ECONOMIC URANIUM DEPOSITS IN GRANITIC DYKES BANCROFT DISTRICT, ONTARIO[1]

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ABSTRACT

The geology and mineral deposits of the Bancroft uranium camp are reviewed briefly. The relation of the deposits of the one type that has been found to be economic, to other types of deposits and to geological features is described. The mineralogy and geochemistry of the ore deposits is described. The ages of the ore deposits, of other mineral deposits and of the principal igneous rocks of the district are compared. It is concluded that there is a genetic relationship linking the ore deposits to certain granite intrusives, and that the deposits were deposited in major part by replacement controlled by type of rock and structure, and in minor part by fissure filling.

INTRODUCTION

Production of uranium in Canada comes from three distinctly different types of deposits. In order of amount of uranium produced they are: (1) the conglomerates of Blind River Ontario, (2) the hydrothermal deposits of Great Bear Lake and Marian River, Northwest Territories and Beaverlodge, Saskatchewan, and (3) the pegmatitic granite dykes of Bancroft, Ontario.

Current production from the two mines in the Bancroft camp is 2,500 tons per day of ore averaging 0.1% U_3O_8 and varying from 0.025 to 0.2% ThO_2. The two each have their own extraction plants. A few other properties in the district contain large tonnages approaching ore grade and a much larger number have small pockets of high-grade ore.

The Bancroft camp is in the western part of the Grenville geological province which forms the southeastern margin of the Canadian Precambrian Shield. Uranium-thorium deposits of pegmatitic, skarn, metasomatic, and fenite type extend through the western part of this geological unit and constitute a metallogenetic province. The greatest concentration of these deposits is in the vicinity of Bancroft, where productive mines are in Faraday and Cardiff townships southwest of the town. Satterly (1957) has published detailed descriptions of most deposits in the district.

GENERAL GEOLOGY

The productive region lies within the southern margin of the highly metamorphosed rocks of the Haliburton Highlands and is bounded on

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the south by rocks of the Hastings basin which are of a distinctly lower grade of metamorphism.

Geology of the area as mapped by Hewitt (1959) is illustrated in Figure 1. Three granitic to syenitic intrusive complexes dominate the geological setting; the Cheddar batholith, an intrusive dome of granite; the Cardiff complex, composed of incomplete concentric cylinders of

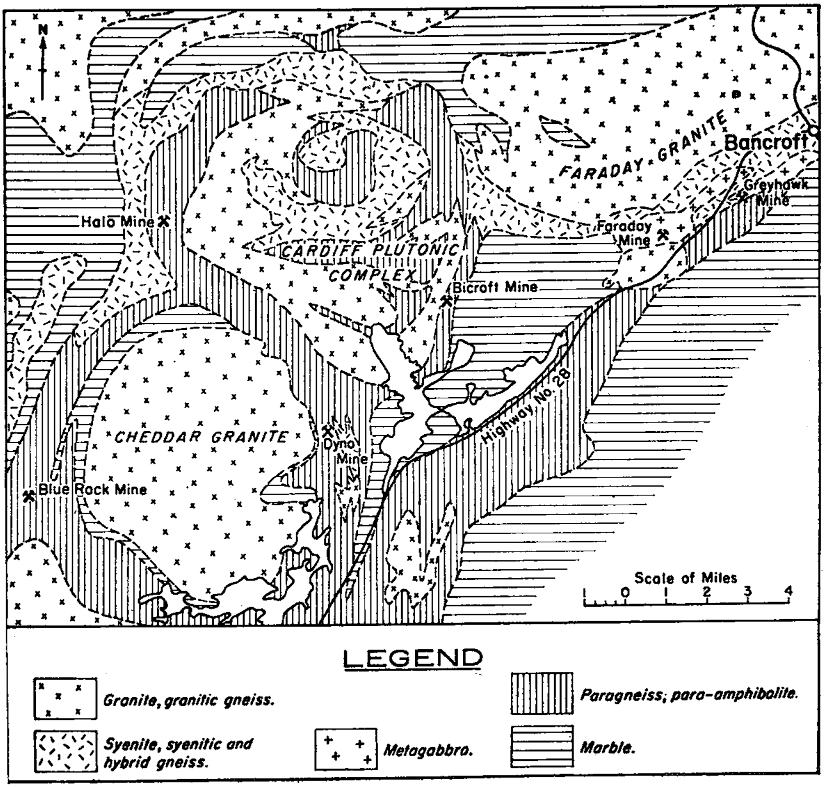

FIG. 1. Geological diagram of Bancroft region, Ontario (after D. F. Hewitt), showing location of uranium mines.

granite and syenite with intervening hybrid gneiss; and the Faraday granite, a sheet-like body dipping to the south. Enveloping these intrusive complexes are variably granitized metasediments comprising marble, amphibolite, limy paragneiss and quartzite, and basic intrusives now metamorphosed to metagabbro, metadiorite and hornblende schist.

Most of the uranium deposits, and all of the productive ones, are in the rocks surrounding these three intrusives. A few minor deposits occur within the intrusives and others are in metamorphic rocks remote from them. The greatest concentration of deposits is around the northern half of the Cheddar batholith, around all but the northern quadrant of the Cardiff complex and on the southern (hanging-wall) side of the Faraday granite.

Uranium Deposits

All deposits of the region are epigenetic and contain uranium, thorium and rare-earth elements as well as zirconium, titanium, and locally niobium (Robinson & Hewitt, 1958). In terms of the writer's classification of Canadian uranium deposits (Robinson, 1958), therefore, those of the Bancroft region would all be included in the igneous group and represent the following types: (1) Granites and syenites, (2) Pegmatites, (3) Metasomatic deposits (*a*) General, (*b*) Fenites.

The radioactivity of the large bodies of granite is greater than that of any of the other major rock types in the region and appears to be slightly higher than that of granites in the Canadian Shield generally. By contrast, radioactivity of the nepheline-syenites is remarkably low. Certain irregular dykes of pegmatitic granite and syenite, however, in the rocks marginal to the main granite masses, are abnormally radioactive and it is in these that the uranium orebodies occur. It is these bodies that are the subject of this paper.

Discrete pegmatites, both massive and zoned are variably radioactive. In some of the zoned types there is a core of calcite-fluorite-apatite which contains uraninite and uranothorite crystals. "Vein-dykes" of similar calcite-fluorite with scattered crystals of biotite, phlogopite, plagioclase, hornblende and apatite, contain a few large crystals of uraninite.

Many small metasomatic lenses and disseminations in pyroxenite and other metamorphic rocks contain uraninite and/or uranothorite with one or more of calcite, quartz, scapolite, feldspar, biotite, and apatite. Several skarn zones in impure marbles are characterized by the association of crystals of uranoan thorianite, phlogopite, and diopside in pink calcite. In a few deposits resembling fenites, discrete crystals of betafite occur with apatite and biotite in calcite veins or lenses.

All types of deposits appear to be of the same age and exhibit similarities in their mineralogy and geochemistry that point to a common epigenetic ancestry. Marked differences in type of deposit, in geological environment and structure, and in major mineral components are probably due to differences in composition and competence of the host-rocks and to distance and path travelled by the epigenetic mineralizing solutions.

Pegmatitic Granite Dykes

Deposits in pegmatitic granite can be exploited economically only where many of them are concentrated in a restricted zone. In the four mines from which production has come, such zones occur in country rocks that are dominantly amphibolites. In these zones the pegmatitic granite occurs in dykes and in irregular pod-shaped, branching lenses, that are usually distributed *en echelon* horizontally and vertically. One lens is 600 feet long and up to 100 feet wide, but the average width of the dykes is about 10 feet. The overall trend of dykes and lenses is usually nearly parallel to the foliation of the enclosing rocks, but in detail, most bodies transect the foliation at low angles and locally cut off rolls in the enclosing rocks at high angles.

Contacts of the granite bodies with the country rocks are usually sharp laterally, but are often poorly-defined longitudinally where the granite usually fades out through a granitized zone, or less commonly "tails" out or pinches out in a number of segregated veins, some of which clearly fill fractures with matching walls in the country rock.

Individual dykes are usually composed of several different lithologic facies, the most common of which are: pink granite gneiss; pink leuco-granite, frequently magnetite-rich; pegmatitic granite or syenite, commonly containing large crystals of peristerite; pyroxene-rich granite and syenite, variably pegmatitic; and cataclastic quartz-rich pegmatite. These facies are irregular in shape and distribution and have defeated every effort to establish a systematic distribution equivalent to zoning. Differences in lithology are attributable in part at least, to the amount and degree of assimilation of inclusions and relict schlieren in the dykes. Contacts between the facies are usually sharp laterally and transitional longitudinally. Where the dykes fade out into country rock, segregations of plagioclase feldspar and quartz are the last recognizable features, but where they pinch out into filled fractures, they exhibit differentiation into assemblages of quartz, quartz-feldspar, calcite-biotite, quartz-sulphide, etc.

Inclusions of wall-rock in the dykes are usually parallel to the walls and commonly exhibit a high degree of assimilation which in extreme cases is represented only by a band rich in femic minerals. Angular, unaltered inclusions are relatively rare, but where found usually indicate some rotation relative to the walls.

Most of the dykes are appreciably radioactive throughout their extent, but are well below ore grade. Ore is usually found in shoots that are irregularly distributed, but which favour the foot-walls, hanging-walls, medial inclusions, constrictions in the dykes, ends of the dykes, and zones of shattering. Ore is usually confined within the dyke, but in rare cases extends short distances into shattered zones in the wall-rocks. Ore shoots are not readily recognized megascopically, but compared with non-ore dyke rocks, may exhibit one or more of the following: deeper red feldspars, generally darker colour, slabby quartz-rich texture, finer and more even grain size.

Mineralogy

Principal minerals in the dykes are soda plagioclase, microcline and quartz with minor pyroxene, amphibole and/or magnetite. Biotite, calcite, chlorite, fluorite, and muscovite are locally present. Of the accessory minerals, zircon and sphene are abundant and tourmaline, apatite, hematite, garnet, molybdenite, chondrodite, and pyrrhotite are less common. Other minerals found only rarely include melanocerite, cenosite, lessingite, ilmenite, a rare-earth apatite, galena, sphalerite and chalcopyrite.

The feldspar crystals average one inch in diameter and attain a maximum of 2 feet. In most occurrences they exhibit perthitic or antiperthitic intergrowth. Graphic granite and myrmekitic intergrowths are less common. Soda and potash feldspars seem about equally abundant. In both, the twinning appears only in patches. Most feldspar is anhedral but euhedral faces have been observed against calcite, fluorite, sulphides and rarely against quartz. Pyroxene is commonly altered in part to either hornblende, biotite, chlorite or assemblages of the three.

The principal ore minerals are uraninite and uranothorite. Allanite is sporadically abundant and betafite is found locally in some ore shoots. Fergusonite and rarely polycrase have been identified in minute amounts. Uraninite (Robinson & Sabina, 1955) is the principal source of uranium, but is not readily recognized because it occurs in rounded to euhedral grains rarely exceeding 1 mm. in diameter. Uranothorite (Robinson & Abbey, 1957) is commonly found in small rounded grains that average 3 mm. in size. Occasionally where it cements brecciated zones and appears to replace brecciated rock, it is found in impure masses up to 6 inches wide. It has been found also in slender prisms embedded in allanite and calcite. Allanite is usually euhedral in plates up to 5 inches long, but which average less than 1 inch. Betafite and fergusonite appear in rounded subhedral grains.

Vugs are common in the dykes, and in them, and in late fractures, green fluorite, hematite, calcite and marcasite are commonly found. Less commonly they contain one or more of celestite, gypsum, talc, kaolinite, cenosite, galena, sphalerite, uranophane and kasolite.

Evidence of paragenetic sequence is not definitive, but the intergrowths suggest that the feldspars and some quartz were contemporaneous and textures indicate they were early. There is evidence of local replacement by aggregates of magnetite, zircon, sphene, uraninite, uranothorite and quartz. Fracture filling in the dykes by quartz, uranothorite, uraninite, magnetite and sulphides has been observed. Calcite and purple fluorite fill interstices in the dykes molded against euhedral faces of other minerals.

GEOCHEMISTRY

In order to ascertain differences in chemical composition brought about by the replacement of the amphibolitic wall-rocks by the dykes, 20 samples were taken from the Bicroft and Faraday mines, comprising 8 samples of dyke-rock, 7 samples of unaltered wall-rock and 5 samples of granitized rock at the ends of the dykes. Analyses within each of these three groups are remarkably consistent, and analyses of the granitized rocks are intermediate between those of the dykes and of the unaltered wall-rocks.

Table 1 presents the average composition of the unaltered wall-rocks, the average composition of the dykes and the relative change in composition. It is evident that the dykes contain 35% more SiO_2 and more

TABLE 1. BANCROFT REGION—ROCK ANALYSES* (Composition %)

Rock	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	TiO_2
Average of 7 host rocks	49.2	16.4	2.9	6.9	7.7	6.0	4.1	1.6	1.4
Average of 8 dyke rocks	66.5	14.6	1.1	1.9	3.3	1.6	4.5	3.8	0.2
Relative Change (%)	+35	−11	−62	−72	−57	−73	+10	+137	−86

*"Rapid Method" analyses made in the Rock and Mineral Analysis Laboratories, Geological Survey of Canada.

than twice as much K_2O as the wall-rocks. There is, however, little difference in the contents of Al_2O_3 and Na_2O. Wall-rocks on the other hand, contain 3 times as much Fe_2O_3, $3\frac{1}{2}$ times as much FeO, $2\frac{1}{2}$ times as much CaO, $3\frac{1}{2}$ times as much MgO and, surprisingly, 7 times as much TiO_2 as the dykes. Results also confirm that the change in composition occurs abruptly at the dyke walls without transition. There is no significant difference in major element content of non-ore dykes and relatively low-grade ore. The difference would be distinct in high-grade pods.

Semiquantitative spectrographic analyses were made of 70 samples of ore and dyke rock in order to ascertain whether there were any elements whose distribution was parallel to that of uranium. As was expected, thorium, the rare-earths, and lead show a consistently parallel distribution. Zirconium is the only other element that is generally similar in this respect. Syngenetic elements whose redistribution as a result of replacement, is often parallel to deposition of uranium are, iron, quartz, titanium and sulphur.

Despite the relatively high anorthite content of plagioclase feldspar in the host rocks and the fairly high content of CaO in the dykes, the plagioclase in the dykes falls almost wholly in the albite range. The

TABLE 2. AGE DETERMINATIONS—BANCROFT REGION

Locality	Rock or Deposit	Mineral	K/A age (m.y.)	Mineral	Lead Isotope Age (m.y.)
Faraday Lake	Faraday Granite	Biotite	1245±30	—	—
Mayo Township	McArthur's Mills Granite	Biotite	955±25	—	—
Methuen Township	Blue Mtn. Nepheline Syenite	Biotite	934±25	—	—
Centre Lake	Centre Lake Granite	Biotite	918±25	—	—
Carlow Township	Boulter Tonalite	Biotite	899±25	—	—
Bicroft Mine	Pegmatitic Granite Dyke	—	—	Uraninite	a. 1065±25 b. 1005±25 955±30
Bicroft Mine	Pegmatitic Granite Dyke	—	—	Uranothorite	600±50
Faraday Mine	Pegmatitic Granite Dyke	—	—	Uraninite	1045±30
Mentor Deposit	Unzoned Pegmatite	—	—	Uraninite	970±20
Nu-Age Deposit	Unzoned Pegmatitic Skarn	Biotite	945±25	Uraninite	a. 955±10 b. 950±45
Cardiff U. Mine	Calcite-Fluoritic "Vein-Dyke"	Phlogopite	1103±30	Uraninite	1070±25
Normingo Deposit	Calcite-Phlogopite-Diopside Skarn	—	—	Thorianite	1040±10
Camex Deposit	Calcite-Phlogopite-Diopside Skarn	—	—	Thorianite	1000±30

NOTES: 1. K/A Branching ratio 0.118, Half Life 1.313×10^9 years.
2. Lead Isotopes by Pb^{207}/Pb^{206}, Pb^{207}/U^{235}, Pb^{206}/U^{238}, Pb^{208}/Th^{232}.

excess CaO is in the pyroxene, calcite, and garnet. Virtually all K_2O is accounted for by microcline, although biotite is a factor locally. Uranium, thorium and the rare-earth elements occur together in all the ore minerals. Uranium is dominant in uraninite ($ThO_2 < 10\%$), and in betafite; thorium is dominant in uranothorite ($U_3O_8 < 20\%$); and the rare-earths are dominant in allanite and fergusonite.

Age Determinations

Although several age determinations of minerals from the area appear in the literature, it was decided to make new determinations on material selected during the study of these deposits. These new ages are listed in Table 2.

It is not intended to attempt to evaluate the large number of variables that may have influenced these results, but the following points are worth noting: (1) Ages listed check satisfactorily with earlier work. (2) Biotites in four intrusions and one pegmatitic skarn, fall in the general range 900–950 m.y. One biotite is much older. One phlogopite at 1105 m.y. corresponds roughly with uraninite at 1070 m.y. (3) The uraninite-thorianite ages are in the range 950–1070 m.y. Uraninites from the pegmatitic granites are in the same age range as uraninites and thorianites from pegmatites and skarns. (4) The wide range in age for uraninites from a single mine exceeds the possible analytical error. (5) Biotites appear to yield lower ages than apparently coeval uraninites. If this is due to differentially higher loss of argon from biotites than lead from uraninites, it may be concluded that the uranium deposits are probably of the same age as the granite intrusions except the Faraday granite. Additional biotite ages are to be determined in order to test this hypothesis.

Conclusions

1. The Bancroft uranium deposits are generally similar in type and age to others in a metallogenic province comprising the western half of the Grenville geological province.

2. In the Bancroft region distribution of deposits around, and similarity of age to, granite intrusions suggests a genetic relationship.

3. All the different types of deposits—skarn zones and other metasomatic deposits; pegmatites zoned and unzoned; calcite-fluorite vein-dykes and the pegmatitic granite dykes—are thought to be products of similar epigenetic infusions on host-rocks that differ markedly in competency and composition.

4. The pegmatitic granite dykes were formed largely by replacement, but partly by fissure filling.

5. There is no systematic repetition of the varying lithologic types within these dykes that can be interpreted as zoning.

6. Although the dykes are radioactive throughout, many ore shoots can be related to cataclastic zones in the competent dyke rocks. In other ore shoots that appear to be transitional to the dykes, there is evidence of late deuteric replacement by patches of uraninite, uranothorite, zircon, sphene,

magnetite, etc. This suggests a progressive change in composition of the epigenetic solutions.

7. Although the dykes lack some aspects of pegmatites; their occasional coarse crystallization; overall composition; enrichment in uranium, thorium, rare-earths, and zirconium; and characteristic mineral intergrowths all suggest that they belong to the pegmatitic line of descent.

8. The widespread occurrence of fluorite indicates the possibility that uranium, thorium, rare-earths and possibly zirconium, travelled as fluoride complexes.

9. Widespread occurrence of similar deposits throughout the Grenville suggests that the source of the rarer elements may have been some coextensive early sediment rather than a granitic magma. It seems certain, however, that the energy causing migration and concentration of these elements was supplied by heat from intruding granitic rocks.

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