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David S. Robertson and C. R. Lattanzi

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Article abstract

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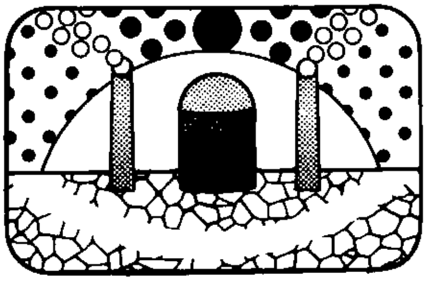


Uranium Deposits of Canada

David S. Robertson and C. R. Lattanzi
David S. Robertson & Associates Limited
Consulting Geologists and Mining Engineers
2000 – 65 Queen Street West
Toronto, Ontario M5H 2M7

Summary

World demand for uranium is expected to increase at an average rate of about 15 per cent per year over the next 20 years. This is a rate of increase not previously faced by any mineral commodity.

Descriptions of Canada's uranium ore bodies and consideration of modes of origin, suggest environments in which new ore bodies can be found and indicate some of the geological problems to be considered in uranium search. Canada, which has been a prominent supplier of uranium to meet the world's needs in the past, will continue to be a major source of this commodity.

Use of Uranium and Future Demand

Natural uranium contains about 0.7 per cent of the isotope U-235. This isotope is the only fissile material which occurs in nature.

The nucleus of the U-235 atom, on absorbing a neutron, will undergo fission or 'split'. The fission reaction is accompanied by the release of energy and by the emission of additional neutrons which may be captured by other U-235 nuclei, thereby sustaining the fission reaction and providing a continuous release of energy.

Although uranium was initially sought as a concentrated energy source for military purposes, the demand for uranium as a strategic material has now virtually ceased. Overwhelmingly, the major use of uranium is now, and will continue to be, as a source of energy for the generation of electricity in large central power stations.

Two basic types of nuclear reactors are now operating commercially in the Western World. The light water reactor, which is in most widespread use, is fuelled with enriched uranium (in which the proportion of U-235 has been increased from its natural level of 0.7 per cent to about three per cent) and is moderated by ordinary water. The heavy water reactor, which has been developed in Canada, is fuelled with natural uranium and moderated with heavy water.

Since nuclear reactors can burn only nuclear fuel, commitment to a nuclear power plant creates a firm demand for nuclear fuel over the life of the plant. Further, since the cost of raw U_3O_8 represents less than five per cent of the total cost of generation, in the case of the light water reactor, this demand for nuclear fuel is relatively insensitive to variations in the price of uranium. This is in marked contrast to fossil-fuelled power stations in which the cost of fuel amounts to some 50 per cent of the cost of generation.

It is generally accepted that nuclear power plants will account for a very high proportion of future additions to generating capacity in the industrialized areas of the Western World. In Canada, for instance, it is anticipated that at least 80 per cent of Ontario Hydro's new generating facilities will be nuclear. Similarly, in the United States, nuclear reactors are expected to constitute between 75 and 90 per cent of all new generating capacity installed after 1980. These high rates of penetration of nuclear power into the total generating market imply strong growth in the demand for uranium.

The United States dominates the market for uranium, being expected to account for about 50 per cent of total Western World demand. Presently, the domestic uranium industry in the United States is protected by an embargo which effectively prohibits the use of foreign uranium in U.S. nuclear reactors. Under these conditions, the United States and the rest of the Western World act as two separate, and approximately equal, trading zones. The U.S. embargo is expected to remain in force until 1977, after which time the embargo is expected to be relaxed in stages. A true world market for uranium will not develop until the embargo is completely removed, probably in 1984.

The most definitive forecast of future uranium demand is that prepared by the U.S. Atomic Energy Commission. Figure 1 shows, separately, the estimated demand in the United States and the rest of the Western World. The most likely estimates of demand exhibit rates of growth, between 1975 and 1990, of 15 per cent, compounded annually, in the United States, and 14 per cent in the Western World as a whole. Sustained rates of growth of this magnitude have never been experienced by any major mineral commodity.

The sources of supply which are potentially available to satisfy this demand comprise reserves in the ground and accumulated inventories. The uranium reserves in the Western World, estimated to be producible at forward costs no greater than $10 per pound of U_3O_8, are shown in Table I. Canada is well endowed with uranium reserves, most of which are contained in the Huronian quartz-pebble conglomerates of the Elliot Lake area, Ontario.

The dynamics of supply and demand, however, relate more to rates of production and consumption than they do to the scale of reserves in the ground. The potential productive capability which could be supported by the known reserves in the Western World, is compared with the anticipated demand for uranium in Figure 2, which also incorporates the supply of uranium which could be obtained from accumulated stockpiles. Of the total potential productive capability shown for 1980, 60 per cent is attributable to existing and committed uranium mills, while the remaining 40 per cent represents the authors' opinion of the potential production which could be supported by known reserves for which no production plans have yet been formulated. Even if new productive facilities are committed in timely fashion, the visible source of potential supply in the Western World as a whole are sufficient to satisfy the anticipated demand for uranium only through 1980.

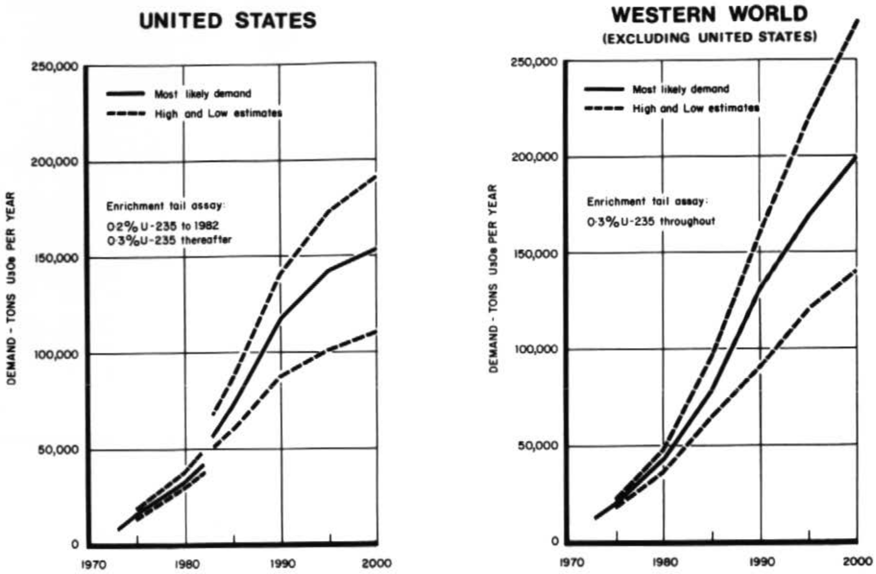


Figure 1
Estimated demand for U_3O_8 *(Compiled from AEC data).*

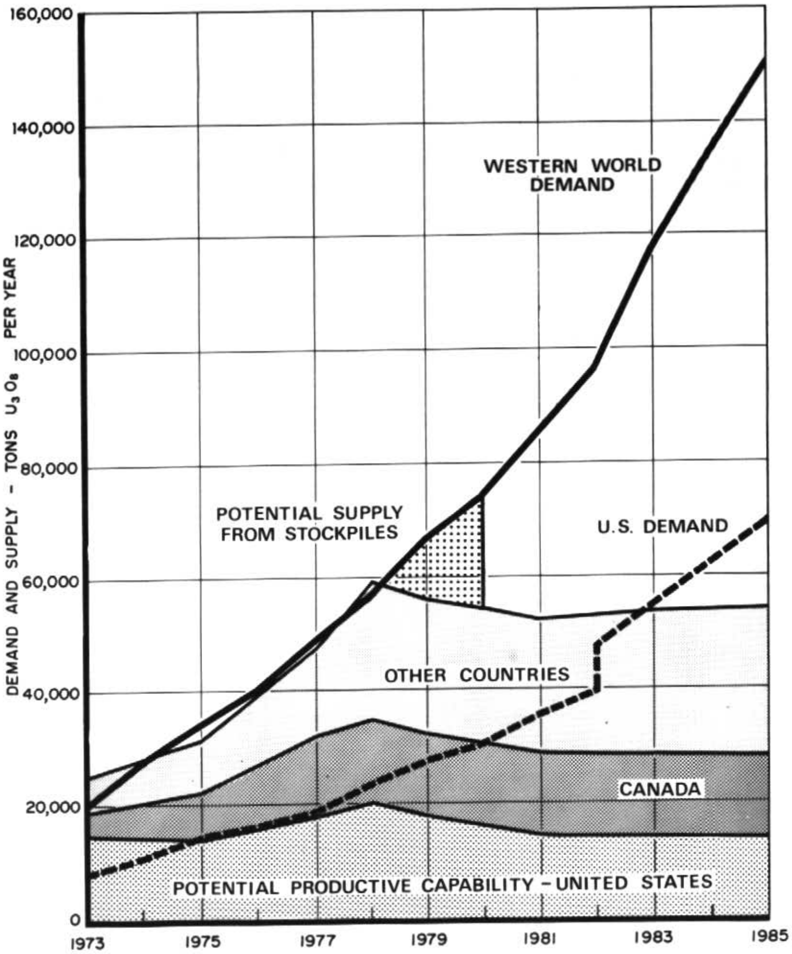


Figure 2
Western world uranium demand versus potential supply from known low-cost sources.

Table I
Uranium reserves of the Western World.

Country	Reserves (Tons U_3O_8)
Australia	210,000
Canada	220,000
France (includes Niger, Gabon, Central African Republic)	120,000
South Africa (includes South West Africa)	300,000
United States	280,000
Other Countries	(50,000)
Total	1,180,000

Thus, although uranium is presently in oversupply, very large increases in reserves are required to meet the rapidly rising demand beyond 1980. In the authors' opinion, it is highly unlikely that low-cost reserves will be discovered at a rate sufficient to satisfy this demand. Substantial price increases are likely to be required to stimulate exploration and to induce production from higher-cost reserves. Since the demand for uranium is relatively insensitive to price, increases in price are unlikely to reduce the future demand significantly. The scale of the anticipated demand and the likelihood of increases in real price suggest that exploration for uranium is warranted.

Canada has always maintained a place in the forefront of the nuclear industry. It was one of the initial major producers of uranium and, to date, has produced about 125,000 tons of U_3O_8, two-thirds of which have come from the conglomerate ores of the Elliot Lake area. Canada possesses about 20 per cent of the Western World's reserves and accounts for some 25 per cent of the potential productive capability of the Western World in 1980. In addition, Canada has successfully developed its own nuclear reactor.

The potential for additional uranium discoveries in Canada is considered excellent, so that the opportunity exists for Canada to continue its significant role in the uranium industry. The remainder of this paper is devoted to a discussion of the known uranium deposits in Canada and the favourable environments in which additional discoveries may be made.

Uranium Ore Deposits of Canada

Uranium ore deposits of Canada are of three types. Table II shows the deposits in order of their relative production of U_3O_8 between 1938, the year of first production from Great Bear Lake, and the end of 1972. The year of maximum production was 1959 in which year Elliot Lake shipped 12,150 tons of uranium as U_3O_8 in yellowcake and the Beaverlodge deposits shipped 2,700 tons. In 1972, Elliot Lake shipped 4,250 tons and Beaverlodge about 700 tons.

In addition to the ore deposits, there are lower-grade examples of each ore type which could be economic in the future. There are also uranium occurrences of other kinds. These latter are referred to by Ruzicka (1971).

Oligomictic, Quartz-Pebble Conglomerates

The uraniferous, quartz-pebble conglomerates are rocks of great age. At all localities where they exist, they lie at, or close to, a profound unconformity with the oldest rocks of their region. These oldest rocks are always heavily contorted and metamorphosed and are normally considered to be of Archean age. There are now at least eight areas of the earth's crust in which these old conglomerates are found. Three of them are in Canada, including the world's leading uranium-producing district, at Elliot Lake (Fig. 3).

Table II
Canadian production of uranium.

Type of Deposit	Production
Oligomictic Quartz-Pebble Conglomerate	83,300 short tons
Epigenetic Pitchblende Veins	33,500 short tons
Syngenetic Pegmatite Deposits	5,800 short tons

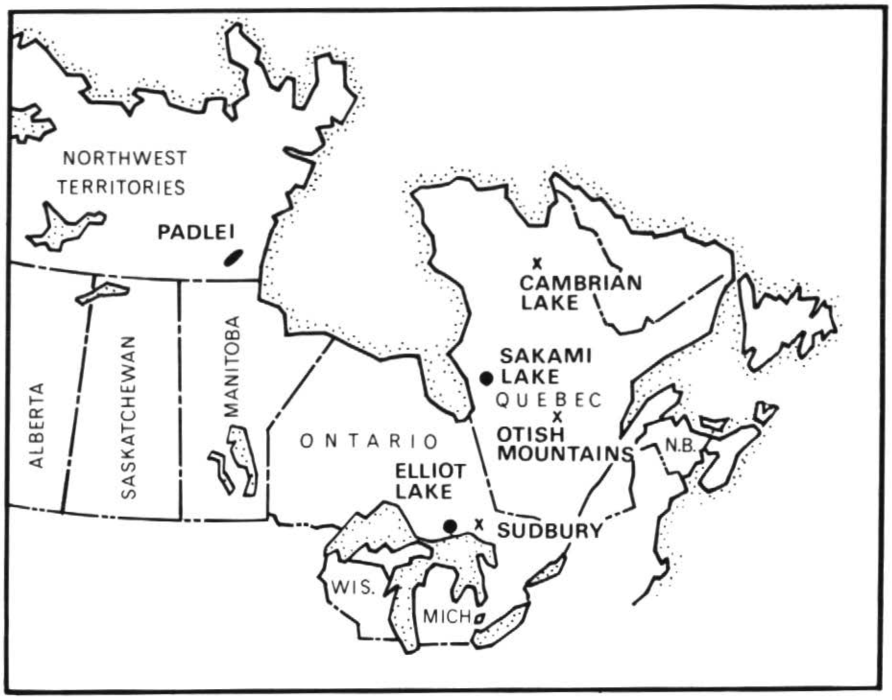


Figure 3
Basal Aphebian quartz-pebble conglomerates in Canada.

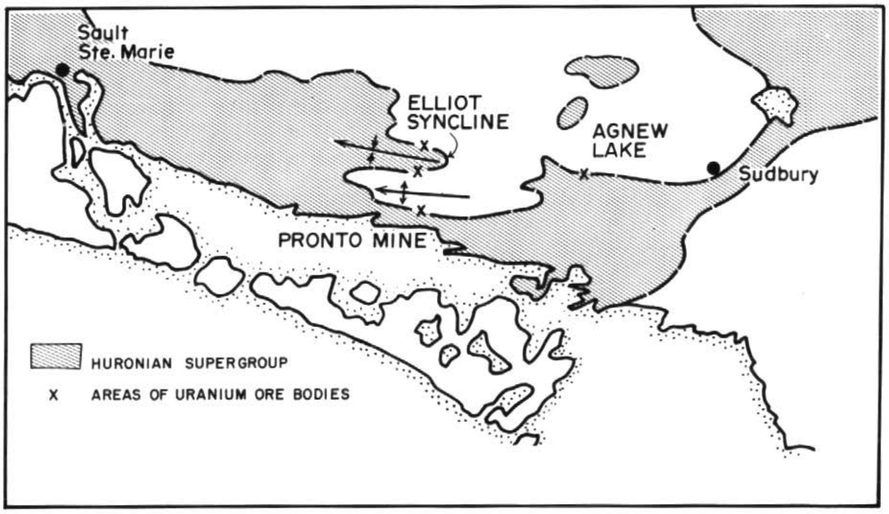


Figure 4
Huronian of the North Shore, Elliot Lake area.

Elliot Lake and region. The uraniferous quartz-pebble conglomerates are found at the base of the Huronian Supergroup, a rock assemblage that stretches from Sault Ste. Marie to the north end of Lake Timagami in Ontario (Fig. 4).

Rocks similar to various parts of the sequence, as seen at Elliot Lake, are found in Wisconsin and Michigan, and east of Lake Albanel in Quebec. The Huronian sequence probably formed on the south edge of a major crustal block of Archean time, stretching a distance of at least 1000 miles.

Erosion during Huronian and post-Huronian time removed parts of the linear zone of Lowest Proterozoic sediment, leaving large, basinlike fragments which are only locally preserved beneath the younger Huronian rocks.

The basement rocks of the larger area comprise highly metamorphosed volcanic and sedimentary material with acid and basic intrusions of various ages. The Huronian rocks normally give evidence only of the lowest grade of regional metmorphism but they are folded and numerous unconformities exist within the sequence.

Along the shore of Lake Huron, where late faulting cuts the sequence, the rocks are locally severely physically distorted. They also show frequent evidence of late sulphide introduction (pyrite, pyrrhotite, chalcopyrite, cobaltite, etc.).

The conglomerates of interest are found regionally, off major drainage (Fig. 5) in an environment considered by the writers to be that of marine deltas (Robertson and Steenland, 1960), although others have considered the rocks to express continental, fluvial conditions (Roscoe, 1967).

Elliot Lake – stratigraphy and sedimentation. Stratigraphy of the broader region is simple and the rocks generally conform to the divisions reflected by the common terminology shown in Figure 6. The ore-bearing conglomerates lie at, or near, the base of the Matinenda Formation in the Elliot Lake area.

At Agnew Lake, which lies half-way between Elliot Lake and Sudbury, the conglomerates are found in Matinenda-type rock of McKim time (Barnes and Lalonde, 1973), these rocks comprising the basal part of the Huronian section at this place.

Similar conglomerates have been found in Turner Township, at the base of the Gowganda which is the base of the Huronian at that point.

It is generally agreed that the rocks of the Huronian Supergroup were derived from the Shield to the north. The provenance area appears to have been largely granitic terrain with abundant uranium accessory minerals.

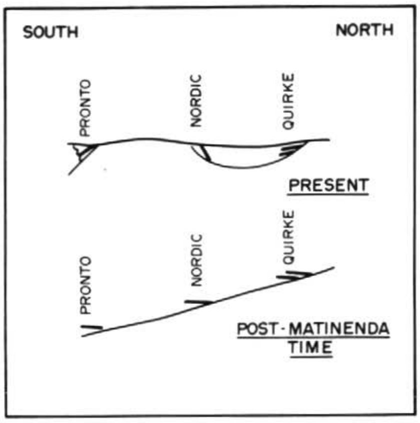


Figure 5
Sections (past and present) through the Elliot Lake area.

Figure 6
Stratigraphy of the Huronian Subgroup (after J. A. Robertson).

COMMON TERMINOLOGY		RECOMMENDED NOMENCLATURE *		
		FORMATION	GROUP	
		BAR RIVER	COBALT	HURONIAN SUPERGROUP
		GORDON LAKE		
LORRAINE		LORRAINE		
GOWGANDA		GOWGANDA		
SERPENT QUARTZITE		SERPENT	QUIRKE LAKE	
ESPANOLA LIMESTONE ESPANOLA GREYWACKE		ESPANOLA		
BRUCE LIMESTONE BRUCE CONG.		BRUCE		
UPPER MISSISSAGI		MISSISSAGI	HOUGH LAKE	
MIDDLE MISSISSAGI		PECORS		
		RAMSAY LAKE		
LOWER MISSISSAGI		McKIM	ELLIOT LAKE	
		MATINENDA		

The rocks of the Elliot Lake and Hough Lake Groups are largely coarse arkoses and quartzites of greenish-yellow to grey colour with interbeds of dark siltstone in the McKim and Pecors Formations. The Quirke Lake Group comprises limestone, sandstones and fine-grained, clean, white quartzite.

The succeeding Cobalt Group has at its base the very widespread Gowganda conglomerate-sandstone-siltstone sequence overlain by the red coloured Lorraine Formation, which is similar in appearance and mineralogy to the Hurwitz Group of the Padlei area, to the Indicator Formation of the Otish Mountains, to the Chakonipau Formation at the base of the Kaniapuskau Group of Labrador and to the Sakami Formation of north central Quebec.

Elliot Lake – structure. The most important structural feature of the region (from the point of view of uranium deposits) is the Elliot Lake basin itself. As can be shown by analysis of isopachs (Robertson and Steenland, 1960), the syncline began development in Early Huronian time and was well developed before the base levelling on which the rocks of Gowganda time were laid down.

The regional movement associated with the development of the Murray fault system further folded the basin area and created the anticline between the Pronto mine and those mines on the south limb of the syncline. A thrust fault, associated with the Murray fault, cuts off the south end of the Pronto ore body, while a regional fault tilts the Agnew Lake ore body into a vertical and locally overturned position (Fig. 7).

Faults of presumably the same age deform the ore units on both north and south limbs of the syncline. These are largely high angle, normal and reverse faults with relatively minor movement. A significant thrust fault with net slip in excess of 1200 feet, causes duplication of the ore units at the Spanish-American and Stanrock mines.

At Agnew Lake, in the vicinity of the Murray Fault, pebbles are stretched to in excess of five times, pyrite in the conglomerate is completely destroyed and the rocks take on a pink-to-red colouration. The uranium, however, does not appear to be significantly moved. The faults are not mineralized and are not normally radioactive.

Elliot Lake – ore units. The ore-bearing units are oligomictic, quartz-pebble conglomerates with pebbles which vary regionally in size but which, in general, are between one-half inch to three inches. Rare pebbles of material other than quartz are found.

The conglomerate beds vary considerably in thickness and in degree of packing but most show evidence of good sorting. Matrix is essentially quartz, sericite and pyrite.

The highest uranium values occur where the conglomerate is best packed, individual well packed conglomerate beds occasionally carrying in excess of one per cent U_3O_8 over one or more feet in width (Fig. 8). The mining unit normally involves a set of beds within which a

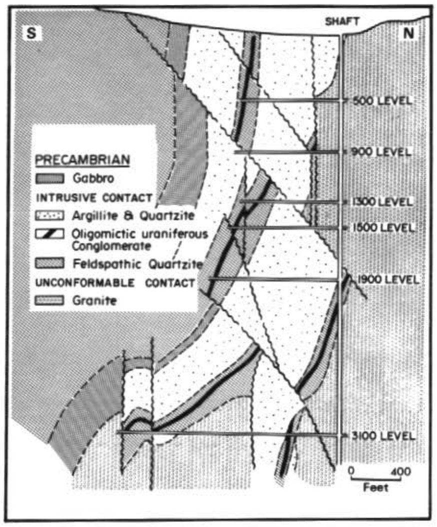
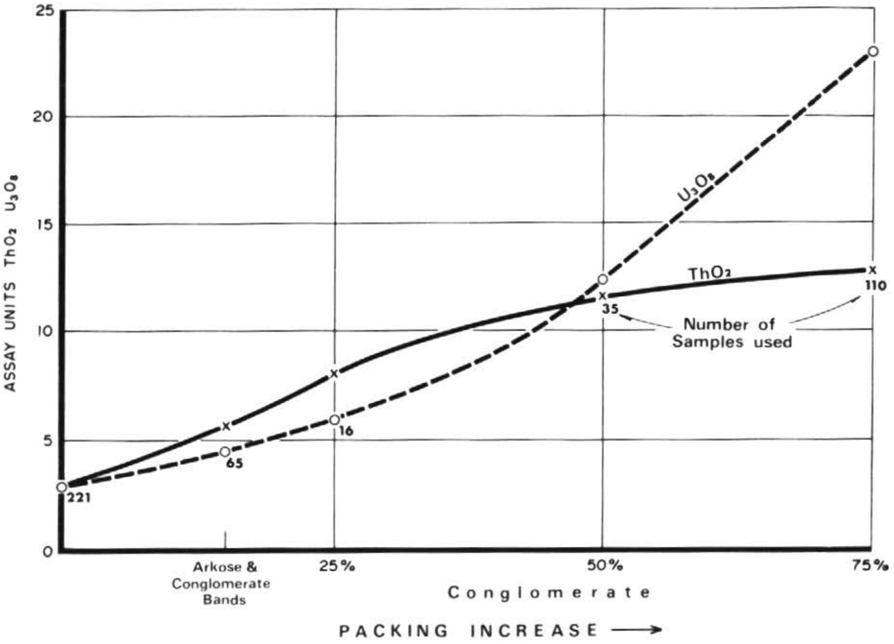
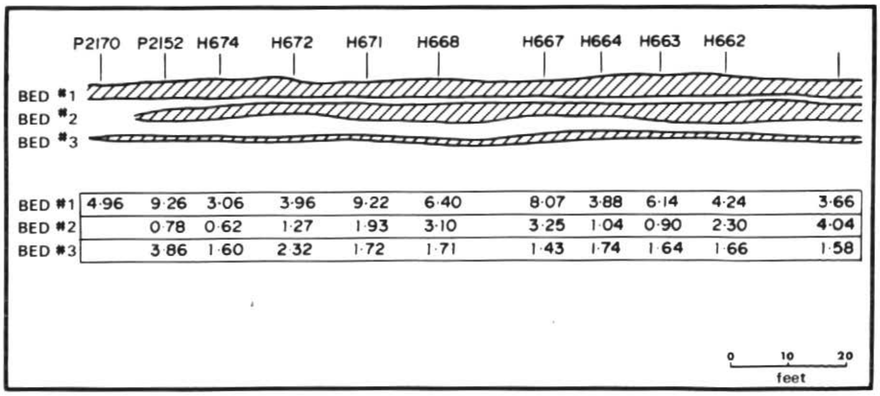


Figure 7
Shaft section, Agnew Lake Mine.

Figure 8
Relation of thorium and uranium content to the conglomerate development and its degree of packing. Assays are radiometric.





	P2170	P2152	H674	H672	H671	H668	H667	H664	H663	H662	
BED #1	4·96	9·26	3·06	3·96	9·22	6·40	8·07	3·88	6·14	4·24	3·66
BED #2		0·78	0·62	1·27	1·93	3·10	3·25	1·04	0·90	2·30	4·04
BED #3		3·86	1·60	2·32	1·72	1·71	1·43	1·74	1·64	1·66	1·58

Figure 9
Section along 11 entry, Stanrock Uranium Mines Ltd. Showing assay variation in beds of conglomerate. Assays are radiometric.

mining width contains enough well packed conglomerate of good grade to carry interbeds of low grade arkose (Fig. 9). Minable widths vary from about five feet to 35 feet.

In the Elliot Lake area uranium occurs in uraninite, in brannerite and intimately associated with monazite. Locally it is associated with thucholite although the amounts so related are very small. At Agnew Lake the ore minerals are uranothorite and monazite.

Minable grade for the district is considered to be two pounds of U_3O_8 per ton of ore milled, although mill heads in excess of three pounds have been maintained by Denison Mines Limited for some years.

Elliot Lake – age of mineralization. The Huronian Supergroup overlies Archean rocks with profound unconformity. Granitic rocks in the Superior Province have been dated at approximately 2.5 million years (m.y.).

Diabase intruding the rocks of the Supergroup yield dates of about 2.2 m.y. The Huronian Supergroup thus appears firmly placed between 2.5 and 2.2 m.y., although, considering the possible inaccuracies involved in interpretation of dates (Goldich, 1972) the rocks may be somewhat older in part.

Of more significance than the absolute age is the similarity in character of rocks, like those of the basal Huronian, which occur around the world. Rocks of this character lie at the base of the oldest Proterozoic strata and are everywhere overlain by reddish-coloured rocks containing hematite. It was suggested (Robertson and Douglas, 1970) that rocks of this kind. "... are restricted in geological time to a period after the development of extensive acid crust which carried relatively large amounts of uranium-bearing accessory minerals, but before the development of an oxidizing atmosphere."

The environment reflected by the presence of rocks of this type and the unique association between these oldest of Proterozoic rocks and overlying red sequences is now so well established that their presence provides a fossil indicator of approximate age which is frequently superior to that available from published dates, many of which reflect relatively young events.

Other areas: Two other areas of Canada have oligomictic quartz-pebble conglomerates with pyrite and uranium. The conglomerates of the Montgomery Lake – Padlei area in the District of Keewatin, unconformably underlie the red rocks of the Hurwitz Group. In addition to uranothorite and other uranium-bearing minerals, the conglomerates carry native gold.

The Montgomery Lake – Hurwitz sequence was laid down prior to the Hudsonian event at 1800 m.y. The conglomerates are of character and age similar to those at the base of the Huronian Supergroup.

In the Sakami Lake area of northern Quebec, folded, metamorphosed greenish-yellow arkose and white, clean quartzites lie, apparently unconformably, on more tightly contorted greywacke and greenstones of the Archean. The arkose carries discontinuous beds of quartz-pebble conglomerate which contain uraninite, with 10 per cent ThO_2 and a thorium silicate.

The younger sediments of the region are the red coloured, flat-lying arkose and conglomerates of the Sakami Formation which is similar to the Chakonipau Formation at the west side of the Labrador Trough. The conglomerates are folded and metamorphosed, presumably by the Kenoran event at 2500 m.y. They appear to be older than other Canadian conglomerates.

Origin. Pyritic, uranium-bearing, quartz-pebble conglomerates have been found in South Africa, in Brazil and in western Australia. Those conglomerates are similar in aspect to Canadian conglomerates described herein and the mineralization is of similar character.

It is the opinion of the authors that the conglomerates are all of similar age and of the same mode of origin. They are unique to their special part of geological time, a time which preceded the formation of the epigenetic deposits described in the next section (Fig. 10). During this period of time, the earth's atmosphere was anoxygenic. Syngenetic uraninite from pegmatite and gneiss areas was carried in detrital form to be deposited as a heavy mineral in what are now 'fossil' placers.

Various kinds of evidence have been adduced to support the concept of a detrital origin for the deposits. The authors believe the uranium minerals to be largely detrital for the following reasons:

1. They exist within a normal detrital assemblage and occur in the same way as other detrital minerals. In particular, the distribution of ThO_2/U_3O_8 ratios varies in manner explicable by concepts of gravity grading (Robertson, 1962).
2. The minerals are compositionally of a kind which is accessory in granitic rocks. The uraninite, for example, with its high content of thorium and rare earths, is distinctly different from the pitchblende which forms veins as described in the following sections.
3. There is no connection between the uranium minerals and faults, veins or other 'late' phenomena.
4. At places where the ore units are eroded by younger conglomerates, the radioactive debris from the former contaminates the latter which are otherwise essentially non-radioactive. The radioactivity is clearly related to the erosion process and implies the existence of uranium mineral in 'older' conglomerate beds prior to the development of the 'younger' conglomerate beds.

Vein-Type Deposits

Vein deposits and related stockworks can be divided into two general types, those with simple mineralogy which contain, principally, pitchblende with minor to trace amounts of minerals of other elements, and those of complex mineralogy of which uranium, in the form of pitchblende, is a significant part but by no means predominant. In the latter group are the deposits of Great Bear Lake formerly worked for uranium but now worked, principally, for silver. In the former group are the deposits of the Beaverlodge camp, the Rabbit Lake and Cluff Lake deposits of the Athabasca sandstone area, the deposits of Makkovik in Labrador and

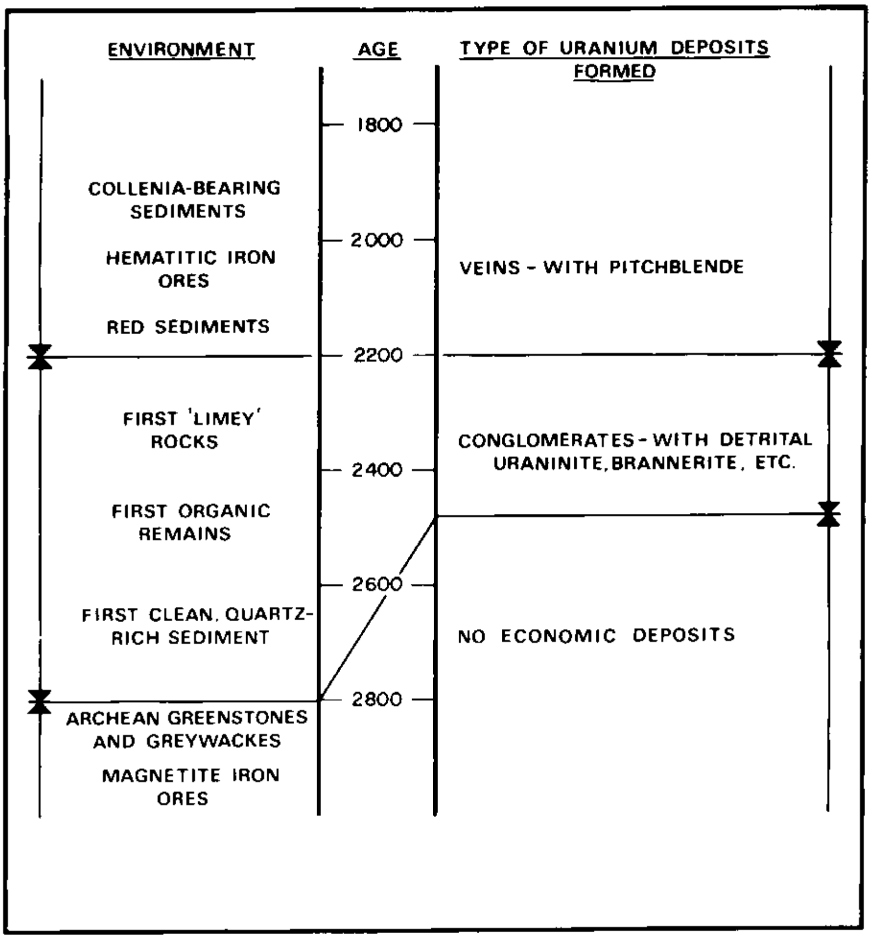


Figure 10
Uranium deposits and geochronology.

the many mineralized areas such as Baker Lake in the Northwest Territories, Theano Point on the east end of Lake Superior and Greenwich Lake north of Thunder Bay.

The following discussion deals only with deposits of simple mineralogy which have been important to Canada's uranium production in the past and which will be more important in the future. The brief descriptions given are designed to suggest the importance of similarities between the environments in which this kind of deposit is found around the world.

While prior literature considers deposits of this kind to be epigenetic, they are almost invariably considered 'hydrothermal' being emplaced from depth. It is suggested here that the deposits, while unquestionably epigenetic, are emplaced from the surface and protected from erosion by younger rocks which only recently have been removed, thus exposing the ore.

Beaverlodge. Pitchblende in the Nicholson gold-copper prospect was described by the Geological Survey of Canada in 1936. Re-study of this occurrence in 1944 led to the work which ultimately resulted in the discovery of hundreds of pitchblende occurrences in the Beaverlodge area north of Lake Athabasca. In 1951, Eldorado (now Eldorado Nuclear Ltd.) announced plans for production from properties which are producing to this day. In 1953, Gunnar Gold Mines Limited began production from the other substantial uranium deposits in the district. One other mill was built, that of Lorado Uranium Mines Limited, and ore was shipped for custom milling from eight other small mines.

Beaverlodge – environment. The geology and uranium mineralization of the region have been well described by Robinson (1955), by Beck (1970) and by others. Figure 11 shows the rock units of the region and their places in the sequence of events derivable by 'dating'.

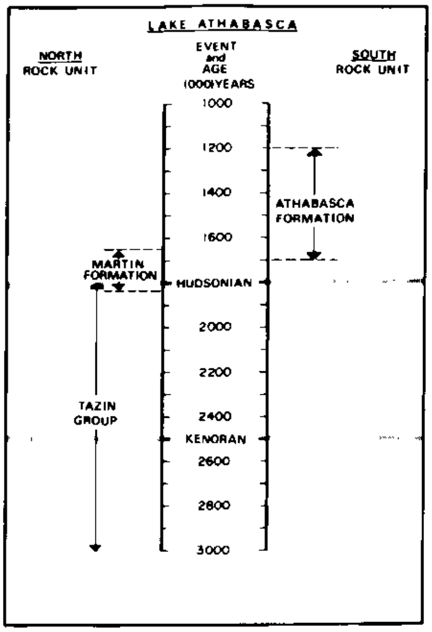


Figure 11
Rock units of the Athabasca Region (Dates after Fraser, 1970).

Uranium deposits of the region are of two types. Of minor interest are the syngenetic, pegmatite deposits in which uraninite occurs as an accessory mineral. These deposits formed prior to the Hudsonian event, sparse data showing minimum ages of about 1930 m.y. Uraninite in these deposits carries significant amounts of thorium and rare earths.

The prominent deposits are epigenetic, pitchblende-bearing veins and stockworks, most of simple mineralogy. These are found in various rock types of the Tazin Group and in the cover rocks of the Martin Formation. As noted by Robinson (1955, p. 74), distribution of the deposits suggests ". . . that uranium deposits occur preferentially near the Athabasca (Martin) – Tazin contact".

The deposits are all localized by structure, zones of brecciation and mylonitization. Uranium is everywhere dispersed in thousands of small fractures. Only where numbers of these occur in a zone of interconnection do the deposits attain size such as to be of economic interest. Deposition of uranium is chiefly by cavity filling of fissures, breccias and fracture zones, all of which are dilatent systems. As noted by Robinson (p. 93), this is "... suggestive of relatively shallow depths." Major faults of the area, the breccias and the mylonitization are pre-Martin in age.

Beaverlodge – ore deposits. The ore deposits and most of the minor spots of mineralization are composed of pitchblende with hematite, calcite, chlorite and quartz. Pitchblende varies in character from disseminated to massive and colloform, the non-disseminated varieties providing the bulk (90%) of the uranium. Colloform pitchblende is usually the oldest and it is frequently brecciated and re-cemented by various minerals including many stages of younger pitchblende.

The two major ore deposits of the district are the Gunnar and Eldorado deposits. The Gunnar deposit is not presently in production. The Eldorado deposit will continue to be in production for many years.

At Gunnar the ore occurred in an albitized monzonite, a metasomatized paragneiss, part of the Tazin Group. Pitchblende and secondary uranium minerals were disseminated through the monzonite with limited evidence of structural control except for higher grade zones which were related to zones of brecciation frequently marked by red hematite. In the breccia zones, euhedral quartz cemented by calcite and large calcite grains suggested that the brecciated, mylonitized zones were porous and vuggy during mineralization.

Secondary uranium minerals, chiefly uranophane, were prominent in the upper parts of the body comprising about 60 per cent of uranium values. Even at depths of 400 feet, some 30 per cent of the uranium was in secondary minerals and secondary mineralization persisted to even greater depth.

Non-metallic minerals were calcite, dolomite, chlorite and quartz. Calcite and dolomite occurred throughout the rock as irregular grains. Toward the base of the ore unit carbonates comprised up to 25 per cent of the rock while at higher levels these amounted to about five per cent.

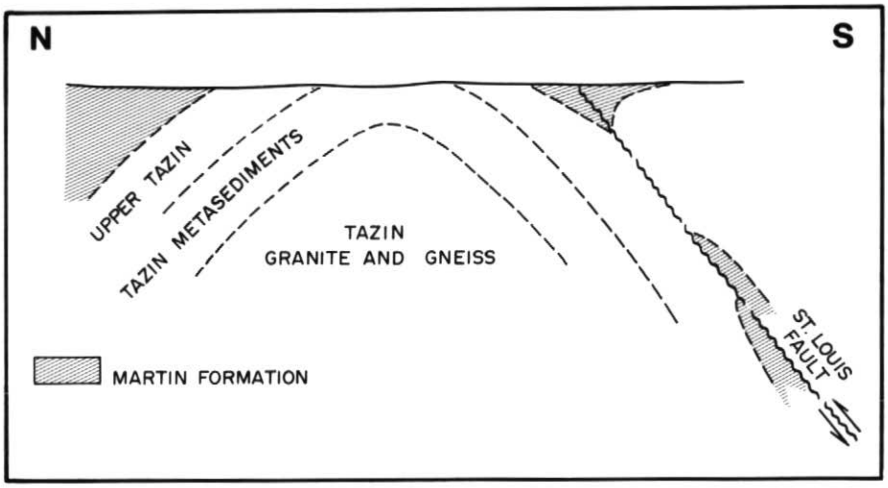


Figure 12
Idealized section through St. Louis Fault.

The various ore shoots that make up the Eldorado mine system, including the shoots mined from the Fay, Ace and Verna shafts, lie along the St. Louis fault over a distance of about two and one-half miles. Ore bodies are found both in the footwall and hangingwall of the fault in veins and in stockwork breccias, all largely within 200 feet of the fault.

Continuing work by E. E. Smith, of Eldorado, suggests that mineralization everywhere is close to the Tazin – Martin unconformity. This situation is illustrated by the idealized section, Figure 12. The mineralization is like that previously described at Gunnar except that there is no great depth to the zone of secondary minerals. All pitchblende-bearing structures are red in colour. Non-metallics, in order of abundance, are calcite, chlorite and quartz.

Beaverlodge – age and origin. Minimum age of the syngenetic-pegmatite bodies is considered to be about 1930 m.y. and prior to the Hudsonian event. Initial epigenetic pitchblende mineralization is dated at about 1780 m.y. Samples selected to represent a single stage of mineralization are dated at various times as young as about 250 m.y. ago. This suggests that mineralization continued, at least in intermittent fashion, to that date and there is little question that uranium is actively going into solution and being re-deposited today.

It has been noted that the deposits are all controlled by pre-Martin structure except for those that lie in the Martin Formation. It is evident that much of the mineralization was deposited in open spaces along with hematite, calcite, chlorite and terminated quartz and that deposition of all minerals was repeated over and over through long periods of time. These appear to be near-surface phenomena.

It is the opinion of the authors that the uranium was emplaced from moving surficial and ground water prior to the laying down of the Martin Formation. The ultimate source of the uranium, of course, would be the syngenetic uranium associated with the pegmatite and gneisses of the pre-Hudsonian rocks. The emplacement of pitchblende reflects the high solubility of uranium in relation to other elements available from the gneisses such as thorium and rare earths.

The restriction of uranium-bearing veins to the area in which the Martin Formation is now found, and presumably, therefore, close to the old Tazin – Martin unconformity, suggests that the Martin Formation protected the deposits from reworking, solution and dissipation. It is a fact, as will be seen, that the only places in which substantial epigenetic deposits are found are close to these old unconformities, this in spite of the fact that syngenetic deposits of uranium-bearing minerals in pegmatites and gneisses are common all over the Shield areas.

Rabbit Lake Deposit. The Rabbit Lake

uranium ore body was located by Gulf Minerals in 1968. An airborne anomaly to the southwest of the ore body was caused by a pitchblende boulder train at the head-end of which the ore is found. The ore body lies off the east side of the Athabasca Formation in the centre of the Wollaston fold belt. Literature references are few (Knipping, 1971; Ruzicka, 1971; and Guidebook, 1972, p. 47-49).

Rabbit Lake Deposit – environment. The deposit lies under and south of Rabbit Lake and appears to have been covered by the Athabasca sandstone at one time. Uranium occurs in a crushed and brecciated carbonate, calc-silicate layer which has been down-folded to form a tight, recumbent syncline, probably during the Hudsonian event at about 1800 m.y. The section, Figure 13, illustrates the relationship of the ore unit to the surrounding environment.

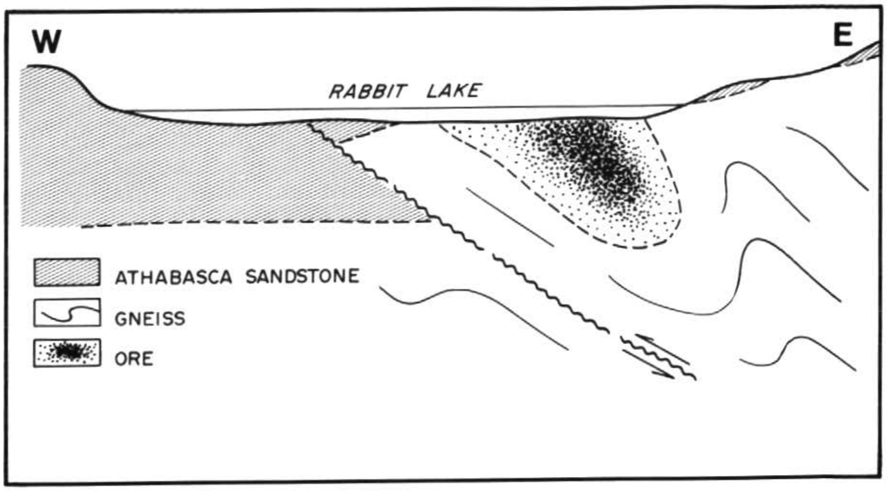


Figure 13
Idealized section through Rabbit Lake area.

Rabbit Lake Deposit – the ore body. The ore consists of hard massive and banded, colloform pitchblende with relatively late quartz and calcite gangue. The pitchblende carries no thorium and no rare earths. Continual leaching and re-deposition has moved uranium from the upper layers and deposited it as sooty pitchblende in the lower parts of the ore unit. Openings of a variety of shapes and sizes were plentiful during mineralization and exist today in the surrounding country rocks.

The ores are essentially monomineralic although secondary uranium minerals, such as uranophane, do occur.

The ore body is roughly a flattened tube plunging gently northeast with a length of about 1,400 feet and a maximum thickness of about 550 feet. Highest grade is in the centre of the body and the shape and grade distribution are suggestive of fluid movement through a funnel or tube-like system with greatest uranium precipitation in the most permeable central part.

Rabbit Lake Deposit – age and origin. Uranium-lead dates vary from an 'oldest' of about 1240 m.y. to a 'youngest' of about 190 m.y. That uranium has moved frequently through time is shown by the variety of ages derived.

Uranium deposition is believed to be of pre-Athabasca time with some re-working after the deposition of the Athabasca which protected the deposit from complete erosion. Syngenetic uraninite (with thorium) in pegmatites is not uncommon through the gneisses of the Wollaston Lake gold belt. This material undoubtedly provides the source of the uranium through the period of epigenetic mineralization.

Cluff Lake Deposits. The Cluff Lake uranium ore bodies were found by Mokta (Canada) Ltée. who located a train of pitchblende boulders by airborne radiometric survey in 1968.

The ore bodies lie below the Athabasca sandstone in the Carswell structure, a circular feature believed to have been caused by meteorite impact.

Cluff Lake Deposits – environment. The Carswell structure is about 35 miles in diameter. At its centre, basement rock is exposed in a circular area with diameter of about 12 miles. The basement is extremely deformed and cut with zones of breccia and beds of rhyolite, presumably generated by impact and dated at about 470 m.y. Around the basement core is a zone of heavily deformed sandstone rubble, followed by a ring of fine-grained sandstone and dolomite, a ring of dolomite and then the flat-lying Athabasca sandstones.

The results of careful, thorough work carried out by Mokta show that the 'typical' Athabasca sandstones in the Cluff Lake area are underlain by a thin, discontinuous band of pelite, a fine- to medium-grained silty rock normally of reddish colour, which occupies hollows in the basement. It is in this pelite and in the basement rocks that uranium occurs. The pelite is overlain by white to cream coloured sandstone and conglomerate. The conglomerate occasionally carries red pelite pebbles.

The basement rocks and the pelite are badly deformed, the basal contact of pelite with gneiss frequently being overturned by structures that appear to be thrust faults. It is in a structurally deformed area that uranium is found.

Cluff Lake Deposits – the ore bodies. The 'D' ore body was found in 1969 by following up the airborne results that located the pitchblende boulder train. The rich ore body, which contains massive pitchblende through thicknesses up to 15 feet, is contained in the basal pelite. While relatively small in size, it contains significant amounts of uranium because of its high grade.

The ore is essentially monomineralic and carries no thorium although significant amounts of gold and platinum occur. The mineralization is in pitchblende that appears to have an intimate relationship with abundant organic material in the pelite. A similar relationship between mineralization and organic material exists in the fault-controlled ores of the basement.

Cluff Lake Deposits – age and origin. Uranium-lead dating suggests primary deposition at between 1100 and 1400 m.y. ago. Older dates have been derived as have dates as young as 80 m.y. These younger dates suggest re-working of uranium through long periods of time.

It is the opinion of the authors that, before the deposition of the Athabasca sandstone, uranium was emplaced from surficial waters that deposited uranium in the pelites and in structural traps in the basement. The uranium has been re-worked by ground waters through time both before and after the development of the Cluff Lake structure. Enrichment by moving, heated waters may have taken place during evolution of the structure.

It is the opinion of the authors that the organic material is oil-derived and remains at the site due to polymerization and fixing in place by the pre-existing uranium.

Other Deposits. Pitchblende mineralization in fracture is not uncommon but major deposits seem to be very few. Of the many mineralized areas in Canada, only two others are presently known to the authors to be of any scale. These are the showings of the Makkovik area in the eastern Nairn geological province of Labrador and the deposits in and around the Kazan Formation (Dubawnt Group) of Baker Lake in the Northwest Territories west of Chesterfield Inlet.

In the Makkovik area syngenetic uraninite occurrences and epigenetic pitchblende occurrences and deposits have been intensively explored by British Newfoundland Explorations Limited. The pitchblende deposits are of potential economic interest. Reference to the area is made by Ruzicka (1971, p. 109).

Mineralization at Baker Lake, located by Pan Ocean Oil Limited, is pitchblende in structurally deformed areas in Kazan clastics of red colour, in Christopher Island volcanics and in the basement below the sediments. The pitchblende in the basement veins is accompanied by euhedral calcite frequently stained by hematite. In the sandstones and eruptive rocks, pitchblende is in disseminated and botryoidal form. Gangue is predominantly drusy calcite with minor quartz.

General. The largest uranium ore discoveries of recent years are those of the Northern Territory of Australia. These deposits are identical in mineralogy to those described in prior paragraphs. Of even more interest, however, is the pronounced similarity between the environment in which the deposits exist and that described for Beaverlodge, Cluff Lake and Rabbit Lake.

All of these Australian deposits lie close to the cliff edge of the Proterozoic Kambolgie sandstone and the older Proterozoic unconformity which is presently being exhumed by the removal of the Kambolgie. One recently found deposit, the Jabiluka 2, lies under the Kambolgie. There is little or no uranium in the overlying rock. These facts suggest that, as with the Canadian deposits described earlier, the ore bodies form at the surface in structurally-controlled openings and are then protected from erosion and dissipation by the younger rock lying on the unconformity.

In some of these Australian deposits, however, age dating implies a time of origin much younger than the dated younger rock or younger than general geological relationships would suggest. The question then arises as to which data are reliable.

The minerals of uranium are pronouncedly soluble under present atmospheric conditions, a fact which has been used by many to illustrate the improbability of a detrital genesis for uranium ore bodies in basal Aphebian conglomerates. This solubility is illustrated by many phenomena including: the rapidity with which yellow uranium salts develop on freshly exposed uranium minerals, the many deposits of sandstone type created by concentration of uranium from ground water and the multiple-stage deposition of pitchblende in the vein deposits described.

Elsewhere in this paper it is suggested that this extremely facile movement of uranium became possible and prevalent with the development of an oxidizing atmosphere. That uranium has moved through long periods of time is shown by the multiplicity of dates derived from all of these vein deposits. In vein type units the upper part of the ore bodies, to greater or lesser extent, is composed of secondary minerals which further confirm movement of uranium.

It is the opinion of the authors that, because of the mobility of uranium, it is highly unlikely that any sample from ore in veins can give a U-Pb date indicative of the initiation of deposition of the uranium in the deposit.

If one accepts that the fluids from which uranium was deposited moved essentially downward in the veins or structures in which the ores exist, it appears impossible to derive the age of older uranium, all material near the 'top' having been re-worked by many hundreds of thousands of years of fluid movement and all material at the 'bottom' being relatively young. The mechanism visualized is akin to that operating today in the southwest United States wherein the deposits are 'alive', uranium being deposited at the downstream end of fluid movement and being taken into solution at the upstream end. Under these circumstances, all dates on vein-type deposits will be younger than the time of emplacement, probably significantly so.

Origin. It appears that subsequent to basal Aphebian time, about 2200 m.y. ago, an atmosphere developed in which exposed uranium-rich minerals were extremely soluble. Atmosphere of this character is maintained today.

Surface waters leached uranium from syngenetic uranium accessory minerals in granites, pegmatites and other rocks and deposited it in structural openings where the uranium was precipitated as pitchblende by change in either pH or Eh. Continued passage of fluids both added more uranium to the system and remobilized and re-deposited that which was previously deposited.

Where the deposits, so formed, were protected from continuing active ground water attack by the development of cover rock, the deposits are preserved to this day. Where not so protected, they were ultimately destroyed, their uranium moving on to other structral or chemical traps and, ultimately, to the sea.

In areas where the deposits and their surrounding rocks have been contorted and metamorphosed, the cover rock has itself developed structural openings into which uranium from the unconformity has moved (as in the case of the Eldorado deposits). In areas where such movement has not taken place, there is no significant uranium in the cover rocks (as at Cluff Lake and Rabbit Lake).

Pegmatite Deposits

Uranium occurs in pegmatite bodies or in pegmatoid phases of granites throughout the Canadian Shield as it does in other Shield areas. In many occurrences uranium is intimately related to typical accessory minerals such as biotite. In the pegmatite bodies, uranium more frequently occurs as uraninite or uranothorite in discrete crystals, also of course, as an accessory mineral. In almost all deposits the presence of uranium is indicated by the bright yellow stain of uranophane which coats biotite and rock joints to a depth of a few feet.

In only one area, the Bancroft area of southern Ontario, has this type of deposit been economic. In many other areas, however, surface mineralization has been of sufficient interest to stimulate extensive work. Two typical areas are the north shore of the Gulf of St. Lawrence and an area of the Kenora Mining District in Ontario.

Bancroft Area. Uranium has been known to be present in the Bancroft area since about 1920: Ellsworth reported on radium in pegmatites of Ontario in 1922.

The deposits that formed the ores of the Faraday mine, the most significant of the district, were found in 1949. Those of the Bancroft mine were found in 1952.

During the 1950's, seventeen deposits were explored from underground openings and many more were drilled. Three small mills (1,000 tpd) were built in the area and one of these (Faraday, now named Metal Mines Limited) is in stand-by condition at this date.

Bancroft Area – environment. The Grenville Province, in which the deposits lie, is characterized by regionally metamorphosed rocks that are now paragneiss, amphibolite and marble. Intrusive rocks, both stock-like bodies and *lit-par-lit* injections, include gabbro, diorite, syenite and granite.

The area of the deposits is permeated by dykes, lenses and diffuse zones of pegmatitic granite and syenite within which the uranium ore bodies lie.

The Grenville event is dated at approximately 950 m.y. while uraninite ages are about 1040 m.y. (Guidebook, 1972, p. 17-23).

Bancroft Area – ore deposits. The ore bodies occur as discontinuous shoots within pegmatoid bodies. While the shoots can occur anywhere within the host rock there is a tendency for them to be concentrated on the edges or contacts. In most cases, the shoots are much more persistent in the vertical sense than in the horizontal.

The main ore minerals are uraninite, uranothorite and uranothorianite. Other radioactive minerals are allanite and zircon. While gangue minerals in the usual sense are not present, there are local associations with magnetite and late-stage quartz. Higher grade zones are frequently red in colour. The ores averaged about two pounds U_3O_8 per ton, the largest ore body carrying about 3,000 tons of U_3O_8.

The deposits are of typical syngenetic origin similar to those of older age in other parts of the Shield. Their ultimate origin is obscure but it is tempting to speculate that their relatively high primary content of uranium is due to rejuvenation of rock and uranium from detrital deposits of Aphebian age which were re-worked during the Grenville event.

Gulf of St. Lawrence. Uranium and thorium mineralization occurs at many localities in Eastern Quebec and significant work has been done on deposits in the Laurentians, north of Montreal, and along the north shore of the Gulf of St. Lawrence. Deposits of this latter region are well described by Baldwin (1970), his descriptions applying equally well to other deposits of the larger region.

Mineralization occurs as disseminated uraninite, uranothorite and uranothorianite, monazite and minor zircon and allanite in pegmatite, pegmatoid granite and in migmatite. Locally, mineralization is distributed over substantial distances on the surface but grade over such distances rarely exceeds 0.05 per cent U_3O_8. The ratio, ThO_2/U_3O_8, in surface samples is low, less than 0.5, reflecting the relative concentration of uranium which is prominently displayed by the yellow uranophane that shows up on fractures to depths of a few feet. At depth uranium content is normally lower and the ratio, ThO_2/U_3O_8, is greater than one.

Kenora District. In this district, as in many other areas, pegmatite bodies with uranium are common. One deposit of sufficient interest to warrant work has anomalous concentrations of uranium in a red, pegmatitic granite phase developed as a marginal facies of a massive to gneissic, equigranular granite that intrudes a paragneiss sequence.

The intense surface anomaly found along the contact zone for a distance of more than three miles has been found to be almost totally due to concentrations of uranophane on a multitude of fractures and joints in the granite at the metasediment contact.

Muck and chip samples from shallow trenches returned assays as high as 2.2 pounds U_3O_8 over 15 feet. Shallow drill holes and deep trenches yielded extremely low values.

Distribution and Origin. Uranium-bearing pegmatoid bodies exist in Shield areas of all ages from Archean to Grenville time (older than 2500 m.y. to 950 m.y.). They are all similar in mineralogy and in character of distribution of minerals. Some of those of Grenville time appear to carry higher concentrations of uranium than the older bodies. These concentrations may be due to re-working of older pegmatoid concentrations during the Grenville event or to re-working of older detrital, sedimentary material incorporated into Grenville metasediments.

The uranium-rich bodies are all erratic and discontinuous in distribution. They frequently have near-surface parts substantially enriched in uranium by the leaching and reprecipitation of uranium caused by the action of surface waters.

Concluding Remarks

Anomalous concentrations of uranium in coals, in young arkoses and in carbonatites occur in Canada as well as economic concentrations of the kinds earlier described. As the commodity becomes of short supply, as Figure 2 suggests it must, search for ores of lower grade than those now worked will be needed and some of these ores may come from environments which have not yet been economic. However, consideration of the geological map of Canada suggests abundant reason to anticipate the finding of more conglomerates and veins of the kind described and permits anticipation that Canada will continue to play its significant role as a sorce of uranium for the world.

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