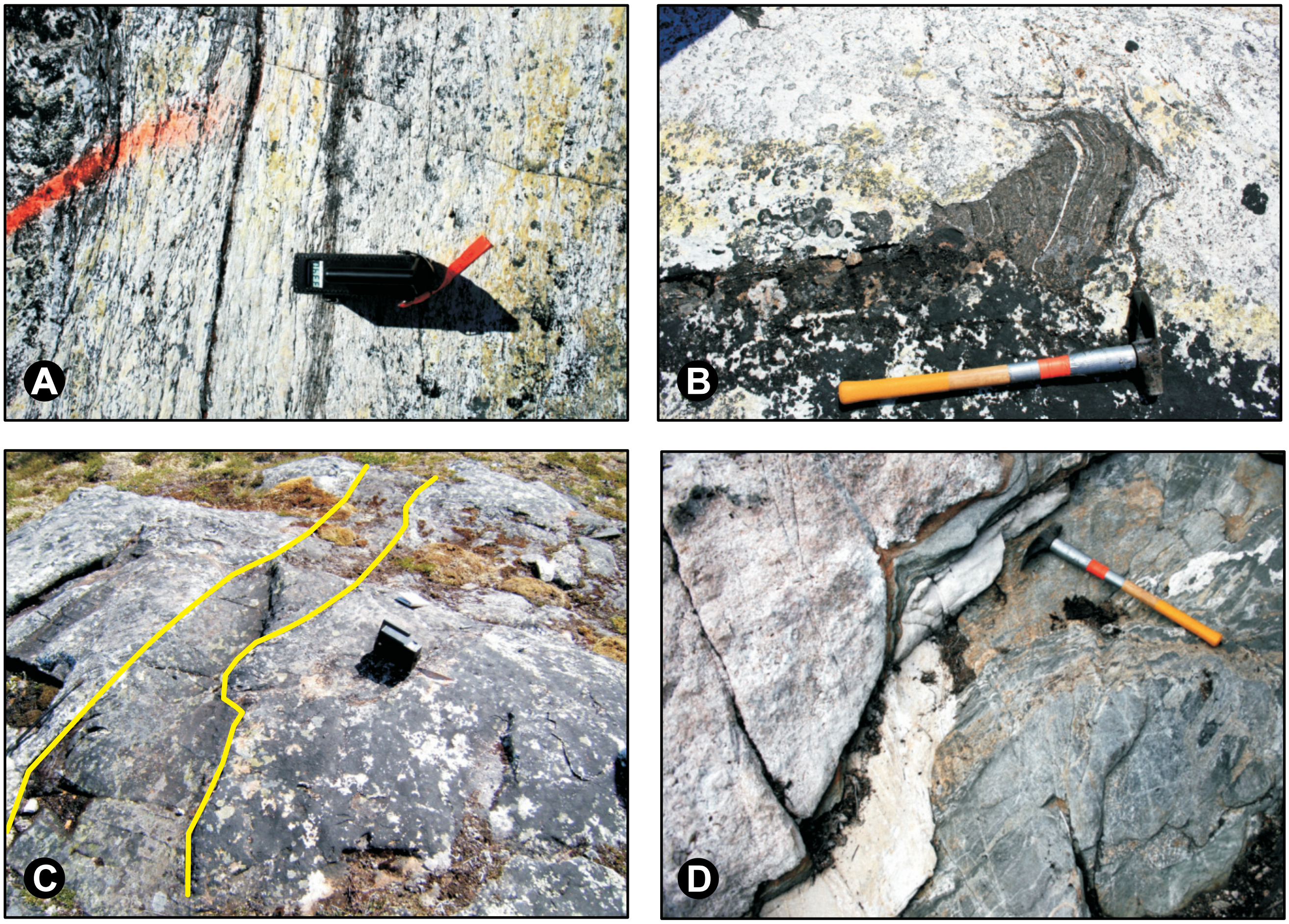

Plate 1. *Representative photographs of uraniferous leucogranite and pegmatite units and their relationship with the country rocks in the southern Nain Province and adjacent Makkovik Province. A) Foliated quartz-feldspar-rich leucogranite displaying a distinctive yellow staining. Elevated radioactivity mostly associated with biotite-rich foliation planes, Dandy prospect. B) Banded orthogneiss inclusion within less-deformed pegmatite, note localized yellow staining; Dandy prospect. C) Uraniferous granitic to pegmatitic rock cut by metamorphosed mafic dyke that postdates mineralization, Kanairiktok Bay prospect. D) Uraniferous pegmatite and aplite cutting foliated mafic gneiss, Stomach Lake prospect.*

eralized boulders indicated about 8.4% U_3O_8. Not surprisingly, much effort continues to be directed toward the search for a possible bedrock source by Aurora Energy Resources (*e.g.*, Aurora Energy Resources, Press Release, May 24, 2006). Lower grade uranium mineralization is present in outcrops of deformed granitoid rocks in the same general area as the high-grade boulder train, and this was examined in 2007. The host rocks at this location belong to the Melody Hill granite, which is undated, but correlated with a lithologically similar unit that was dated at 1891 ± 5 Ma by Kerr *et al.* (1992). Typical features of this mineralization are illustrated in Plate 2.

The stripped outcrops consist predominantly of white-weathering, quartz and feldspar-rich, medium- to coarse-grained granite transected by strongly hematitic zones that display a brecciated texture suggestive of cataclastic processes; these have sharp contacts with the unaltered granite, and there are also discrete mylonitic zones that are both magnetic and intensely hematitic. The radioactivity in the outcrop is associated with zones of strong deformation and/or intense hematitic alteration. Although the outcrop was undoubtedly sampled in the 1970s, it has so far proven difficult to locate information on its uranium contents.

A recent prospecting discovery by Silver Spruce Resources southwest of Stag Bay, in the area of the Benedict Mountains (Figure 2), is also hosted by sheared (?) and altered granitoid rocks, assigned to the ca. 1800 Ma Stag Bay granodiorite by Kerr (1994). This zone, known as the T-649 showing, is hosted by fine- to medium-grained granodiorite within which pervasive zones of moderate to strongly magnetic hematitic alteration correspond to the most intense radioactivity. Initial results from the T-649 showing are encouraging, with five representative grab samples averaging 0.467% U_3O_8 over the 10-m-wide zone of mineralization

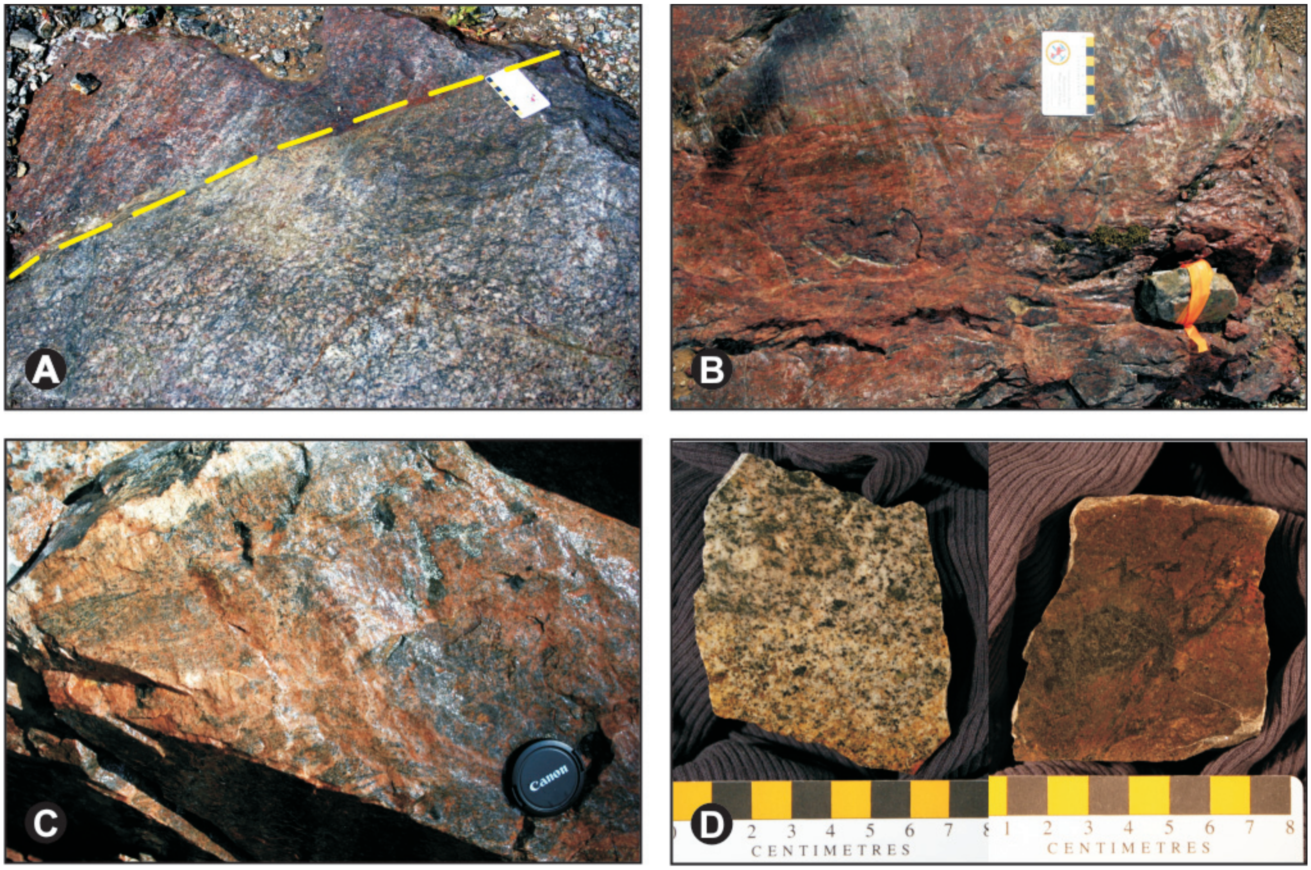

Plate 2. *Representative photographs showing typical features of mineralization hosted within deformed granitoid rocks in the CMB region. A) Sharp contact between highly fractured but relatively unaltered granite and a zone of hematitic alteration associated with radioactivity, Melody Hill area. B) Mineralized mylonitic granite showing intense hematitic alteration, Melody Hill area. C) Strong hematitic alteration in weakly to moderately deformed granodiorite, T-649 prospect, Stag Bay area. D) Polished samples showing the contrast between relatively unaltered granodiorite and its mineralized and intensely hematized equivalent, T-649 prospect.*

(Silver Spruce Resources, Press Release, July 26, 2007). Loose material located downstream from the bedrock mineralization returned assays of up to 3.37% U_3O_8 (Silver Spruce Resources, Press Release, August 2, 2007). The company announced intentions to drill the showing late in 2007, but to date this has not been completed.

URANIUM MINERALIZATION HOSTED BY FELSIC VOLCANIC ROCKS

Within the CMB, uranium mineralization occurs widely within subaerial felsic (meta)volcanic rocks and associated volcaniclastic sedimentary rocks in the Aillik and Bruce River groups and these are traditionally considered to be the most prospective units. Uranium mineralization hosted by these rocks varies in characteristics, but fall broadly into two types. The first type (Type 3) comprises disseminated or fracture-hosted mineralization that is not associated with strong deformation or widespread metasomatic effects, although it may be associated with localized alteration. In contrast, the second type of mineralization (Type 4) is associated with discrete zones of strong deformation and much more extensive metasomatism of the host rocks. This second type includes deposits of possible economic importance at Michelin and Jacques Lake. Note that many small uranium occurrences, notably in the Aillik Group, are difficult to assign firmly to Types 3 or 4, and some could also belong to Type 9 (hydrothermal veins).

Type 3: Disseminated or Fracture-Hosted Mineralization in Felsic Volcanic Rocks without Associated Deformation or Metasomatism

Several uranium occurrences within the Aillik Group are located within areas of relatively weak deformation, and previous workers have suggested that this mineralization may be stratigraphically controlled. At the Burnt Lake prospect (Figure 2), mineralization is associated with the development of chlorite–hematite alteration, and is accompanied by F, Pb, Zn and Mo (Kontak, 1980; Gower *et al.*,

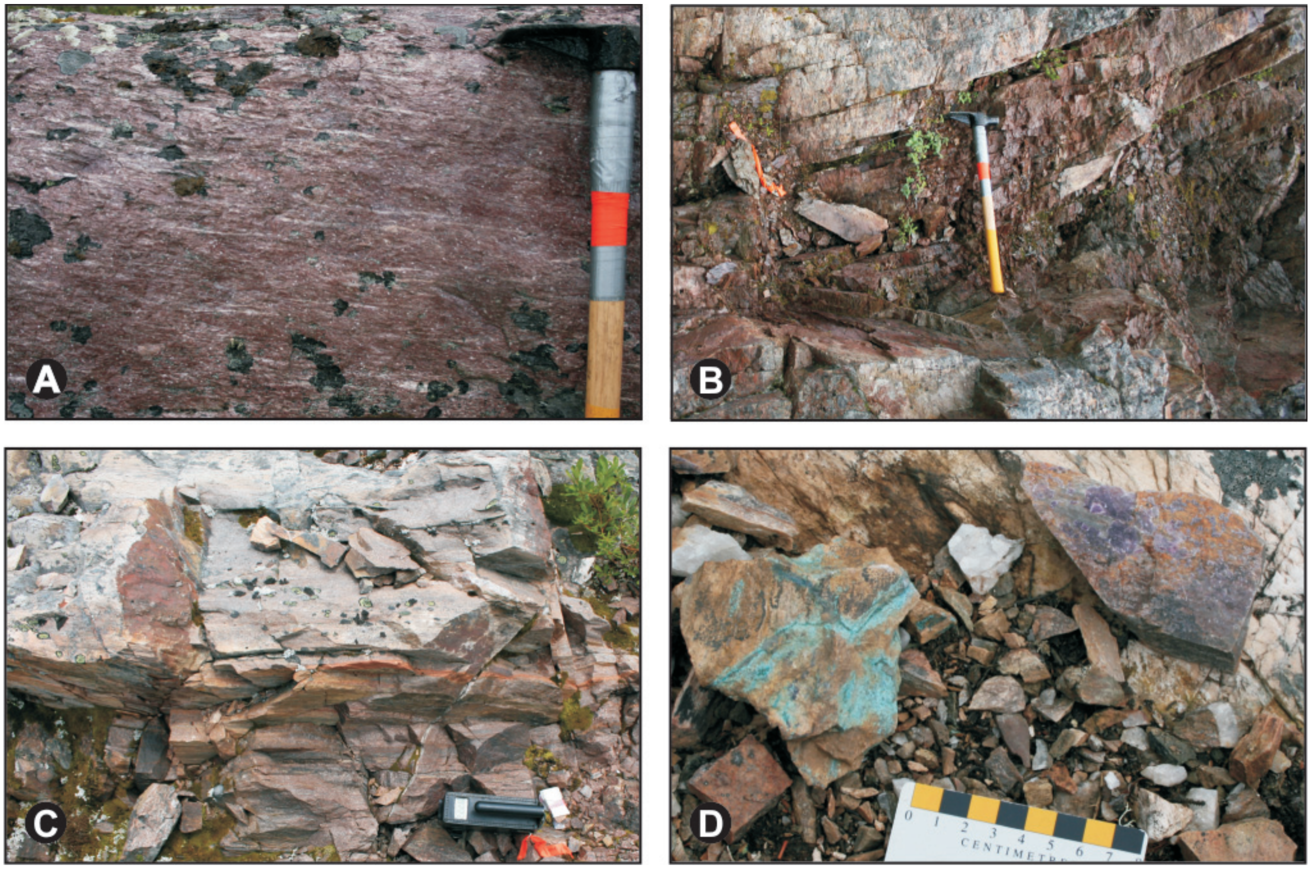

Plate 3. *Representative photographs of uranium mineralization in felsic volcanic rocks of the CMB area. A) Ash-flow tuff of the Sylvia Lake Formation of the Bruce River Group, showing well-developed eutaxitic foliation, Sylvia Lake prospect. B) Main zone of uranium mineralization hosted within a discrete fracture zone in ash-flow tuff, Sylvia Lake prospect. C) Sheared felsic volcanic rock hosting uranium mineralization adjacent to the basal unconformity of the Seal Lake Group, Stormy Lake prospect. D) Fracture-hosted fluorite and malachite staining, which locally accompanies uranium mineralization in the felsic volcanic rocks, Stormy Lake prospect.*

1982; MacKenzie and Wilton, 1987). The Burnt Lake prospect has historical drillhole intersections of up to 0.256% U_3O_8 over 16.5 m. More recent drilling carried out by Aurora Energy Resources gave similar results of 0.25% U_3O_8 over 15 m (Aurora Energy Resources, Press Release, August 16, 2007). A genetic link to the felsic volcanic host rocks was suggested for these occurrences, which appear to be confined to a porphyritic unit within a sequence of welded tuffs (Kontak, 1980; Gower *et al.*, 1982; Kerr, 1994; Wilton, 1996). However, molybdenite also occurs within local fine-grained granitic rocks that are probably of ca. 1650 Ma age (MacKenzie and Wilton, 1987; Kerr, 1994). Uranium occurrences that form a belt between Cape Aillik and the Makkovik area (the Aillik–Makkovik belt of Gower *et al.*, 1982) are also associated with Mo, although examination of the most important Mo occurrence suggested that it was more likely of epigenetic, granite-related character (Kerr, 1994; Wilton, 1996). The presence of many small granitic plutons in the eastern part of the CMB complicates interpretation of the numerous minor uranium occurrences in the Aillik Group in this area, as some could represent hydrothermal veins (see Type 9).

Many workers suggested that the felsic volcanic rocks of the Aillik Group were an important source of uranium for much of the mineralization in the surrounding region (*e.g.*, Marten, 1977; Gandhi, 1978; Gower *et al.*, 1982; Kerr, 1994; Wilton, 1996), and these rocks are typically enriched in uranium. For example, unmineralized metarhyolites from the Michelin area contain from 4 to 56 ppm U, with an average of about 10 ppm U; ash-flow tuffs contain from 2 to 47 ppm U, with an average of about 15 ppm U in more sodic rocks and 12 ppm U in more potassic rocks (Evans, 1980). Regional data reported by Kerr (1989) indicate average U contents for various Aillik Group units from 3 to 8 ppm. These uranium values are similar to those reported from the host rocks in much younger uraniferous felsic caldera complexes such as the McDermitt Complex in Nevada (Dayvault *et al.*, 1985).

Uranium mineralization is also present in the felsic volcanic rocks of the ca. 1650 Ma Bruce River Group, notably at the Madsen Lake and Sylvia Lake prospects (Ryan, 1984; see *also* Piche, 1957; Bernazeud, 1965; Figure 2), which are currently under exploration by Crosshair Exploration and Mining and Mega Uranium, respectively. This mineralization is sporadically distributed throughout discontinuous fractures and minor shear zones within well-preserved ash-flow tuffs, and also within crosscutting veins developed in mafic dykes that intrude these volcanic rocks. Typical features of this mineralization are illustrated in Plate 3. The mineralization is of limited extent, and grades are variable. Grab samples from the Madsen Lake prospect contained up to 4.6% U_3O_8, but drilling failed to intersect significant mineralization at depth; the best result to date was 0.054% U_3O_8 over 1.5 m (Crosshair Exploration and Mining, Press Release, January 9, 2007). Fluorite is associated with uranium in some of the showings. As in the case of the Aillik Group (see above) the felsic volcanic rocks of the Bruce River Group are relatively enriched in uranium, although their average U content is less than 5 ppm (Ryan, 1984), about half of the values reported for the Aillik Group. However, regional airborne radiometric surveys completed by Crosshair Exploration and Mining indicate a strong response over the felsic volcanic rocks of the Bruce River Group, implying that they are regionally enriched in uranium.

The Stormy Lake showing (Figure 2) is generally considered to be an example of possible unconformity-style uranium mineralization associated with the base of the ca. 1270 Ma Seal Lake Group, which here sits upon the Bruce River Group (Smyth and Marten, 1975; Kontak, 1978; Ryan, 1984). Our examination in 2007 suggests that the rocks hosting most of the radioactivity more closely resemble the Bruce River Group than the Seal Lake Group. Also, radioactivity at the main showing is associated with malachite staining and fluorite. In this respect, the mineralization more closely resembles the volcanic-hosted mineralization seen elsewhere in the Bruce River Group. The Stormy Lake showing, including possible mineralization in Seal Lake Group conglomerates, is discussed further in a subsequent section.

Type 4: Disseminated Mineralization in Felsic Metavolcanic Rocks Associated with Shear Zones and Widespread Metasomatism

This enigmatic style of mineralization includes the large and potentially economic Michelin deposit, the potentially significant Jacques Lake deposit, and several other smaller examples, including Rainbow, Mustang Lake and Otter Lake (Figure 2). All of these examples are hosted by felsic metavolcanic rocks of the Aillik Group.

The Michelin deposit is described in detail by Gandhi (1978, 1984), Evans (1980) and Gower *et al.* (1982); it is also reviewed in NI 43-101 reports by Cunningham-Dunlop (2007). Surface exposures of the mineralized rocks are very scarce, and most information about the deposit comes from drilling, coupled with underground exploration. The exploration adit is sealed, and no longer available for examination. The Michelin deposit consists of several subparallel *en-echelon* zones of uranium mineralization that are broadly concordant with the strongly deformed and recrystallized felsic metavolcanic host rocks, and collectively define a tabular zone. The deposit is more than 1 km in length and up to 40 m thick, dips steeply to the south, and has very predictable geometry (Figure 4a). Within the mineralized zone, the thickest and most U-enriched material defines a linear zone that plunges steeply to the southwest (Figure 4b), and achieves its greatest thickness below depths of about 400 m. Typical features of mineralization at the Michelin deposit and similar occurrences are illustrated in Plate 4.

Recrystallized felsic rocks, derived from ash-flow tuffs and porphyritic rhyolites, form the main host to uranium mineralization, but these are accompanied by generally unmineralized mafic units that have variable relationships to the fabric, suggesting pre-, syn- and post-kinematic timing. The general absence of mineralization in the mafic units implies that they postdate the introduction of uranium. However, mineralization is locally reported from mafic rocks, which suggests that some of these may predate the introduction of uranium, unless such effects are due to later remobilization. Granitoid plutonic rocks and quartz-feldspar porphyries also form subconcordant sheets within the metavolcanic host rocks, and are similarly considered to mostly be of post-mineralization timing, although they do locally contain radioactivity associated with vuggy zones.

The uranium occurs mostly in the form of finely disseminated uraninite, much of which is associated with metamorphic or metasomatic minerals such as sodic amphibole, aegirine–augite, titanite, iron–titanium oxides and zircon. Uraninite also occurs in the fine-grained quartz–albite aggregates that dominate the host rocks, but this mode of occurrence is less important. In drill core, radioactivity is commonly associated with a red, hematitic alteration, and these altered zones define a very strong banding, suggesting that they have experienced intense deformation. Uranium mineralization is also correlated with widespread albitization of the host rocks (*i.e.*, sodium metasomatism), coupled with depletion in potassium. Evans (1980) noted the high Zr contents of mineralized rocks, and the apparent correlation between U and Zr. The relationships observed in drill core, and the detailed work by Evans (1980) suggest that the introduction of uranium and related metasomatism occurred prior to, or synchronously with, the intense deformation of the host rocks.

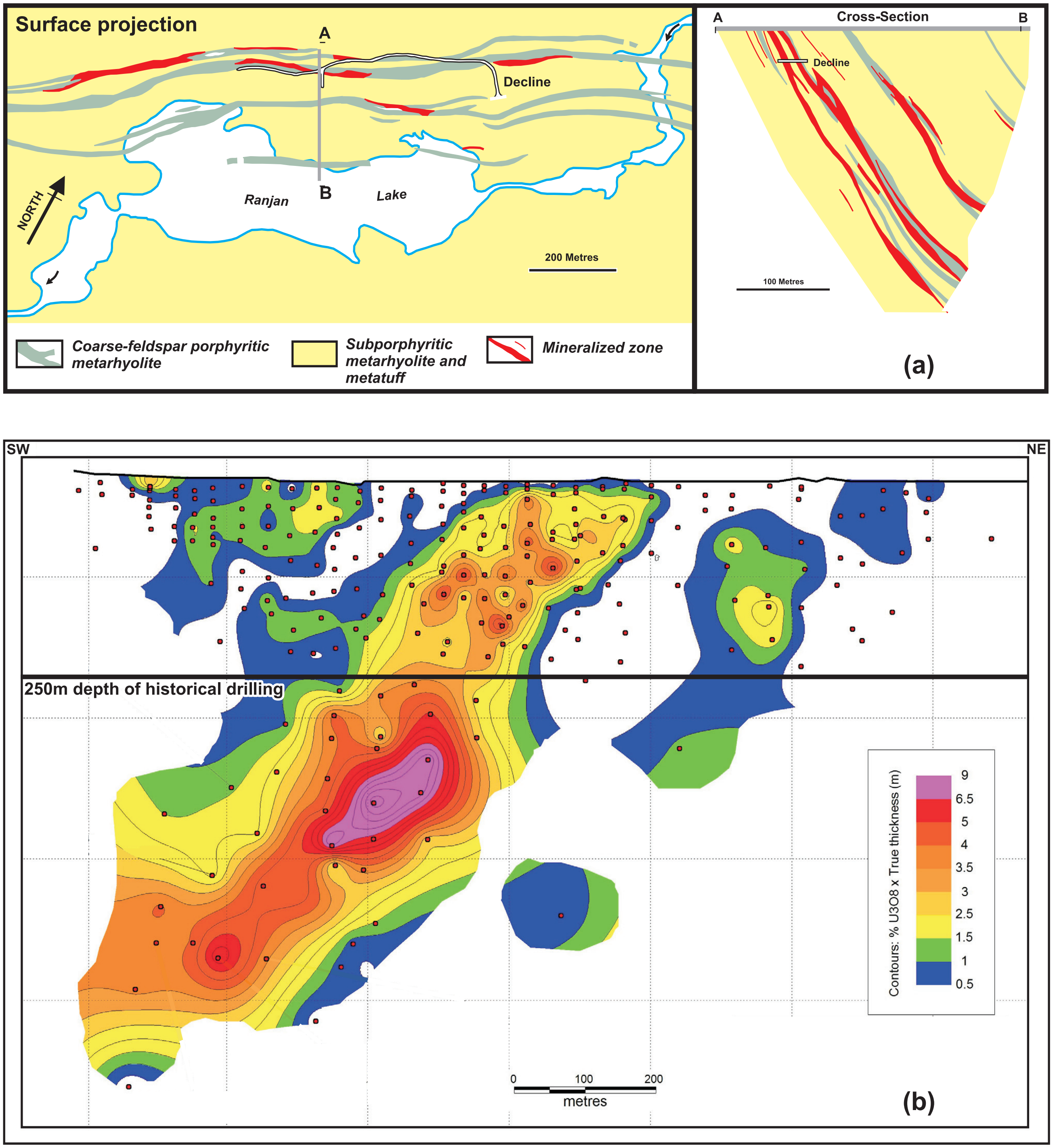

Figure 4. *a) Generalized plan view and north-south cross-section through the Michelin deposit, illustrating the general geometry of the mineralization. Based on work in the 1970s, modified from Gandhi (1978). b) Longitudinal section through the Michelin deposit as visualized in early 2007, contoured according to (grade x thickness) values; the depth limit of 1970s drilling is indicated; modified after diagrams released on the Aurora Energy Resources website.*

The range of uranium grades at Michelin appears to be relatively restricted, typically between 0.05 and 0.5% U_3O_8, with most intersections averaging 0.1 to 0.2% U_3O_8. According to Gower *et al.* (1982), 97% of the 1970s samples assayed contained less than 0.3% U_3O_8. The mineralization is Th-poor, depleted in sulphides, and there is no reported enrichment in base metals or Mo. However, pyrite is locally present, and minor chalcopyrite was reported by previous workers.

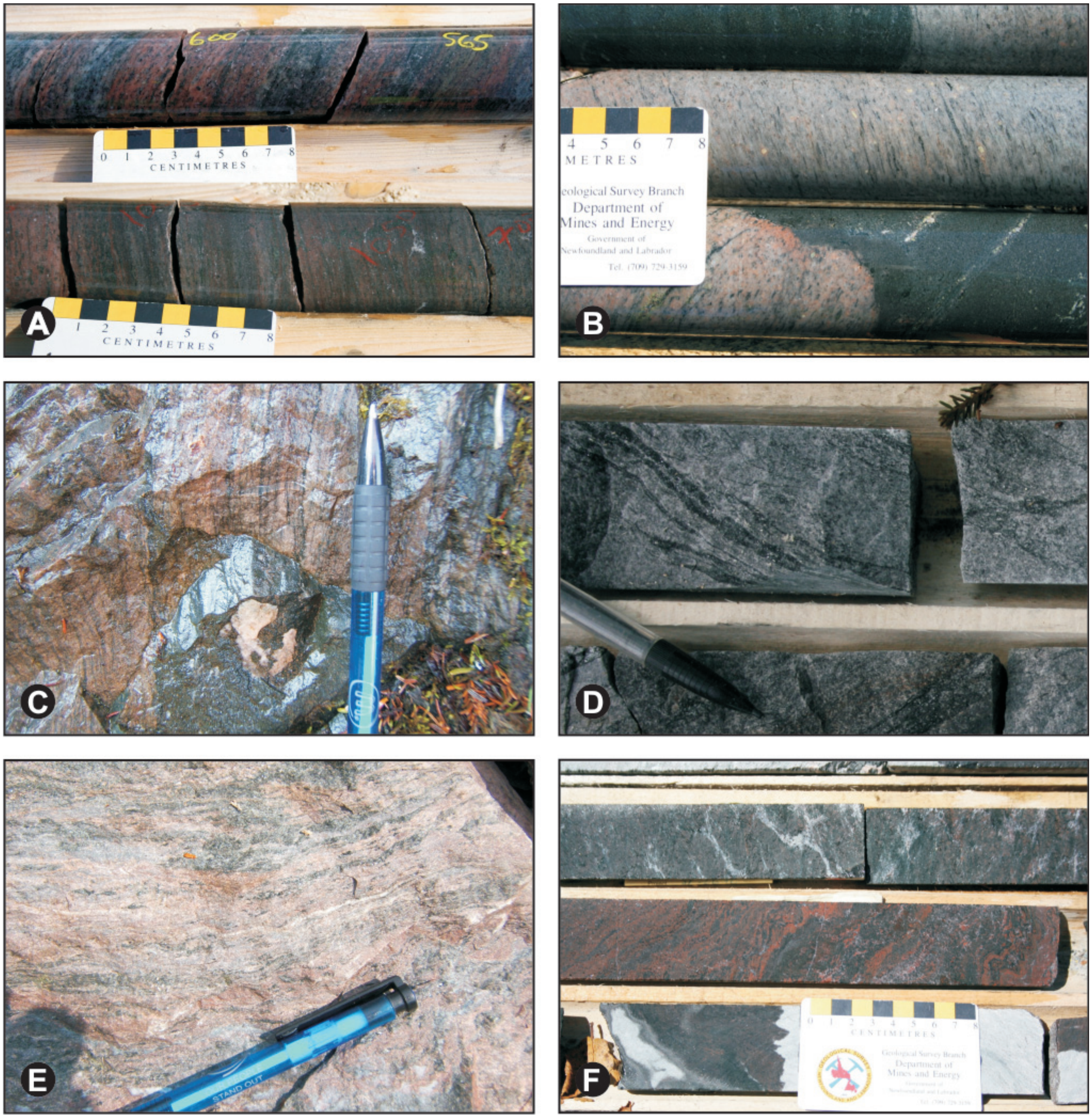

Plate 4. *Representative photographs showing typical features of disseminated uranium mineralization hosted within felsic metavolcanic rocks of the Aillik Group. A) Strongly foliated mineralized felsic metavolcanic rocks showing variable degrees of hematite alteration, Michelin deposit. B) Foliated felsic volcanic rocks cut by a mafic dyke interpreted to be of post-mineralization and post-deformation timing, Michelin deposit. C) Outcrop of the strongly foliated, mineralized felsic to intermediate metavolcanic host rocks to the Jacques Lake deposit. D) Mineralized core from the Jacques Lake deposit showing distinctive biotite–actinolite bands (veins ?) that are locally associated with uranium mineralization. E) Strongly deformed, mineralized felsic metavolcanic rocks at the Aurora West prospect, located in an inferred regional shear zone approximately 12 km southwest of the Jacques Lake deposit. F) Strongly deformed felsic metavolcanic host rocks showing intense hematization associated with uranium mineralization (at centre of photo), Mustang Lake prospect, 9 km northeast of Michelin. Light and dark areas in the lower part of photo indicate dry versus wet core and have no geological significance.*

The recently discovered Jacques Lake deposit appears to have several features in common with Michelin, including generally similar, strongly deformed felsic metavolcanic host rocks. As at Michelin, there are mafic rocks that are generally unmineralized and probable post-mineralization quartz-feldspar porphyry units. However, exploration at Jacques Lake is at a much earlier stage and public-domain information on petrology and geochemistry is presently limited. Recent regional work by Aurora Energy Resources suggests that Michelin and Jacques Lake may be related to a regional shear-zone structure, which may also host other occurrences such as the smaller Rainbow deposit and the Burnt Brook and Aurora West prospects (Figure 2). This inferred structure also passes through the Mustang Lake area (Mega Uranium) where drilling in 2006 yielded an intersection of 0.12% U_3O_8 over 9.1 m (Santoy Resources, Press Release, January 18, 2006). Drill core from Mustang Lake is similar to material from Michelin, in that the mineralization and alteration appear to have experienced strong deformation.

MINERALIZATION HOSTED BY SEDIMENTARY AND METASEDIMENTARY ROCKS

Uranium mineralization in sedimentary and metasedimentary rocks within the CMB falls into two categories. The first is hosted by broadly pelitic (argillaceous) metasedimentary rocks in the Post Hill group, and includes the important Kitts deposit and smaller analogues within the same unit. The second is hosted by terrestrial sedimentary rocks in the Bruce River Group, and includes the potentially important "Lower C-zone" deposit at Moran Lake. Minor occurrences include some small radioactive zones in the lower part of the Moran Lake Group, and also in the Seal Lake Group.

Type 5: Mineralization hosted by Pelitic (Argillaceous) Metasedimentary Rocks

This style of mineralization is presently known only from the Post Hill group, and is exemplified by the Kitts deposit and its analogues. These deposits are described by Gandhi (1978, 1984), Evans (1980) and Gower *et al.* (1982), and form a group of four deposits associated with the same geological unit. From north to south, these are the Kitts, Gear, Inda and Nash deposits (Figure 2). Although Kitts is currently classed as EML and closed to exploration, Aurora Energy Resources has completed some exploration drilling at Gear, Inda and Nash. A recent intersection of mineralization at the Gear deposit extends mineralization 100 m below the deepest intersections, suggesting that there may be potential for expanding the total uranium resource in deposits of this type (Aurora Energy Resources, Press Release, October 10, 2007).

Mineralization at the Kitts deposit is almost entirely restricted to a thin sequence of metasedimentary rocks that is sandwiched between a sequence of mafic metavolcanic rocks (originally pillow lavas) and a metagabbro thought to represent a pre-mineralization intrusive unit. The metasedimentary rocks (termed the "Mine volcaniclastic sequence" by Evans, 1980) are thought to be derived from mafic tuffs, fine-grained greywackes and sulphide-bearing graphitic argillite. The mineralization is best developed in the sulphide-bearing argillitic unit, and occurs in both concordant and weakly discordant veinlets and shears. Gandhi (1978) contended that mineralization was conformable with relict sedimentary layering in the host rocks, but Evans (1980) suggested that structural controls were important; however, all are agreed that the mineralized zones were subjected to intense deformation and small-scale folding. This metasedimentary unit appears to have been a focus for deformation and shearing throughout the Post Hill group. The features of mineralization at the Kitts deposit and similar occurrences are illustrated in Plate 5. The overall geometry of the Kitts deposit is illustrated in Figure 5, modified after Gandhi (1978); the most important section of the deposit is the "B-zone", which contains 85% of the uranium resource, but is defined only to a depth of less than 200 m. The mineralization is cut by younger quartz-feldspar porphyry and "dioritic" intrusions, which remain undated. Wall-rock alteration at Kitts is minimal, and geochemical data presented by Evans (1980) suggests that there is a zone of soda-metasomatism in the surrounding rocks, coupled with Fe-enrichment and oxidation. Calcite veins and seams are also very abundant in the vicinity of the mineralization. The grades at Kitts vary widely, but some parts of the deposit are extremely high-grade, containing up to 20% U_3O_8. Bulk samples collected during 1970s exploration (summarized by Evans, 1980) indicate that base-metal contents are low, although material is anomalous in Cu and Mo (about 500 ppm of each).

The Gear, Inda and Nash deposits are located in the same metasedimentary unit as the Kitts deposit, but lie much closer to the assumed tectonic contact between the Post Hill group and the adjacent Aillik Group. The host rocks at the Gear deposit are less argillitic in composition, but also contain primary sulphides; complex folding of uranium-bearing layers here indicates that mineralization predates much of the deformation (Evans, 1980). Mineralization at Inda and Nash is hosted by variegated red and green mafic to felsic tuffaceous metasedimentary rocks, rather than by sulphide-bearing pelitic rocks. In general, the grades at Gear, Inda and Nash are lower than at Kitts, ranging from 0.14% to 0.20% U_3O_8.

The Moran Lake Group also contains argillaceous and sulphide-bearing sedimentary rocks that are similar to the host rocks to the Kitts deposit and related occurrences.

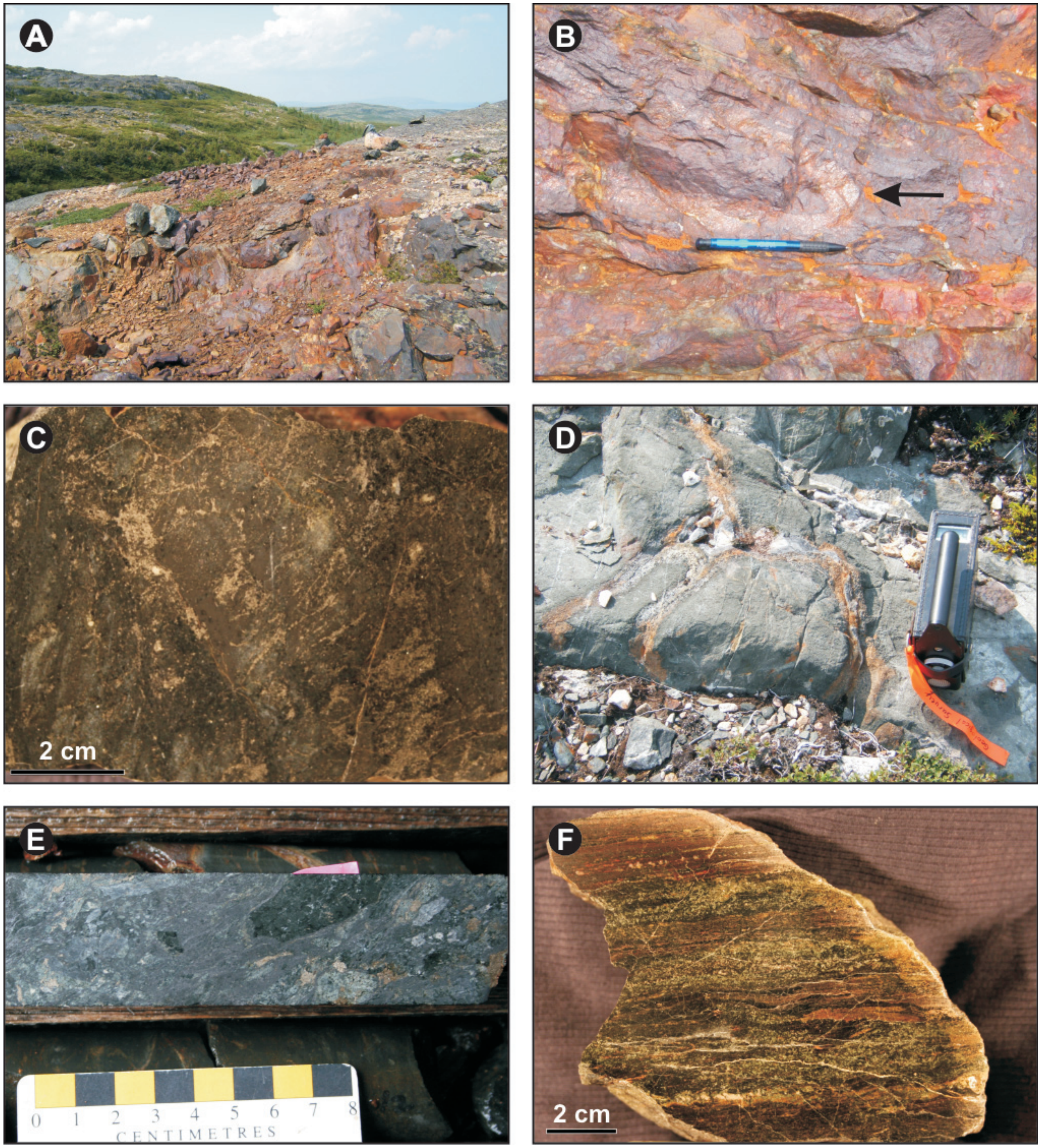

Plate 5. *Representative photographs showing typical features of uranium mineralization and associated host rocks at the Kitts deposit and Nash prospect. A) Surface outcrop of the A-Zone at the Kitts deposit; the gossan zone, which hosts the uranium mineralization, is approximately 5m in width, and is bounded by metagabbro to the left and deformed pillow basalt to the right. B) Sulphide-rich metasedimentary rock that hosts uranium mineralization at Kitts; note fold defined by sulphide band at centre of photo. C) Polished sample of uranium-bearing metasedimentary rock from the Kitts A-Zone, showing abundant sulphides and strong deformation. D) Pillow structures that are locally preserved within mafic volcanic rocks adjacent to the Kitts deposit. E) Mineralized drill core showing debris-flow textures that are locally preserved within the host metasedimentary rocks at the Kitts deposit; note abundant sulphides. F) Polished sample of strongly deformed mineralized metasedimentary rocks at the Nash prospect.*

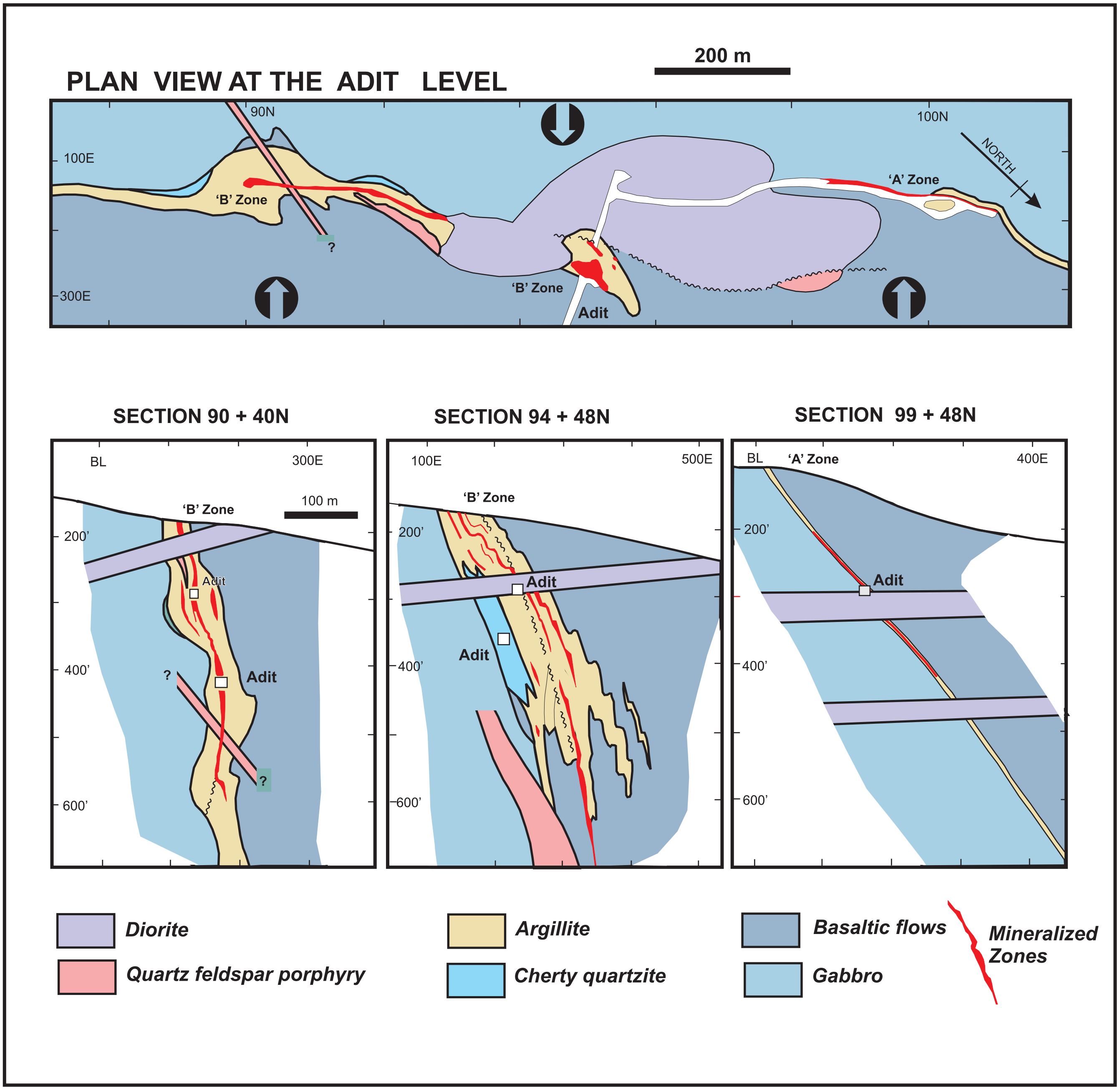

Figure 5. *Generalized plan view and northwest-southeast cross-sections through the Kitts deposit, illustrating the general geometry of the mineralization and presence of post-mineralization intrusive rocks; based on work in the 1970s, modified from Gandhi (1978).*

However, these equivalent rocks of the Moran Lake Group are not known to be mineralized. Some minor uranium enrichment occurs in dolostones within these sedimentary rocks, and sporadic radioactivity over a strike length of about 1.2 km has been documented by Crosshair Exploration and Mining at the Area 51 prospect (LaCroix and Cook, 2007). Results from recent drilling show broad zones of low-grade mineralization within the lower sedimentary units, with intersections assaying up to 0.012% U_3O_8 over 24.7 m. However, the most significant mineralization in the Moran Lake Group is associated with mafic volcanic rocks (see discussion, page 212), which are generally unmineralized in the Post Hill group. This is but one of the many contradictions inherent in the uranium metallogeny of the CMB!

Type 6: Mineralization hosted by Sandstones and Conglomerates

This style of mineralization is mostly present within the lower part of the ca. 1650 Ma Bruce River Group, and is exemplified by the "Lower C-Zone" deposit at Moran Lake. In this area, initial work by Shell Canada Resources (Gordonier, 1979) identified radioactive zones within sandstones and interbedded pebble conglomerates of the Heggart Lake Formation, close to its unconformable basal contact with mafic volcanic rocks of the older Moran Lake Group. The host rock units form a coarsening-upward sequence in which a basal fine-grained tan to grey quartz arenite passes upwards into medium-grained, pink to red, thinly bedded arkose and interbedded conglomerate, and eventually into polymictic pebble to boulder conglomerate (Ryan, 1984).

The area of the Moran Lake C-Zone deposits is complex, and mineralization occurs both in the Bruce River Group and the Moran Lake Group. Smyth and Ryan (1977) recognized that the contact region of these units was complex, and that the Moran Lake Group is locally placed above the Bruce River Group by reverse faults, inferred to be of Grenvillian timing. Interpretation of recent drilling confirms this interpretation, and also suggests that the basal unconformity of the Bruce River Group is repeated by thrusting (Figure 6). The mafic host rock and much of the uranium mineralization is now interpreted as part of the Moran Lake Group, rather than a mafic sill within the Bruce River Group, as previously suggested by Smyth and Ryan (1977). Thus, the "Lower C-Zone" mineralization is actually hosted by younger rocks than the overlying "Upper C-Zone" mineralization (Figure 6). Typical features of mineralization in sedimentary rocks of the Bruce River Group are illustrated in Plate 6.

Uranium mineralization in the lower C-Zone is mostly hosted in selectively reduced zones within a medium- to coarse-grained, pale to dark-green sandstone that locally contains centimetre-scale rip-up clasts of green to red mudstone. The mineralization within the sandstones is generally subparallel to the underlying unconformable contact with the Moran Lake Group. Drilling in the 1970s gave a best result of 0.27% U_3O_8 over 2.6 m (Gordonier, 1979; Ryan, 1984). More recent drilling by Crosshair Exploration and Mining has given wider intersections up to 0.13% U_3O_8 over 11 m. Higher grade material is present on a local scale, *e.g.*, 1.15% U_3O_8 over 0.70 m (Crosshair Exploration and Mining, Press Release, May 30th 2007). The uranium mineralization is associated with vanadium enrichment, and the two elements appear to be correlated; the high-grade uranium intersection noted above also contained 0.33% V_2O_5.

Locally, uranium is also present in crosscutting chlorite- and sericite-rich shear zones that also contain pale-pink veinlets of carbonate. These appear to be later features into which uranium has been remobilized from the sandstones.

Approximately 7 km northeast of the lower C-Zone deposit (Figure 2), similar mineralization occurs in equivalent rocks of the Heggart Lake Formation at a location known as the Moran Heights prospect (Crosshair Exploration and Mining website). The uranium enrichment is associated with similar selectively reduced zones in medium-grained sandstone, about 20 m above the unconformable contact with pillow basalt of the Moran Lake Group. Mineralized boulders in this area, located in the 1970s, contained up to 3.7% U_3O_8 (Hopfengaertner *et al.*, 1985) and recent grab samples contained up to 4.5% U_3O_8 (Crosshair Exploration and Mining, Press Release, October 4th 2005). Recent drilling in this area gave results similar to intersections noted above from the lower C-Zone, including 0.10% U_3O_8 over 5 m (Crosshair Exploration and Mining, Press Release, January 9th 2007). Enrichment in Cu and Ag is also noted at the location (LaCroix and Cook, 2007).

The Moran Lake "B" Zone (Figure 2) is also hosted by the sedimentary rocks of the Heggart Lake Formation. Descriptions by Ryan (1984) indicate that mineralization occurs in red sandstones adjacent to (and locally within) minor intrusive rocks of leucogabbroic composition. The latter exhibit strong iron-carbonate alteration. Exploration in the 1970s gave some interesting results over narrow widths, including an intersection of 0.19% U_3O_8 over 3.6 m. The average value for 62 surface samples was 0.7% U_3O_8 (LaCroix and Cook, 2007), and high uranium values were accompanied by enrichment in V_2O_5 (up to 0.53%), Cu (up to 0.87%) and Ag (up to 25 ppm). Recent drilling in the region resulted in an intersection of 0.27% U_3O_8 over 7.6 m (Crosshair Exploration and Mining, Press Release, October 3rd 2006).

Uranium mineralization is also present at higher stratigraphic levels within the Heggart Lake Formation, notably at the Moran Lake A-Zone prospect (Bernazeud, 1965; Ryan, 1984). Here, mineralization is hosted within pale-grey pebble to boulder conglomerate and interbedded sandstone. The host rocks are sheared, with downdip elongation of clasts, and uranium is accompanied by weak to moderate sericite-pyrite alteration. Malachite staining suggests that copper is enriched in the mineralized zones. Pyrite appears to be preferentially developed within the conglomeratic layers, rather than the sandstone beds, suggesting that its deposition may have been controlled by permeability contrasts. Areas of elevated radioactivity generally correspond with the strongly sheared, pyrite-rich zones. Surface mineralization at the A-Zone is widespread, but shallow drilling in the 1970s failed to intersect significant mineralization. There has been no recent drilling at the prospect, which is currently held by Mega Uranium.

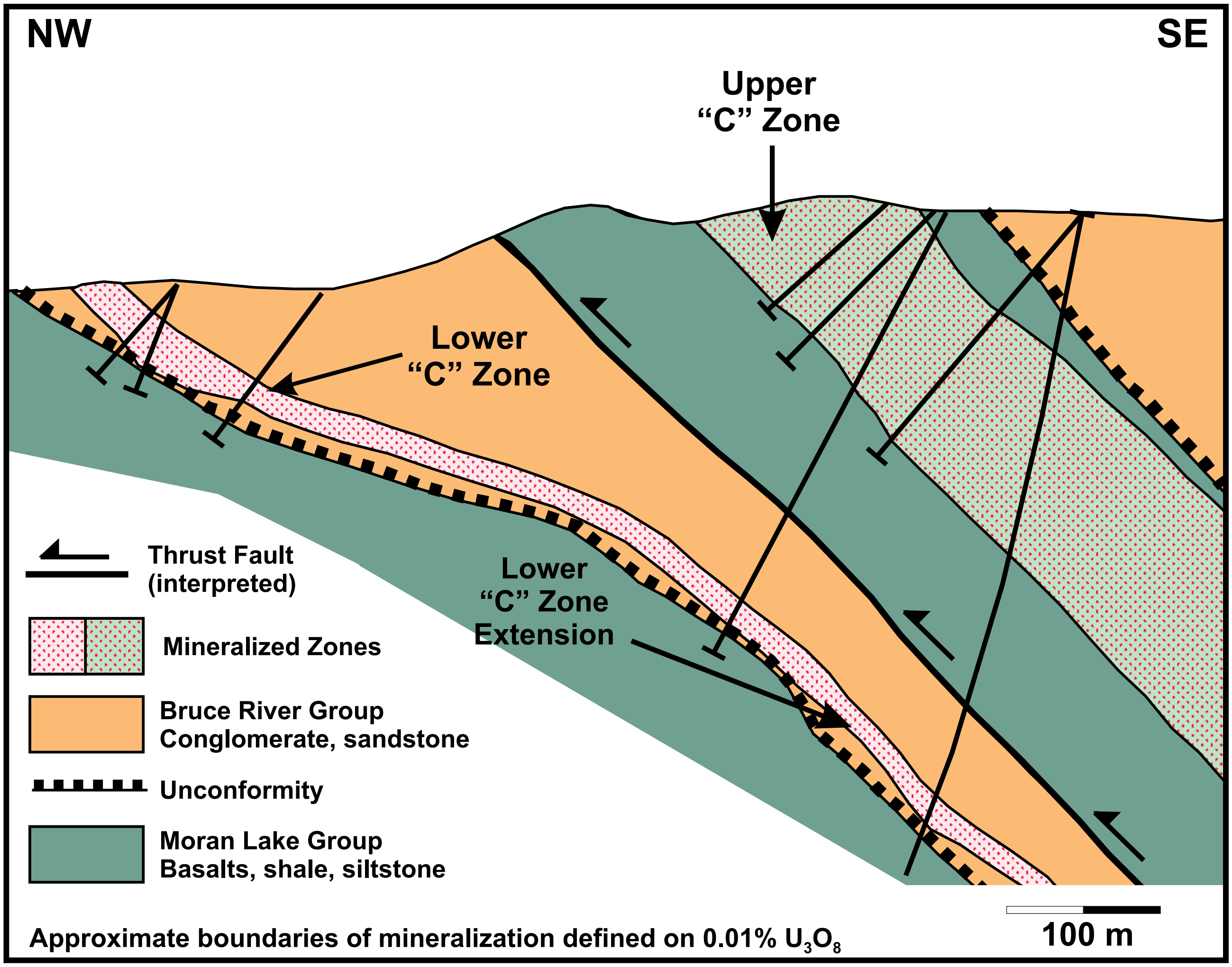

Figure 6. *Partly schematic cross-section through the area of the Moran Lake C-Zone uranium deposits, showing thrusts inferred to repeat the basal contact of the Bruce River Group above the Moran Lake Group; modified after diagrams released on the Crosshair Exploration and Mining website.*

Radioactivity is reported from quartzite and conglomerate of the Seal Lake Group at the Stormy Lake showing, a short distance above the basal unconformity (Marten and Smyth, 1975; Kontak, 1978). Recent examination by Altius Minerals (Smith *et al.,* 2004) suggests that radioactivity here is minor, which is consistent with the low assay of 0.004% U_3O_8 reported during 1950s exploration (Marten and Smyth, 1975). Marten and Smyth (1975) also make reference to a radioactive conglomerate in the northern Seal Lake Group, described by Barager (1969); we have not visited this locality.

MINERALIZATION ASSOCIATED WITH HYDROTHERMAL BRECCIA ZONES AND IRON-RICH ALTERATION

Uranium mineralization at two localities within the CMB is associated with zones of hydrothermal brecciation that are characterized by possible iron-rich alteration and metasomatism. The host rocks at these prospects are distinctly different, and this parameter is used for subdivision, although the two types are suspected to be closely similar in other respects.

Type 7: Mineralization hosted by Breccia Zones in Mafic Volcanic Host Rocks

This style of mineralization is exemplified by the Moran Lake "Upper C-Zone" deposit (Figures 2 and 6), described in detail by Cooke (1980) and reviewed by Ryan (1984). This deposit is located structurally above and adjacent to the "Lower C-Zone" described in the preceding section (Figure 6). Smyth and Ryan (1977) recognized structural repetition here, and recent exploration underlines the importance of such effects (see previous discussion, page 211). The Upper C-Zone deposit is now believed to be situ-

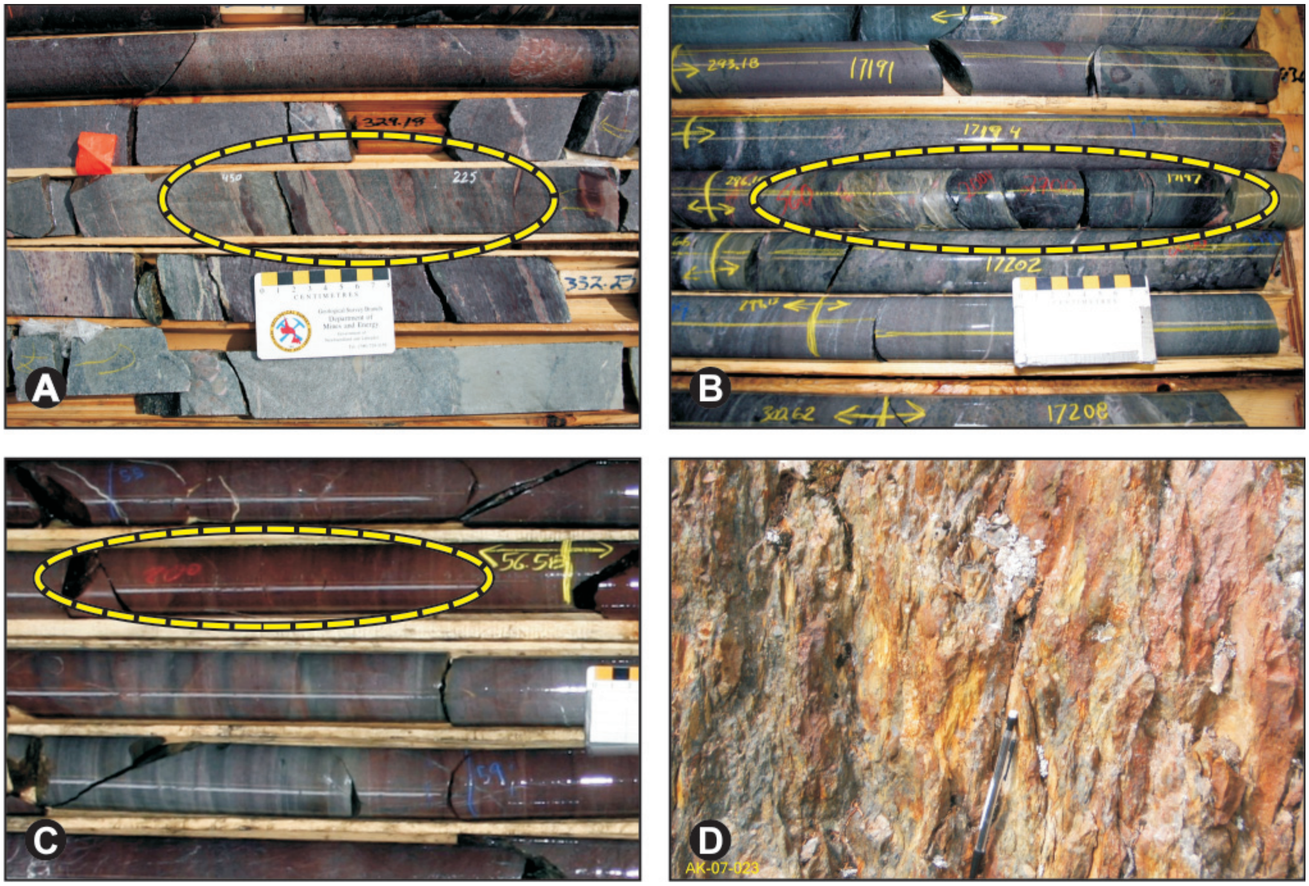

Plate 6. *Representative photographs of mineralization hosted by sedimentary rocks of the Bruce River Group. A) Host rocks to the Moran Lake Lower C-Zone deposit, showing oxidized (red) and reduced (grey-green) areas; uranium mineralization is associated mostly with the latter, as indicated. B) Mineralized chlorite–sericite-rich shear zone cutting the sandstone host rocks of the Moran Lake Lower C-Zone deposit, indicating local remobilization of uranium. C) Discrete zones of uranium mineralization associated with strong hematization of medium- to coarse-grained sandstone, Moran Lake B-Zone prospect. D) Strongly sheared pebble conglomerate hosting uranium mineralization associated with sericite-pyrite alteration, Moran Lake A-Zone prospect.*

ated within a thrust sheet that is dominated by mafic pillow lavas of the Moran Lake Group (Joe Pond Formation), with lesser amounts of argillitic sedimentary rocks (Warren Creek Formation). This contrasts with the previous interpretation that the mafic host rocks formed a flow or sill within the younger Bruce River Group (Smyth and Ryan, 1977; Ryan, 1984). Extensive drilling over the last few years also suggests that the basal unconformity between the Bruce River Group and Moran Lake Group is repeated, and sits structurally above the mineralization (Figure 6). However, the uppermost panel of Bruce River Group rocks is not known to contain any uranium mineralization akin to that seen in the Lower C-Zone. Typical features of the Upper C-Zone mineralization are illustrated in Plate 7.

Within the mafic volcanic host rocks, there is widespread development of hematite- and iron-rich carbonate alteration, and a strong association between radioactivity and deep-red, intensely hematized rocks that appear essentially featureless. LaCroix and Cook (2007) describe these as "jasper and chert", but their gradational boundaries with recognizable basalts are also consistent with them being the end product of intense hematite alteration. The most striking features of the mineralized zone are discrete brecciated zones containing intensely altered fragments within an iron-carbonate-rich matrix. These zones display evidence of intense fracturing and repeated brecciation of the host rocks, accompanied by mechanical erosion of the fragments. The breccia zones commonly show elevated radioactivity, but they are not everywhere mineralized. Cooke (1980) recognized multiple stages of hematite–carbonate alteration and associated brecciation, and suggested that uranium and minor copper were introduced late in the sequence, forming vein and fracture fillings that locally crosscut the alteration and brecciation. B. Ryan (personal communication, 2008) indicates that albitization is developed in some of the altered

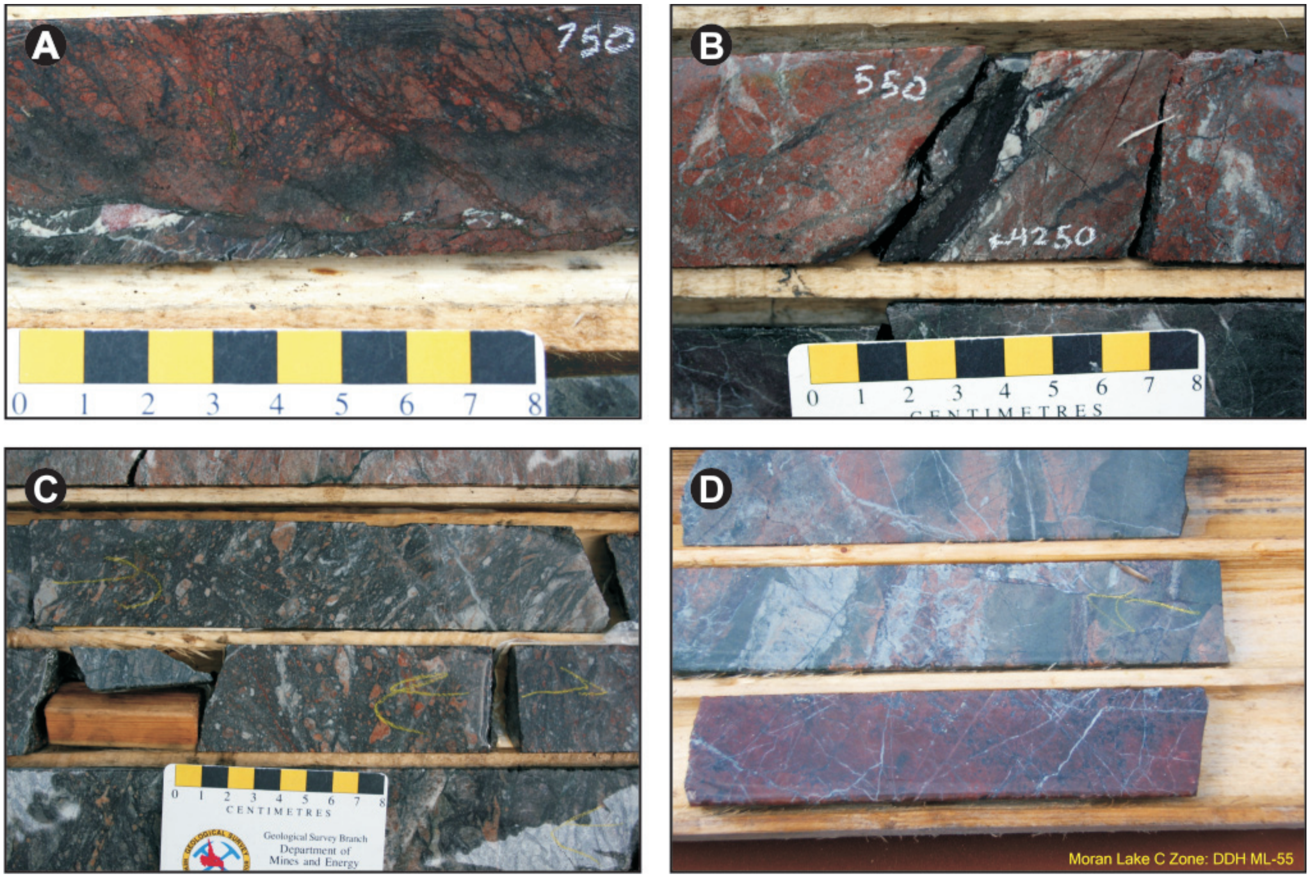

Plate 7. *Representative photographs of uranium mineralization and associated breccia textures at the Moran Lake Upper C-Zone deposit. A) Mineralized material, showing intense hematite alteration and early brecciation cut by later zones of brecciation associated with chalcopyrite. The exact location of the uranium mineralization in this sample is not presently known. B) Hematite-rich mineralized breccia cut by a later fracture that contains high-grade uranium mineralization. Note also extensive carbonate that postdates the hematite alteration. C) Spectacular breccia zone with hematite and carbonate-rich matrix surrounding strongly altered fragments of uncertain protolith. The fragments appear to have been "milled", suggesting mechanical erosion during interaction with hydrothermal fluids. D) Unbrecciated and locally mineralized host rocks from the Moran Lake Upper C-Zone deposit, which are in part of volcanic origin. Localized hematite alteration in the upper part of photo is not associated with strong radioactivity, but the intensely hematitic material in the lower part contains high-grade mineralization.*

mafic rocks, but the full extent of such alteration remains to be established.

Observations in 2007 do indicate strong radioactivity within dark-purple, hematite-filled fractures that postdate earlier breccia development. However, radioactivity is not restricted to such zones, and seems to be broadly correlated with the intensity of hematitic alteration in the host rocks. More work is required to better understand the distribution of uranium amongst pervasively altered rocks, breccia zones and discrete veinlets. The Upper C-Zone deposit also contains significant amounts of vanadium, and is reported also to contain some copper and silver. Re-sampling of drill core from exploration in the 1970s shows local concentrations of up to 0.10% Cu over 8.1 m, including 0.42% Cu and 2.3 g/t Ag over 1.0 m. Individual assays contain up to 0.63% Cu and 13.9 g/t Ag (Crosshair Exploration and Mining, Press Release, March 29, 2005).

The Anomaly 15 showing (Figure 2) consists of radioactive zones developed in mafic rocks assigned to the Moran Lake Group, and Ryan (1984) suggested that the alteration is locally similar to that observed at the Upper C-Zone. At this locality, altered and mineralized rocks are reported to be overlain by unmineralized conglomerates and breccias assigned to the Brown Lake Formation of the Bruce River Group (Ryan, 1984; Wilton, 1996; B. Ryan, personal communication, 2008). However, radioactivity is locally associated with fractures and veins that crosscut the contact between the two units (Wilton, 1996).

Type 8: Mineralization hosted by Breccia Zones in Granitoid Plutonic Rocks

Recent mineral exploration by Silver Spruce Resources within the southwestern corner of the Nain Province (Figure 1) has identified breccia-hosted uranium mineralization within granitoid plutonic rocks of the Late Archean Kanairiktok intrusive suite. Similar brecciation is also developed locally within the older gneissic country rocks to these granitoid suites. This area is now known as the Two-Time Zone, and is one of the most interesting new discoveries in the CMB. Typical features of this mineralization are illustrated in Plate 8. The plutonic host rocks are cut by numerous zones of fracturing and *in situ* brecciation, which locally exhibit textures suggesting mechanical erosion of individual granitic fragments. The matrix to the breccia zones is dark, extremely fine grained, and is believed to be a mixture of chlorite and hematite, with variable amounts of iron carbonate. The style of brecciation is in many respects reminiscent of so-called "tuffisite" breccia zones developed in high-level plutonic rocks. Chloritic fractures are widely developed in the host granites distal to discrete breccia zones, suggesting that chloritic alteration may have developed prior to hematization and brecciation. The breccia zones appear to have a random orientation, and there is no sign of any pervasive deformation or shearing, although they are crosscut by brittle fractures. Pale-white silicification, which locally coincides with carbonate alteration and veining, is developed around the wider breccia zones. The altered granitoid host rocks are weakly radioactive, but the most intense radioactivity is invariably associated with discrete breccia zones. Overall, many features of the Two-Time Zone are reminiscent of those observed at the Moran Lake Upper C-Zone deposit (see above description, page 213), but the breccia development is more local and the original host rocks are easier to discern. Currently, the Two Time Zone is defined over a strike length of 475 m and is known to be present to a depth of about 250 m. The best intersection reported to date is 0.1% U_3O_8 over 32 m (Silver Spruce Resources, Press Release, June 21, 2007).

Both the granitoid host rocks and the mineralized breccia zones are cut by undeformed, post-mineralization diabase dykes. The ages of these dykes is unknown, but it is possible that they belong to the ca. 2237 Ma Kikkertavak dyke swarm, which is widespread in the Nain Province. If this proves to be the case, mineralization at the Two-Time Zone may be one of the oldest examples of uranium mineralization in the CMB. Although the dykes clearly crosscut the breccia zones, they do appear to have remobilized uranium, because their margins display locally anomalous radioactivity.

OTHER STYLES OF MINERALIZATION

Type 9: Mineralization Associated with Hydrothermal Veins

This style of mineralization is present mostly in the eastern part of the CMB, in the area south of Makkovik, where several small granitoid plutons intrude rocks of the Aillik Group. In the area around Round Pond, numerous Mo, Cu and U occurrences appear to define a zoned vein system associated with a cupola considered to be an offshoot of the ca. 1650 Ma Monkey Hill Granite. Hydrothermal veins and pegmatite segregations containing minor uranium are developed in the outermost shell of the vein system (MacDougall, 1988; Wilton, 1996). There are numerous small zones of radioactivity in this region, and many could be related to the late granites; however, there is little information about them, and many could also be related to the felsic volcanic host rocks of the Aillik Group, *i.e.*, akin to Type 2 as described above. This style of mineralization likely includes the original discovery site for uranium in Labrador, the Pitch Lake showing, which is located at the contact of a granitic dyke (Wilton, 1996).

GEOCHRONOLOGICAL CONSTRAINTS ON MINERALIZATION

Although they would appear, at first sight, to be ideal candidates for geochronology, uranium deposits are difficult to date. This is because uranium ore minerals (such as uraninite or brannerite) suffer structural damage from the cumulative effects of radioactive decay. These metamict minerals are prone to open-system behaviour involving the loss (or gain) of parent and/or daughter elements and the interpretation of isotopic data is fraught with difficulty. The mobility of both uranium and lead also leads to complications, as ore minerals may interact with later fluids, and there could be more than one generation of uranium mineralization in a given deposit. Multigrain analytical methods may thus yield ages that reflect mixtures of such material, and lack geological significance. Although the unmineralized host rocks to the uranium may be more amenable to dating using a variety of methods, this information is of limited value if mineralization is epigenetic, unless it can be coupled with ages from units that clearly postdate mineralization. However, the identification of the latter may, in itself, be problematic. For example, barren dykes that generally appear to postdate mineralization may host pockets of radioactivity elsewhere, because uranium has been remobilized locally. Interpretation of any results from such situations is unavoidably subjective.

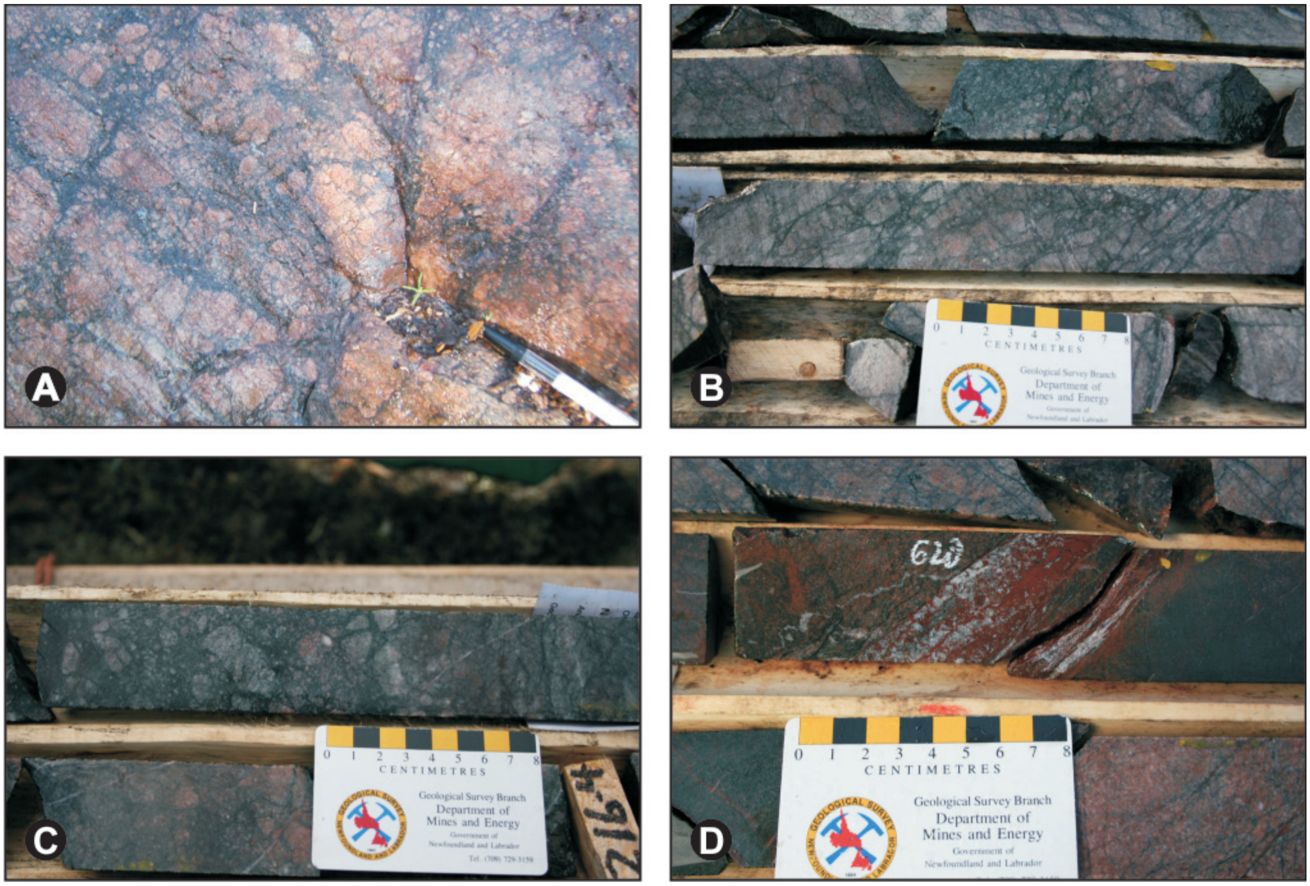

Plate 8. *Representative photographs of uranium mineralization at the Two-Time Zone. A) Outcrop of well-developed, mineralized hydrothermal breccia, reminiscent of "tuffisite" textures developed in some high-level plutonic rocks. B) Pervasive fracturing and localized brecciation developed within granitoid rocks of the Kanairiktok intrusive suite, marginal to a mineralized zone. C) More extensive brecciation associated with higher grade mineralization, showing fragments of altered granitoid rocks in a chlorite–hematite-rich matrix. D) Contact of a post-mineralization mafic dyke (dark material); intense hematization and elevated radioactivity at the dyke contact is considered to reflect local remobilization of uranium from the surrounding mineralized granitoid rocks.*

This short section summarizes existing geochronological information on uranium mineralization in the CMB. Most of this comes from studies of uraninite (termed pitchblende in older reports) reported by Gandhi (1978), Evans (1980), Kontak (1980) and Wilton and Longerich (1993). Under ideal circumstances, such data provide direct information on the timing of mineralization, but this may not be the case for many CMB results. Indirect constraints on the timing of mineralization are mostly maximum ages provided by dates from the host rocks or (more rarely) minimum ages provided by results from rocks (or events) that postdate mineralization.

SUMMARY OF U-Pb URANINITE AGES

Gandhi (1978) reported U-Pb ages from several uranium deposits in the eastern CMB, including Kitts and Michelin, but did not provide the numerical isotopic data upon which these were based. The oldest near-concordant U-Pb ages were from Kitts, which gave a $^{207}Pb/^{206}Pb$ age of ca. 1730 Ma, and the John Michelin showing, which gave an age of ca. 1745 Ma. Note that this latter showing should not be confused with the Michelin deposit proper. The data from Michelin itself were also close to concordia, but indicated a significantly younger $^{207}Pb/^{206}Pb$ age of ca.1244 Ma; an age of 1364 Ma was indicated for the nearby "Emben showing", which is now referred to as Otter Lake by Aurora Energy Resources. Data from other deposits in the same general area as Kitts (Gear and Inda deposits) plotted well above concordia, suggesting significant isotopic disturbance (likely uranium loss), and the original Pitch Lake showing gave a relatively young $^{207}Pb/^{206}Pb$ age of 934 Ma. Taken together, these data were not very informative, although the age from Kitts was consistent with what was known at the time concerning the age of its host rocks and the age of "Hudsonian deformation" that had affected the deposits (Gandhi, 1978).

At face value, the ages from the Michelin deposit indicated that it was much younger than its metavolcanic host rocks, which were at that time constrained by Rb-Sr isochron ages of ca. 1676 Ma (Gandhi, 1978). However, the samples from Michelin and Emben (Otter Lake) were collected from vein-style mineralization rather than the dominant disseminated material. Gandhi (1978) interpreted the younger ages to reflect remobilization of uranium during a later event, rather than primary ages for the mineralization, which he considered syngenetic. Direct U-Pb dating of the dominant disseminated uranium mineralization at Michelin has not been attempted to date, but such results would obviously be of great interest.

Subsequent studies of the Kitts deposit provided broadly similar results to those reported by Gandhi (1978). Kontak (1980) analyzed several samples and obtained broadly concordant $^{207}Pb/^{206}Pb$ ages ranging from 1720 to 1780 Ma; based on the most concordant samples, an age of ca. 1770 Ma was suggested. A later ICP-MS study by Wilton and Longerich (1993) obtained essentially identical $^{207}Pb/^{206}Pb$ ages of 1758 ± 3 Ma and 1777 ± 9 Ma, with both results plotting close to concordia. Wilton and Longerich (1993) also obtained an age of 1766 ± 8 Ma for the John Michelin showing, similar to previous results reported by Gandhi (1978), but their results for the Inda prospect and Pitch Lake showing were distinctly different. Their age from Inda of 1738 ± 5 Ma was slightly discordant, but below concordia, and their data from Pitch Lake indicated a much younger (Paleozoic) age of 495 ± 7 Ma, compared to the previous estimate of 934 Ma. Ages for other (generally minor) uranium occurrences reported by Wilton and Longerich (1993) ranged from ca. 1805 Ma to ca. 1697 Ma, but some of these data plotted above concordia, and are thus more difficult to interpret. Wilton and Longerich (1993) suggested that the ca. 1740 Ma mean age obtained from all of their data (excluding Pitch Lake) had geological significance reflecting a common metallogenic event associated with late-stage plutonism in the Makkovik Province.

Evans (1980) employed a somewhat different approach using microprobe analyses of uraninite grains for U and Pb, which can be interpreted in the form of a "chemical isochron" expressing the time required to generate all Pb via radioactive decay. This method carries certain assumptions, notably that the uraninites were originally Pb-free, and that there was no subsequent gain or loss of Pb. Using this approach, Evans (1980) obtained ages for the Kitts deposit (ca. 1785 Ma), the Inda prospect (ca. 1844 Ma) and the Nash deposit (ca. 1795 Ma). The same method was applied to Michelin, where results suggested a much younger age of ca. 1017 Ma.

Kontak (1980) also analyzed uraninites from volcanic-hosted mineralization in the Burnt Lake area, east of Michelin (discussed above). The $^{207}Pb/^{206}Pb$ ages of 1770 Ma and 1680 Ma corresponded reasonably well with the Rb-Sr isochron ages available at the time from the host volcanic rocks. He suggested that these results recorded the original timing of uranium mineralization in the area, and that the ages previously reported by Gandhi (1978) from Michelin and Emben (Otter Lake) recorded resetting and/or remobilization during the Grenvillian Orogeny. He pointed out that many of the U-Pb data from uraninites in the CMB fall on a linear array that had an upper intercept of about 1800 Ma, and a lower intercept of about 1000 Ma, suggesting variable lead-loss from Paleoproterozoic mineralization during the Grenvillian Orogeny.

In the western part of the CMB, the study of Kontak (1980) provides the only U-Pb data on uraninites, but these results are difficult to interpret. At the Moran Lake C-Zone, analyzed samples came from the mineralized breccias hosted by altered mafic volcanic rocks (Upper C-Zone), and did not include any mineralization hosted by sandstones in the lower C-Zone. None of the three samples analyzed were concordant, but they had $^{207}Pb/^{206}Pb$ ages from 1540 Ma to 1470 Ma; an isochron suggested an age of ca. 1590 Ma. This is consistent with the assignment of the host rocks to either the Moran Lake Group or the Bruce River Group, but its geological significance is questionable. Kontak (1980) also analyzed samples from the Moran Lake B-Zone, hosted within the Bruce River Group sedimentary rocks. Most of these data were also strongly discordant, but the one concordant analysis had a $^{207}Pb/^{206}Pb$ age of ca. 1740 Ma; his suggested isochron age was ca. 1785 Ma. This result conflicts with the age of the Bruce River Group host rocks, defined at the time by a Rb-Sr isochron of 1538 ± 25 Ma (reported by Ryan, 1984). It remains in conflict with the subsequent U-Pb age of ca. 1650 Ma from the Bruce River Group (Schärer *et al.*, 1988), although it must be pointed out that ages from the Bruce River Group characterize the volcanic rocks in the upper part of the sequence, rather than the lower sedimentary sequence.

Kontak (1980) also analyzed samples from the Stormy Lake showing, which all plotted above concordia, and had $^{207}Pb/^{206}Pb$ ages of 1230 Ma to 650 Ma. He suggested that two ages of 990 Ma and 860 Ma were the most reliable results, and suggested that mineralization formed during the waning stages of the Grenvillian Orogeny.

The information from direct U-Pb dating of uraninites is not easily interpreted, but it is clear that many of the $^{207}Pb/^{206}Pb$ ages, particularly from areas outside the Grenville

Province, fall into the interval between 1800 and 1700 Ma. This pattern is illustrated well by a simple histogram of available data (Figure 7), and it must have some geological significance. Even if the ages do not truly indicate the time of mineralization, they do suggest that the late Paleoproterozoic was an important period of uranium deposition in the CMB. Note that younger ages for the most part come from areas within the Grenville Province.

SUMMARY OF INDIRECT AGE CONSTRAINTS

In the case of the Post Hill group, which hosts the Kitts deposit and several other prospects, there is little reliable information on the exact age of the host rocks. Ketchum *et al.* (2001) obtained an age of ca. 2178 Ma from rocks inferred to be in the lowermost part of the sequence, but also suggested on the basis of detrital zircon populations that a metasedimentary formation inferred to be stratigraphically below mineralization was actually younger than ca. 2013 Ma. Mineralization at Kitts was affected by strong deformation and is locally folded; the timing of this deformation is considered to be ca. 1800 Ma, based on U-Pb ages from foliated and massive plutonic rocks (Kerr *et al.*, 1992), and also from migmatitic granites and syntectonic pegmatites in nearby areas (Schärer *et al.,* 1988; Ketchum *et al.*, 1997). Based on what is presently known about geological relationships, this provides a minimum age for mineralization at Kitts, indicating that the U-Pb ages from uraninites are too young, although they still may have geological significance.

Similar arguments apply to mineralization hosted within the Aillik Group, including Michelin and Jacques Lake. The U-Pb data on these rocks indicate that the felsic volcanic precursors crystallized ca. 1860 Ma (Schärer *et al.*, 1988; Ketchum *et al.*, 2002). Younger magmatic events are indicated by quartz-feldspar porphyry of ca. 1807 Ma age, which corresponds well with the ages of both syntectonic and posttectonic plutonic rocks throughout the area (Kerr *et al.*, 1992; Ketchum *et al.*, 2001). If these latter ages provide minimum constraints on the deformation that affected the Aillik Group, it is hard to escape the conclusion that uranium must have been introduced prior to ca. 1800 Ma. The Mesoproterozoic U-Pb uraninite ages from the Michelin deposit thus cannot indicate the time when most of the mineralization formed, as pointed out by Gandhi (1978). Using similar reasoning, mineralization hosted by deformed granitoid rocks at Melody Lake must be younger than its ca. 1895 Ma host rocks, but older than ca. 1800 Ma deformation; however, the age of the host rock in this case is dependent on correlation with a dated unit.

The indirect age constraints on other types of mineralization discussed in this report are generally poor. The ca. 2838 Ma age for the Kanairiktok intrusive suite provides a maximum age only for mineralization at the Two-Time Zone. The post-mineralization dykes noted here, and also the Kanairiktok Bay showing, are of interest, but remain undated. The leucogranites and pegmatites that contain uranium at the Dandy prospect likely correlate with synkinematic intrusions dated at 1870 ± 2 Ma by Ketchum *et al.* (2001), but the dated samples come from a different locality. Although the Moran Lake Group is commonly correlated with the Post Hill group, it has never been dated accurately. It is unconformably overlain by the Bruce River Group, of which the uppermost formations are dated at ca. 1650 Ma, so this provides a minimum age for its deposition; its maximum age is provided by the ca. 2230 Ma Kikkertavak dykes that cut older basement rocks. Thus, the reinterpretation of the host rocks to the Moran Lake Upper C-Zone as part of the Moran Lake Group, rather than the Bruce River Group, renders the timing of uranium mineralization very uncertain. The data from uraninite analyses in the Upper C-Zone suggest a much younger (ca. 1590 Ma) age, but may be unreliable. As discussed previously, relationships at the Anomaly 15 locality may imply that some mineralization in the Moran Lake Group predates deposition of much of the Bruce River Group (B. Ryan, personal communication, 2008), but no such constraint exists in the immediate area of the Upper C-Zone.

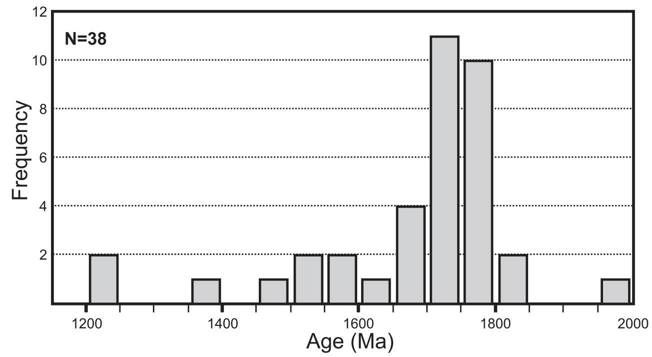

Figure 7. *Histogram of $^{207}Pb/^{206}Pb$ ages obtained from analyses of uraninites from uranium deposits in the CMB of Labrador. The original data for the diagram were obtained from Gandhi (1978), Kontak (1980) and Wilton and Longerich (1993).*

However, the nearby mineralization in the sedimentary rocks of the Bruce River Group must be younger than ca. 1650 Ma, assuming that the age from the volcanic rocks of the Sylvia Lake Formation does indeed apply to the sedimentary rocks in the lower part of the group.

DISCUSSION

The diversity of the uranium mineralization in the CMB of Labrador is truly bewildering. Not only does uranium occur within a wide variety of igneous, metamorphic and sedimentary rock types, but there is significant variation in geometry, alteration signatures and geochemical associations amongst deposits hosted in a common rock type. It is naïve to assume that a single classification or genetic model could accommodate such diversity, and it is more likely that several different processes contributed to the introduction of uranium and its subsequent remobilization and redistribution over time. The final section of this report evaluates and discusses the key features of the 9 types of uranium mineralization described above in terms of classifications for uranium deposits (*e.g.*, Dahlkamp, 1993) and wider ideas about the genesis of mineralization. The following discussion is preliminary, but is an important step in developing better genetic and exploration models, and also in developing a research program that might fill important gaps in the data and resolve at least some of the contradictions. It goes without saying that opinions expressed below are tentative and subject to change.

In a general sense, the 9 types of mineralization can be divided into three broad categories according to the processes that were likely involved in their formation. On this basis, this section is broken into separate discussions of uranium deposits considered to be of largely magmatic origin, metamorphic and/or metasomatic origin, and sedimentary origin.

URANIUM MINERALIZATION OF BROADLY MAGMATIC ORIGIN

Within this category, there are likely two variants. Uranium mineralization assigned to Types 1 and 3 are considered to be of syngenetic magmatic origin, *i.e.*, spatially, temporally and genetically associated with felsic plutonic and volcanic host rocks, respectively. In contrast, uranium mineralization assigned to Types 7 and 8 are considered to be epigenetic with respect to the host rocks, and of magmatic-hydrothermal affinity (although the genetically associated magmatic rocks are not presently identified). Minor uranium mineralization assigned to Type 9 (hydrothermal veins) also falls into this latter group.

Syngenetic Magmatic Uranium Mineralization

Uranium deposits assigned to Type 1 above correspond well to "intrusive deposits", as defined by Dahlkamp (1993). Deposits of this type consist of primary disseminated, non-refractory uranium minerals in rocks of intrusive magmatic or anatectic origin. There are subtypes associated with specific rock types, namely alaskite, quartz-monzonite, carbonatite, peralkaline syenite and pegmatite. The most significant uranium deposit of this type is the Rossing mine in Namibia, southern Africa, which contains about 390 million pounds of U_3O_8, in sheeted alaskite and pegmatite, with a low average grade of some 0.035% U_3O_8 (compilation of Thomas *et al.*, 2007). This style of deposit was employed as an exploration model by Bayswater Uranium Corporation at their Dandy prospect and, at least in terms of geological environment, it seems an appropriate choice. However, the nature of the uranium-bearing mineral at this prospect remains to be determined. The sheeted pegmatite and leucogranite veins at the Dandy prospect are generally low in grade, and there is every indication that the uranium was concentrated by fractionation of evolved granitic magmas. Uraniferous pegmatites discovered at other localities within the Nain Province probably have similar origins, although the mineralization at these appears to be of more limited extent than at the Dandy prospect.

This type of syngenetic magmatic mineralization likely includes some of the earliest uranium concentrations in the CMB, if the age of 1870 ± 2 Ma obtained by Ketchum *et al.* (2002) applies to the Dandy prospect host rocks. Uraniferous pegmatites at the Kanairiktok Bay showing are cut by metamorphosed dykes that may correlate with the ca. 2236 Ma Kikkertavak dykes, suggesting that this mineralization could be older still, and perhaps Archean. Early periods of magmatic uranium mobilization and deposition in the Archean Nain Province and its reworked equivalents may have wider importance, as the same rocks likely underlie much of the CMB. Widespread but small-scale magmatic uranium concentrations of this type could provide important source regions for uranium mobilized through younger magmatic or hydrothermal processes.

Uranium deposits assigned to Type 3 above correspond best to "volcanic deposits", as defined by Dahlkamp (1993). These syngenetic, magmatic deposits associated with felsic volcanism include both structurally controlled and stratabound styles of mineralization (Dahlkamp, 1993). Uranium deposition is generally linked to the broadly synvolcanic movement of hydrothermal and/or meteoric fluids within the volcanic pile. The source of the uranium is believed to be the host volcanic sequences, from which it is released by devitrification of volcanic glass. Uranium is subsequently deposited within favourable horizons in the volcanic stratigraphy, or localized in synvolcanic or slightly younger fault zones. Uranium is commonly associated with Cu, Mo, Sn, W, F, Th and rare-earth element (REE) enrichment. The associated alteration is varied, and includes albitization, hematization, silicification, and clay-mineral (argillic) alteration. Many examples are associated with felsic volcanic sequences of alkaline to peralkaline type that are regionally enriched in U (up to 20 ppm). Several volcanic-hosted deposits have produced uranium, but most examples tend to be small and low-grade. In a recent review of global data, Thomas *et al.* (2007) indicated a mean size of some 2.4 million pounds of U_3O_8, at a mean grade of 0.13% U_3O_8. The largest known example (and the only current producer) is the Streltsovska deposit in Russia, which contains in excess of 200 million pounds of U_3O_8, at a higher average grade of some 0.21% U_3O_8.

The Aillik Group is a compositionally evolved volcanic sequence that is alkali–calcic to alkaline in affinity (Gower *et al.*, 1982; Kerr, 1989). Studies of glass inclusions also suggest that the parental magmas were of alkaline affinity (Payette and Martin, 1986). The Bruce River Group is a potassic, calc-alkaline volcanic suite that tends instead toward peraluminous compositions (Ryan, 1984; Kerr, 1989). Volcanic-hosted uranium deposits are known to occur in rocks of broadly equivalent compositions around the world (Dahlkamp, 1993). Mineralization in the Burnt Lake area (Aillik Group) and in the Sylvia Lake area (Bruce River Group) exhibits many of the features listed above for volcanic-hosted uranium deposits. Some of the uranium mineralization in the eastern CMB, south of Makkovik, could also be of this type, although a hydrothermal vein association (Type 9) is also possible. Much of the mineralization at the Stormy Lake showing is probably also of this general type, although it lies in close proximity to the unconformity at the base of the Seal Lake Group.

It is likely that the Aillik Group contains syngenetic, volcanic-related uranium deposits other than those noted above, but locally strong deformation and recrystallization complicates their recognition. Previous models for uranium mineralization in the eastern CMB (*e.g.*, Gandhi, 1978, Evans, 1980; Gower *et al.*, 1982) classified the important Michelin deposit as an example of a strongly deformed but originally synvolcanic deposit, and Dahlkamp (1993) actually lists Michelin as an example of such. This interpretation certainly remains possible, but information from renewed exploration indicates a very strong structural control on this deposit, implying that it could instead represent an epigenetic-style deposit hosted in a regional shear zone, temporally associated with deformation and metamorphism of its host rocks. This option is preferred here, and discussed in more detail below. However, it must be stressed that many key aspects of uranium mineralization at Michelin remain enigmatic, and that the timing relationship between the introduction of uranium and deformation is anything but clear. The possibility that Michelin represents a strongly deformed example of originally synvolcanic mineralization (cf., Gower *et al.*, 1982) cannot be discounted on the basis of existing data. Resolution of this problem is only possible through geochronological data that can confidently be interpreted to record the timing of mineralization, rather than subsequent events. The acquisition of such data is unlikely to be easy.

Epigenetic Magmatic-Hydrothermal Mineralization

Uranium mineralization assigned to Types 7 and 8, *i.e.*, deposits associated with breccia zones developed in mafic volcanic rocks or granitoid rocks, is considered to be of magmatic-hydrothermal origin. Specifically, these deposits are believed to have affinities to so-called "Iron-Oxide–Copper–Gold" deposits, or IOCG deposits. This is not a new concept in CMB geology, as it was in part responsible for the resumption of exploration activity prior to recent increases in uranium prices. The similarity between the Moran Lake Upper C-Zone and some IOCG deposits was noted by exploration geologists, and this model is presently used by Crosshair Exploration and Mining as an exploration model in the Moran Lake area (e.g., LaCroix and Cook, 2007).

The classification of Dahlkamp (1993) does not include IOCG deposits as such, because they were not widely recognized at that time, and none are mined for uranium as a primary commodity. Iron-oxide–copper–gold deposits are a broad class of magmatic-hydrothermal ore deposits characterized by iron-rich metasomatism, and associated with calc-alkaline to alkaline magmas. They are a complex subject well beyond the scope of this report and readers are referred to a review by Corriveau (2007) for more details and information on Canadian examples. The best-known IOCG deposit is the giant Olympic Dam deposit in Australia, which contains some 3810 million tonnes at 1.1 % Cu, 0.5 g/t Au and 0.04% U_3O_8. Although uranium is a byproduct of copper mining, Olympic Dam represents the largest single global resource of uranium (aside from black shales and phosphorites) with some 3.4 billion pounds of contained U_3O_8 (compilation by Thomas *et al.*, 2007). Several other IOCG deposits are reported to have uranium enrichment, but quantitative data on their U_3O_8 grades are not easily located. Most such deposits are primarily resources of Fe and Cu, with variable amounts of Au, Ag, Bi and REE (Corriveau, 2007).

The Moran Lake Upper C-Zone deposit (Type 7) and the recently discovered Two-Time Zone (Type 8) have many features in common, despite differences in their host rocks. They share some features of IOCG deposits, most notably the presence of textures suggesting hydrothermal brecciation, and iron-rich alteration. At the present time, these are the only CMB uranium deposits in which iron metasomatism is clearly documented. However, both deposits are uranium-rich, rather than being strongly enriched in Cu, Au and Ag. There is some enrichment in these latter elements in the Upper C-Zone, and this also contains significant amounts of vanadium. If these deposits are of magmatic-hydrothermal origin, the identity and location of any associated magmatic rocks remains obscure. However, the CMB contains abundant granitoid plutonic rocks emplaced between ca. 1800 Ma and ca. 1650 Ma, so there is no shortage of candidates on a regional scale.

The age(s) of the mineralizing event(s) manifested at these deposits are a subject of some interest. The host rocks at the Upper C-Zone must be older than 1650 Ma, and are possibly as old as 2100 Ma. However, mineralization could be much younger than the host rocks. The host rocks at the Two-Time Zone are of presumed Archean age and thus offer few constraints on the timing of mineralization. However, the breccia zones at this prospect are cut by diabase dykes for which the most obvious correlatives are the ca. 2236 Ma Kikkertavak dykes. If this inference is correct, it implies that the mineralization at Two-Time is significantly older than that at the Upper C-Zone, and it could even be of Archean age. The post-mineralization dykes at the Two-Time Zone are thus an obvious target for geochronology.

Finally, uranium mineralization associated with hydrothermal veins (Type 9) in the eastern part of the CMB, notably around Makkovik and Round Pond, corresponds well with the features of magmatic-hydrothermal vein-type deposits, as described by Dahlkamp (1993).

URANIUM MINERALIZATION OF METAMORPHIC AND/OR METASOMATIC ORIGIN

This category is tentatively considered to include some of the most important deposits in the region, *i.e.*, those of Type 4, associated with zones of strong deformation and metasomatism in metamorphosed felsic volcanic rocks. These deposits include Michelin and Jacques Lake, and several smaller examples. It is further suggested that mineralization associated with shearing and alteration in granitoid rocks (Type 2, *e.g.*, Melody Hill) also belongs to this category, rather than being of synmagmatic origin. The potentially important uranium mineralization hosted by metapelitic (argillaceous) rocks at the Kitts deposit and related prospects (Type 5) continues to be problematic in terms of origins. However, following previous workers (*e.g.*, Evans, 1980; Gower *et al.*, 1982), it is tentatively suggested that this belongs to the same family of deposits, even though the host rocks are very different. It is interesting to note that early genetic models for the uranium deposits in the Kitts–Post Hill area (Marten, 1977; Evans, 1980) suggested that uranium was introduced synchronously with strong deformation and shear-zone development. The recognition of important structural controls at Michelin during recent exploration work (*e.g.*, O'Dea, 2005) has revived interest in this model, and it is currently used as an exploration model by Aurora Energy Resources.

The host rocks to mineralization of Types 2, 4 and 5 are obviously different, but all of these host rocks formed prior to ca. 1800 Ma, and they were all affected by deformation of this age. All these deposits are characterized by strong deformation of their host rocks, and those in the Aillik Group appear to be related to an important shear zone of regional extent. The same argument can be made for Kitts and other uranium deposits in the Post Hill group, where the host metasedimentary unit is a locus for intense deformation. Deposits of Types 4 and 5 are known to be associated with soda-metasomatism and potash depletion, and Na-bearing minerals such as aegrine–augite and arfvedsonite are reported from Michelin (Evans, 1980). However, these alteration patterns are not yet established for granitoid-hosted deposits assigned to Type 2.

A possible analogue for these deposits is provided by a class of uranium deposits termed "metasomatites" by Dahlkamp (1993). Further information is presented in a review by Barthel (1987). These are defined as disseminated uranium deposits in strongly deformed rocks that were affected by sodic metasomatism (*i.e.*, albitization). In some earlier classifications of uranium deposits, they were termed "albitite" deposits. We do not find either label entirely satisfactory, but we lack a suitable alternative to put forward at this time. Metasomatite or albitite deposits of this type are mostly known from the Baltic Shield region and from Russia, and there is thus limited published information in English to facilitate detailed comparisons. Dahlkamp (1993) states that deposits of this type are hosted by strongly deformed granites and by metasedimentary rocks, which exhibit pervasive sodic metasomatism and the development of Na-rich minerals such as aegirine–augite and arvfvedsonite (sodic amphibole). The regional host rocks to such deposits commonly have elevated uranium contents, suggesting that they were the source for much of the uranium. Enrichment in Zr, REE, P and Ti is also a feature of at least some of these deposits, and the grades are akin to those observed in the CMB, *i.e.*, generally <0.5% U_3O_8 (Barthel, 1987; Dahlkamp, 1993; G. Zaluski, personal communication, 2007). Although felsic metavolcanic rocks are not specifically listed as host rocks by Dahlkamp (1993), there seems to us no reason why such deposits could not form within them, and other sources (Barthel, 1987; G. Zaluski, personal communication, 2007) indicate that some examples have metavolcanic host rocks. Available information (Dahlkamp, 1993) suggests that most examples of "metasomatite" or "albitite" uranium deposits are relatively small in terms of contained U_3O_8 (*i.e.*, generally less than 1 million pounds of U_3O_8). If the Michelin and Jacques Lake deposits belong to this class, they may be the largest examples yet recognized, and may in time act to better define the characteristics of this class.

Some current classifications of so-called IOCG deposits are extremely broad, and could potentially include deposits known elsewhere as “albitites” or “metasomatites”. Corriveau (2007) included a brief discussion of the CMB as a potential IOCG province on this basis. Although we concur that some aspects of this mineralization might fit within such expanded “IOCG-type” models, we believe that its distinct features require that it be treated differently in terms of controls and genesis.

This suggestion is presently tentative, and more research is required to establish if the deposits described from the Baltic Shield and Russia provide valid analogues for Michelin, Jacques Lake and perhaps Kitts. The published information on such deposits is very limited, and much of it is in Russian. If the suggested association does not stand up to detailed examination, these important deposits in Labrador have no obvious analogues amongst existing classifications of uranium deposits.

URANIUM MINERALIZATION IN SEDIMENTARY ENVIRONMENTS

Disseminated uranium mineralization in sandstones and conglomerates of the Bruce River Group (Type 6) seems to have affinities with much younger sandstone-type uranium deposits. According to Dahlkamp (1993), deposits of this type are hosted by marginal marine or terrestrial clastic sedimentary rocks. Mineralization forms via the actions of oxidized meteoric waters, which transport uranium and deposit it when they encounter reducing environments. There are several varieties, which are controlled by sedimentary facies and also by crosscutting faults, but all such deposits reflect the same basic process. The potential source of the uranium in these occurrences could be the host sedimentary sequence as in the Moran Lake B-Zone prospect, but may also be sourced from uranium-enriched basement rocks or from overlying felsic volcanic successions. Deposits of this type are important sources of uranium around the world, and some are of considerable size; the Beverly deposit in Australia contains almost 100 million pounds of U_3O_8, at a relatively high grade of 0.18% U_3O_8 (compilation by Thomas *et al.*, 2007). Many deposits of this type contain associated vanadium, however, deposits of this type are for the most part hosted by Phanerozoic sedimentary sequences, and there are few known Precambrian examples. It is generally inferred that organic matter (notably plant and animal debris) played an important role in controlling local redox conditions. Mineralization in sandstones is also locally associated with unconformity-style deposits such as those in the Athabasca basin, where it is controlled by similar oxidation-reduction reactions in permeable strata. However, mineralization in unconformity-related settings commonly also involves basement rocks at or beneath the unconformity, coupled with intense local alteration of both basement and cover.

The uranium mineralization in the Moran Lake Lower C-Zone is visibly associated with local zones of reduction in generally oxidized sedimentary rocks, and it is associated with significant vanadium enrichment. On this basis, analogies with younger sandstone-hosted uranium deposits, or perhaps unconformity-style deposits, are worthy of some consideration. The proximity of this mineralization to the basal unconformity of the Bruce River Group, and to the uranium mineralization of the Upper C-Zone (see *above*) suggests that there may have been a local source for uranium, which could have been remobilized into the overlying sedimentary sequence and precipitated through redox effects. Such a model is consistent with the host rocks to the Upper C-Zone sitting below those of the Lower C-Zone prior to Grenvillian thrusting, but it would also require that the mineralization in the former zone developed prior to ca. 1650 Ma.

POTENTIAL FOR UNCONFORMITY-STYLE URANIUM MINERALIZATION

Unconformity-style deposits, exemplified by those of the Athabasca basin and parts of northern Australia, are amongst the most important sources of uranium in the world. Of the ten largest uranium deposits known, three are of this type (McArthur River and Cigar Lake in Saskatchewan, and Jabiluka in Australia), and each of these contains more than 400 million pounds of U_3O_8 (compilation by Thomas *et al.*, 2007). Deposits of this type are associated spatially with regional unconformities between intracontinental quartz-rich clastic sedimentary basins and older basement rocks. The uranium mineralization occurs in lenses, veins, breccias and replacement bodies located both above and below the unconformity. Post-depositional fault systems and conductive graphitic zones in the underlying basement exert the most important local controls on the development of mineralization. These deposit types are a complex subject in their own right, and their origins are a subject of much debate. These details are beyond the scope of this report; Jefferson *et al.* (2007) provide the most recent review, focused on Canadian examples.

The CMB of Labrador contains three regional unconformities (Figure 1). The Moran Lake Group sits unconformably upon the Archean basement of the Nain Province, and the lowermost strata consist of marine sedimentary rocks including siltstones, quartzites and dolostones. It is in turn overlain unconformably by the Bruce River Group, which includes a lower sequence of sandstones and conglomerates of terrestrial origin. The most widespread unconformity is at the base of the Seal Lake Group, which sits upon Archean basement, the Moran Lake Group, the Bruce River Group and also upon a variety of granitoid rocks. Farther to the west, beyond the traditional confines of the CMB, the Seal Lake Group sits upon metamorphic rocks of the Churchill Province, Mesoproterozoic anorthosites and granites, and also upon felsic volcanic rocks of the Letitia Lake Group.

The Stormy Lake showing, west of Nipishish Lake (Figure 2) has for many years been viewed as a possible example of unconformity-style mineralization at the base of the Seal Lake Group, based upon previous descriptions (summarized by Ryan, 1984). The exact position of the unconformity at this location is difficult to discern, and observations in 2007 suggest that the host rocks to most of the mineralization are felsic volcanic rocks of the Bruce River Group, and that only low-level radioactivity is present in the Seal Lake Group conglomerates and sandstones. The mineralization has many features in common with occurrences hosted by the Bruce River Group in areas where no nearby unconformity is present.

At the present time, the most obvious target area for unconformity-style deposits is the basal unconformity of the Bruce River Group, for which there is empirical evidence of spatially associated mineralization. The mineralization at the Moran Lake Lower C-Zone and at Moran Heights lies very close to the base of the Bruce River Group. The Upper C-Zone mineralization is located in close proximity to the base of the Bruce River Group, but its temporal relationship to the unconformity is not completely clear. At the present time, we prefer to view the Upper and Lower C-zones in terms of different processes, but much remains to be learned about this area.

Finally, the extensive basal unconformity of the Seal Lake Group should not be discounted as a possible target area for future exploration, even though the relationship between the Stormy Lake showing and the unconformity may be coincidental (see previous discussion, page 205). There is some evidence of minor radioactivity in conglomerates above the unconformity, and elsewhere in the Seal Lake Group (Marten and Smyth, 1975), and this regional environment has yet to be systematically explored.

CONCLUSION

More than 50 years have passed since uranium was first discovered in Labrador, but many of the questions asked at the very beginning (*e.g.*, Beavan, 1958) remain to be answered. Large amounts of data were collected in the first phase of exploration in the CMB, but relatively little has been published concerning this diverse and interesting uranium district. The recent resurgence of exploration, and the prospect of future production from deposits such as Michelin, promise a new era of exploration and research. The discussion in this report is of necessity preliminary in nature, and it is likely that parts of it will be proved incorrect by future research. Nevertheless, we hope that it will provide useful information for explorationists, and also a useful focus for discussion that will guide the course of more systematic research in years to come.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of Justin Quinton in the field. The exploration companies active within the CMB region, which are too numerous to mention, are thanked sincerely for their assistance and hospitality, and for allowing access to their properties and drill core. The interest and cooperation of the exploration community was invaluable in conducting field work during 2007. Wayne Tuttle is thanked for logistical assistance, and for making sure that we were able to get in and out of remote locations more-or-less on schedule. The article was reviewed comprehensively by Bruce Ryan, who is thanked for many suggestions that improved its content.

REFERENCES

Barthel, F.H.
1987: Uranium occurrences in albitized rocks. *In* Uranium Mineralization: New Aspects of Geology, Mineralogy, Geochemistry and Exploration Methods. Gerbruder-Borntraeger, Berlin and Stuttgart, pages 1-9.

Beavan, A.P.
1958: The Labrador uranium area. Geological Association of Canada Proceedings, Volume 10, pages 137-145.

Bernazeud, J.
1965: Labrador uranium project, progress report for 1965. Unpublished Mokta report on file with Newfoundland Department of Mines and Energy, Mineral Development Division.

Brummer, J.J. and Mann, E.L.
1961: Geology of the Seal Lake area. Bulletin of the Geological Society of America, Volume 72, pages 1361-1382.

Cadman, A.C., Heaman, L., Tarney, J., Wardle, R.J. and Krogh, T.E.
1993: U-Pb geochronology and geochemistry within two Proterozoic mafic dyke swarms, Labrador. Canadian Journal of Earth Sciences, Volume 30, pages 1490-1504.

Cooke, B.J.
1980: Re-evaluation of uranium mineralization, C zone, Moran Lake Property, Central Mineral Belt, Labrador. Shell Canada Limited, unpublished assessment report.

Corriveau. L
2007: Iron oxide-copper-gold deposits: A Canadian perspective. Geological Association of Canada, Mineral Deposits Division, Special Publication 5, pages 307-328.

Culshaw, N.G., Brown, T., Reynolds, P.H. and Ketchum, J.W.F
2000: Kanairiktok shear zone: the boundary between the Paleoproterozoic Makkovik Province and the Archean Nain Province, Labrador. Canadian Journal of Earth Sciences, Volume 37, pages 1245-1257.

Culshaw, N.G. and Ketchum, J.W.F
1995: The Kaipokok zone of the Makkovik orogen – an early Proterozoic terrane boundary? *In* Eastern Canadian Shield Onshore–Offshore Transect (ECSOOT), Report of the 1994 Transect Meeting. *Compiled by* R.J. Wardle and J. Hall. The University of British Colombia, Lithoprobe Secretariat, Lithoprobe Report 45, pages 7-21.

Culshaw, N., Ketchum, J. and Barr, S.
2000: Structural evolution of the Makkovik Province, Labrador, Canada: tectonic processes during 200 m.y. at a Paleoproterozoic active margin. Tectonics, Volome 19, pages 961-977.

Cunningham-Dunlop, I.R. and Giroux, G.H.
2007: The exploration activities of Aurora Energy Resources on the CMB uranium property, Labrador, Canada, during the period January 2006 to January 2007. Aurora Energy Resources, NI 43-101 Technical Report (filed at www.sedar.com).

Dahlkamp, F.J.
1993: Uranium Ore Deposits. Berlin, Springer-Verlag.

Dayvault, R.D., Castor, S.B. and Berry, M.R.
1985: Uranium associated with volcanic rocks of the McDermitt Caldera, Nevada and Oregon. *In* Uranium Deposits in Volcanic Rocks. IAEA, Vienna, pages 379-410.

Ermanovics, I.F.
1993: Geology of the Hopedale Block, southern Nain Province, and the adjacent Proterozoic terranes, Labrador, Newfoundland. Geological Survey of Canada, Memoir 431, 161 pages.

Ermanovics, I.F. and Raudsepp, M.
1979: Geology of the Hopedale Block of eastern Nain Province, Labrador. *In* Current Research, Part B. Geological Survey of Canada, Paper 79-1B, pages 341-348.

Evans, D.
1980: Geology and petrochemistry of the Kitts and Michelin uranium deposits and related prospects, Central Mineral Belt, Labrador. Unpublished Ph. D. thesis, Queen's University, Kingston, Ontario, 311 pages.

Gandhi, S.S.
1978: Geological setting and genetic aspects of uranium occurrences in the Kaipokok Bay – Big River area, Labrador. Economic Geology, Volume 73, pages 1492-1522.

1984: Uranium in early Proterozoic Aillik Group, Labrador. *In* Proterozoic Unconformity and Stratabound Uranium Deposits. *Edited by* J. Ferguson. IAEA, Vienna, Technical Document 315, pages 35-68.

Gandhi, S.S. and Brown, A.C.
1975: Cupriferous shales of the Adeline Island Formation, Seal Lake Group, Labrador. Economic Geology, Volume 70, pages 145-163.

Gordonier, W.D.
1979: Central Mineral Belt project, report on exploration, 1979 (winter). Unpublished Shell Canada Resources Limited report on file with Newfoundland Department of Mines and Energy, Mineral Development Division.

Gower, C.F., Flanagan, M.J., Kerr, A. and Bailey, D.G.
1982: Geology of the Kaipokok Bay – Big River area, Central Mineral Belt, Labrador. Newfoundland and Labrador Department of Mines and Energy, Mineral Development Division, Report 82-7.

Hopfengaertner, F., Quarch, H., Harris, J.F. and Fryer, B
1985: First and second year assessment report on geological, geochemical, geophysical and trenching exploration for the Heggart Lake project for licences 100m-r1, 106m, 212m-214m and 107m-r1 on property in the Moran Lake and Loon Lake areas, Labrador, 3 reports. Newfoundland and Labrador Geological Survey, Assessment File 13K/0169, 1985, 121 pages.

Jefferson, C.W., Thomas, D.J., Gandhi, S.S., Raemakers, P., Delanet, G., Brisban, D., Cutts, C., Quirt, D., Portella, P. and Olson, R.A.
2000: Unconformity-associated uranium deposits of the Athabaska Basin, Saskatchewan and Alberta. Geological Association of Canada, Mineral Deposits Division, Special Publication 5, pages 273-307.

Kerr, A.
1989: Early Proterozoic granitoid magmatism and

crustal evolution in the Makkovik Province of Labrador: A geochemical and isotopic study. Unpublished Ph.D. thesis, Memorial University of Newfoundland, 528 pages.

1994: Early Proterozoic magmatic suites of the eastern Central Mineral Belt (Makkovik Province), Labrador: Geology, geochemistry and mineral potential. Newfoundland Department of Mines and Energy, Geological Survey, Report 94-3, 149 pages.

Kerr, A., Krogh, T.E., Corfu, F., Schärer, U., Gandhi, S.S. and Kwok, Y.Y.
1992: Episodic Early Proterozoic granitoid plutonism in the Makkovik Province, Labrador: U-Pb geochronological data and geological implications. Canadian Journal of Earth Sciences, Volume 29, pages 1166-1179.

Kerr, A., Ryan, B., Gower, C.F. and Wardle, R.J.
1996: The Makkovik Province: extension of the Ketilidian Mobile Belt in mainland North America. *In* Precambrian Crustal Evolution in the North Atlantic Region. *Edited by* T.S. Brewer. Geological Society of London, Special Publication No. 111, pages 155-177.

Kerr, A., Wardle, R.J., Wilton, D., Sparkes, G. and Hinchey, A.
2007: Uranium in Labrador, Canada: Its geological framework, important new exploration results and metallogenic questions. SGA Meeting, Dublin 2007, extended abstract.

Ketchum, J.W.F., Barr, S.M., Culshaw, N.G. and White, C.E.
2001a: U-Pb ages of granitoid rocks in the northwestern Makkovik Provinces, Labrador: evidence for 175 million years of episodic synorogenic and postorogenic plutonism. Canadian Journal of Earth Sciences, Volume 38, pages 359-372.

Ketchum, J.W.F., Culshaw, N.G. and Barr, S.M.
2002: Anatomy and orogenic history of a Paleoproterozoic accretionary belt: the Makkovik Province, Labrador, Canada. Canadian Journal of Earth Sciences, Volume 39, pages 711-730.

Ketchum, J.W.F., Culshaw, N.G. and Dunning, G. R.
1997: U-Pb geochronological constraints on Paleoproterozoic orogenesis in the northwestern Makkovik Province, Labrador, Canada. Canadian Journal of Earth Sciences, Volume 34, pages 1072-1078.

Ketchum, J.W.F., Jackson, S.E., Culshaw, N.G. and Barr, S.M.
2001b: Depositional and tectonic setting of the Paleoproterozoic Lower Aillik Group, Makkovik Province, Canada: evolution of a passive margin – foredeep sequence based on petrochemistry and U-Pb (TIMS and LAM–ICP–MS) geochronology. Precambrian Research, Volume 105, pages 333-358.

Kontak, D.
1978: Investigation of four uranium showings in the Central Mineral Belt of Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 27-43.

1980: Geology, geochronology and uranium mineralization in the Central Mineral Belt of Labrador. Unpublished M.Sc. Thesis, University of Alberta, Edmonton, 383 pages.

LaCroix, P.A. and Cook, R.B.
2007: Technical Report on the Central Mineral Belt uranium project, Labrador, Canada. Crosshair Exploration and Mining, NI 43-101 Technical Report (filed with www.sedar.com).

Loveridge, W.D., Ermanovics, I.F. and Sullivan, R.W.
1987: U-Pb ages on zircon from the Maggo Gneiss, the Kanairiktok Intrusive Suite and the Island Harbour Plutonic Suite, coast of Labrador, Newfoundland. Geological Survey of Canada, Paper 87-2, pages 59-65.

Marten, B.E.
1977: The relationship between the Aillik Group and the Hopedale gneiss, Kaipokok Bay, Labrador. Unpublished Ph. D. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 389 pages.

Marten, B.E. and Smyth, W.R.
1975: Uranium potential of the basal unconformity of the Seal Lake Group, Labrador. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 75-1, pages 106-115.

MacDougall, C.S.
1988: A metallogenic study of polymetallic granophile mineralization within the early Proterozoic Upper Aillik Group, Round Pond area, Central Mineral Belt, Labrador. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 245 pages.

McKenzie, L.M. and Wilton, D.
1987: Uranium, molybdenum and base-metal mineralization in the Burnt Lake area, central Labrador: three different styles of ore formation. *In* Current Research,

Part A. Geological Survey of Canada, Report 87-1A, pages 457-466.

O'Dea, M.
2005: Fronteer at the forefront of Canada's next major uranium district. Canadian Institute of Mining Conference, St. John's, 2005 (abstract).

Payette, C. and Martin, R.F.
1986: The glass inclusions and mineralogy of rhyolites, Upper Aillik Group, Labrador. Unpublished contract report to the Geological Survey of Canada.

Piche, W.T.
1957: Exploration on the block "D" concession, Labrador, during 1956. Unpublished Frobisher Limited report on file with Newfoundland Department of Mines and Energy, Mineral Development Division.

Plant, J.A., Simpson, P.R., Smith, B. and Windley, B.F.
1999: Uranium ore deposits–products of the radioactive earth. *In* Uranium: Mineralogy, Geochemistry and the Environment. *Edited by* P.C. Burns and R. Finch. Reviews in Mineralogy, Volume 38, pages 255-319.

Romer, R.L., Schärer, U., Wardle, R.J. and Wilton, D.
1995: U-Pb age of the Seal Lake Group, Labrador: relationship to Mesoproterozoic extension-related magmatism in Laurasia. Canadian Journal of Earth Sciences, Volume 32, pages 1401-1410.

Ryan, A.B.
1984: Regional geology of the central part of the Central Mineral Belt, Labrador. Government of Newfoundland and Labrador, Department of Mines and Energy, Mineral Development Division, Memoir 3, 200 pages.
1981: Volcanism, sedimentation, plutonism, and Grenvillian deformation in the Helikian basins of central Labrador. *In* Proterozoic Basins in Canada. *Edited by* F.H.A. Campbell. Geological Survey of Canada, Paper 81-10, pages 361-378.

Ryan, A.B., Kay, A. and Ermanovics, I.F.
1983: Notes to accompany maps 83-38 to 83-41 showing the geology of the Makkovik Subprovince between Kaipokok Bay and Bay of Islands, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, 21 pages.

Schärer, U., Krogh, T.E., Wardle, R.J., Ryan, B. and Gandhi, S.S.
1988: U-Pb ages of early to middle Proterozoic volcanism and metamorphism in the Makkovik Orogen, Labrador. Canadian Journal of Earth Sciences, Volume 25, pages 1098-1107.

Smith, R.L., Marshall, L., Butler, R., Wilton, D.H.C., Madore, C., Annesley, I.R. and Elieff, S.
2004: First year assessment report on geological, geochemical and geophysical exploration for licences 9410M-9417M, 9441M and 9482M on claims in the Post Hill, Burnt Lake, Melody Lake, Michinappi Lake, Croteau Lake, Stormy Lake and Letitia Lake areas, central Labrador, 3 reports. Newfoundland and Labrador Geological Survey, Assessment File LAB/1393, 2004, 280 pages.

Smyth, W.R., Marten, B.E. and Ryan, A.B.
1978: A major Aphebian-Helikian unconformity within the Central Mineral Belt of Labrador: definition of new groups and metallogenic implications. Canadian Journal of Earth Sciences, Volume 15, pages 1954-1966.

Smyth, W.R. and Ryan, B.
1976: Geological setting of the Moran Lake uranium showings, Central Mineral Belt, Labrador. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-1, pages 57-62.

Thomas, A.
1981: Geology along the southeastern margin of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-4, 80 pages.

Thomas, D., Zaluski, G., Brisbin, D. and Drever, G.
2007: Uranium deposit types: in the context of 2007 North American exploration. Canadian Institute of Mining and Metallurgy Meeting, St. John's, NL, November 2007, abstract.

Wardle, R.J.
2005: Uranium in Labrador. Newfoundland and Labrador Department of Natural Resources, commodity series report 5.

Wardle, R.J. and Bailey, D.G.
1981: Early Proterozoic sequences in Labrador. *In* Proterozoic Basins of Canada. *Edited by* F.H.A. Campbell. Geological Survey of Canada, Paper 81-10, pages 331-359.

Wardle, R.J, Gower, C.F., Ryan, B., Nunn, G.A.G., James, D.T. and Kerr, A.
1997: Geological map of Labrador; 1:1 million scale. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Map 97-07.

White, M.V.W. and Martin R.F.
1980: The metasomatic changes that accompany uranium mineralization in the nonorogenic rhyolites of the Upper Aillik Group, Labrador. Canadian Mineralogist, Volume 18, pages 459-479.

Wilton, D.H.C.
1996: Metallogeny of the Central Mineral Belt and adjacent Archean basement, Labrador. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Mineral Resources Report 8, 178 pages.

Wilton, D.H.C. and Longerich, H. P.
1993: Metallogenic significance of ICP-MS-derived trace element and Pb isotope data on uraninite separates from the Labrador Central Mineral Belt. Canadian Journal of Earth Sciences, Volume 30, pages 2352-2365.

Wilton, D.H.C., MacDougall, C.S., MacKenzie, L.M. and Pumphrey, C.
1988: Stratigraphy and metallogeny of the Moran Lake Group, northeast of Moran Lake. *In* Current Research, Part C. Geological Survey of Canada, Paper 88-1C, pages 277-282.

Wilton, D.H.C. and Wardle, R.J.
1987: Two contrasting granophile and non-granophile metallogenic styles in the Early Proterozoic Upper Aillik Group, Central Mineral Belt, Labrador, Canada. *In* Mineral Deposita, Volume 22, pages 198-206.