New Nouveau Brunswick

Natural Resources
Lands, Minerals and Petroleum

Uranium

Mineral Commodity Profile No. 6

Uranium (U) is a silvery-white, metallic element in its pure state. It is radioactive, abundant both in and on the earth, and the heaviest of the naturally occurring elements. Most commonly, it combines with oxygen to form the oxide mineral uraninite (UO_2), also called pitchblende, or the compound triuranium octoxide (U_3O_8); however, numerous other minerals contain uranium. The earth's crust contains an average of about 2.8 parts per million (ppm) U. Typical granite contains 4-5 ppm U and normal seawater contains 0.003 ppm U. In uranium ore deposits, 20 000 ppm (2.0%) U is considered to be high grade while 1000 ppm (0.1%) U and 100 ppm (0.01%) U are considered low and very low grades, respectively.

Pitchblende is the massive or colloform (globular in texture) variety of uraninite.

Atoms of radioactive elements decay at variable rates and are considered unstable. Elements with the same number of protons but differing numbers of neutrons in their nuclei are called isotopes. During the decay process, an unstable isotope can change to other isotopes of the same element, or change to another unstable or stable element. The radioactive intensity of a given isotope or element is related to its rate of decay or half-life; the time it takes for half the number of radioactive atoms to change. Three uranium isotopes occur naturally: U^{238}, U^{235}, and U^{234}. They account for about 99.28 %, 0.71 %, and 0.01% of the substance, respectively. U^{238} and U^{235} have exceptionally long half-lives of millions to billions of years. U^{234} has a half-life of only a few hundred thousand years making it the more intensely radioactive isotope.

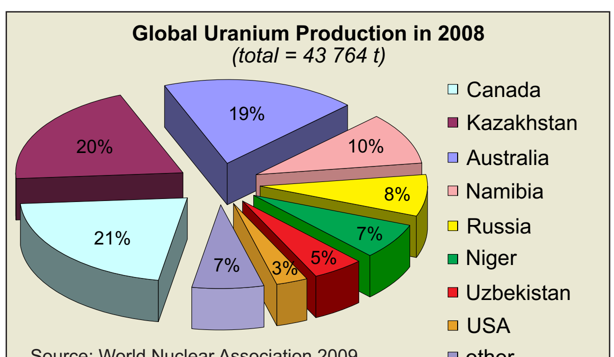
Uses

The large amount of energy produced when uranium is processed in nuclear reactors makes it useful for a variety of applications. Most of this energy is used as a fuel source to generate electric power, or in smaller-scale applications, to power such things as ocean-going vessels. Radioisotopes of many elements are manufactured in reactors and are used for medical and agricultural purposes, food preservation, and many other industrial and research applications. Secondary energy from reactor operation is used for heating in some jurisdictions.

Nuclear alternatives are increasingly becoming preferred energy sources. Global warming concerns, resulting in part from CO_2 emissions from fossil fuel fired electric generating plants, and massive energy requirements of developing nations are driving this preference. In 2007, nuclear energy accounted for 15% of the power generated globally making it the fourth largest source of electricity. As of October 2009, there were 436 operable reactors, 52 more under construction, 135 planned, and 295 proposed (World Nuclear Association, 2009).

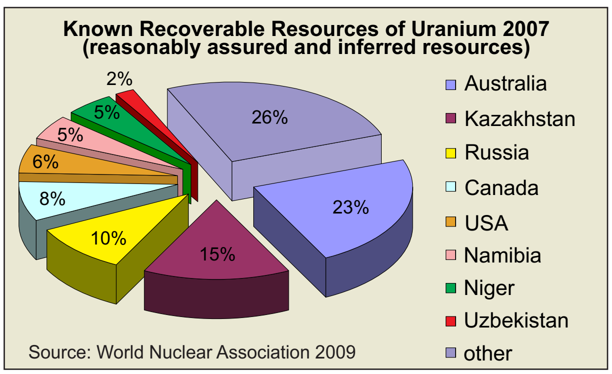
World Production and Reserves

According to the World Nuclear Association (2009), in 2008, global mining operations produced 43 764 tonnes of uranium, 9 000 tonnes of which was extracted in Canada. Canada lead the world in uranium production accounting for 21% of the total produced in 2008, followed by Kazakhstan at 20%, and Australia at 19%. Lesser amounts are



mined in Russia, Niger, Namibia, Uzbekistan, and the USA, while minor ores are extracted in several other countries. Conventional underground and open pit uranium mining accounted for 62% of primary production and 10% of production as a by-product. Newer, in situ leach technology (solution mining) accounted for 28%. Stockpiles of nuclear weapons, accumulated as a result of disarmament treaties, are another important source of high-grade uranium for fuel in nuclear reactors. It is estimated that the amount consumed from this source is roughly equivalent to 10 600 tonnes of uranium oxide produced from mining operations.

Based on production costs of less than $130 US / kg, known global uranium resources (reasonably assured and inferred) from producing mines and significant exploration projects as of 2007, amount to about 5.5 million tonnes with Canada's share at 8% (World Nuclear Association, 2009).



In Canada, most known uranium resources occur within ancient sedimentary basin fill and associated basement rocks of the Neoproterozoic Precambrian Shield. By far, the highest grade and most prolific of these are in the Athabasca Basin covering much of northwestern Saskatchewan and a small part of northeastern Alberta. Currently, Canada has three producing mines in Saskatchewan and several advanced projects with plans for mining in that province as well as in other jurisdictions.

The economic viability of a uranium deposit depends on a variety of factors such as grade, tonnage, location, mining method(s), and the presence of associated value-added minerals. To demonstrate the grades and tonnages required for an economic or potentially economic deposit, Canadian and selected Australian examples are shown on Figure 1. Very large deposits, for example Olympic Dam in Australia from which uranium is produced as a by-product of a primary copper mine, can be economic at very low grades. In Canada, uranium from the relatively low- to medium-grade and medium-tonnage deposits in the Rabbit Lake area (i.e., the Rabbit Lake and nearby Collins Bay deposits) were developed as open pit operations (as were the producing Ranger deposits in Australia). The more recently discovered and higher tonnage deposit at Eagle Point utilizes existing milling facilities at Rabbit Lake and is viable as a more expensive underground mine. The Canadian Cigar Lake and producing McArthur River deposits are very high-grade and are therefore viable as underground operations. To date, uranium mineralization of sufficient grade and tonnage to be extracted economically has not been identified in any area of New Brunswick.

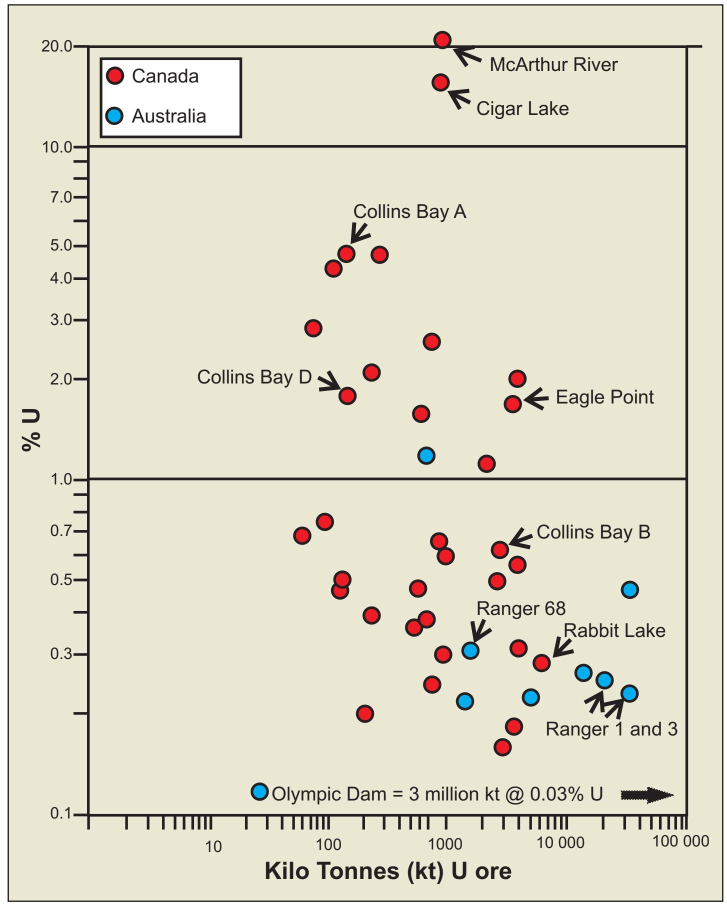


Figure 1. Grade (% U) versus tonnage (kt U ore) plot of selected Canadian and Australian uranium deposits (modified after Jefferson et al., 2007).

Uranium Mining and Milling

Mined uranium ore, from open pit or underground, is crushed and milled, then leached with acid to separate the uranium from the host rock. The uranium in the resulting liquid is then treated through chemical processes, recovered as a chemical precipitate, filtered and dried. The weakly radioactive product, called milled uranium or yellowcake, typically contains greater than 80% U and is the primary product of mining operations. This subsequently enriched to highly radioactive product is used for purposes discussed above.

In some geological situations, uranium can be extracted through solution mining without actually removing rock from the ground. This process involves circulating solutions, under pressure, to dissolve uranium in the deposit. Injection wells are drilled through host rocks (where

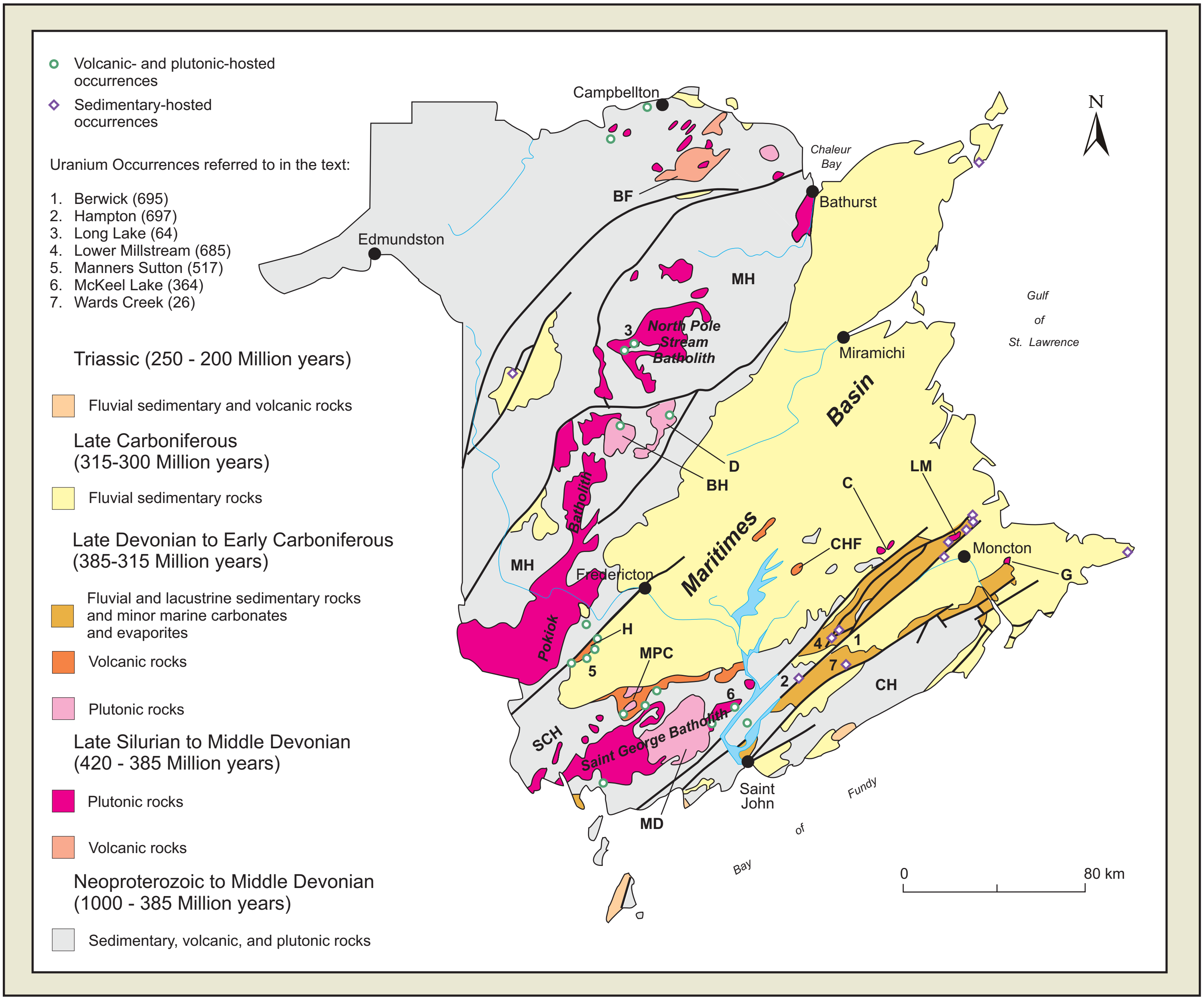


Figure 2. General geology map showing selected uranium occurrences. The numbers in brackets refer to the Unique Record Number in the New Brunswick Department of Natural Resources (NBDNR) Mineral Occurrence Database (NBDNR, 2009).

BF = Benjamin Formation, BH = Burnt Hill Pluton, C = Canaan River Pluton, CH = Caledonian Highlands, CHF = Cumberland Hill Formation, D = Dungarvon Pluton, G = Gaytons Pluton, H = Harvey Group, LM = Lutes Mountain plutonic rocks, MD = Mount Douglas Pluton, MH = Miramichi Highlands, and MPC = Mount Pleasant Volcanic Complex, SCH = St. Croix Highlands

permeable) and the uranium-rich solutions are obtained from recovery wells. Depending on the groundwater chemistry in the deposit, solutions used are normally weakly acidic, but alkali leaches may also be used. Yellowcake is then produced as in conventional mining practices.

Uranium Exploration in New Brunswick

Soon after World War II, the potential of nuclear energy for peaceful purposes was realized. By the mid 1950s, government agencies were publishing information about known uranium occurrences in New Brunswick. At that time, prospectors and mining companies were beginning to investigate these occurrences. In 1972, the advent of commercial electric generating reactors and the resulting demand for fuel drove exploration, particularly in the southern part of New Brunswick, by BP Oil Ltd. (later BP Minerals Ltd.). Other major companies, including Canadian Nickel Co. Ltd., Canadian Occidental Petroleum Ltd., Uranerz Exploration and Mining Ltd., and Seru Nucleaire (Canada) Ltd., along with junior exploration companies and prospectors, followed suit. This exploration boom lasted until demand fell in the early 1980s. After a 22 year hiatus, nuclear power was once again in the spotlight. Global uranium exploration renewed and exploration renewal in this province followed a few years later. Much of the ground staked in the initial exploration boom was re-staked, along with other newly-defined targets of interest. However, public resistance to uranium exploration, and ensuing changes in governing legislation, significantly curtailed uranium exploration in the most densely populated areas of southern New Brunswick.

Geological Setting of Uranium in New Brunswick

The Appalachian Mountain belt in New Brunswick can be divided into two distinctive geological domains (Fig. 2); (1) Neoproterozoic to Middle Devonian (1000-385 million years) sedimentary and igneous basement rocks that underlie and surround the Maritimes Basin, and (2) Late Devonian to Carboniferous (385-300 million years) largely sedimentary rocks that infill the Maritimes Basin. Igneous (i.e., volcanic and plutonic) rocks in the province (see McLeod, 1991; Whalen, 1993; Yang et al., 2003; Yang et al., 2008) are known to contain uranium and can be divided into the following: (1) Late Silurian to Middle Devonian (420-385 million years) volcanic and plutonic rocks that underlie the Miramichi and St. Croix highlands; these basement igneous rocks were emplaced near the end of and immediately after plate-tectonic events that formed the Appalachian Mountains and (2) Late Devonian to Early Carboniferous (385-315 Million years) volcanic and plutonic rocks situated within and along the margin of the Maritimes Basin; these younger igneous rocks were emplaced during periods of extensional tectonic activity associated with basin development. The Maritimes Basin contains thick deposits of fluvial (river) and lacustrine (lake) sedimentary rocks that contain debris eroded from the Miramichi, St. Croix, and Caledonian highlands of the Appalachian Mountains, and local deposits of marine carbonates and evaporites (St. Peter and Johnson, 2009). These sedimentary rocks are also known to contain important uranium occurrences in New Brunswick.

Uranium in New Brunswick

In New Brunswick, uranium occurrences are broadly divided into (1) volcanic- and plutonic-hosted, and (2) sedimentary-hosted categories. For detailed descriptions of uranium occurrences in the province, see Gross, 1957; Dunsmore, 1977; Venugopal, 1985; Ruzcka and Le Cheminant, 1986; Hassan et al., 1987; and NBDNR, 2009.

Uranium is an incompatible element within magmas, and as such it tends to become concentrated within highly evolved silica-rich melts. Consequently, these magmas tend to be inherently enriched in uranium and are extruded or intruded as components of felsic volcanic complexes and granitic plutons. Uranium is further concentrated in porphyritic and aplitic dykes and pegmatites formed during the latest stages of crystallization of granite plutons, and in volcanic and plutonic rocks as fracture-fill veins along which hot, metal-charged hydrothermal fluids have migrated.

Uranium becomes concentrated in sedimentary rocks when circulating groundwater, that is relatively oxygenated, leaches the metal from somewhat uranium-enriched source rocks in the subsurface. When the metal-charged groundwater encounters a reducing environment, the dissolved uranium precipitates (comes out of solution) and forms uranium-bearing minerals. The position of this change from relatively oxygen-rich to oxygen-poor conditions is referred to as a redox boundary. Redox boundaries may form along organic- or sulphide-rich sedimentary horizons, or along fracture systems and faults that serve as transportation conduits for reducing fluids within the sedimentary pile.

Volcanic- and Plutonic-hosted Uranium Occurrences

The Late Devonian Mount Pleasant Volcanic Complex and the Late Devonian Harvey Group (York Mills, Cherry Mountain, and Harvey Mountain formations) located along the southwestern margin of the Maritimes Basin represent major volcanic centers associated with uranium mineralization. (McCutcheon et al., 1997; Payette and Martin, 1986a, 1986b, 1987, 1988) Aeromagnetic and gravity surveys suggest the Harvey Group, in all likelihood, represents the western margin of the Mount Pleasant Volcanic Complex.

In the Mount Pleasant and Harvey areas, highly evolved volcanic and volcaniclastic rocks contain uranium mineralization in intensely altered fracture zones and along permeable horizons within the volcanic pile (Fig. 3). The uranium, in this case, was scavenged from the volcanic pile itself. Fluorite-veining and bleaching of bedded units associated with some of the highest values in drill core attest to migrating hydrothermal fluids in this system. During a recent exploration program near Harvey, uranium values, up to 4470 ppm U_3O_8 (Capella Resources Ltd., 2009), were intersected in welded ash-flow tuffs and volcaniclastic rocks near the Manners Sutton occurrence (Fig. 2).

Anomalously high uranium contents associated with Early Carboniferous alkali felsic volcanic rocks of the Cumberland Hill Formation (Mabou Group) in the central part of the Maritimes Basin are indicated by airborne and ground radiometric surveys. The subsurface extent of these rocks is

Figure 3. Anomalous uranium (and thorium) values are found in altered volcaniclastic rocks of the Mount Pleasant Volcanic Complex.

they may be rather extensive. Furthermore, other bulls-eye and linear aeromagnetic anomalies in the area suggest the existence of buried plutons similar in composition to the Cumberland Hill volcanic rocks (Johnson 2008).

The Late Silurian to Early Devonian Saint George, Pokiok, and North Pole Stream batholiths all contain evolved granite plutons that have the potential to produce significant uranium mineralization. Middle Devonian plutons (Gaytons and Canaan River plutons, and possibly some of the plutonic rocks at Lutes Mountain), partially exposed under a shallow cover of Carboniferous rocks within the Maritimes Basin, are also potentially uranium-bearing and could act as a source of uranium to the sedimentary rocks infilling the Maritimes Basin. High aeromagnetic signatures suggest the Canaan River Pluton is quite extensive below Carboniferous cover, however, the subsurface extent of the Gaytons and plutonic rocks at Lutes Mountain are unknown. The highly evolved Late Silurian Utopia and Late Devonian Mount Douglas plutons of the Saint George Batholith in southern New Brunswick, and the Late Devonian Burnt Hill (MacLellan and Taylor, 1989; MacLellan et al., 1990) and Dungarvon plutons in central New Brunswick (Fig. 2) contain tin, tungsten, and molybdenum as well as uranium mineralization.

The McKeel Lake occurrence in southern New Brunswick and Long Lake occurrence in central New Brunswick (Fig. 2) are examples of contrasting styles of uranium mineralization hosted by Late Silurian and Early Devonian plutonic rocks. At McKeel Lake, late-stage alkali pegmatite-aplite dykes, with uranium values averaging 153 ppm, intrude the host alkali granites of the Welsford pluton (Seidler et al., 2005). The dykes contain a number of uranium- and rare-earth-element-bearing minerals. Unlike the radiogenic mineralization at McKeel Lake, uranium in the Long Lake occurrence occurs in polymetallic veins along fractures and is associated with quartz-feldspar porphyry dykes. The dykes and mineralized veins (up to 3440 ppm U) are apparently related to the youngest and most highly evolved muscovite granite phase of the North Pole Stream Batholith (Shinkle et al., 2008).

In addition to the recognized potential for uranium mineralization in plutonic rocks of Late Silurian to Early Devonian age, there has recently been some interest in exploring for uranium in volcanic rocks of that age. For example, felsic volcanic rocks of the Late Silurian Benjamin Formation (Chaleurs Group) that exhibit distinct geochemical and airborne radiometric anomalies are being investigated by a junior mining company (Cornerstone Capital Resources Inc., 2009). In addition, felsic volcanic or granitic rocks are likely the source of geochemical and airborne radiometric anomalies in the Caledonian Highlands.

Sedimentary-hosted Uranium Occurrences

Uranium is concentrated in relatively oxygenated waters, circulating through lithified and permeable, fluvial sedimentary rocks of the Maritimes Basin. The dissolved uranium is deposited upon encountering reducing fossilized plant matter, pyritiferous horizons, or reducing percolating solutions. The uranium in the circulating waters may have been derived from any or all of the following uranium-rich sources: (1) directly from bedrock in the surrounding basement uplifts, (2) from debris derived from the basement uplifts and deposited as sedimentary fill within the basin, (3) from organic-rich shales, containing adsorbed uranium, deposited in lakes within the basin, or (4) from water-lain volcaniclastic or airborne tuffaceous debris derived from contemporaneous explosive volcanic activity and deposited in the basin. Bedrock mapping, deep drilling and seismic surveying indicate that organic shales that were deposited in oxygen-poor lacustrine and swamp environments are widespread, on the surface and in the subsurface, throughout much of the southern part of the Maritimes Basin. The Lower Millstream and Berwick occurrences (Fig. 2) are examples of uranium mineralization in such lacustrine and swampy environments. In this area, anomalous uranium values have been found in the Albert and Bloomfield formations (Horton Group) mainly within limey beds that are associated with organic-rich shales and subaerial redbeds (Fig. 4). Uranium contents are relatively low in these rocks (up to 600 ppm), but their probable widespread distribution, the stratiform nature of the mineralization, and possible higher uranium concentrations along brittle fractures make these rocks a viable exploration target. The Hampton occurrence (Fig. 2) is a possible example of this type of fault-controlled mineralization, where uranium values up to 600 ppm are associated with hydrocarbon seams in a fault zone that separates shales of the Albert Formation from uplifted Silurian rocks (New Brunswick Department of Natural Resources, 2009).

The Wards Creek occurrence (Fig. 2, 5), is an example of fluvial sandstone-hosted uranium. Coarse-grained redbeds of the Late Devonian to Early Carboniferous Memramcook Formation (Horton Group), the oldest sedimentary fill in the Maritimes Basin, contain uranium values of up to 1100 ppm (New Brunswick Department of Natural Resources, 2009). Since the redbeds were deposited in a fluvial environment not far from their uplifted Neoproterozoic granitic source areas in the Caledonian Highlands, the uranium could have been leached from detritus in these redbeds or leached directly from granitic basement rocks. Volcaniclastic or airborne tuffaceous debris eroded from the Mount Pleasant Volcanic Complex and deposited in the basin may also have served as a source of the uranium.

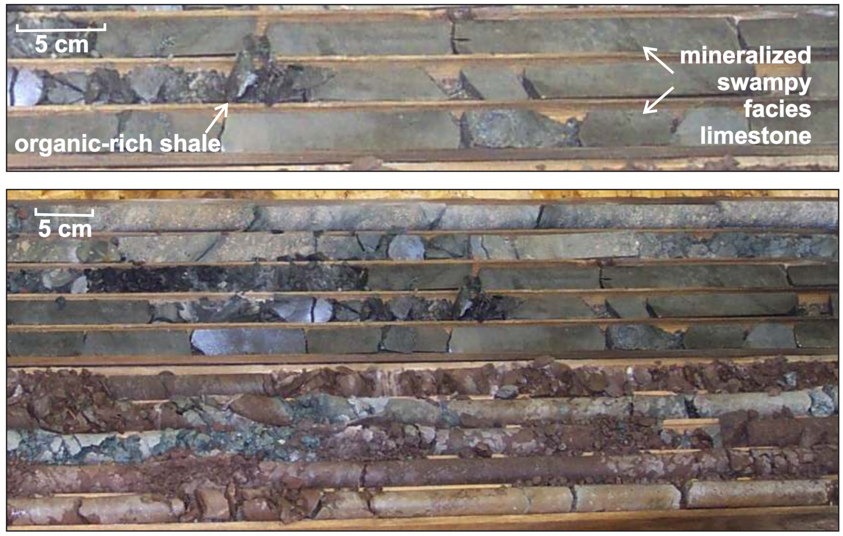


Figure 4. Black to grey, organic-rich shale and limestone interbedded with red nodular mudstone and shale of the Bloomfield Formation.

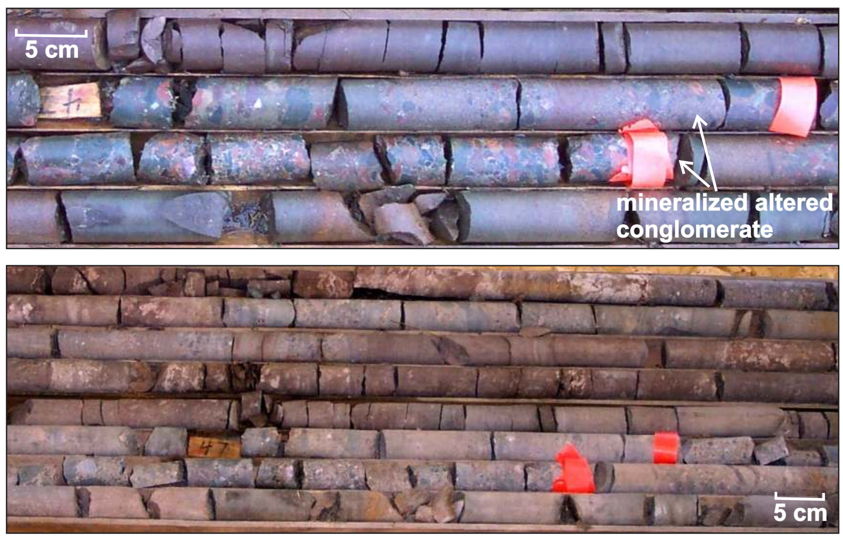


Figure 5. Fine- to coarse-grained redbeds of the Memramcook Formation rich in debris derived from Neoproterozoic granitic rocks.

Summary

In New Brunswick, Late Silurian volcanic rocks in the northern area of the province, Late Silurian to Middle Devonian volcanic and plutonic rocks in the Miramichi and St. Croix highlands, and Late Devonian to Carboniferous volcanic and sedimentary rocks that infill the Maritimes Basin are naturally enriched in uranium. Based on the nature of the rocks hosting the mineralization, uranium occurrences can be classified into two groups (i.e., igneous or sedimentary) in New Brunswick: (1) volcanic- and plutonic-hosted, and (2) sedimentary-hosted. The distinct styles of uranium mineralization in these occurrences reflect contrasting magmatic and sedimentary processes that concentrated the uranium in the host rocks. Pending further research, these simplistic, broad classifications will undoubtedly be expanded and refined, and accurately adapted to well established, global models. Before a mine is established, uranium must occur in sufficient grade and tonnage to be economically extractable. To date no such occurrences exist in New Brunswick.

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For More Information

For more information on uranium and other New Brunswick mineral commodities, please see the NBDNR Mineral Occurrence Database (NBDNR 2009) or contact:

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