Earth 471
Individual Essay

An Overview of McArthur River Uranium Deposits in the Athabasca Basin, Canada

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1.Introduction

Discovered in 1789, uranium was first isolated and found radioactive in 1896 by Henri Becquerel. Since mid-1950s, uranium has been the source for nuclear energy, which is more efficient than traditional energy and does not produce greenhouse gases. Being the most important source of naturally occurring uranium, uranium ore was first found near the Port Radium in Saskatchewan, Canada, and the exploration began in 1942 in response to the military demand. Although uranium deposits are found in many countries, more than a half of uranium production is concentrated in Canada, Australia, Kazakhstan and Africa (Stevens, 2012). Among theses districts, Canada has been the world's largest uranium producer for years until in 2009 replaced by Kazakhstan, and it is estimated that Canada has contributed to 22% of the world uranium output (World Nuclear Association, 2014, Figure 1).

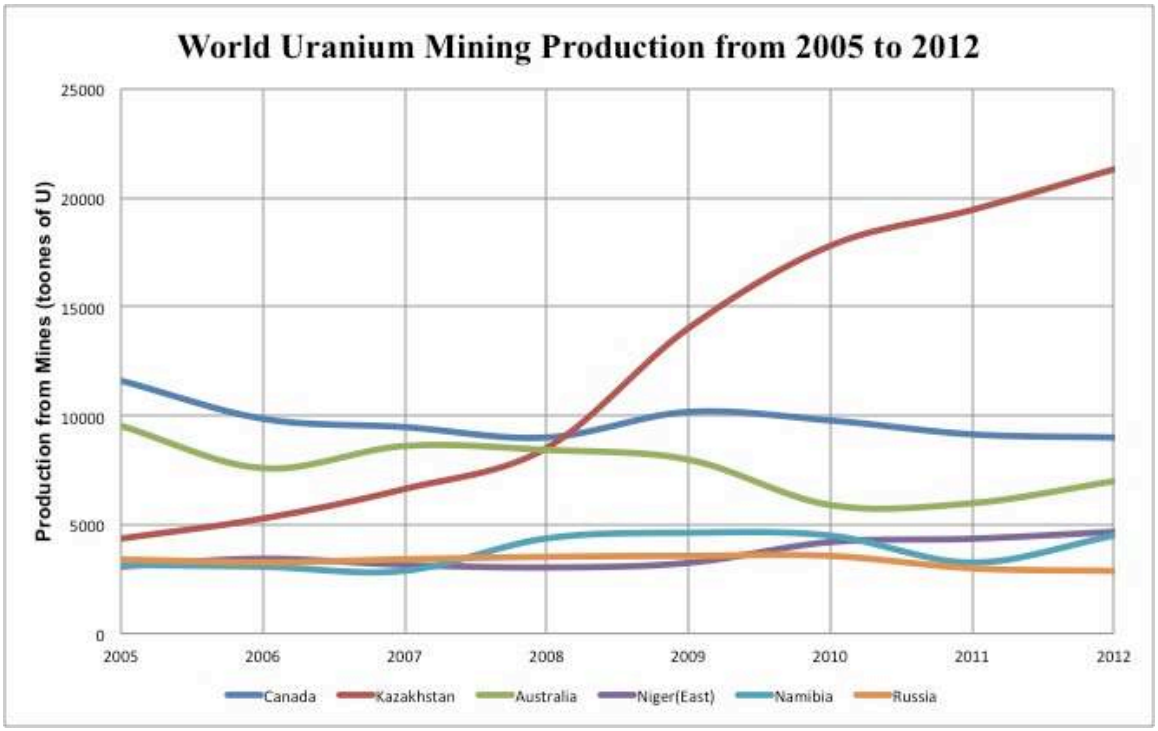


Figure 1. World uranium production from 2005-2012, data retrieved from World Nuclear Association

There are many types of uranium deposits, but the major type is unconformity-associated, which means that the deposits are located near the major unconformity that separates two rock masses at the base of a sedimentary basin. Most of the uranium deposits, regardless of their types, are low to moderate grade (Stevens, 2012), but the unconformity deposits of Athabasca Basin (Figure 2.) is typical of high grade (Jefferson et al., 2007).

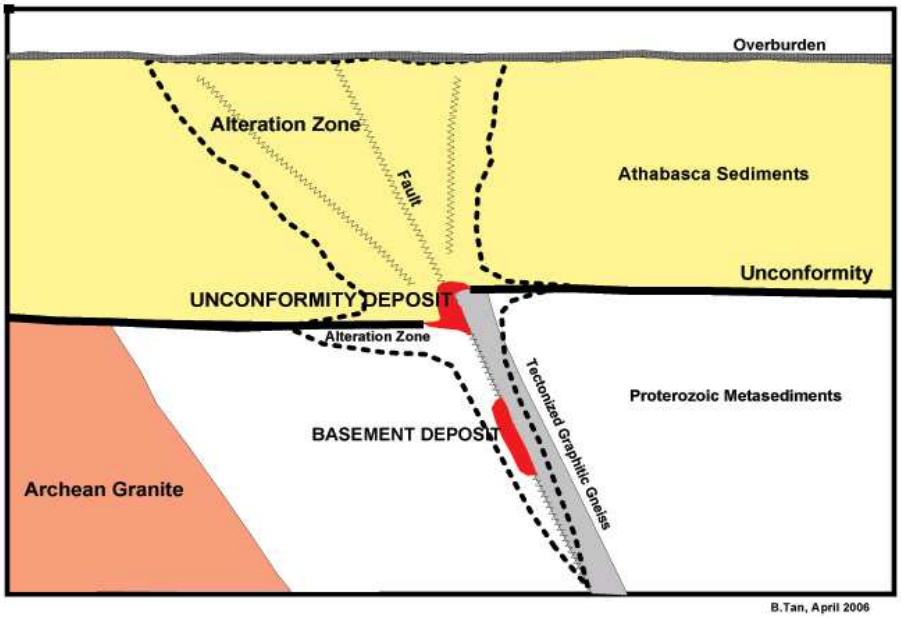


Figure 2. Model for unconformity-associated uranium deposits in the Athabasca Basin, Canada

The essay will be focused on McArthur River Uranium Mine in Athabasca Basin in Canada, which is claimed to be the world's largest high-grade mine. The McArthur River Uranium Mine is located about 620 kilometers north of Saskaton, Saskachewan. Located underground for about 600m, the uranium reserves is enormous (192,085 tonnes of U) at an anomalous high grade (22.8%). The production of uranium on this site was initiated by Cameco Corporation in 1999, and has accumulated to 211 million pounds of U_3O_8 until 2012 (Cameco Corporation, 2012).

2.History of the deposit and Economic Value

Uranium deposits, according to the their geological settings, can be categorized into 14 major types (World Nuclear Association, 2010). The scope of this essay is confined to the unconformity-related deposits, which constitute about one third of the world uranium deposits (World Nuclear Association, 2010). Unlike other types of the uranium deposits, unconformity-associated type can have much higher grade of uranium at a similar tonnage.

The McArthur River Basin is the most productive uranium deposit ever since, which produces 13% of the world's uranium (World Nuclear Association, 2013), and it is located near the south-east margin of the Athabasca Basin, which covers more than 85,000 km2 in northern Saskatchewan province.

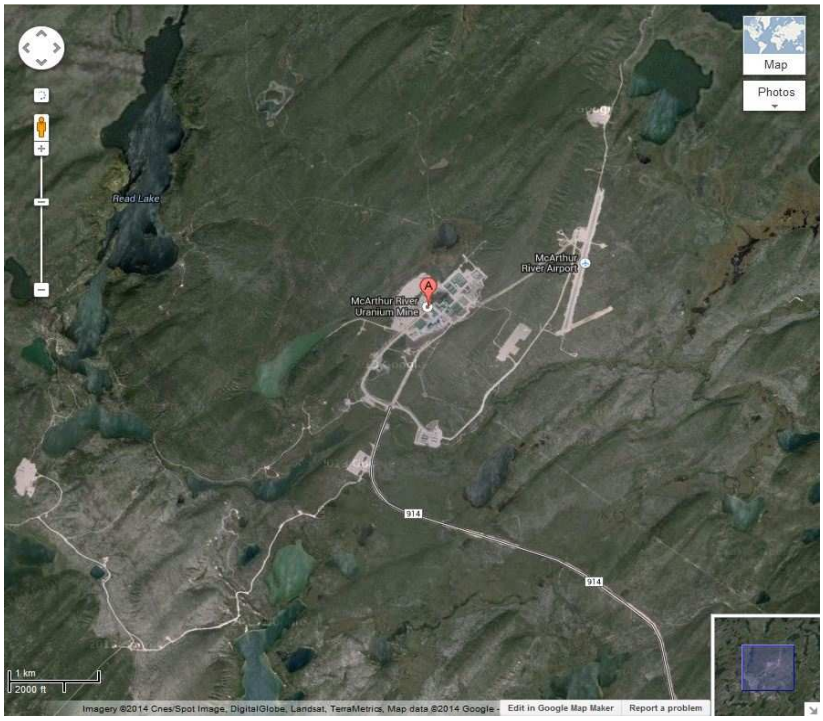


Figure 3. Location Map of the McArthur River Basin Mine

Although Canada's role of the world's largest uranium producer was replaced by Kazakhstan in 2009, its major uranium production contributor, McArthur River Uranium Mine, has been the most productive mine since it achieved full commercial production in 2000 (Table 1 . The estimated reserves and grades of U3O8 in the McArthur River Basin are 386 million pounds and 16.46%, respectively (Cameco Corporation Annual Report, 2012).

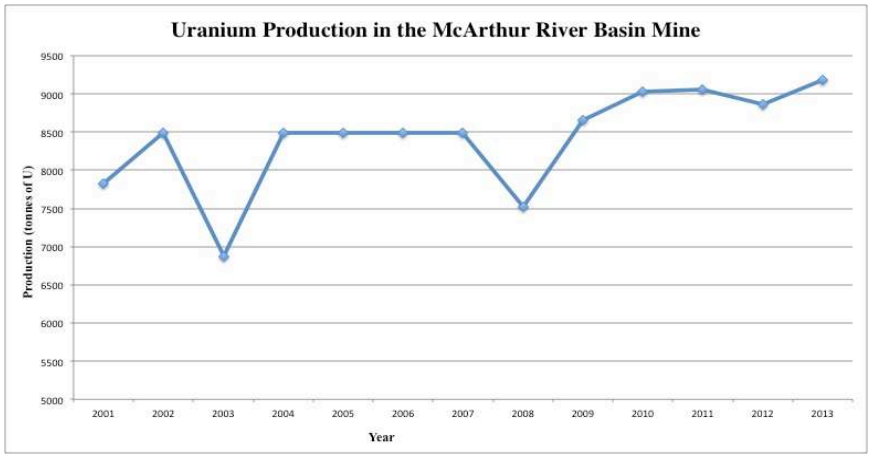


Table 1. Uranium Production from McArthur River Basin Mine, 2011-2013, data retrieved from World Nuclear Association

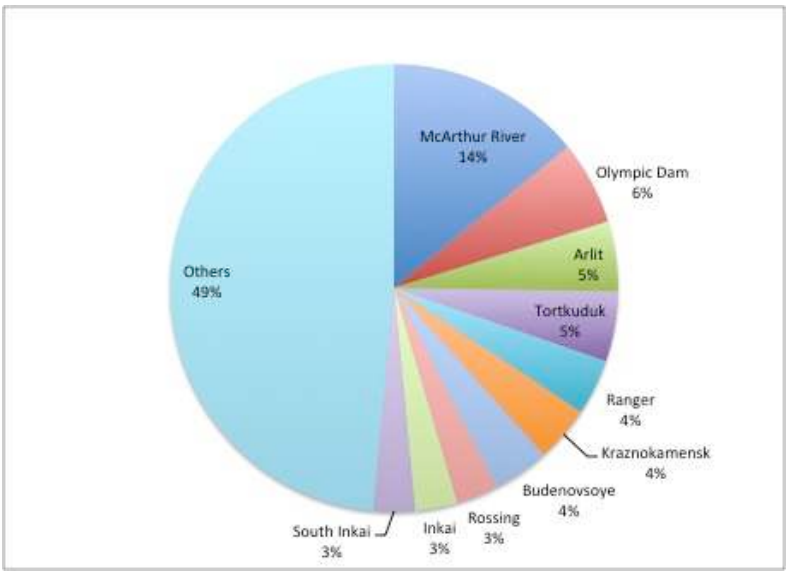


Table 2. Pie chart showing the contribution of the McArthur River Mine in the Global uranium production

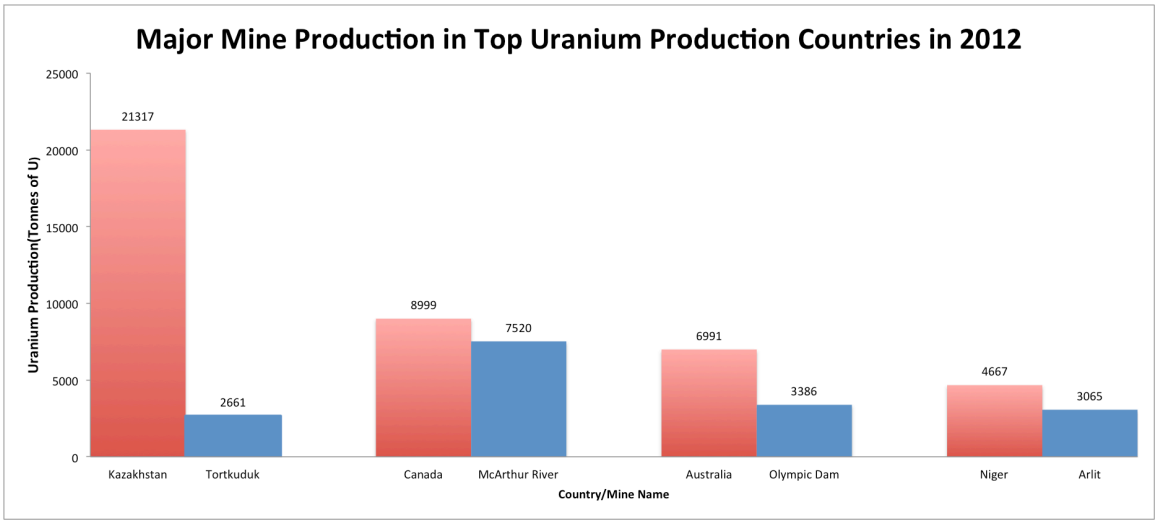


Table 3. Comparison of the world's most uranium-productive countries and the major mine, data retrieved from World Nuclear Association

The uranium deposits in the McArthur River basin were discovered by Cameco Coporation in 1988, when the prices of uranium mine sank to the bottom level. (Figure showing the price curve!) From the figure it can be seen that the high prices of uranium oxide (U3O8) in the late 1970s induced the depression in the whole period of 1980s and 1990s. The reason is that there was a burst of exploration in the 1970s, when some major discoveries were made in the Athabasca Basin. Those mines that started in the late 1970s and early 1980s had been accounting for most of Canadian uranium production by 2000 (World Nuclear Association). The spot price of uranium oxide experienced an exponential increase since 2003, and peaking

at over 130 US dollars/lb in 2007, after which the prices decreased to a lesser extent and remained relatively stable since 2009.

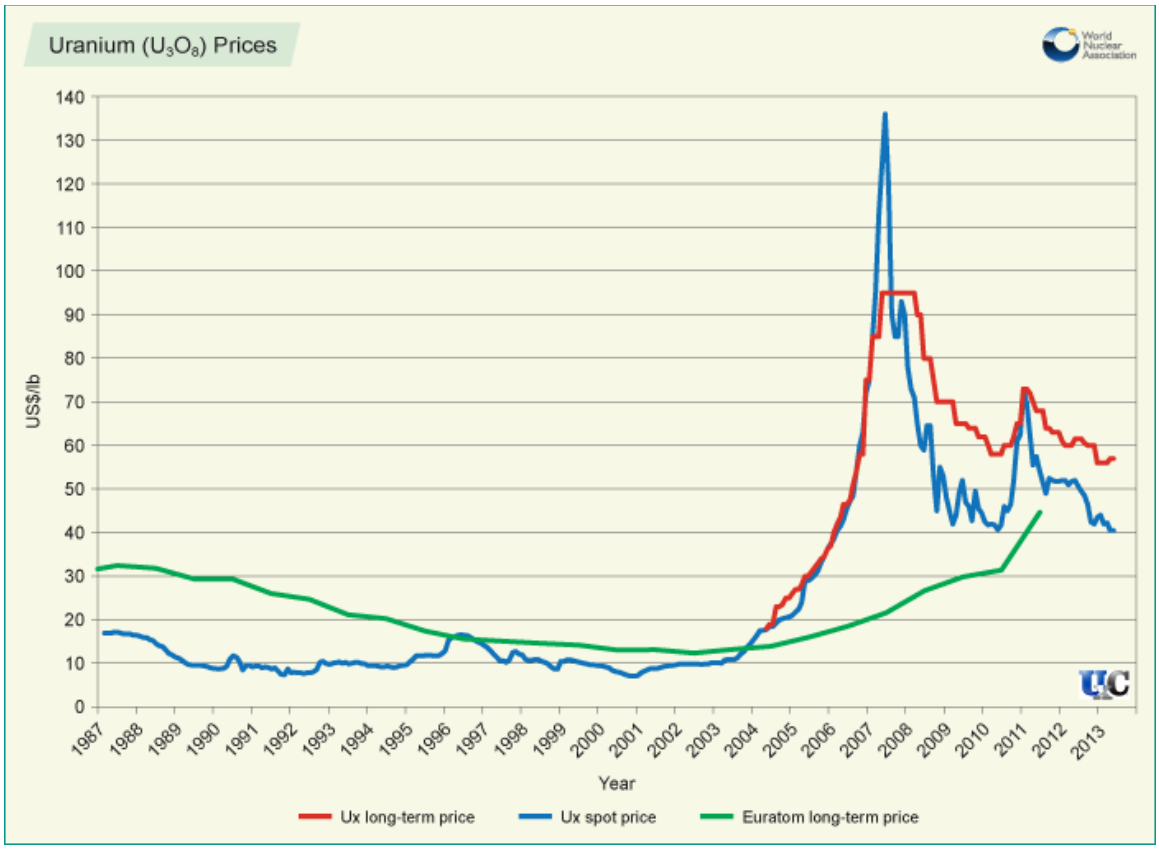


Figure 4. Uranium Oxide Price since 1987, World Nuclear Association

The uranium mines play an important role in Canada's economy. In terms of energy supply, the energy contained in the uranium deposits in the Athabasca Basin is equivalent to 19 billion barrels of oil, which is more than 15 years of Canadian current total crude oil production (Saskatchewan First Nations Natural Resources Centre of Excellence). Contributing directly over 1.5 billion US dollars to the revenue of the provincial government, uranium mining is a major patron to Saskatchewan's economy (Saskatchewan Mining Association, 2012). In addition, over 286,000 person years of direct employment will be generated by 2028, and the mining employment is expected to rise by 17% (Saskatchewan Mining Association, 2012).

Cameco Corporation has 69.8% ownership, and the rest 30.2% ownership belongs to AREVA Resources. With a licensed capacity of 18.7 million pounds U3O8 per year, Cameco made a production of 14.1 millions pounds U_3O_8 in 2013.

In the near future, it is likely that Canadian uranium production will increase dramatically, as several new mines are now under construction and will be in operation soon.

3.Regional Geology

The McArthur River Basin is located on the eastern margin of the Athabasca Basin in Saskatchewan, Canada. The Athabasca Basin is regarded as the most significant U metallogenic district in Canada, but more than 90% of its uranium resources are concentrated near the eastern margin (Jefferson et al., 2007). The two giant high-grade uranium deposits in the Athabasca Basin are both unconformity-associated, which can be subdivided into two categories: sediment-hosted and basement-hosted (Alexandre, Kyser, Thomas, Polito, & Marlat, 2009) . The McArthur River deposits are basement-hosted, situated below the unconformity surface (Alexandre et al., 2009).

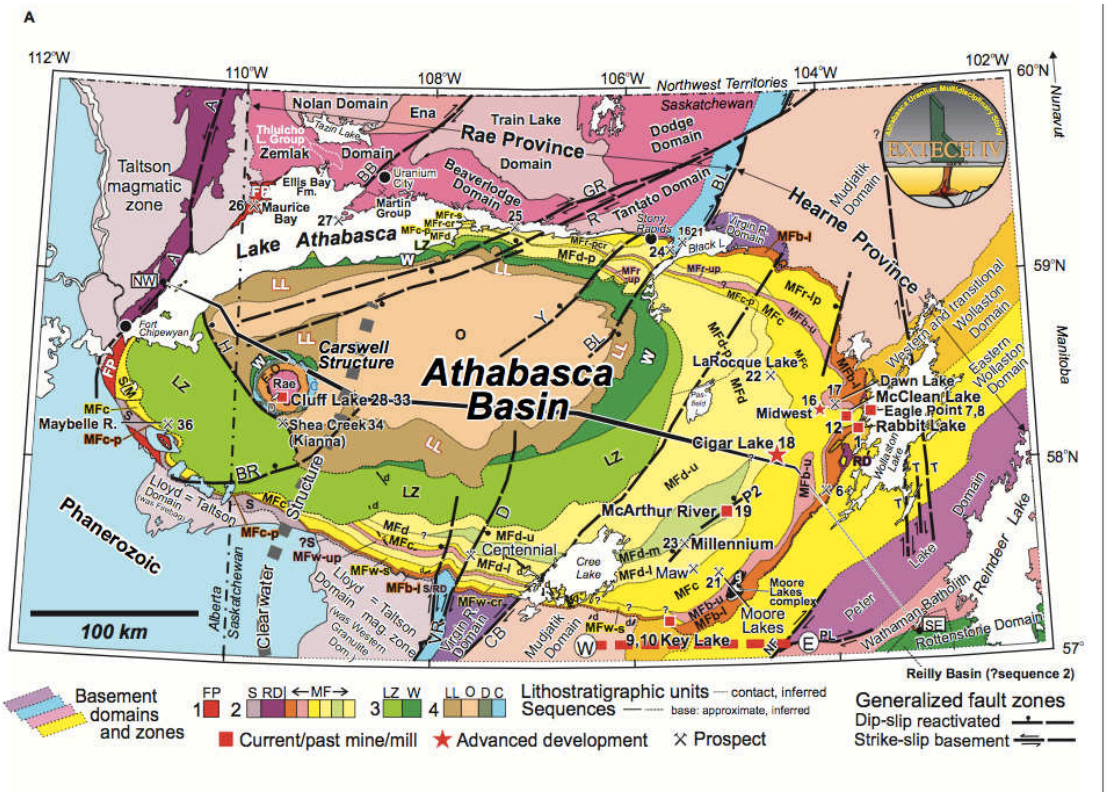


Figure 5. Geology Map of the Athabasca Basin, figure taken from (Jefferson et al., 2007)

The Athabasca Basin formed at about ca 1,730 Ma (Alexandre et al., 2009), and the basement of the Athabasca Basin is located on the western Churchill Province of the Canadian Shield where the two structural provinces Hearne Province and Rae Province share the border. The portions of the two provinces that lie in the Athabasca Basin are evidenced to be the eroded remnants of the ca 1.8 Ga Trans-Hudson Orogen during an ductile transpression and following rapid exhumation (Ramaekers, 1990; Hoffman, 1988). The granitoid intrusions in the orogens may give rise to the high temperature fluid flow (Jefferson et al., 2007). The Hudson orogen event concluded with uplift and sedimentation of a series of marine sandstones, conglomerates, and pelites that overprinted a hematized regolith with a maximum depth of 50 meters

(Keith, 1981). The basin can be divided into a series of subbasins, and most of the uranium deposits happen to locate in the eastern Cree sub-basin (Jefferson et al., 2007).

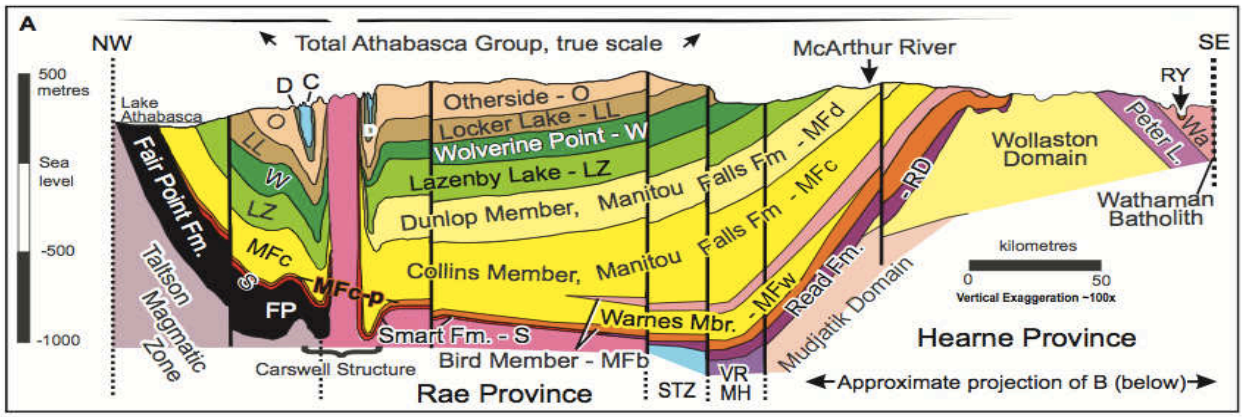


Figure 6. Sequence Stratigraphy of the Athabasca Basin, figure taken from Jefferson et al., 2007

In terms of sedimentary sequence, the Athabasca Group has been subdivided into eight formations (Ramaekers, 2004). As can be seen from the map of the stratigraphy (Figure 6.), the six main formations in an ascending order are: the Fair Point, Manitou Falls, Lazenby Lake, Wolverine Point, Locker Lake and Otherside. Other two formations are Douglas and Carswell formations, with the latter one intruding into those earlier formations. Broadly the Athabasca Basin uranium deposits can be classified into two groups: (i) syngenetic deposits that have uranium in pegmatites, calcsilicates and other rocks that are associated with the Hudson Orogeny, and (ii) epigenetic deposits and the unconformity associated with the contact between the basement and the Athabasca Basin (Hoeve, 1978).

4. Geology of the Deposit

The McArthur River Basin is located in the eastern part of the Athabasca Basin, where a majority of the mines in the Athabasca Basin, and where the Athabasca Basin unconformity exists (Jefferson et al., 2007). The basement of the eastern Athabasca Basin is located within the Cree Lake zone, which can be sub-divided into rocks of Wollaston and Mudjatic domains (Annesley, Madore, & Portella, 2005).

The north-east trending fold thrust of Wollaston domain comprises paleoproterozoic metasediments covering on Archean granitoid gneisses, while the Mudjatic Domain is composed of Archean felsic gneisses (Annesley et al., 2005). The McArthur River deposit mainly comprises five ore bodies that are sandstone-hosted and one basement- hosted body (Ng et al., 2013) . The six mineralized zones extend in the north direction over 1,700 meters with variable widths (Ng, Alexandre, & Kyser, 2013) . A major reverse zone, namely the P2 structure, structurally controlled the ore bodies (McGill et al., 1993).

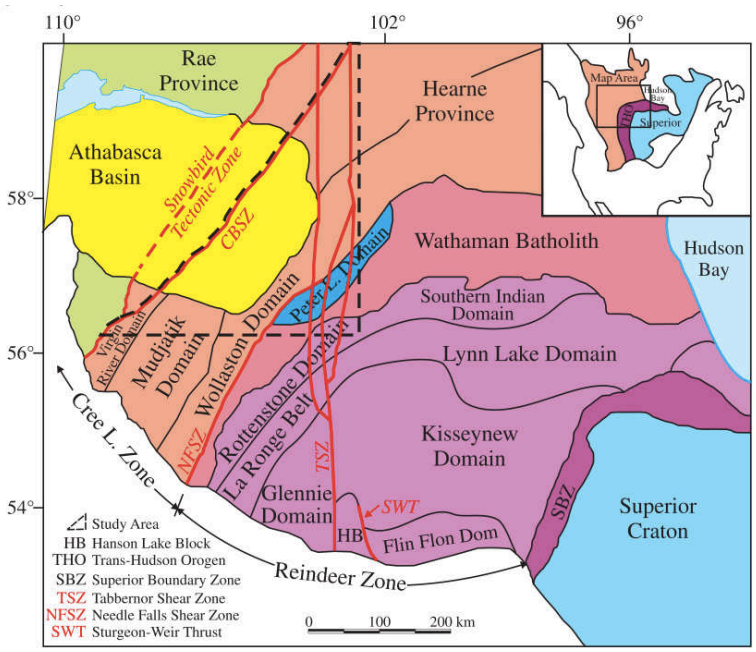


Figure 7. Lithotectonic domains in northern Saskatchewan, figure taken from Annesley, Madore, & Portella, 2005

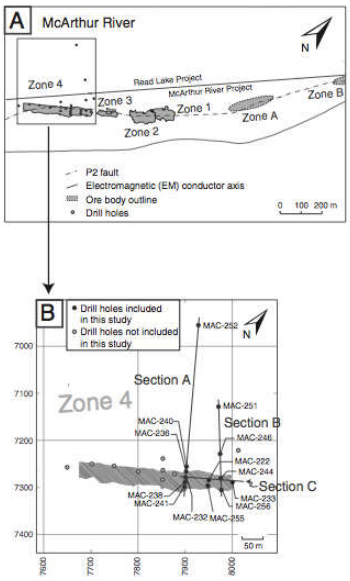


Figure 8. Plan View of the McArthur River property showing the main ore bodies

The age and chemistry of uranium mineralization have been examined thoroughly by previous studies (RW.ERROR - Unable to find reference:45; Cumming & Krstic, 1991; Fayek, Kyser, & Riciputi, 2002; Ng et al., 2013; Richard et al., 2010) . The examination under the ore microscope of the sample M121-517.7

taken from the deposit suggested two periods of early mineralization, and the following Pb isotope composition measurement obtained on a Micromass 30 mass spectrometer defined two distinct lines, with the younger one yields calculated age of 1327 ± 8 Ma while the older one 1514 ± 18 Ma (Cumming & Krstic, 1991).

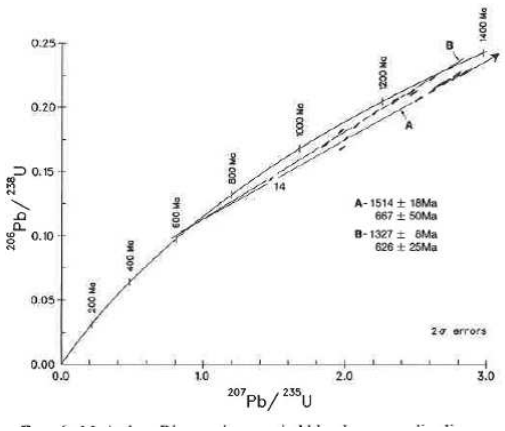


Figure 9. The results of the U/Pb dating of the uranium rich minerals from the studied mineralizations, figure taken from Alexandre et al., 2009

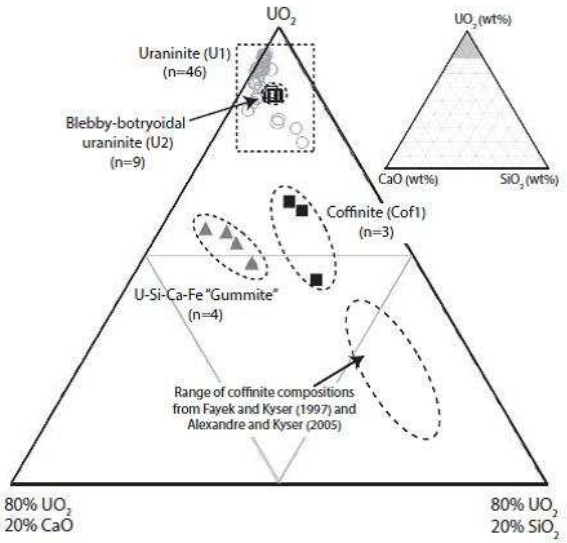


Figure 10. Ternary diagram showing the composition of the uranitite in the studied area (Ng et al., 2013)

The chemical compositions of uranium mineral (i.e., uraninite) are plotted in a UO_2-CaO-SiO_2 ternary diagram (Figure 10.), which illustrates three distinctive compositional groups (Ng et al., 2013) Dating of these minerals of uraninite, however, can be very challenging, as uraninite is very active, resulting in a

partial release of the radiogenic Pb if the uraninite exhibits recrystallization, which accounts for the disagreement upon the age of the uranium minerals from various studies (Alexandre et al., 2009) a major improvement, all the samples are examined under reflected light microscopy, and only those with the highest reflectance are chosen for the U-Pb dating of the LA-HR-ICP-MS analysis (Alexandre et al., 2009) The samples are collected from the massive ore zone at the McArthur River basement-hosted deposit, and the results of U/Pb isotopic compositions yield three distinctive discordia lines, as can be seen from Figure 9 (Alexandre et al., 2009).

The result shows that the ages of uraninite obtained in the McArthhur River Basin is 1,540+- 19 Ma (Alexandre et al., 2009) , revising the previous biased results. The chemical analysis obtained by 40Ar/39Ar of the clay minerals in the deposits shows that the Athabasca Basin dated from 1,742+-25 Ma (Alexandre et al., 2009).

For sake of effective and efficient exploration, alteration mineralogy should be examined, which is pervasive in the McArthur River Basin (Jefferson et al., 2007) The McArthur River Basin is sandstone-hosted and the basinal fluids are the predominant source of fluids for the sandstone and basement alteration (Ng et al., 2013). Four alteration stages are involved in the McArthur River Basin Zone 4, where the samples are taken and analysis are performed (Ng et al., 2013).

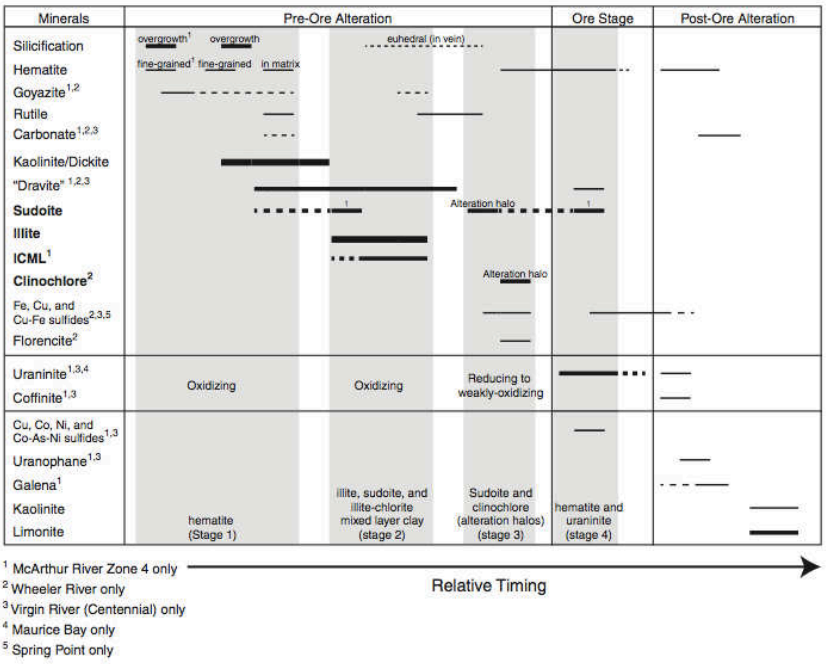


Figure 11. Simplified paragenesis in Athabasca Group (Ng et al., 2013)

5.Genetic Model

The genetic model for unconformity-associated uranium deposits remains controversial in terms of ore-forming fluid flow mechanisms (Cui, Yang & Samson, 2010), but the overall scenario is well understood. Based on field observation and chemical analysis, the ore bodies in the Athabasca Basin can be categorized into two end members according to the characteristics of associated metals: one is monometallic, and the other is polymetallic (Everhart & Wright, 1953).

The McArthur River Basin uranium deposits contain just traces of metals other than Cu and U, so the ore bodies are monometallic, which are generally hosted in the basement fractures and faults (See the discussion in geology of the deposits, Jefferson et al., 2007).

The geochemistry studies from various sources show pretty good constancy in terms of the age of uranite precipitation, which is the source of the uranium. According to (Alexandre et al., 2009) the age of basin formation dated back to 1,730 Ma, followed by diagenetic alteration, and the uranitite precipitation at ca 1,590 Ma followed the pre-ore alteration. The significance of the pre-ore events is that during this period, uranium is leached out of the uranium-rich minerals in the rocks within the basin as a result of the oxidization of the basin fluids, providing the source of uranium for the ore bodie (Kyser, 1997). In addition, the formation of the fractured zones in the basement and sandstones provides structural traps, while the proven chlorite alteration zone provides chemical trap (Alexandre et al., 2009).

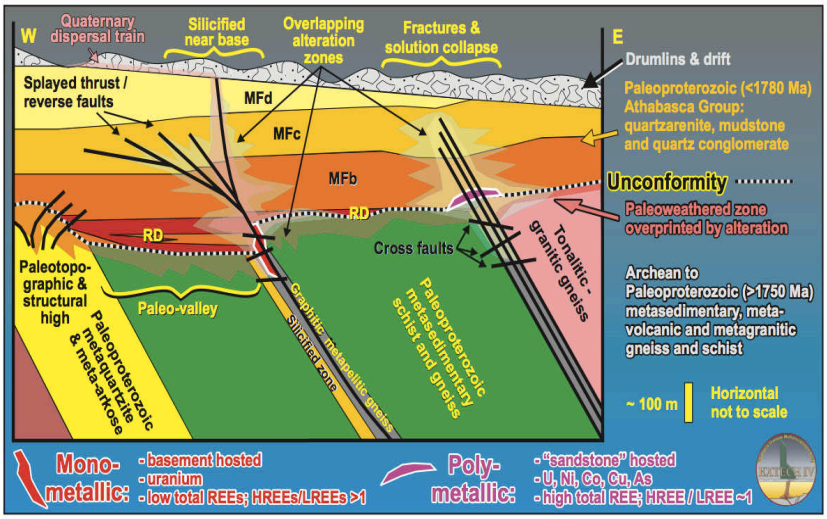


Figure 12. Two Types of unconformity-associated uranium deposits, Jefferson et al., 2007

The uranium deposited in the Athabasca Basin sometime after 1,500 Ma, and increased in concentration during several magmatic and sedimentary events before they became available for transportation (Bell,

1981). The hydrothermal fluids that pass along the faults cutting across the unconformity encounter the existing oxidized fluids that are already enriched in uranium, and give rise to the reaction that cause the uranium deposit out of the solution and form the deposit (Stevens, 2012).

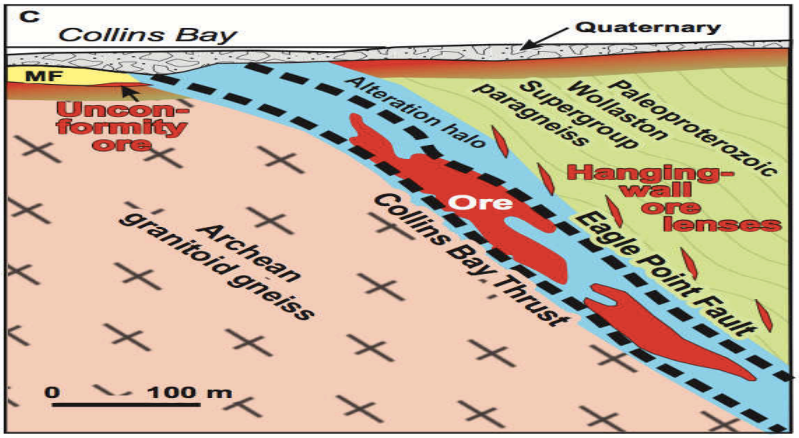


Figure 13. Genetic model of the monometallic uranium deposit, Jefferson et al., 2007

6.Conclusions

The McArthur River Basin provides the main uranium output in the Athabasca Basin in Canada, and it is also the most developed and most giant uranium deposit in terms of tonnage and grade. To make a simplified estimation, the total recoverable uranium in the deposit will contribute a total of 1.14×10^{10} US dollars (calculation based on statistics provided by World Nuclear Association), and provide sufficient employment for proximal districts.

The deposits are unconformity-associated, which is usually low to moderate grade. However, in this case, the uranium deposits are at a very high grade, yielding tremendous production. Numerous studies have been carried out to examine the U/Pb ratio of the core samples along the main faults, unconformity, and in the sandstone host to investigate the age of the uranitite mineralization as well as the paragenesis sequence.

Genetic models are also discussed in great detail, based on the results from the tectonic history, U/Pb ratio, alteration zones and trace element composition. It is believed that the uranium is mainly leached out from the modified groundwater (Stevens, 2012).

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