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GEOLOGY OF THE URANIUM DEPOSITS RELATED TO THE SUB-ATHABASCA UNCONFORMITY, SASKATCHEWAN

L.P. TREMBLAY

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GEOLOGY OF THE URANIUM DEPOSITS RELATED TO THE SUB-ATHABASCA UNCONFORMITY, SASKATCHEWAN

Abstract

The Athabasca Basin is a large oval, dish shaped structure, 425 km by 225 km (80 000 km^2) containing about 1500 m of mainly flat lying quartz-rich sandstone of the Athabasca Group. The sandstone has a white clay cement and is chiefly white but locally is grey to black or multicoloured. The basin lies with marked angular unconformity across a Hudsonian basement of deformed and metamorphosed Archean and Aphebian sedimentary, volcanic and plutonic rocks trending north to northeast beneath the basin. The basement rocks in the southeast half of the basin are mainly Aphebian whereas those in the northwest appear to be predominantly Archean. In the Carswell Circular Structure in the central western half of the basin basement rocks are brought to surface through 1200 m of sandstone. The rocks of the basin are less than one per cent exposed. Overburden locally reaches 90 m thick.

Uranium deposits have been found near the southeast edge of the basin, within the Carswell Circular Structure, and along the northern rim of the basin. They are (1) at the unconformity as high grade masses elongated in and parallel to major faults, hosted mainly in highly white clay-altered feldspar-rich basement rocks and associated with graphitic metasediments and calc-silicate rocks; (2) within the first 40 m above the unconformity in grey to black and multicoloured Athabasca sandstones and shales as a coating on quartz grains, as disseminations in the clay matrix and as veins; and (3) within 100 m below the unconformity as fracture fillings and disseminations in basement rocks. Pitchblende and coffinite are the main uranium minerals. Many of the deposits have a multielement association and some have appreciable amounts of nickel, cobalt, gold, arsenic and/or other elements in addition to uranium. The richest zones are at the intersections of faults or where faults change direction.

Several stages of uranium concentration were required for the formation of these deposits. Some of the stages took place before deposition of the Athabasca rocks, that is, during the deposition, anatexis and subsequent weathering of the basement rocks. The significant deposits formed after deposition of the Athabasca rocks by remobilization of the uranium from the basement rocks and the regolith in hot circulating groundwater, and by its precipitation at the unconformity and spatially related traps in highly white clay-altered basement rocks and/or grey to black and multicoloured sandstone.

Uranium is being mined (1981) at Rabbit Lake and Cluff Lake (D orebody).

Résumé

Le bassin d'Athabasca est oval et a la forme d'une grande assiette. Il a 425 km par 225 km (80,000 km carrés), et renferme environ 1500 m de grès surtout quartzeux du groupe d'Athabasca, en position horizontale. Les grès ont un ciment argileux blanc et sont surtout blancs, mais en certains endroits ils sont gris à noirs ou variolés. Le bassin repose en discordance angulaire prononcée sur un socle hudsonien de roches sédimentaires, volcaniques et plutoniques de l'Archéen et de l'Aphébien. Ces roches sont déformées et métamorphisées et dans la région du bassin sont orientées vers le nord-est. Les roches du socle dans la moitié sud-est du bassin sont surtout aphébiennes tandis que celles dans la partie nord-ouest semblent appartenir surtout à l'Archéen. Dans la Structure circulaire de Carswell vers le centre de la moitié occidentale du bassin les roches du socle ont été déplacées vers la surface à travers 1200 m de grès. Les affleurements représentent moins de 1 pour cent de la surface du bassin. En certains endroits le mort-terrain atteint 90 m d'épaisseur.

Les gîtes d'uranium se trouvent près de la bordure sud-est du bassin, dans la Structure circulaire de Carswell et le long de la bordure septentrionale du bassin. Ils sont: (1) à la discordance en masses à forte teneur, allongées le long et dans des failles majeures, encaissées surtout dans des roches du socle, riches en feldspath et fortement altérées en argile blanc, et associées à des métasédiments graphitiques et roches calcosilicatées; (2) dans les premiers 40 m au dessus de la discordance dans des grès gris à noirs et variolés de la succession d'Athbasca en minces recouvrements sur grains de quartz, en disséminations dans la matrice argileuse et en filons; et (3) dans les premiers 100 m au dessous de la discordance sous forme de remplissage de fractures et en disséminations dans des roches du socle. La petchblende et la coffinite sont les principaux minéraux d'uranium. Plusieurs des gîtes sont caractérisés par une association de plusieurs éléments et quelques-uns renferment des quantités appréciables de nickel, cobalt, or, arsénic et/ou d'autres éléments en plus de l'uranium. Les zones les plus riches sont aux intersections de failles et aux endroits où les failles changent de direction.

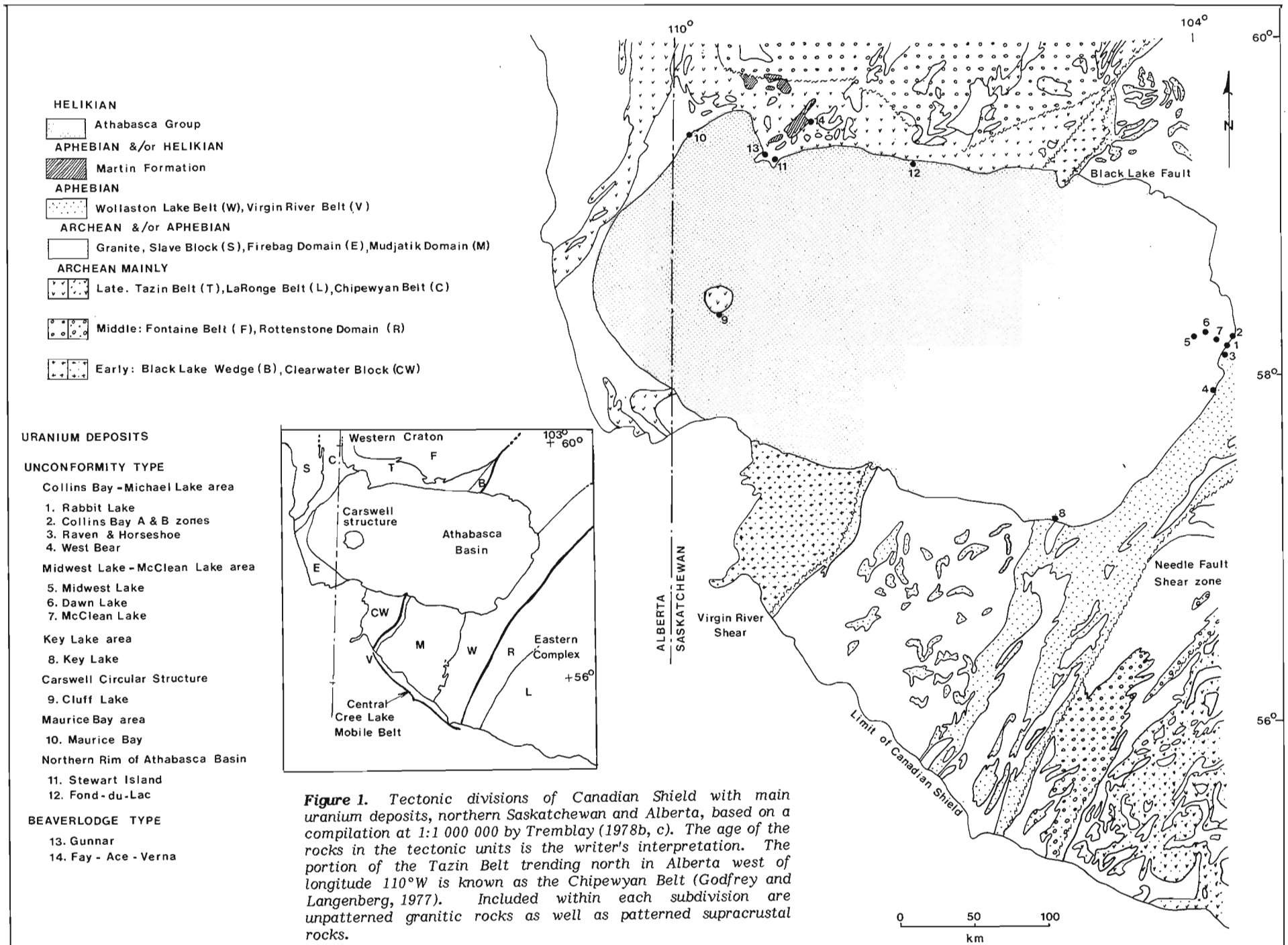

Figure 1. *Tectonic divisions of Canadian Shield with main uranium deposits, northern Saskatchewan and Alberta, based on a compilation at 1:1 000 000 by Tremblay (1978b, c). The age of the rocks in the tectonic units is the writer's interpretation. The portion of the Tazin Belt trending north in Alberta west of longitude 110°W is known as the Chipewyan Belt (Godfrey and Langenberg, 1977). Included within each subdivision are unpatterned granitic rocks as well as patterned supracrustal rocks.*

Les gîtes ont requis pour leur formation plusieurs stages de concentration d'uranium. Quelques uns de ces stages ont eu lieu avant la déposition des roches d'Athabasca i.e. durant la déposition, l'anatéxie et les effets d'altération de surface, des roches du socle. Les gîtes importants se sont formés après la déposition des roches d'Athabasca et sont le résultat de la remobilisation de l'uranium à partir des roches du socle et du régolithe. Le transport de l'uranium s'est fait dans des eaux chaudes souterraines en mouvement. L'uranium s'est précipité à la discordance et dans des pièges associés spatialement dans des roches du socle fortement altérées en argile blanc, et/ou dans des grès gris à noirs et variolés.

On exploite présentement (1981) l'uranium aux lacs Rabbit et Cluff (gîte D).

INTRODUCTION

Exploration for uranium in northern Saskatchewan started in 1945 and at first was concentrated in the Beaverlodge (Uranium City) area (Fig. 1, 2) where pitchblende was discovered in 1935 (Alcock, 1936). In the late 1940's and early 1950's, exploration spread rapidly north of Lake Athabasca and to the Wollaston Lake and Virgin River belts east and south of the Athabasca Basin, everywhere oriented towards veins of Beaverlodge type. Many deposits were discovered in the Beaverlodge area and several were developed for production, among them the Fay-Ace-Verna and Gunnar deposits (Fig. 1). The Fay-Ace-Verna deposits of Eldorado Mining & Refining Limited, later renamed Eldorado Nuclear Limited, (Lang et al., 1962; Tremblay, 1972, 1978a) which were still in operation in 1981 producing about 500 tonnes uranium a year are due to close in June 1982 because the operation has become uneconomical. The Gunnar deposit is believed to be exhausted. Its operations ended in October, 1963. At that time and for many years after, the Athabasca Basin was not considered a favourable uranium bearing area because only one uranium occurrence had been reported (Kermeen, 1955) and exploration was discouraged by thick overburden (Lang, 1952; Beck, 1977). Systematic exploration of the basin began in 1965 when models of sandstone-type mineralization (Finch, 1967) and of the supergene concept (Moreau et al., 1966) became exploration tools and were applied to the basin by companies such as Mokta (Canada) Ltd. (now operating under the name of Amok Ltd.) and Gulf Minerals Canada Limited. The Rabbit Lake deposit was found first, in 1968. This was followed in 1969 by the discovery of the D orebody at Cluff Lake. Since then, a new deposit has been discovered almost every year until the present (1981). Indeed, the basin is now being actively explored for uranium deposits, particularly along its margin, and mainly toward unconformity- and sandstone-type deposits. The basin appears destined to become possibly the main uranium producing area of Canada.

The purpose of this paper is to describe the main characteristics of the uranium deposits related to the Athabasca Basin as presently known, to define the characteristics of each type or group, to compare the main types with one another, and to attempt a classification.

The main uranium deposits related to the Athabasca Basin are: Rabbit Lake, Raven and Horseshoe, West Bear, Collins Bay A and B zones, Midwest Lake, Dawn Lake, McClean Lake, Key Lake, the deposits of the Cluff Lake area, Maurice Bay, Stewart Island and Fond-du-Lac (Fig. 1). The Eldorado Fay-Ace-Verna deposits at Beaverlodge and the Gunnar deposit some 35 km to the southwest are vein-type deposits of the Beaverlodge type. They occur north of the Athabasca Basin and are assumed not to be genetically related to the unconformity- and sandstone-types of uranium deposits. Most deposits related to the Athabasca Basin occur along the southeast margin of the basin, where Aphebian rocks constitute most of the basement to the Athabasca rocks (Fig. 1). Those in the Cluff Lake area within the Carswell Circular Structure are in the interior of the basin, whereas the remaining deposits are scattered along the northern margin of the basin. The latter and those in the Carswell Circular Structure are within an area where basement to Athabasca rocks is mostly granitoid and possibly mainly Archean age. All uranium deposits are within 20 km of the outer margin of the basin except those in the Carswell Structure, which are toward the centre of the basin. The grade and size of the deposits vary widely (Table 1). Some are high grade, above one per cent U, such as the D orebody in the Cluff Lake area with an average of over 4 per cent U, but most average about 0.4 per cent U. Large deposits have more than 20 000 tonnes of contained uranium whereas some have only a few tonnes. The deposits occur in three levels relative to the sub-Athabasca unconformity: (1) within the basal 40 m of the Athabasca succession; (2) along the unconformity and extending down into the basement and to a lesser extent up into the Athabasca rocks; and (3) in the basement rocks as much as 100 m below the unconformity. All the deposits are characterized by pitchblende and coffinite in pods and fractures and as disseminations within the adjacent wallrocks and in the matrix of the Athabasca layered rocks. The deposits are epigenetic and, actually in detail, mainly of the vein-type. Finally, most were first located by tracing radioactive boulder trains since all were covered by glacial till, gravel and silt and some by eolian sands as much as 90 m thick. They were formed about 1280 Ma ago.

Acknowledgments

This synthesis would not have been possible without the co-operation of the staff of the companies listed below and without their willingness to discuss the geology of their respective deposits. Amok Ltd., Asamera Oil Corp. Ltd., Canadian Occidental Petroleum Ltd., Eldorado Nuclear Limited, Esso Minerals Canada, Goldak Exploration Technology Limited, Gulf Minerals Canada Limited, Key Lake Explorations Ltd., Saskatchewan Mining Development Corp., and Uranerz Exploration & Mining Ltd. were all most kind and co-operative during the writer's visits to their properties, in most cases on more than one occasion. Their assistance was most fruitful and is greatly appreciated. I am also grateful to all of these companies for their permission to publish this information. Finally I wish to thank T.I.I. Sibbald and A.J. Gracie of Saskatchewan Geological Survey and Jan Hoeve of Saskatchewan Research Council for assistance and information in the field, and André Boyer of Canada Centre for Mineral and Energy Technology (CANMET) for assistance in the preparation of some of the figures. M.N. Henderson of the Geological Survey of Canada studied several thin sections of altered rocks associated with the deposits, made a few mineral identifications and drafted all the figures. The paper was critically read by W.H. Poole.

GENERAL GEOLOGY

The Athabasca Basin is a broad, oval, dish shaped structure, 425 km (east to west) by 225 km (north to south) containing about 1500 m of mainly flat lying Helikian sandstone of the Athabasca Group. It lies with marked angular unconformity across a Hudsonian basement of intensely deformed, medium to highly metamorphosed Archean and Aphebian sedimentary, volcanic and plutonic rocks trending north to northeast beneath the basin.

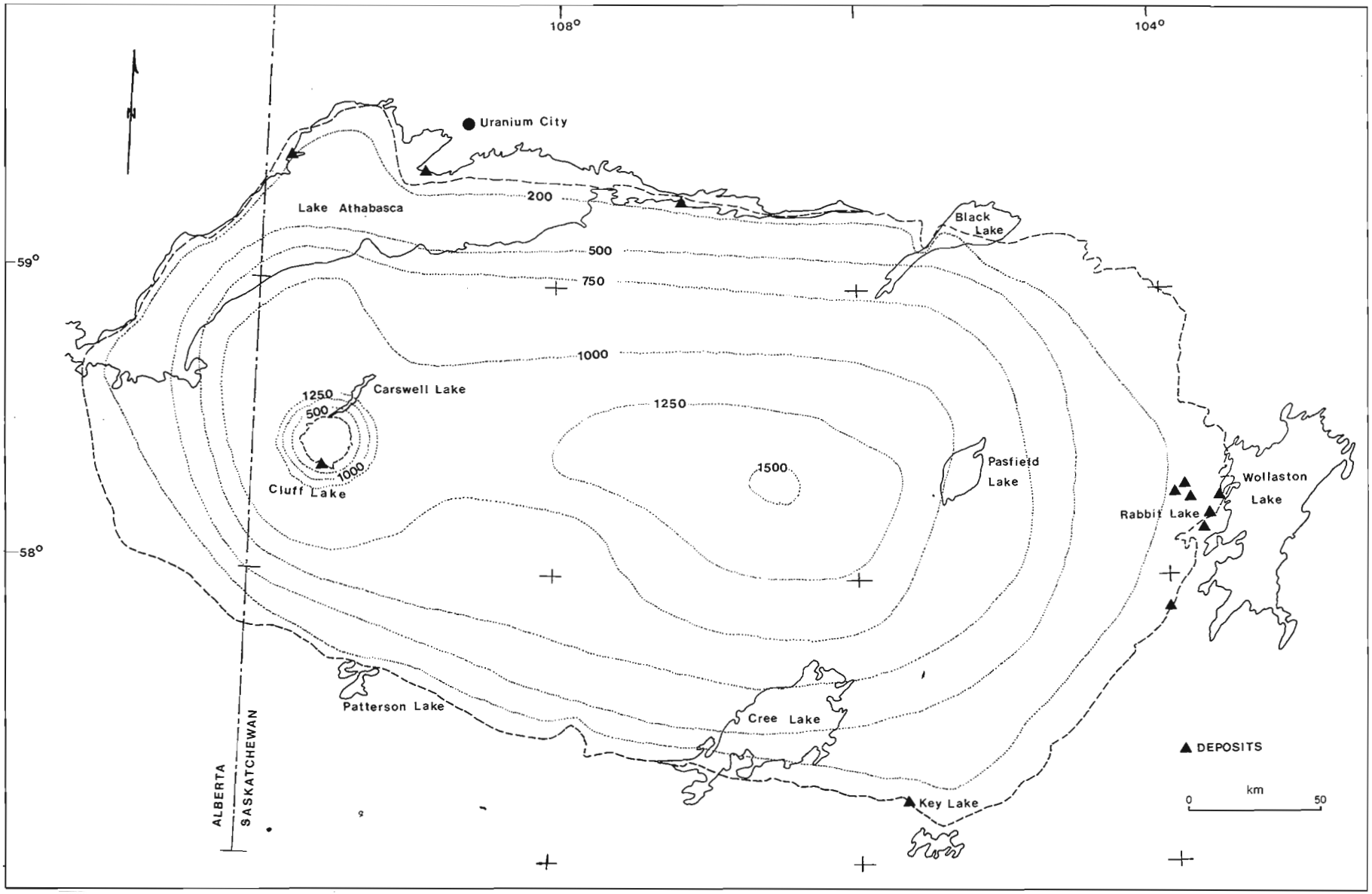

Figure 2. *Schematic isopach map of Athabasca unconformity drawn from maps and cross-sections of Ramaekers (1980) and Burrill and Davies (1979).*

Table 1. Table showing the published reserves of the main uranium deposits related to the Athabasca Basin.

Corresponding Number on Figure 1	Name of Deposit		Ore Tonnes	U Tonnes	U %
1	Rabbit Lake		4 900 000[1]	15 400[2]	0.31[3]
2	Collins Bay A & B zones			> 15 500[4]	
3	Raven and Horseshoe			N.A.	
4	West Bear			425[5]	
5	Midwest Lake		2 000 000[6]	21 500[6]	1.06[6]
6	Dawn Lake			> 7 700[7](?)	
7	McClean Lake (North & South zones)		354 000[8]	5385[8]	1.53[8]
8	Key Lake	Gaertner	880 000[9]	23 100[9]	2.64[9]
		Deilmann	2 122 000[9]	46 500[9]	2.19[9]
		overburden[15]	842 000[9]	4200[9]	0.50[9]
9	Cluff Lake	D	123 000[10]	5211[10]	4.25[10]
		Claude	960 000[10]	4800[10]	0.50[10]
		NRF	1 428 600[10]	5000[10]	0.35[10]
		OP	276 900[10]	1800[10]	0.65[10]
10	Maurice Bay			577[11]	<0.42[11]
11	Stewart Island		2324[12]	9[12]	0.40[12]
12	Fond-du-Lac			385[13]	<0.21[13]
1 to 12	total for above deposits (unconformity type)		18 000 000[1]	180 000[1]*	1.04[1]
13 & 14	Fay-Ace-Verna and Gunnar (Beaverlodge-type)		15 875 000[14]	26 925[14]	0.17[14]

N.A. Information not available

[1] Estimated from published information
[2] The CIM Reporter 1979
[3] Carino, A.B., 1979
[4] Jones, B.E., 1980
[5] The Northern Miner, August, 1980
[6] Globe and Mail, August 29, 1979
[7] The Northern Miner, January 8, 1981 (increased to 8077 tonnes U, The Northern Limited Jan 7, 1982)
[8] The Northern Miner, January 1st, 1981
[9] Key Lake Mining Corporation, personal communication, 1980
[10] Cluff Lake Board of Inquiry, Chairman Hon. Mr. Justice E.D. Bayda, 1978 and Harper, 1978.
[11] Lehnert-Thiel and Kretschman, 1979b and Mellinger, M., 1979
[12] Assessment Files, Saskatchewan Department of Mineral Resources, Regina
[13] Eldorado Nuclear Limited, personal communication, 1980
[14] Estimated from production between 1955-79 and published reserves
[15] See page 42 for description.

* Clark, Homenuik and Bonnar (1980) with Eldorado Nuclear Limited have estimated this total at 161 532 tonnes U whereas Clark (1980) with Saskatchewan Mining Development Corporation has put this figure at 191 000 tonnes U.

The uranium production in Canada and Saskatchewan in 1979 was 6817 and 2495 tonnes respectively.

The Saskatchewan producers were Eldorado Nuclear Limited and Cenex Limited in the Uranium City area north of the Athabasca Basin and Rabbit Lake Mine in the Athabasca Basin. Their productions were 387, 43 and 2065 tonnes uranium respectively. (EMR Report EP80-3, Ottawa, Canada).

In 1980 Amok Ltd. started production at Cluff Lake.

The basement rocks have been divided into three tectonic zones: the Western Craton, the Cree Lake Mobile Zone and the Eastern Complex (Fig. 1). Each is further divided into tectonic belts and blocks (Tremblay, 1978c). Lewry and Sibbald (1979) referred to the blocks and belts as crustal domains.

The central Cree Lake Mobile Zone (Lewry and Sibbald, 1977) is bounded on the northwest by the Virgin River Shear and Black Lake Fault and on the southeast by the Needle Falls Shear Zone. The mobile zone comprises a core (Mudjatik Domain) consisting of Archean granitic gneisses, locally charnockitic, and numerous small remnants of Aphebian metasedimentary rocks like those in the flanking Virgin River and Wollaston Lake belts. The metasedimentary rocks are believed to lie unconformably upon the Archean rocks, and together they were intensely deformed and metamorphosed during the Hudsonian Orogeny. The metasedimentary rocks consist of shelf to miogeosynclinal assemblages with graphite-bearing pelites interlayered locally with clean quartzite at the base, passing upward into arkoses and calc-silicate rocks with minor amphibolite and finally at the top into clean quartzite, amphibolite and more calc-silicate rocks. Some of these rocks, particularly the graphitic pelites at the base and some of the biotite-feldspar gneisses, are locally rich in uranium, nickel, cobalt and a few other elements (Dahlkamp, 1978, p. 1444 and personal communication). Values of up to 0.5 per cent U_3O_8 in the form of uraninite were mentioned by Dahlkamp (1978), averaging 50 ppm for the biotite-feldspar-cordierite gneiss in the Key Lake area. The Cree Lake Mobile Zone is characterized by arcuate metasedimentary remnants in the granitic gneisses of the core, by the occurrence of elongated domes of mainly granitic rocks in the bordering sedimentary belts, particularly the Wollaston Lake Belt, by metamorphic facies of granulite and amphibolite grades in the core, and in part by lower grades in the bordering linear belts. The rocks of the Cree Lake Mobile Zone have characteristically less brittle deformation than the rocks of the Western Craton to the west, where mylonitic rocks and zones of close fracturing are common.

The Western Craton relative to the Cree Lake Mobile Zone is interpreted as a former stable cratonic foreland with old Archean crust overlain by minor remnants of Aphebian supracrustal sedimentary rocks (Lewry and Sibbald, 1979). It comprises: the Clearwater Block and the Black Lake Wedge, which are possibly two elevated blocks of granulitic gneisses of older, lower crust; some anatectic granite domes (Beck, 1969) of probable Archean age which constitute a major part of the Fontaine Belt north of the Athabasca Basin and are also widely distributed in Alberta (Slave Block); and some linear to arcuate metasedimentary and metavolcanic mobile belts, such as the Tazin and Chipewyan belts which envelope or separate the granitic domes. The Chipewyan Belt is possibly the extension of the Tazin Belt in Alberta. The Western Craton is generally characterized by late Kenoran high grade metamorphism, by extensive Aphebian anatexis and by Hudsonian large scale brittle deformation with the formation of several wide and long mylonite zones and possibly later wide zones of close fractures. Retrogressive chloritic alteration is widespread. Movements along the mylonite zones gave rise to crustal block vertical displacements. This is well exemplified in the Uranium City area by the major St. Louis, Black Bay and Boom Lake faults which divide the area into large blocks displaying slightly different crustal levels. This type of deformation also characterizes the Carswell Circular Structure and the area west of the Black Lake Fault, thus suggesting that most basement rocks beneath the northwestern half of the Athabasca Basin have this type of deformation and are probably mainly Archean.

The Eastern Complex, in contrast to the Cree Lake Mobile Zone and Western Craton, is believed to be mainly an Aphebian eugeosynclinal zone, possibly in part the site of generation of oceanic crust, a volcanic island arc and subsequent continental collision. The complex comprises abundant Hudsonian migmatite including much Archean rock and some granite bodies in the Rottenstone Domain and very thick, complexly folded metasedimentary and metavolcanic rocks in the La Ronge Belt to the east. The latter rocks are believed to represent the western end of a large east-trending belt associated with the Kisseynew assemblage in Manitoba.

The Athabasca Basin covers an area of about 80 000 km^2. The basin area has generally less than 30 m relief and is thickly mantled by up to 90 m of glacial drift and outwash. Outcrops represent less than one per cent of the area and are found mainly at the margins and along some deeply incised rivers. The strata of the basin, the Athabasca Group (Table 2), overlie the Hudsonian basement and are believed to be younger than the thick conglomerate, red arkose and siltstone, and mafic flows of the Martin Formation with which they are nowhere in contact. The Martin Formation is late Aphebian or early Helikian, occurs only in the Beaverlodge area north of the Athabasca Basin and locally caps the large Fay-Ace-Verna uranium deposits. It is traversed in a few places by narrow pitchblende-carbonate veins believed to be late remobilized uranium from the Beaverlodge deposits. Part of the southwestern edge of the basin is covered by flat lying Cretaceous shale and sandstone which has overstepped Devonian sandstone, shale and dolomite about 50 km to the southwest (Lewry and Sibbald, 1977, Fig. 4).

Below the sub-Athabasca unconformity is a thin, red to mauve layer of weathered regolithic material, which grades over a metre or two downward into a buff, white to light green weathered basement, and thence gradationally downward, generally over a few metres, into unweathered basement. Locally the light-coloured zone extends to greater depth into the basement, particularly along fractures and breccia zones or in depressions in the old erosional surface. In this zone all the original minerals except quartz are altered to a fine grained felted mass of clay (kaolinite, dickite, illite), sericite and possibly chlorite. The thin red zone at the top of the regolith is not everywhere present, and may have been locally removed by erosion before deposition of Athabasca sediments. A composite analysis of this red zone (regolithic clay) is given in Table 3.

The Athabasca sediments are about 1500 m thick at the centre as indicated by drillholes (Fig. 2). The basin is filled mainly with quartz-rich pebbly sandstone, together with conglomerate and minor amounts of shale and siltstone. The sandstone is generally poorly sorted near the base, conglomerate forms discontinuous layers of variable thickness, and shale and siltstone are more abundant in the upper half of the succession. Locally above the unconformity are thin siltstone lenses which pass upward into sandstone and conglomerate. The strata are flat lying and unmetamorphosed; locally they are silicified and well indurated or are partly altered to clay and softened. Chemical analyses of the various coloured sandstones and clay within the Athabasca rocks are given in Table 3.

The succession of the Athabasca Basin was described by Fahrig (1961) as the Athabasca Formation consisting predominantly of sandstone with minor shale and conglomerate and abundant shale chip fragments on bedding surfaces. Later, Lerand (1970) subdivided the succession into two members: a lower, massive, thick sandstone which is poorly sorted, medium- to coarse-grained, hard, and cemented by quartz and clay, and an upper, well stratified, medium

Table 2. Generalized Stratigraphy of Athabasca Group[1]

Formation	Thickness metres	Lithology
Carswell	185	Dolomite: buff to pink, finely laminated, dark oolitic and stromatolitic; minor chert; contorted and fragmented
Douglas	?	Siltstone, shale and fine sandstone; interbedded
Tuma Lake	< 80	Quartz pebbly sandstone and interstitial clay; characteristic quartz pebbles; crossbedded
		local discontinuity
Otherside	< 350	Quartz sandstone, minor siltstone; well sorted, fine grained and crossbedded
Locker Lake	< 120	Pebbly sandstone, massive, friable, crossbedded; sandstone and Tazin(?) quartzite fragments; gypsum (?)
		local discontinuity
Wolverine Point	< 700	Quartz-rich and arkosic sandstones, pebble-free, 10 per cent siltstone and mudstone; interbedded, crossbedded and rippled; fresh feldspar grains, local carbonate cement; mainly sandstone in the east; siltstone and mudstone of upper part of formation are more radioactive than those of underlying and overlying formations; phosphorites, tuffs; collophane, apatite, fluorapatite; up to 200 ppm U
Lazenby Lake	< 100	Quartz pebbly sandstone, convolute bedding, crossbedded
		local discontinuity
Manitou Falls	<1400	Quartz sandstone, poorly sorted, cross-bedded and rippled, interstitial clay; local basal conglomerate interbedded with sandstone at base; abundant current ripples and clay interclasts at top of section
Fair Point	300	Conglomeratic quartz sandstone, abundant interstitial clay; abundant large well rounded quartz pebble and smaller mafic clasts
	Unconformable upon Hudsonian basement of Archean and Aphebian rocks	

[1]From Ramaekers (1979d, 1980), Fahrig (1961) and Amok Ltd. (Tapaninen, 1976).

grained, clay cemented sandstone containing up to five per cent shaly beds. Recently, Ramaekers (1979d) subdivided the succession into two laterally equivalent basal formations; the Manitou Falls in the east and the Fair Point in the west, and seven overlying conformable formations, from bottom to top, the Lazenby Lake, Wolverine Point, Locker Lake, Otherside, Tuma Lake, Douglas and Carswell formations. The Douglas and Carswell formations are restricted in their distribution to the Carswell Circular Structure. Table 2 shows a generalized stratigraphy of the Athabasca Group and includes a brief lithological description of each formation (Ramaekers, 1979d, 1980). The distribution of these formations is shown in Figure 3.

The Manitou Falls Formation underlies the central and eastern part of the basin and forms the entire succession in the east. The lower part of the Manitou Falls grades laterally northwestward into the Fair Point Formation whereas its upper part pinches out westward above the Fair Point. The Manitou Falls and Fair Point formations are overlain in the central part of the basin by the Wolverine Point Formation which in turn is overlain in about the same area by the Locker Lake, Otherside and Tuma Lake formations. Finally, undifferentiated Athabasca rocks are assumed to be overlain conformably in the Carswell Circular Structure by the Douglas (Harper, 1978a) and Carswell formations (Fahrig, 1961). The Wolverine Point Formation rarely outcrops and the Lazenby Lake Formation has been recognized only along the southern central part of the basin.

Most sediments in the Athabasca Group were carried westerly and northwesterly probably by streams from an uplifted area in the Wollaston Lake Belt east and south of the basin towards a lacustrine (?) or marine shoreline in the west (Ramaekers, 1979d). The formations were deposited in open water (shelf facies) or nearshore (shore facies) as the shoreline moved easterly. Five marine transgressions (Fair Point, Lazenby Lake, Locker Lake, Tuma Lake and Carswell) were suggested by Ramaekers (1980) interspaced by periods of uplift and of little deposition.

The age of the Athabasca Group is Helikian (Table 4), but when during the Helikian is uncertain and under debate. Rock chips from several stratigraphic levels of the Wolverine Point Formation yielded a Rb-Sr isochron of 1428 ± 30 Ma* (Ramaekers, 1979b, 1980). A slightly older Rb-Sr whole-rock age (1513 ± 24 Ma) was obtained by Bell (Ramaekers, 1980) on altered tuffs from the same rock succession (upper part of Wolverine Point Formation). Paleomagnetic studies on siltstone and sandstone on the other hand yielded an ambiguous result of 1550 Ma or 1700 Ma (Fahrig et al., 1978); the former age was suggested to be supported somewhat by a Rb-Sr isochron of 1632 ± 32 Ma on sub-Athabasca, deeply weathered basement (Fahrig and Loveridge, 1981). In summary, the Athabasca Group was deposited probably some time during the 1500-1650 Ma period of the Helikian (Table 4).

Gabbro dykes cut the Athabasca rocks. They occur generally in swarms but are apparently not abundant throughout the basin or in the mineralized areas. Many are reflected as aeromagnetic lineaments. They mainly trend northwest, dip steeply northeast or southwest, are columnar jointed, and range from a few to a hundred metres in width. Some may be along north- trending faults. They are composed mainly of labradorite, augite and magnetite with minor olivine, orthoclase, quartz, biotite, hornblende and chlorite (Ramaekers and Hartling, 1979). Some dykes

* K-Ar and Rb-Sr ages quoted in this report and from published reports have been calculated or recalculated where possible using the new constants recommended by Steiger and Jager (1977). The time scale used in this report is that of Armstrong (1978), constructed using the new constants.

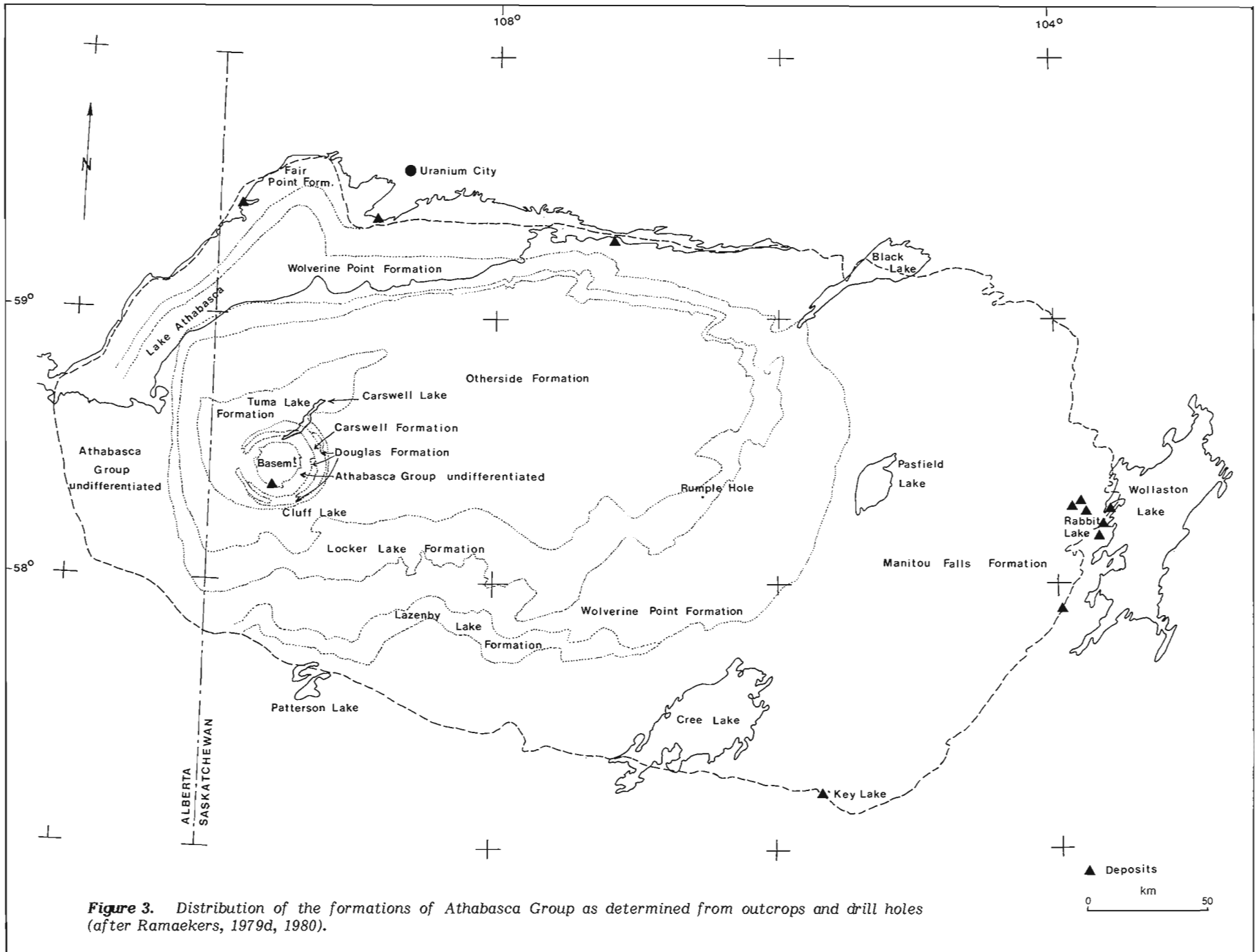

Figure 3. *Distribution of the formations of Athabasca Group as determined from outcrops and drill holes (after Ramaekers, 1979d, 1980).*

intersected by drillholes are serpentinized. Contacts with sandstone are very rarely exposed. Athabasca rocks are indurated generally for only a few metres away from the dykes. The dykes are assumed to be part of the Mackenzie swarm found throughout the central and western shield, and are probably about 1200 Ma old (Fahrig and Jones, 1969). Dates of 949 ± 33 Ma (Wanless et al., 1979) and 1230 Ma (Burwash et al., 1962) were obtained on two dykes cutting Athabasca strata (Table 4). The younger age (949 ± 33 Ma) comes from a dyke in the vicinity of the Carswell Structure and may represent an older age affected by the deformaiton associated with the formation of the Carswell Structure.

The Carswell Circular Structure (Currie, 1969) in the western half of the Athabasca Basin interrupts the otherwise simple form of the basin (Fig. 3). It is a multiring structure 35 km in diameter, consisting of an uplifted core of basement gneiss and pegmatite, 18 km in diameter, surrounded by inner and outer rings, each from 3 to 8 km wide, consisting of deformed but unmetamorphosed strata of the Athabasca Group (Tapaninen, 1975; and Harper, 1978a). The outer ring has dropped relative to the strata outside the Carswell Circular Structure and relative to the strata of the inner ring. It contains the only known exposures of Carswell carbonates and Douglas siltstone, the youngest formations of the Athabasca Group. These strata are faulted and isoclinally folded, with axial surfaces dipping inwards. The inner ring consists of faulted and moderately to vertically dipping Athabasca conglomerate and sandstone in both unconformable and faulted contact with the core rocks, and appears to have been uplifted with the core against the down-dropped outer ring. Rocks of the structure exhibit features characteristic of shock metamorphism such as shatter cones, deformation lamellae in quartz, glassy material, and shattered cobbles and boulders in the basal Athabasca strata. They are also cut by seams and dykes of Cluff breccia, related to faults and fractures and composed of angular fragments of Athabasca sandstone and dolomite and basement rocks in a multicoloured matrix of comminuted host rock grading to cryptocrystalline texture and glass (pseudotachylite). Lightcoloured and green parts of a glassy sample, 1.5 km east of Cluff Lake, yielded K-Ar whole-rock ages of 475 ± 28 Ma and 495 ± 55 Ma, suggesting an Ordovician age for the breccia and the Carswell Circular Structure (Wanless et al., 1968, p. 84-85; Currie, 1969). The structure originated by hypervelocity meteoritic impact (Innes, 1964; Pagel, 1975a; Robertson and Grieve, 1975), or by a cryptovolcanic or cryptoexplosive episode (Fahrig, 1961; Currie, 1969).

Glacial drift thickly mantles the Athabasca Basin and bordering basement areas, and outcrops are sparse particularly in the basin. The direction of ice transport of rock fragments derived from uranium-bearing deposits is important for exploration. Till in the form of drumlins and ground moraine is overlain by eskers, glaciofluvial sand and gravel, and some lacustrine silt and windblown sand and silt. The drumlins were formed by a continental glacier moving southwest throughout most of the basin area. Along the northern edge of the basin, the ice moved more westerly (Schreiner, 1979).

Shortly after the deglaciation northwesterly-blowing winds (Tremblay, 1961; David, 1981) slightly modified the surface of the glacial drift, locally obscuring the main ice transport direction and consequently hindering the discovery of some of the transported radioactive boulders and their source area.

Athabasca strata are flat lying or dip only a few degrees except in the Carswell Circular Structure and near faults. No regional folds have been recognized. Fractures and faults trend mainly east-northeast, north-northeast, north and northwest. They are found particularly near the basin margin where the rocks have been drilled and exposed by exploration activities, and within the Carswell Circular Structure. Block faults have been revealed by drilling at several uranium deposits where the unconformity has been offset vertically by as much as 40 m. Thrust faults cut the eastern margin of the basin in the Collins Bay-Michael Lake area. Fractures are more abundant in Athabasca rocks above buried faults in the basement, attesting to late movements on old faults. This indeed, is supported by changes in the lithology and texture of Athabasca sediments and in the direction of sediment transport near such faults (Ramaekers and Hartling, 1979), indicating that some faults were reactivated from time to time during deposition of the Athabasca Group.

The isopachs on the unconformity, sparse though the data may be, suggest a gentle inward slope in the east, moderate to steep slopes in the north and south and a steeper slope in the west (Fig. 2). The basin is presumed to have developed from a series of early northeasterly trending fault bounded sub-basins that became filled and coalesced to form the present Athabasca Basin (Ramaekers, 1979a, 1980). Northeast-trending subbasin faults have been recognized in the basement at the margins of the basin and some have been indicated and traced by various geophysical surveys or from sedimentary studies of Athabasca sediments.

DESCRIPTION OF DEPOSITS

Deposits with established reserves or deposits that may be mined in the future are described in the following pages. The nature of the description varies with each deposit either because of a lack of information available to the writer or because drilling is insufficient to assess them fully. The deposits are grouped in six general areas (Fig. 1): Collins Bay-Michael Lake area (Rabbit Lake, Collins Bay A and B zones, Raven and Horseshoe and West Bear deposits), Midwest Lake-McLean Lake area (Midwest Lake, Dawn Lake and McClean Lake deposits), Key Lake area (Key Lake deposits), Carswell Circular Structure (Cluff Lake deposits), Maurice Bay area (Maurice Bay deposit), and the northern rim of the Athabasca Basin (Stewart Island and Fond-du-Lac deposits).

Information on the deposits has been compiled from numerous sources, among which are published papers and company news releases, oral presentations at public scientific meetings, study of core, trenches and pits at the deposits and of specimens at the Geological Survey of Canada, and finally and perhaps most important, discussions with company geologists and engineers at the deposits. This report must be regarded as preliminary since exploration and development continue at a high level, and new information and interpretations continue to accumulate.

Each deposit description is headed by a list of principal references in order to reduce the number scattered throughout the text. Much of the information gathered in the description was obtained from these sources.

Collins Bay – Michael Lake Area

The Collins Bay-Michael Lake area (Fig. 1, 4) is on the east margin of the Athabasca Basin and to date (1981) has proved to be one of the richest parts of the basin. The area includes the following deposits: Rabbit Lake Mine, Collins Bay A zone and Collins Bay B zone and other zones within the Collins Bay subarea, Raven and Horseshoe, and West Bear. Rabbit Lake Mine is presently the only operating mine. Collins Bay B zone will likely be the next deposit to be exploited in this area.

Table 3. Chemical analyses (arithmetic means) of sandstones and clays within the Athabasca Basin.

Rock Types	SANDSTONE White		Buff	Grey	Black	Pink, red orange, brown	CLAY In sandstone grey, brown	Regolithic red	In basement buff
	more than 30 m above	----less than 30 m above---- ----unconformity at base of Athabasca Group----							less than 10 m below
Number of Samples Analyzed	6	9	9	10	3	12	6	5	7
SiO_2	95.0	92.6	90.5	89.7	81.3	88.1	45.8	33.96	42.9
TiO_2	.08	.16	.35	.26	.82	.17	1.7	1.48	1.48
Al_2O_3	3.08	4.3	4.5	3.6	4.3	4.2	28.3	20.9	31.7
Cr_2O_3	-	-	-	-	-	-	-	-	-
Fe_2O_3	.02	.03	.6	.44	3.8	4.4	3.47	25.8	1.4
FeO	-	.07	.46	2.1	-	.35	.82	.4	.5
MnO	-	.03	.01	.04	.1	.01	.02	.15	.01
MgO	.08	.21	.37	.17	.43	.27	2.22	2.01	4.98
CaO	-	.01	.07	.06	.35	.02	.15	.17	.13
Na_2O	-	.01	-	-	-	-	-	-	-
K_2O	.33	.84	.46	.55	.77	.79	6.88	4.12	6.11
H_2O	1.28	1.2	1.5	1.7	3.4	1.4	8.38	8.2	8.9
P_2O_5	.03	.04	.06	.07	.25	.07	.27	.39	.22
CO_2	.03	.03	.56	.7	.17	.29	.37	.4	.2
S	.02	.05	.02	.42	3.1	.05	.17	.11	.22
volatile	-	-	-	-	-	-	-	-	-
Rb	.001	.001	.001	.003	.033	.001	.007	.006	.008
Zn	.001	.001	.002	.011	.033	.001	.006	.008	.005
Total	99.95	99.58	99.45	99.82	99.86	100.12	98.6	98.1	98.7

Most samples were pieces of core obtained from the drilling in the vicinity of the main uranium deposits related to the basin.

The analyses were done in the Analytical Chemistry Laboratory of the Geological Survey of Canada in Ottawa by the XRF method for most of the elements except H_2O, FeO and CO_2 which were done by rapid chemical method.

Most of the Al_2O_3 and K_2O of the sandstones is believed to be in the clay material and to be contained in illite, or sericite and muscovite.

Table 4. Isotopic ages of the main geological features associated with the Athabasca Basin and its uranium mineralization.

Feature dated	Method	Age Ma	Material Used and Dated	Locality	References
Deposition of Athabasca rocks	Rb-Sr	1428 ± 30	Shale chips from several levels	Rumpel Lake (?)	Ramaekers, 1979b, 1980
	Rb-Sr	1513 ± 24	Altered tuffs	Wolverine Pt Fm	Bell (Ramaekers, 1980)
	Paleomagnetic	1550 ± 1700	Shale chips from several levels	Rumpel Lake	Fahrig et al., 1978
Weathering at base of Athabasca Group	Rb-Sr	1632 ± 32	Deeply weathered basement		Fahrig and Loveridge, 1981
	K-Ar*	1541 ± 40	Highly altered basement (muscovite)	Maurice Bay	Stevens et al., 1982
Hudsonian effect on basement rocks	K-Ar*	1801 ± 44	Clay 20 m above unconformity (muscovite)	Midwest Lake	Stevens et al., 1982
	Rb-Sr*	1698 ± 127	Archean granitoid	Key Lake	Stevens et al., 1982
	K-Ar	1752 ± 41	Biotite in Archean granitoid	Key Lake	Stevens et al., 1982
Light green argillization associated with the mineralization	K-Ar*	1266 ± 39	Highly altered basement (illite)	Collins Bay A	Stevens et al., 1982
	K-Ar*	1296 ± 34	Highly altered basement (muscovite)	Collins Bay B	Stevens et al., 1982
	K-Ar*	1212 ± 33	Clay at unconformity (muscovite)	Midwest Lake	Stevens et al., 1982
	K-Ar*	1128 ± 450	Sheared dark green chloritic Athabasca siltstone (chlorite)	Cluff Lake	Wanless et al., 1979
	K-Ar	988	Alteration products of cordierite (sericite)	Cluff Lake	Herring, 1976
	K-Ar*	765 ± 120	Sheared grey clay 8 m below unconformity (chlorite)	Key Lake	Stevens et al., 1982
	K-Ar*	1411 ± 36	Clay 3 m below unconformity (muscovite)	Midwest Lake	Stevens et al., 1982
	K-Ar	1320 ±	Clay (illite)...	McClean Lake	Derek York[1], 1981
U mineralization	U-Pb	1075	Pitchblende	Rabbit Lake	Little, 1974
	U-Pb	1281 ± 11	Pitchblende	Rabbit Lake	Cumming & Rimsaite, 1979
	U-Pb	1320	Pitchblende	Rabbit Lake	Knipping, 1974
	U-Pb	1238	Pitchblende	Collins Bay B	Jones, 1980
	U-Pb	1270	Pitchblende	Key Lake	Wendt et al. 1978
	U-Pb	1228	Pitchblende	Key Lake	Gatzweiler et al., 1979
	U-Pb	1100	Pitchblende	Cluff Lake	Tapaninen, 1975
	U-Pb	1050	Country rocks	Cluff Lake	Gancarz, 1979
	U-Pb	646[2] & 418[2]	Pitchblende	Stewart Island	Fahrig, 1961
Gabbro dykes cutting Athabasca rocks	K-Ar*	949 ± 33	Grab sample	Cluff Lake	Wanless et al., 1979
	K-Ar	1230	Hornblende	Cree Lake	Burwash et al., 1962
Carswell Circular Structure	K-Ar	475 ± 28	Cluff breccia	Cluff Lake	Wanless et al., 1968 &
	K-Ar	495 ± 55	Cluff breccia	Cluff Lake	Currie, 1969

*new age determination
[1]Ontario Geoscience Seminar, Toronto, December 1981
[2]Two other ages (318 and 24 Ma) were reported from this deposit (anonymous, 1981)

Most of the samples were pieces of core, except where indicated otherwise.

The pitchblende ages are the highest values presented by the various authors.

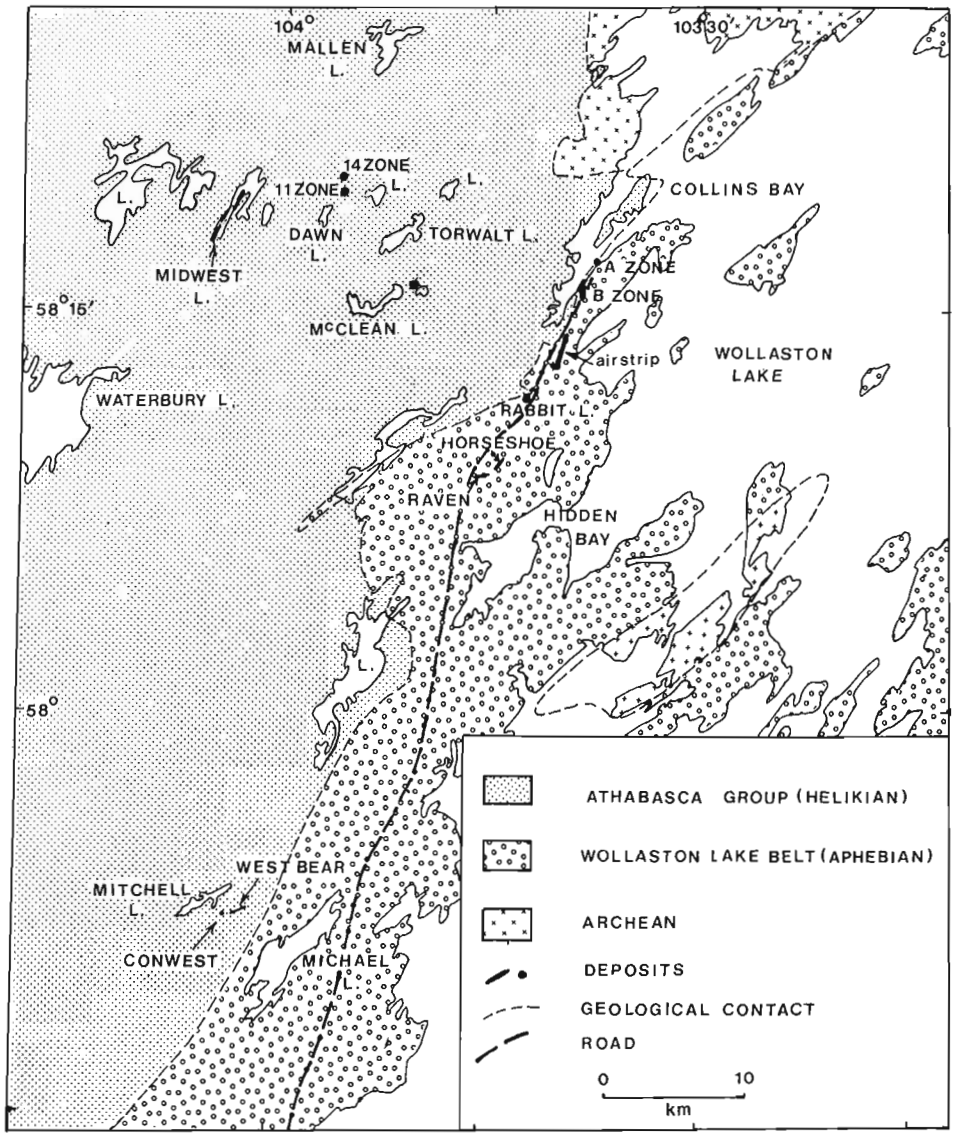

Figure 4. *Generalized geological map of the eastern margin of the Athabasca Basin showing the location of the uranium deposits.*

Rabbit Lake Mine

References:

Carino, 1979; Dunning and Parslow, 1979; Hoeve, 1977, 1978a, b; Hoeve and Sibbald, 1976, 1978a, b; Knipping, 1974; Rimsaite, 1977a, 1978a, b, 1979; Sibbald, 1977, 1978.

Rabbit Lake Mine (Fig. 4) is 4 km west of Wollaston Lake and 354 km north-northeast of La Ronge. The all-weather gravel Saskatchewan Highway 102-105 from La Ronge, and scheduled air flights (Norcanair) to Wollaston Lake village provide access to the area. The deposit is owned by Gulf Minerals Canada Limited (45.9 per cent interest), Uranerz Canada Ltd. (49 per cent) and Gulf Canada Limited (5.1 per cent).

The deposit was discovered in 1968 at the apex of a radioactive boulder train and appraised by drilling on a 30 m grid. Much of the deposit was under Rabbit Lake, and the northern part of the lake was dammed and drained in 1972. Stripping of about 15 m of overburden started in October 1974 and the first ore was milled in June 1975. To improve grade control, the deposit was subsequently drilled on a 6 m grid. The deposit is mined by Gulf Minerals Canada Limited by open pit at the rate of 1800 tonnes per day and treated on the site by the sulphuric acid leach process (Fig. 5a, b, c). By the end of 1978, about 1 400 000 tonnes of ore averaging about 0.36 per cent U had been treated in the mill (Gulf Minerals Canada Limited, personal communication). During 1979, 2065 tonnes of uranium were produced from 650 000 tonnes of milled ore with an average grade of 0.32 per cent U. 1 552 600 m^3 of waste was removed, for a waste to ore ratio of 5:1 (Allman, 1980; The Northern Miner, August 21, 1980, p. C12). Assuming a constant rate of production, reserves (Table 1) are expected to be exhausted by early 1986. The mine will be mined out by late 1983 and all the ore processed by early 1986.

The Rabbit Lake deposit is in metasediments of the Aphebian Wollaston Group (Fig. 6) a few tens of metres below the projected unconformity with the Athabasca Group at the eastern edge of the Athabasca Basin (Hoeve and Sibbald, 1978b). In the open pit, the metasediments comprise three moderately dipping units at amphibolite facies metamorphic grade (Fig. 7). The lower unit is a feldspathic quartzite, dark grey, fine grained and soda-rich and has been called locally 'plagioclasite' (Sibbald, 1976). It forms the footwall of the orebody near surface but at depth much of the ore is in it. This unit is massive except for local streaks and pods richer in biotite and clinopyroxene. Feldspar is granoblastic albite. The quartzite is gradationally overlain by the second unit, the host of the main part of the orebody on surface, which is an assemblage about 45 m thick of calc-silicate rocks, impure feldspathic metaquartzite, glassy quartzite, marble and graphitic rocks. These are in turn overlain by coarse grained quartzofeldspathic paragneisses in narrow layers interbanded with narrow dark grey layers resembling meta-greywacke, and thin layers of amphibolite and mafic-rich rocks. The paragneiss and dark coloured layers originated mainly from calcareous and arkosic sediments, were mapped as 'Upper Gneisses' by Knipping (1974), and are the hangingwall of the orebody. Athabasca Group sandstone and conglomerate lie unconformably upon the feldspathic quartzite of the lower unit in subsurface on the northwest side of the Rabbit Lake Fault, 100 m northwest of the ore zone (Fig. 7).

The rocks in and near the pit trend northeast and dip southeast, are part of the northwestern limb of a northeasterly trending syncline (F_2 folds of Hoeve and Sibbald, 1978b) whose axial trace lies about 1½ km to the southeast (Fig. 6). The 65 degree dip at the surface decreases to only a few degrees at depth. The rocks have been multiply deformed despite their apparent simple structure (Hoeve and Sibbald, 1978b). Penetrative

a. *Looking northeast at the pit in July 1976. Rabbit Lake appears at lower left; 6 m mining bench. (GSC 203712-I)*

c. *Looking north toward the mill, July 1976. Ore stockpiles are in the foreground. (GSC 203712-D)*

b. *Looking at the south wall of the pit, June 1978. (GSC 203712-M)*

d. *The dark areas above and to the right of the book are rich in pitchblende and coffinite. In these areas there are also 2 cm wide massive pitchblende veins. (GSC 203712-F)*

Figure 5. *Rabbit Lake Mine.*

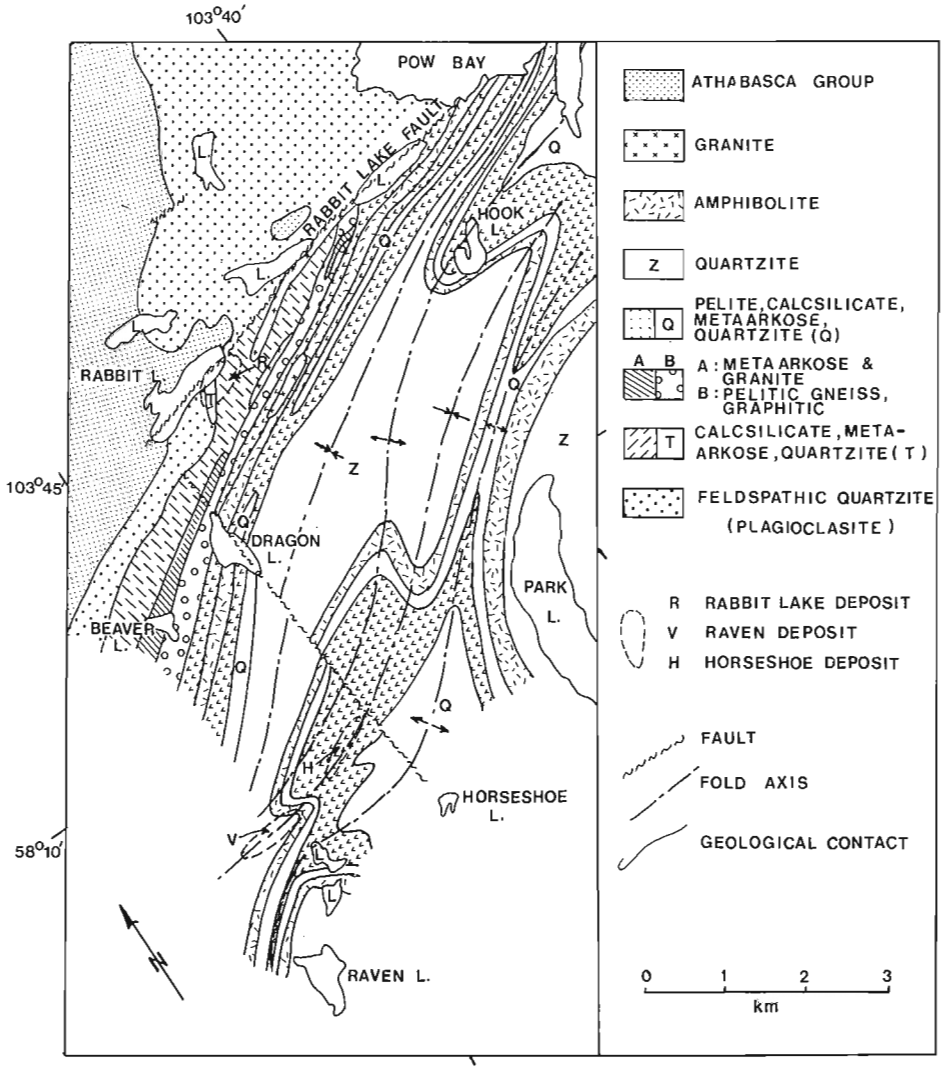

Figure 6. *Geology of the Rabbit Lake-Park Lake area (slightly modified from Hoeve and Sibbald, 1978b and Dunning and Parslow, 1979). The uranium deposits shown are along the eastern edge of the Athabasca Basin and they occur at two different levels of the Aphebian succession of the Wollaston Lake Belt.*

deformation accompanied by amphibolite grade metamorphism produced a homoclinal structural form and, as suggested by small gently rolling structures on the northeast and southwest faces of the pit, this structure appears to be repeated in a series of "rolls" parallel to the syncline mentioned above. Additional small structures on the east flank of the pit suggest two later episodes of folding, with possible retrograde metamorphic effects, one being represented by large open northwest-trending cross folds and the other, slightly later, represented by smaller, tighter, northwest-trending folds overturned to the northeast. The Wollaston Group rocks have been thrust northwestward upon the Athabasca sandstone along the Rabbit Lake Fault. The fault trends northeast, dips about 30 degrees southeast at the surface where it consists of several steep splays, and dips more gently at depth. Vertical displacement on the fault is probably at least 75 m. Brecciation and fracturing occurred repeatedly during mineralization and alteration, and largely controlled the sites of these processes.

The host rocks of the deposit are intensely and extensively altered. Several alteration types have been recognized: dark green chloritization, red hematization, white clay to light green argillization, silicification, dolomitization and tourmalinization. Alteration of the host rocks extends over a long period, from pre-mineralization retrograde metamorphism during the late stages of the Hudsonian Orogeny (e.g. some of the dark green chloritization) to white clay alteration continuing up to present day weathering. Alteration of the second unit in the pit is the more intense while the footwall and hanging wall units are only locally altered. Alteration is most intense within the ore zone, particularly in the form of white clay and light green argillization, and especially in the upper, more brecciated and fractured part of the deposit.

Dark green chlorite has pseudomorphously replaced mafic minerals and feldspar as well as pervading the rock in the central part of the ore zone and obliterating the original texture. Chlorite is common also as coatings on fracture surfaces. Chlorite probably formed during several episodes before, during and after mineralization. Red hematite has developed by oxidation of some chlorite and discolours and pervades brecciated rocks and ore as seams and fracture coatings. It too perhaps formed in several episodes. Some is regarded as mainly a metamorphic event, older than and unrelated to mineralization. Much hematite in the upper part of the orebody and below the sub-Athabasca unconformity is part of the Helikian regolith known to be as deep as 50 m. Other hematite is related to the mineralizing processes.

Development of white clay and light green argillization is especially intense within the ore zone. Kaolinite, illite and dickite have formed mainly from feldspar, and have produced buff and grey rocks which are locally red at the top of the regolithic zone and black in the ore zone. Most if not all these clay minerals developed in the sub-Athabasca weathering zone and some were carried downwards along fractures in the brecciated rocks of the ore zone. Argillization is characterized by light green chlorite, sericite and possibly talc(?), and is normally magnesium-rich in comparison to the regolithic clays (Rimsaite, 1977a; Hoeve and Sibbald, 1978a, b; see Table 3). This argillization appears to be of hydrothermal origin since fluid inclusion studies on quartz and carbonate (see below) suggest a temperature of formation as high as 260°C (Pagel, 1975b; Pagel and Openshaw, 1979; Little, 1974). Argillization is younger than the white regolithic clay formation and is more prevalent in the lower part of the ore zone. In addition some of the clay in the upper part of the deposit may be due to recent weathering. Silicification, dolomitization and locally tourmalinization are intimately associated with the complex mineralization and brecciation process. They have resulted in quartz veins and stringers, and growth of dolomite rhombs and tourmaline crystals (some is pink dravite), apparently mainly from recrystallization and hydrothermal extraction from host rocks. These processes are not as useful indicators of uranium mineralization as the clay and Mg-rich

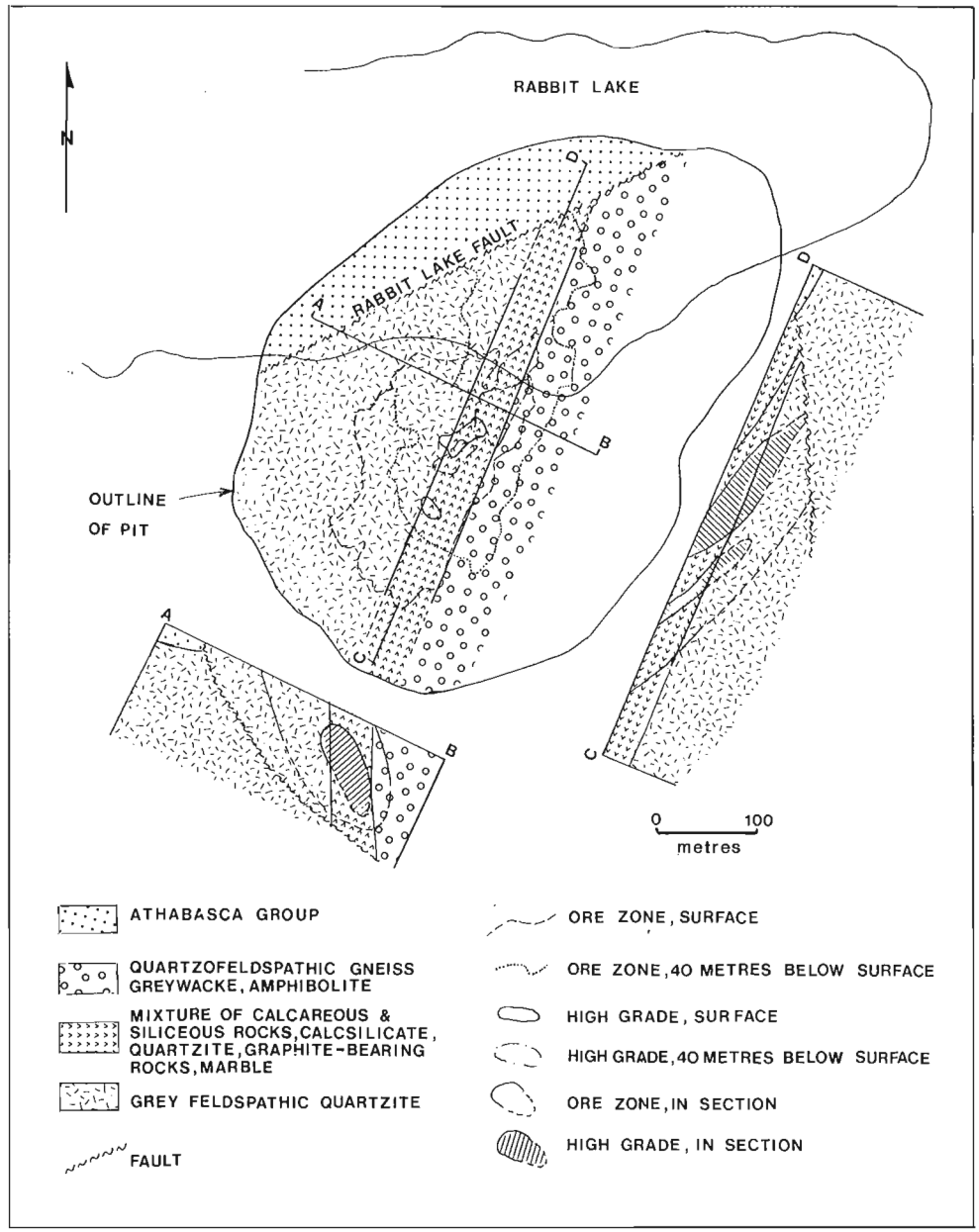

Figure 7. *Generalized geology of Rabbit Lake Mine prepared by the writer.*

argillization alteration. However, they appear to have accompanied local redistribution of some uranium minerals in the upper part of the ore zone.

The Rabbit Lake orebody is shaped like a plunging, flattened pipe (Fig. 7). It subcropped below about 15 m of overburden and is cut off at depth by the southeast dipping Rabbit Lake thrust fault about 40 m below the northwest part of the body and as much as 125 m below the central and southeastern part. Mineralization equivalent to that of the deposit has not been found below the Athabasca sandstone northwest of the fault. Only insignificant mineralization below and downdip along the fault has been encountered in drillholes (Gulf Minerals Canada Limited, personal communication, 1978); the writer believes this mineralization to be younger than and remobilized from the deposit.

The orebody trends N26°E, plunges northeast on average about 20 degrees but at about 40 degrees near the surface, and dips about 30° southeast (Fig. 7). The axial length is about 550 m to where it is cut off by the underlying Rabbit Lake thrust. In plan, the ore zone varies from about 90 by 170 m at the surface to about 125 by 365 m at the 30 m level. Within the ore zone is a high grade elongate core which in plan at the 30 m level is 30 m wide and 125 m long (Fig. 8). Smaller pods of similar high grade ore are scattered throughout the low grade part of the ore zone which is referred to as a dispersion halo by Hoeve and Sibbald (1978b). They believe that the ore minerals in the halo were derived from the high grade core by remobilization and redeposition. This would suggest that the uranium has not moved far since the formation of the high grade core.

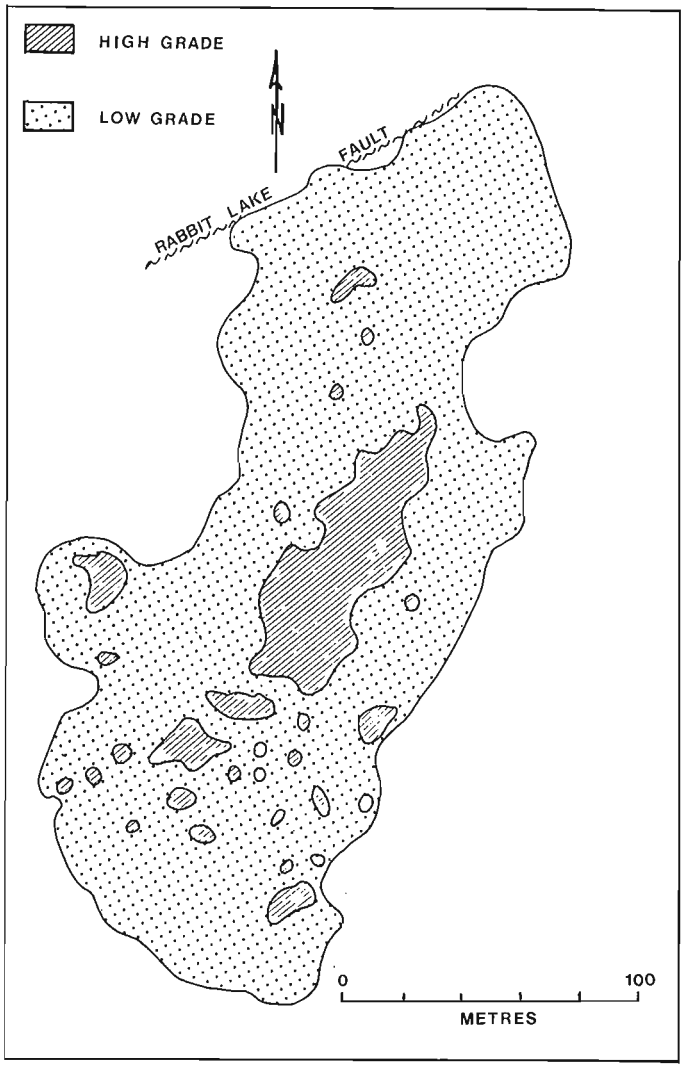

Figure 8. *Outline of Rabbit Lake orebody 40 metres below surface showing the distribution of the high grade areas within the orebody.*

The ore (Fig. 5d) consists mainly of colloform and sooty pitchblende and coffinite occurring as blebs, veins, seams, and disseminations in highly altered and brecciated rocks composed mainly of light green chlorite, sericite, clay minerals (kaolinite, illite, dickite), carbonate, quartz, tourmaline and some sulphides (Hoeve and Sibbald, 1978b). Near the surface the ore contains also much uranophane and minor sklodowskite and boltwoodite (Carino, 1979). Samples have yielded 0.05 per cent vanadium and 0.005 per cent molybdenum (Gulf Minerals Canada Limited, personal communication, 1979). The mineralogy of the deposit would seem to be complex since a broad suite of minerals (carbon, galena, clausthalite, sphalerite, pyrite, chalcopyrite, bornite, chalcocite, covellite, nickeline, carrollite, hematite, geothite, numerous uranium-bearing minerals, calcite, dolomite, ankerite, siderite, malachite, apatite, anhydrite, gypsum, barite, tourmaline and others) have been identified (Rimsaite, 1977a, b) but in fact the complex suite of minerals represents only a very small proportion of the deposit. Nevertheless, the mineralizing process has indeed been complex as evidenced by the occurrence of five age types of pitchblende (Rimsaite, 1977a, 1978b).

The minimum age for the main emplacement of pitchblende, in the Rabbit Lake area, has been determined by Cumming and Rimsaite (1979) using U-Pb methods as 1281 ± 11 Ma with several later episodes of uranium remobilization up to present day weathering. This age is significantly older than the 1075 Ma age on pitchblende obtained by Little (1974).

Raven and Horseshoe Deposits

Reference:
Gulf Minerals Canada Limited, personal communication, 1978.

The Raven and Horseshoe deposits are 5.5 km southeast of Rabbit Lake Mine (Fig. 4). The all-weather gravel Saskatchewan Highway 102-105 between La Ronge and Rabbit Lake passes over the western end of the Raven deposit. The deposits are owned by Gulf Minerals Canada Limited and Gulf Canada Limited. Gulf Minerals Canada Limited is the field operator.

The deposits are in terrain lacking outcrop and were discovered by drilling the northeast extremity of a poorly defined radioactive boulder train. The Raven was discovered in 1972 and the Horseshoe in 1974. Drilling to evaluate the deposits was done mainly from 1973 to 1976 with a minor amount during 1977 and 1978.

The deposits are entirely within Wollaston metamorphosed sedimentary rocks; the nearest Athabasca strata are 3.5 km to the west (Fig. 6). The metasedimentary rocks are mainly feldspathic and graphitic quartzite, intercalated with biotite gneiss and overlain by biotite gneiss, and minor pegmatite, amphibolite and calc-silicate rocks, all prograded to amphibolite facies and subsequently retrograded to greenschist facies. Feldspars and mafic minerals have been altered to fine sericite, chlorite and clay minerals. The host rocks are about 1000 m stratigraphically above the Rabbit Lake horizon (Hoeve and Sibbald, 1978b).

The deposits are less than one kilometre apart in the keel of a syncline (not the Rabbit Lake syncline: Fig. 6, 9) and probably represent somewhat higher grade portions of a single mineralized zone which was at least 2750 m long. Each deposit has the shape of a subhorizontal cigar, possibly plunging gently west, is 800-900 m long, and as much as 120 m wide and 150 m thick (Fig. 9). Both deposits appear to be cut into blocks by late north- and northwest-trending vertical cross faults.

The mineralized zone is covered by 12-18 m of glacial till and occurs mostly between 90 and 240 m below surface (Canadian Mining Journal, August 1979, p. 41). Mineralized rocks do occur above the 90 m depth, however, and some reach the base of the glacial till in the Raven deposit area (and presumably contributed to the radioactive boulder train). In addition minor erratic mineralization occurs as deep as 340 m. Most of the mineralization is in graphitic quartzite and in biotite gneiss intercalated in the quartzite. Some rocks in the mineralized areas are soft and porous from alteration of feldspar to white clay and locally they are red from hematization. However, not all white or red rocks are mineralized. Large (up to 2 mm) white mica and chlorite flakes have been developed in the clay-altered rocks, presumably during the mineralization process.

The ore minerals fill fractures and are disseminated in altered rocks adjacent to fractures. The high grade portions of the deposits dip steeply south. Grades are generally low, but locally reach 0.42 per cent U in one-metre sections of drill core. Uraninite, sooty pitchblende and uranophane, the main ore minerals, are accompanied by pyrite, chalcopyrite and bornite.

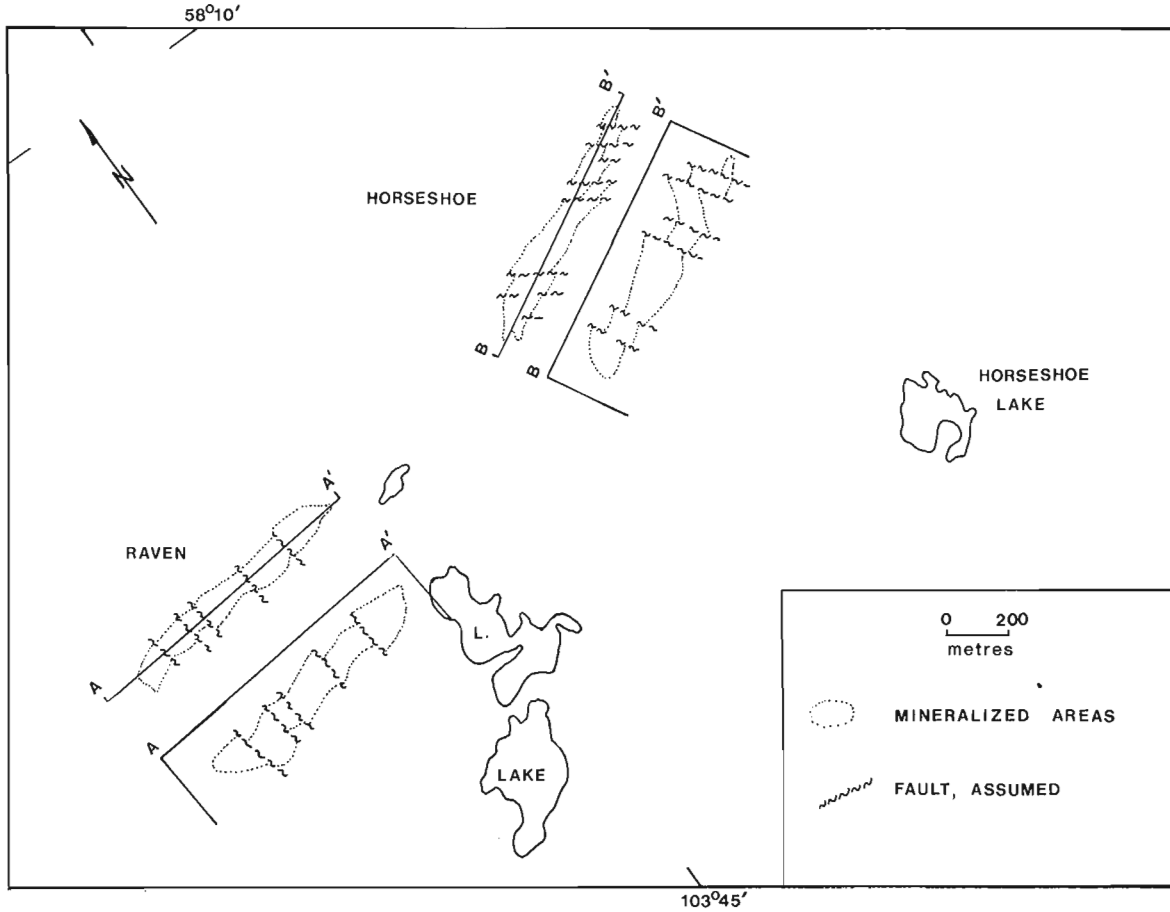

Figure 9. *Outlines of Raven and Horsehoe deposits as indicated by mineralized intersections in drill cores. The shape of the mineralized areas in plan and section and the faults are the writer's interpretation. Ore zones not shown within the mineralized areas. For location relative to Rabbit Lake Mine see Figure 6. No rocks are exposed at surface.*

West Bear Deposit

Reference:

Gulf Minerals Canada Limited, personal communication, 1978.

The West Bear deposit is 43 km south of Rabbit Lake Mine and 1.3 km southeast of Mitchell Lake (Fig. 4, 10). There is no road to the deposit which can be reached by helicopter or plane on floats to Mitchell Lake. The deposit is owned by Gulf Minerals Canada Limited (33 1/3 per cent), Noranda Exploration Company Limited (33 1/3 per cent) and Saskatchewan Mining Development Corp. (33 1/3 per cent). Exploration, managed by Gulf Minerals, is continuing (1980).

The deposit was discovered by Gulf Minerals in the spring of 1977 in a swampy lowland lacking outcrops. A few radioactive glacial erratics and uranium anomalous soil samples led to a drilling program. Delineation and evaluation of the deposit has continued to the present (1981).

The mineralized zone occurs along, above and below the unconformity of flat lying Athabasca strata upon Wollaston paragneiss. In the deposit area, as revealed in drill core, the paragneiss trends N65°E and dips 20 degrees southeast. Impure quartzite is overlain by sillimanite augen gneiss and then by pyrite-chlorite-graphite schist plus, in the south-western part of the deposit, quartz-biotite schist and gneiss, all of amphibolite grade. Along the unconformity, schist and gneiss are thoroughly altered to a regolith of white, buff, greenish-yellow and brown clay as much as 3 m thick, the top several centimetres of which is red. Below the clay, feldspars are altered to white clay as deep as 60 m below the unconformity. These basement rocks are generally chloritized and stained with red hematite. Some pegmatite layers are unaltered. Between 15 and 21 m of Athabasca sandstone, conglomerate and minor mudstone overlie the weathered paragneiss. Most Athabasca strata are white and bleached, and some are red, grey and black. Sandstone near the base has white clay cement and alteration. The Athabasca strata are covered by 4.5-12 m of glacial till. The paragneiss and Athabasca strata are cut by several steeply dipping, northwest-trending normal and reverse faults with horizontal and vertical offsets of as much as 25 and 9 m respectively (Fig. 10).

The mineralized zone occurs in Athabasca strata immediately above the unconformity, in the clay alteration zone at the unconformity and in pyrite-chlorite-graphite schist below the unconformity. Most of the mineralization is in the schist. The mineralized zone is elongate and tabular, 9-61 m wide and 3-12 m thick, and has been traced by drilling along the schist trend for over 800 m (Fig. 10). The zone lies between 17 and 40 m below surface. The southwest end is narrow and of low grade; its southwestward extension may be represented by one of the drill intersections of mineralization about 750 m from the West Bear deposit

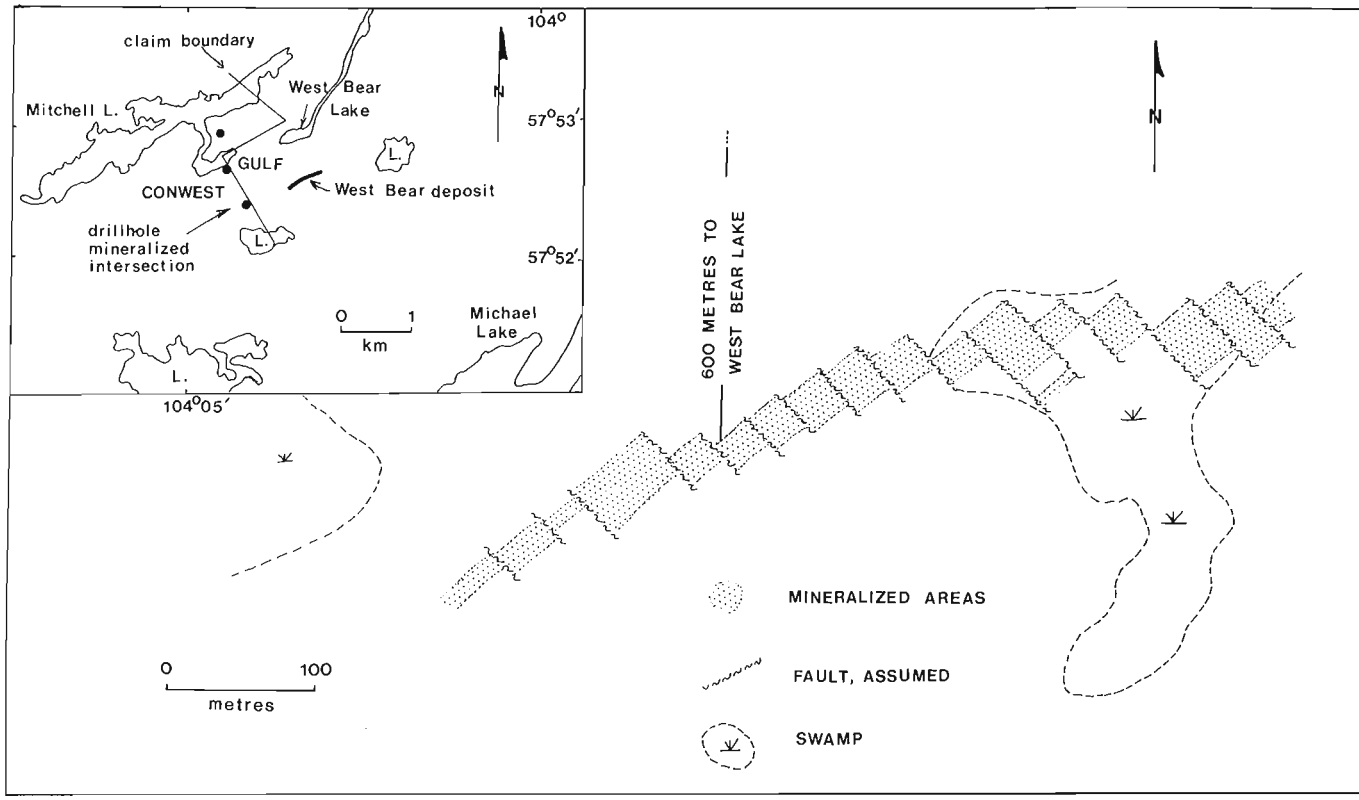

Figure 10. *Outline of the West Bear deposit as prepared from information supplied by Gulf Minerals Canada Limited (personal communication, 1979). The northwest trending faults are the writer's interpretation. No rocks are exposed at surface. For location relative to Rabbit Lake Mine see Figure 4.*

reported by Conwest Exploration Co. Limited (The Northern Miner, July 6, 1978). The deposit was reported to contain about 425 tonnes of uranium and the grade to average 0.34 per cent U, (The Northern Miner, August 21, 1980, p. C12) at which time the northeastern end of the deposit had not been completely delineated. One 12-metre section of core yielded 1.91 per cent U. The deposit also contains some silver, lead and nickel. Minerals identified in addition to graphite, pitchblende and coffinite are pyrite, galena and nickeline.

Collins Bay Subarea

The Collins Bay subarea (Fig. 4) is a belt, 6 km long by one km wide, about the trace of the Athabasca unconformity along the eastern edge of the Athabasca Basin north of Rabbit Lake Mine, where mineralization has been encountered intermittently, and locally in economic amounts. The mineralization is on both sides of the trace and in both basement and Athabasca strata. The belt probably corresponds with the location of a major fault structure in the basement. Two deposits, Collins Bay A and B zones, have been outlined and evaluated; a new one, Eagle Point zone situated about 2 km northeast of Collins Bay A zone, has been announced (Globe and Mail, June 27, 1980; Sibbald, 1980) and other deposits are probably present, along the same structure. By March 1979 about 15 400 tonnes of uranium had been outlined in the Collins Bay area, principally in the A and B zones (Jones, 1980). Development of the Collins Bay B zone is expected to start in 1982-83.

Collins Bay A Zone

References:

Jones, 1980; Gulf Minerals Canada Limited, personal communication, 1975-78.

The Collins Bay A zone deposit is 10.5 km north of the Rabbit Lake Mine (Fig. 4). It occurs under the waters of Collins Bay (Wollaston Lake), about 250 m off the east shore of the bay. The all-weather gravel Saskatchewan Highway 102-105 from La Ronge in the south passes through Rabbit Lake Mine and northwards to within 1200 m of the A zone deposit (Fig. 4). A company-maintained landing strip is about 4 km to the south. The deposit is owned by Gulf Minerals Canada Limited (90 per cent) and Gulf Canada Limited (10 per cent). At present (1981), the deposit has been outlined and evaluated but is not under development leading to production.

Ground investigation of an airborne electromagnetic anomaly in 1970 followed by discovery and delineation of a radioactive boulder train and then by a radiometric survey under the waters of the Collins Bay area led to further geophysical surveys and drilling which intersected the A zone deposit in 1971. Additional drilling, starting in the winter of 1976-1977, on a 8 metre grid outlined the ore zone.

The A zone is a small high grade, lenticular, uranium-nickel body within clay-altered paragneiss of the Wollaston Group beneath small erosion remnants of Athabasca rocks (Fig. 11). Near and beneath the deposit, the Wollaston Group consists of quartzofeldspathic gneiss and graphitic pelitic gneiss. In subsurface west of the Collins Bay Fault is

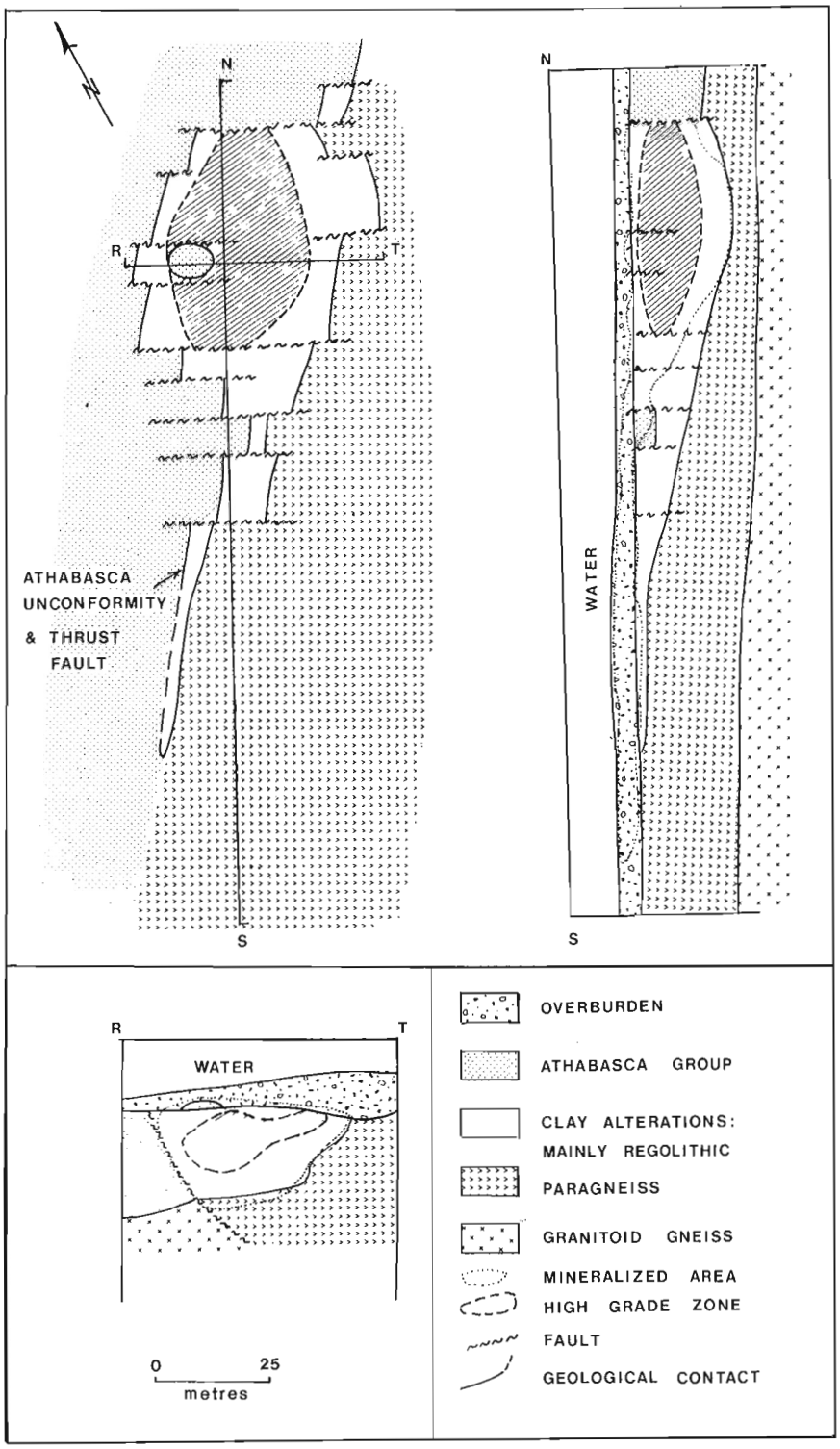

Figure 11. *Generalized geology of Collins Bay A zone beneath Collins Bay. The northern part of the mineralized area and the high grade area are in regoliith but the southern part of the mineralized area is mainly in glacial till. Modified slightly from Jones (1980) and after Gulf Minerals Canada Limited (personal communication, 1979).*

granitoid gneiss with minor paragneiss believed to be remobilized Archean basement to the Wollaston paragneiss. An elongate lens of clay-altered paragneiss 100 m long, and as much as 46 m wide and 18 m thick lies east of and parallel to the Collins Bay Fault and envelops the high grade zone and most of the broader low grade mineralized zone. The "clay zone" grades downward into unaltered paragneiss, and is believed to be mainly a sub-Athabasca regolith which has become further altered to more clay plus sericite (illite) and chlorite by mineralizing processes. Strangely, the granitoid gneiss beneath the Athabasca sandstone west of the Collins Bay Fault has little intervening regolithic alteration. The Athabasca Group is mainly sandstone and pebbly sandstone with conglomerate at the base. East of the Collins Bay Fault, only small outliers of sandstone are preserved. One such remnant overlies the ore-bearing regolith and underlies glacial overburden; drillholes showed it to be 12 m long and 1.5 m thick. As at Rabbit Lake Mine, the mineralized clay-rich regolith and underlying Wollaston paragneiss have been thrust west along the Collins Bay Fault upon Athabasca sediments and underlying granitoid gneiss. The fault trends about N30°E and dips 70-80 degrees east. Vertical displacement is about 15-20 m (Fig. 11). Several northwest-trending vertical faults offset the rocks, mineralized zone and thrust fault laterally and vertically no more than a few metres each. The north and south ends of the high grade zone appear to be at faults. The mineralized zone is covered by 4-7 m of till and some overlying lacustrine clay and by 7-12 m of water of Collins Bay. Two tills (Gulf Minerals Canada Limited, personal communication, 1978) have been recognized, the lower one found only in the eastern part of the deposit area and rich in Athabasca sandstone boulders, and the upper one, with few sandstone boulders, covering the lower till and the mineralized zone in the western part of the deposit area.

The mineralized zone is mainly within the regolith, but extends a little into less altered paragneiss at depth and into Athabasca sandstone west of the Collins Bay Fault. Till locally above, and for more than 100 m south of, the high grade zone is well mineralized, forming a highly radioactive boulder train derived probably mainly from the high grade zone where it subcrops at the base of the till. The high grade zone, enclosed within the low grade zone, is disc-shaped, 50 m long, 34 m wide and 13 m thick. It consists of clay which is grey green to black and graphitic in the centre, grading outward to grey and thence to red hematitic (ochre) and light green chloritic clay. The clay contains disseminated sooty pitchblende and coffinite, nodules, lenses and irregular bodies of hard massive pitchblende, and seams and veins of late pitchblende. Drill core of typical ore assays 0.5 per cent U over 6 m, but some cores are extremely rich: 68 per cent U over 2 m and 50 per cent U over 9 m (Jones, 1980). Significant amounts

Figure 12

Looking southeast along the Collins Bay B zone: the area is flat and a metre or so above Wollaston Lake. Vertical pickets mark the closely spaced (15 m) drilling. June 1978 (GSC 203712-C).

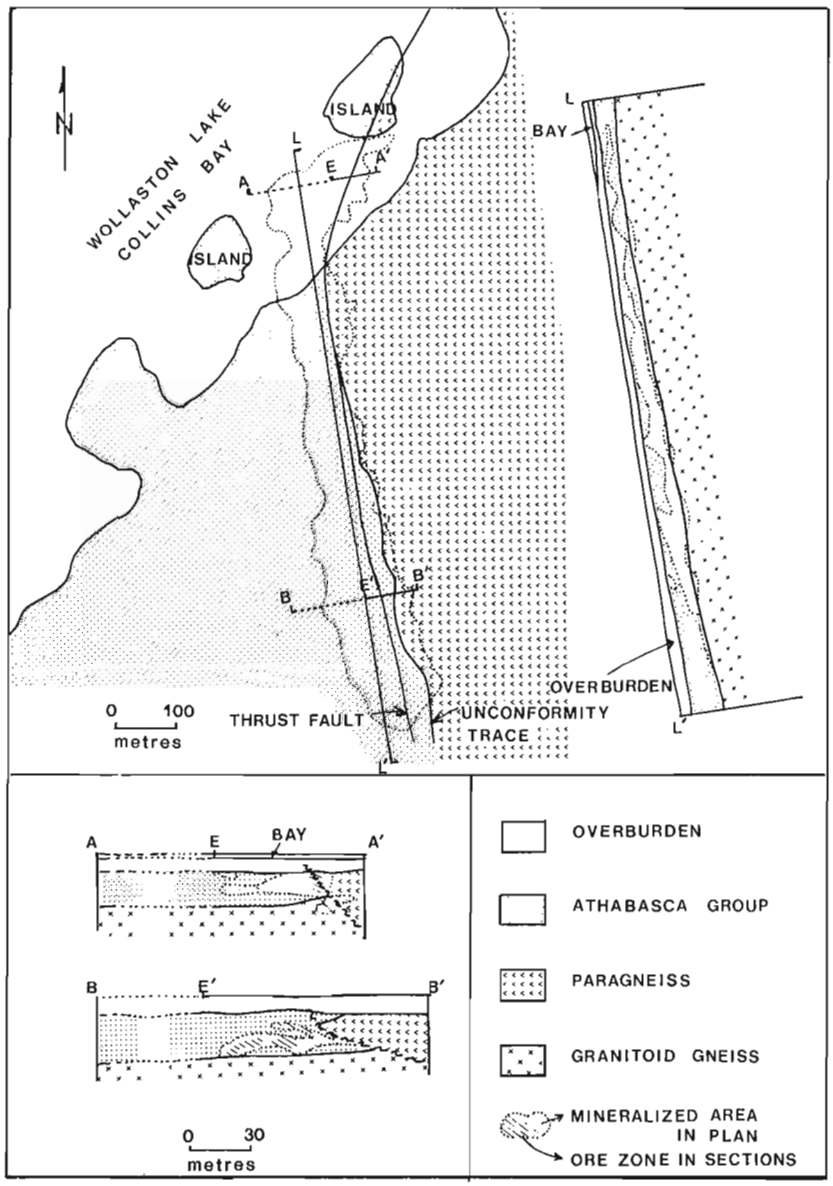

Figure 13

Generalized geology of Collins Bay B zone. The mineralized zone parallels the thrust fault, plunges gently south and is almost entirely in rocks of Athabasca Group. Modified slightly from Jones (1980) and after Gulf Minerals Canada Limited (personal communication, 1979). Outline of ore zone not shown in plan.

of arsenic, nickel, lead, silver and gold accompany the uranium. Nickel occurs mainly below the high grade zone and in the sandstone near the Collins Bay Fault. In addition to pitchblende and coffinite, the mineralized zone contains rammelsbergite, pararammelsbergite, galena, sphalerite, nickeline and kasolite. A whole-rock sample of red ochrous clay in the ore zone, partly altered to sericite and chlorite, presumably by mineralizing processes, yielded a K-Ar age of 1266 ± 39 Ma (Stevens et al., 1982), a reasonable age of mineralization as it corresponds very closely to the date of the main emplacement of uranium mineralization at Rabbit Lake (Cumming and Rimsaite, 1979).

Collins Bay B Zone

References:
Jones, 1980; Gulf Minerals Canada Limited, personal communication, 1979.

The middle of the Collins Bay B zone deposit is 2.5 km south of the A zone and 8 km north of Rabbit Lake mine (Fig. 4). The northern third of the zone lies under Collins Bay and the rest in low land, partly swampy, at and near the shore (Fig. 12). The all-weather gravel Saskatchewan Highway 102-105 from La Ronge and Rabbit Lake passes over the middle of the zone. A company maintained landing strip is 2 km to the south. The deposit is owned by Gulf Minerals Canada Limited (90 per cent) and Gulf Canada Limited (10 per cent).

Exploration from 1970 to 1976 on the A zone focussed attention on radioactive till to the south. In 1977, drilling of graphitic rocks extending south from the A zone led to the discovery of the B zone and its subsequent delineation in 1978 and 1979. Development in 1981-82 for production starting in 1982-83 is anticipated. The ore will be processed at the Rabbit Lake mill where the current solvent extraction ammonium precipitate process will be replaced by an ion exchange process and hydrogen peroxide precipitation.

The B zone lies mainly within heavily clay-bearing multicoloured Athabasca sandstone above granitoid gneiss in thrust contact to the east with graphitic paragneiss (Fig. 13). The granitoid gneiss is red and, like that at the A zone is believed to be remobilized Archean rock that is basement to Wollaston paragneiss. The paragneiss east of the Collins Bay thrust fault is granoblastic and some is graphitic. Unlike the A zone, the B zone deposit lacks a well developed regolith below the Athabasca sandstone although feldspars and mafic minerals in the granitoid gneiss and paragneiss at the unconformity have been altered to clay. The intensity of alteration decreases downward through about 20 m of gneiss to fresh rock. The Athabasca strata, about 15-20 m thick at the deposit, dip a few degrees west and consist of basal conglomerate overlain by light grey to white sandstone with some interbedded shale. Most of the sandstones and shales in the mineralized area are multicoloured, that is buff, red, green, grey and black and are variously white clay altered. Along the Collins Bay Fault, paragneiss and its overlying remnant of sandstone have been thrust west upon granitoid gneiss and thicker overlying Athabasca sandstone, with a vertical displacement of about 15 m. The fault dips moderately east, and where it bounds sandstone on the west, it splits into several splays within the mineralized sandstone area. Slivers of clay-altered sub-Athabasca rocks have been carried along the thrust over Athabasca rocks and are now within the fault zone and the mineralized area. The fault trends north and at the shore of Collins Bay curves 30-40 degrees into the northeast. Thrust imbrication and clay alteration are more intense near the bend and there the grades of uranium and nickel are highest. The deposit is everywhere covered by till, average depth 16 m, and the north end by an additional 4 m of water of Collins Bay. The mineralized zone subcrops at the base of the till in several localities along its length, suggesting that part of it has been eroded away. Locally the till above the mineralized area contains mineralized rocks, and some is of ore grade.

The mineralized zone is shaped like a flattened cigar, 1100 m long, 30-130 m wide and 17 m thick, lying mainly within sandstone west of and within the Collins Bay Fault (Fig. 13). The zone extends east into the paragneiss in the hanging wall of the fault at the northern end of the deposit. The zone parallels the Collins Bay Fault and trends N10°W for 750 m onshore and curves to N40°E for 350 m in the north beneath Collins Bay. The zone plunges only a few degrees southerly, and at each end it narrows and pinches out within sandstone in the north and within the sandstone and paragneiss in the south. Laterally, the zone pinches out in sandstone to the west and to the east ends against the fault or locally in altered paragneiss east of the fault. Within the zone, clay in the normally light coloured matrix of sandstone and in minor intercalated siltstone and shale, is buff, red, green, grey and black, giving rise to multicoloured sandstones. Masses of variously coloured clay occur along and adjacent to the Collins Bay Fault and its splays. They appear to be altered paragneiss, either fault slices or parts of the hanging wall, and some clay masses appear to have been squeezed and injected as dykes as much as several centimetres wide, possibly along fractures. Clay in the central parts of the mineralized zone is sericitic and chloritic, particularly near the fault. The major position of the masses of clay is assumed to have originated by alteration associated with mineralizing processes, but parts are believed to be derived from the sub-Athabasca weathering and fault movement.

Pitchblende and pitchblende-nickel arsenides in the multicoloured sandstone occur as fine disseminations in the clay matrix and as pods and veins, and in the clay masses as disseminations and pods of massive pitchblende-nickeline. Some white sandstone outside the mineralized area has black specks (less than 1 mm across) rich in arsenic. Average ore grade was quoted as being similar to Rabbit Lake ore grade; about 0.3 per cent U (Oilweek, Sept. 29, 1980). Rich ore occurs within the clay masses along the Collins Bay Fault and its splays, and one of the richest parts of the zone is near the curve of the fault near the northern end, where 20 m drill cores average 0.8-2.5 per cent U (Jones, 1980). One 1.7 m section of core assayed 21 per cent U. There are probably other similar rich ore portions within the ore zone but so far their location, extent and number are not known. In addition to pitchblende and nickeline, the following minerals have been identified: coffinite, gersdorffite, skutterudite, galena, chalcopyrite, millerite, pyrite, ankerite, graphite and carbonaceous material (Jones, 1980).

A whole-rock sample of sericitic and chloritic clay from the high grade zone within the Collins Bay Fault yielded a K-Ar age of 1296 ± 34 Ma (Stevens et al., 1982). U-Pb ages on two samples of coarse pitchblende and one of sooty pitchblende were reported by Jones (1980). The data are difficult to interpret as the coarse pitchblende yielded ^{207}Pb-^{206}Pb ages of 410 and 1238 Ma and the sooty pitchblende a ^{207}Pb-^{206}Pb age of 517 Ma. However the other isotopic ratios gave slightly older or markedly younger ages. The 1238 Ma age appears to be closer to the generally accepted age of the main mineralization in the Rabbit Lake area, like 1296 Ma K-Ar age above.

Midwest Lake – McClean Lake Area

The Midwest Lake-McClean Lake area is about 20 km in diameter, and about 15 km northwest of Rabbit Lake (Fig. 4). It includes the Midwest Lake deposit (now known as the Canada Wide Mines Ltd. deposit), the Dawn Lake deposits and the McClean Lake deposits. These deposits in general are similar to the Collins Bay and Key Lake deposits in that they

are rich in nickel, cobalt and arsenic in addition to uranium except a few at Dawn Lake which have only uranium. On the other hand, all the deposits are well within the Athabasca Basin; no basement rocks are exposed and the unconformity is between 110 and 200 m below surface.

Midwest Lake Deposit

References:

Kirwan, 1979a, b; Canadian Mining Journal, August 1979; Saskatchewan Department of Mineral Resources assessment files; Esso Minerals Canada, personal communication, 1978-79; Canada Wide Mines Ltd., 1981; Wray et al., 1982.

The Midwest Lake deposit is 25 km northwest of the Rabbit Lake Mine and 13 km northeast of Waterbury Lake. The deposit is mainly under the water of Mink Arm of Midwest Lake (Fig. 4, 14). It can be reached by float-equipped aircraft from Wollaston Lake village, 55 km to the east, and from La Ronge, 350 km to the south. Scheduled air flights (Norcanair) from Saskatoon reach Wollaston Lake village twice a week. The winter road connecting the property to the all-weather gravel Saskatchewan Highway 102-105 is expected to be upgraded to an all-weather road by summer 1982.

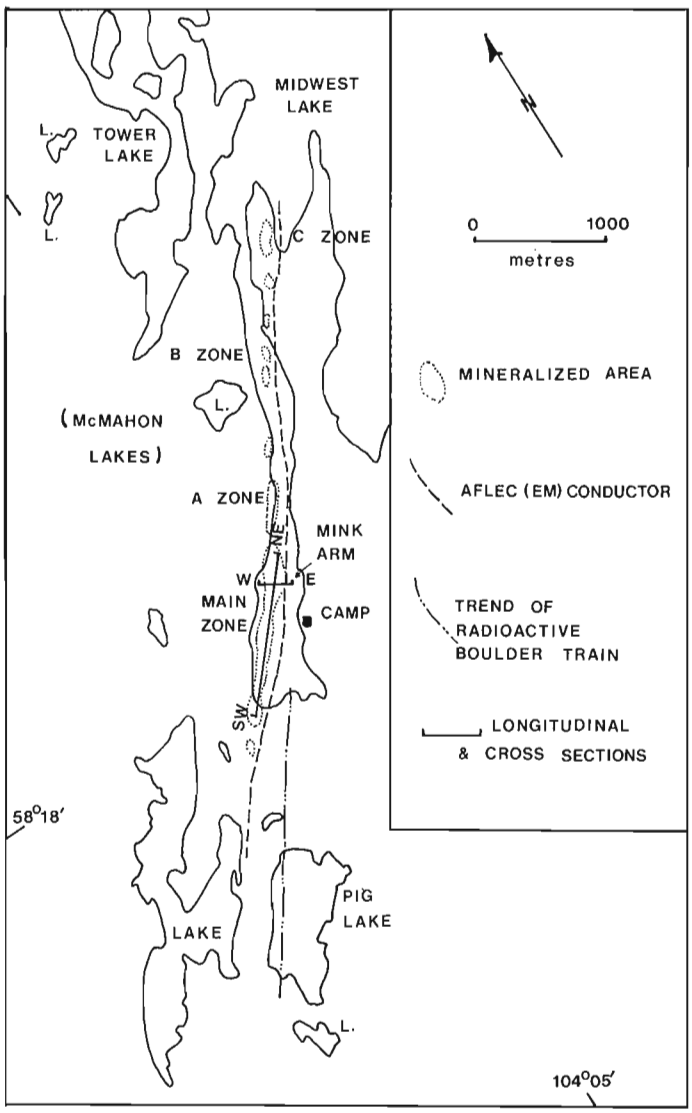

Figure 14. *Outline of mineralized areas along Mink Arm of Midwest Lake. The mineralized zones lie along the sub-Athabasca unconformity about 200 m below lake surface. Cross-sections are on Figure 15 and 16. Prepared from information supplied by Esso Minerals Canada Limited (personal communication, 1979) and Kirwan (1979a, b). See Figure 4 for location relative to Rabbit Lake Mine.*

The area containing Midwest Lake deposit was known for several years as the Numac or Waterbury Lake property. It was first acquired in 1968 by Numac Oil & Gas Ltd. for the Numac-Imperial Oil joint venture. Numac was the field operator until 1977 when Esso Minerals Canada (a division of Esso Resources Canada Ltd.) became the new operator. The property is now held by Esso Resources Canada Ltd. (50 per cent), Numac Oil & Gas Ltd. (25 per cent), and Bow Valley Industries and others (25 per cent) under the name of Canada Wide Mines Ltd.

The property has been explored almost continuously since 1969. Details of the exploration activities up to recovery of the first high grade drill core in 1978 were described in an interesting account by Kirwan (1979a, b). In 1969, a geochemical survey of lake waters and an airborne total count radiometric survey followed by ground prospecting led to the discovery of pitchblende-bearing sandstone float south of Midwest Lake (but no mineralized outcrops) and to the realization that the airborne survey was responding to a train of radioactive basement erratics, and that the sandstone float probably originated beneath the Mink Arm of Midwest Lake. Various geophysical surveys were conducted during the winter of 1969-1970. Short hole drilling program in 1970 and 1971 failed to locate any mineralization in bedrock. During the next two years, geochemical surveys of soils, lake sediments and lake water in and near Mink Arm yielded an encouraging anomalous zone in lake sediments in the Arm. In 1974, a radon soil survey south of Mink Arm traced the radioactive glacial train but trenches through 1.5-2 m of overburden failed to expose mineralized sandstone bedrock. A short hole drilling program in 1975 likewise was unsuccessful. A glimmer of hope fueled otherwise fading optimism in 1977 when a deep drillhole under Mink Arm intersected some weakly radioactive sandstone just above the unconformity. Finally several deep holes in 1978 intersected high grade uranium mineralization near the base of the sandstone. Thus ten metres of one core presumably entirely within sandstone, yielded 21.5 per cent U and 12.04 per cent Ni (Kirwan, 1979a, p. 78). The Midwest Lake deposit had been discovered. Since then the deposit has been systematically drilled to delineate and evaluate it. About 625 holes have been put down. The deposit previously scheduled to start up production about 1986 has been put on a slowdown basis. Its development has been postponed to 'late 1980 or 1990' (The Northern Miner, Dec. 10, 1981).

The deposit (Fig. 14) occurs beneath Mink Arm along the unconformable contact of Athabasca sandstone and conglomerate upon Wollaston paragneiss about 200 m below surface. The paragneiss consists mainly of arkose and pelite metamorphosed to amphibolite facies. Some of the gneiss is fine- to medium-grained, garnet-bearing and granoblastic; some is coarse grained, granitoid and pegmatitic; and some contains graphite in amounts as great as 20 per cent. There are also some sillimanite and cordierite-rich bands. The graphitic gneiss was probably mainly pelite. The paragneisses form a belt trending north-northeast beneath the mineralized zone. There the belt is less than 1 km across but widens sensibly to the north, northwest, and southwest. It dips steeply east and has been interpreted from geophysical data and inspection of core to be in contact on both sides with granitoid rocks of possibly Archean age (Sibbald, 1980). These graphitic gneisses are probably near the base of the Aphebian succession. The western contact of this belt coincides with a marked west-facing declivity (Fig. 16) of the

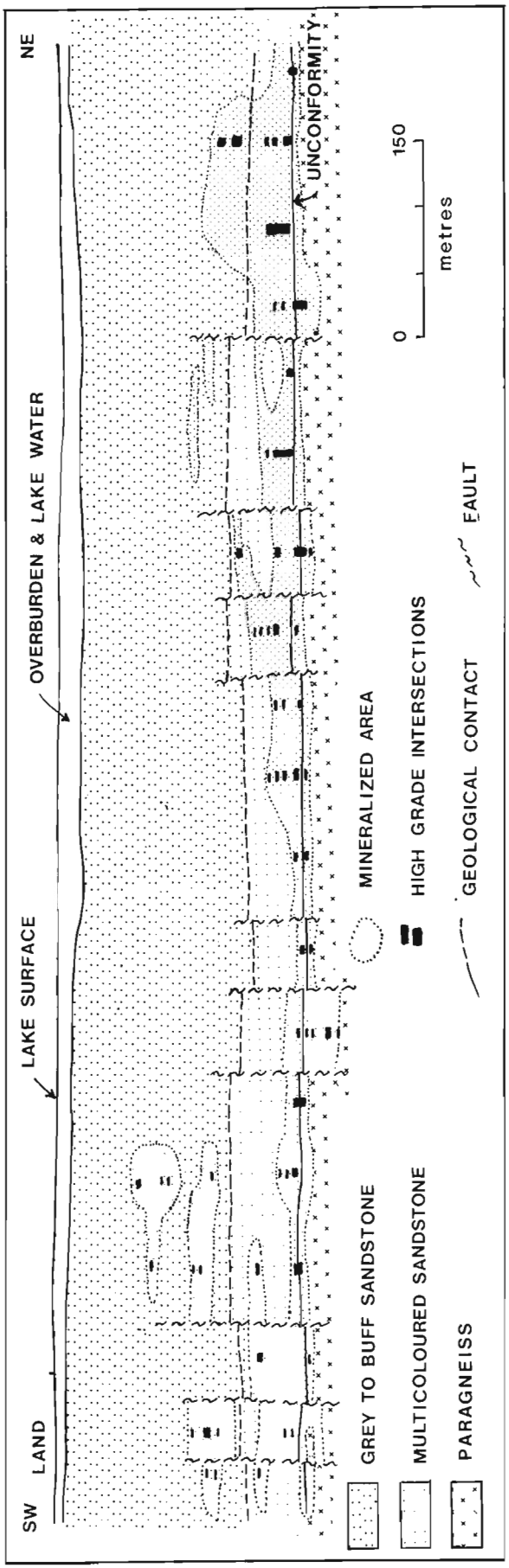

Figure 15. *Longitudinal section of Main Zone of Midwest Lake deposit. Section location is shown on Figure 14. Prepared from information supplied by Esso Minerals Canada Limited (personal communication, 1979) and from Kirwan (1979a, b). Upper contact of multicoloured sandstone approximated by writer from examination of ten drill cores. Cross faults are writer's interpretation. Ore zones not shown within the mineralized areas.*

unconformity and, down the slope, with a thick conglomerate in the basal Athabasca succession. It may be the location of a major basement structure such as a fault.

Near the deposit the paragneiss is completely altered to a light greenish-white clay mass composed of muscovite, sericite, chlorite, clays and quartz. The intensity of alteration decreases downward to 45 m below the unconformity where fresh rock is generally encountered. The alteration probably resulted from pre-Athabasca weathering later modified by mineralizing processes. Alteration is most intense at the unconformity and along zones, possibly shear zones, extending downward where locally large clay masses have formed mainly from the paragneisses. Clay masses extend upward into Athabasca sandstone here and there. Most of these represent altered sandstone but some were probably orginally intercalated mudstone beds. This is suggested by the presence of shard-like fragments in some of the clay zones, as if they are original beds containing volcanic material.

The Athabasca succession above the unconformity near the mineralized zone consists of 185-215 m of sandstone (80 per cent), conglomerate (17 per cent) and siltstone and mudstone (3 per cent). The upper 120 m is almost entirely grey, white and tan quartz sandstone. The lower 60-100 m, containing some of the mineralization, is also mainly sandstone but is particularly multicoloured: grey, black, red, brown, buff, white and olive green (Figs. 15, 16). This multicoloured section is widespread in the south in the area of Mink Arm but appears to be erratic north of the arm where the sandstone is again mainly grey, black and tan. A whole rock K-Ar age of 1801 ± 44 Ma was obtained from an unmineralized mudstone (clay) layer interbedded with sandstones 20 m above the sandstone-basement contact (Stevens et al., 1982). This is older than normally assumed for the Athabasca succession and for the white clay alteration associated with the mineralization, and presumably was influenced by inherited radiogenic argon in detrital muscovite and possibly rare potash feldspar clasts from the basement rocks.

Diabase dykes and sills (?) cut paragneiss and sandstone in the Midwest Lake area. Most dykes trend northwest, but one intersected in a drill hole and believed to trend northeast is intensely altered, even possibly serpentinized (?), and part of it is mineralized. Unfortunately, its age is unknown. No northwest-trending dykes are known to be similarly altered and mineralized.

From 2-20 m of till and lacustrine clay, plus water of Mink Arm as deep as 8 m cover the Athabasca strata above the mineralized zone.

The Athabasca strata dip a few degrees west above an undulating unconformity. Steeply dipping northwest-trending cross-faults cut and offset paragneiss, sandstone and the mineralized zone (Fig. 15). Vertical and horizontal displacements appear to be small on most faults. A maximum vertical displacement of 30 m has been reported (Canada Wide Mines Ltd., 1981, p. 38).

The mineralized zone is 3800 m long and as much as 150 m wide and 120 m thick. It extends from 200 m southwest of Mink Arm N30° to 40°E along the arm to the main body of Midwest Lake in the northeast (Fig. 14). The zone lies along the western border of the belt of paragneiss where the unconformity rolls down to the west, possibly coincident with a major pre-Athabasca fault in the basement. The zone comprises lenticular high grade areas within much larger low grade areas of mineralization. In general the high grade areas occur within the clay masses at and near the unconformity and appear to be controlled in part also as to location by some of the west-northwest trending cross-faults. Most mineralization above the unconformity is confined to

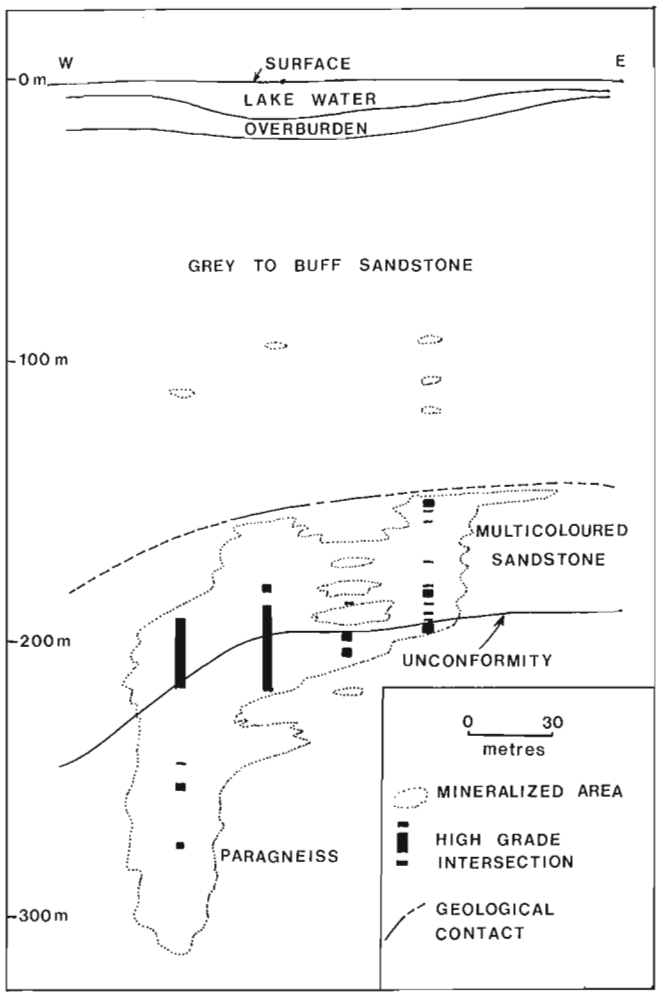

Figure 16. *Cross-section of Main Zone of Midwest Lake deposit. Section location is shown on Figure 14. Prepared from information supplied by Esso Minerals Canada Limited in 1979, and from Kirwan (1979a, b). Upper contact of multicoloured sandstone approximated by writer from examination of three drill cores. Ore zones not shown within mineralized area.*

the multicoloured section of the sandstone, that is, the mineralization in the multicoloured sandstone is more extensive and of higher grade than that in the areas of the grey, white and black sandstone above the multicoloured section and to the north along the strike of the multicoloured sandstone succession, also in general the mineralization in the sandstone is not as rich as that in the clay masses. That in the clay masses at the unconformity averages 10 per cent U whereas the mineralization in the sandstone varies between 0.1 per cent and 1.0 per cent U (Canada Wide Mines Ltd., 1981, p. 39). Moreover within the thick clay masses at and near the unconformity, there is abundant sericite and chlorite closely associated with the mineralization, suggesting that their development is specifically related to mineralizing processes which are assumed to be responsible also for much of the clay masses.

The mineralization along the mineralized zone is in discontinuous bodies. The largest and most extensive body of mineralization in the zone, here called the Main Zone, is the only presently known portion of the zone to contain an orebody (Fig. 14). It lies almost entirely under Mink Arm, is about 1400 m long, as much as 150 m wide and from 3-90 m thick (Figs. 15, 16). The other smaller mineralized bodies, zones A, B and C to the northeast of the Main Zone, have not yet been sufficiently drilled to be delineated and evaluated satisfactorily (1981).

The ore minerals occur as irregular pitchblende-nickeline masses within clay masses near the unconformity, as fracture filling in altered basement and sandstone, as disseminations bordering fractures, and in the matrix and as fine coatings on quartz grains in certain sandstone beds. The largest uranium concentrations are at and near the unconformity at the north end of the zone and within the clay masses. Mineralized fractures and shears in paragneiss locally extend downward to 100 m below the unconformity but they do not account for much uranium. In the sandstone, most of the mineralization is within the first 60 m above the unconformity. This mineralization constitutes most of the ore of the orebody of the Main Zone but not necessarily most of the uranium. Mineralizaed sandstone well above the multicoloured sandstone unit is sparse but some of it subcrops beneath glacial till, as indicated by recent drilling, and is presumably the source of radioactive sandstone erratics of the train southwest of the Lake.

In addition to pitchblende, coffinite, gersdoriffite nickeline and rammelsbergite, the deposit contains minor amounts of bravoite and millerite. Other minerals identified are marcasite, arsenopyrite, cobaltite, galena, sphalerite, chalcopyrite and molybdenite (Canada Wide Mines Ltd., 1981, p. 39). Lead, cobalt and silver are relatively rich locally.

Analyses of mineralized samples (Canadian Mining Journal, August 1979, p. 35) are:

	"Low grade"	"High grade"
U_3O_8(U)	0.29 (0.246)	13.9 (11.79)
ThO_2	0.016	0.037
As	1.68	7.62
Ni	0.94	4.80
Cu	0.18	0.42
Pb	0.04	1.19
Zn	0.11	0.52
Fe	2.85	5.42
S	0.82	1.78
Co	0.19	0.11
Bi	0.017	0.057
C	0.09	0.12
CO_2	0.56	0.08
Ag	trace	68.3*
Au	0	0

*Gram/tonne

The property in 1978 was reported to have reserves of 2 000 000 tonnes averaging 1.06 per cent U for an estimated 21 500 tonnes of uranium (Canadian Mines Handbook, 1980-81, p. 101). A study conducted at the end of the 1979 exploration season indicated recoverable ore reserves in the Main Zone and the sparsely drilled areas to the north (Fig. 14) to contain about 29 000-31 000 tonnes of uranium, 27 000 tonnes of nickel and 3 200 tonnes of cobalt (The Northern Miner, January 17, 1980, p. A8). In 1981, the company reported ore reserved of 19 000 tonnes of uranium within one million tonnes of rock from the Main Zone alone.

Sericitic and chloritic clay from a high grade zone near the unconformity in the Main Zone yielded a whole rock K-Ar age of 1212 ± 33 Ma (Stevens et al., 1982), an age close to that of the main mineralization episode in the Athabasca Basin.

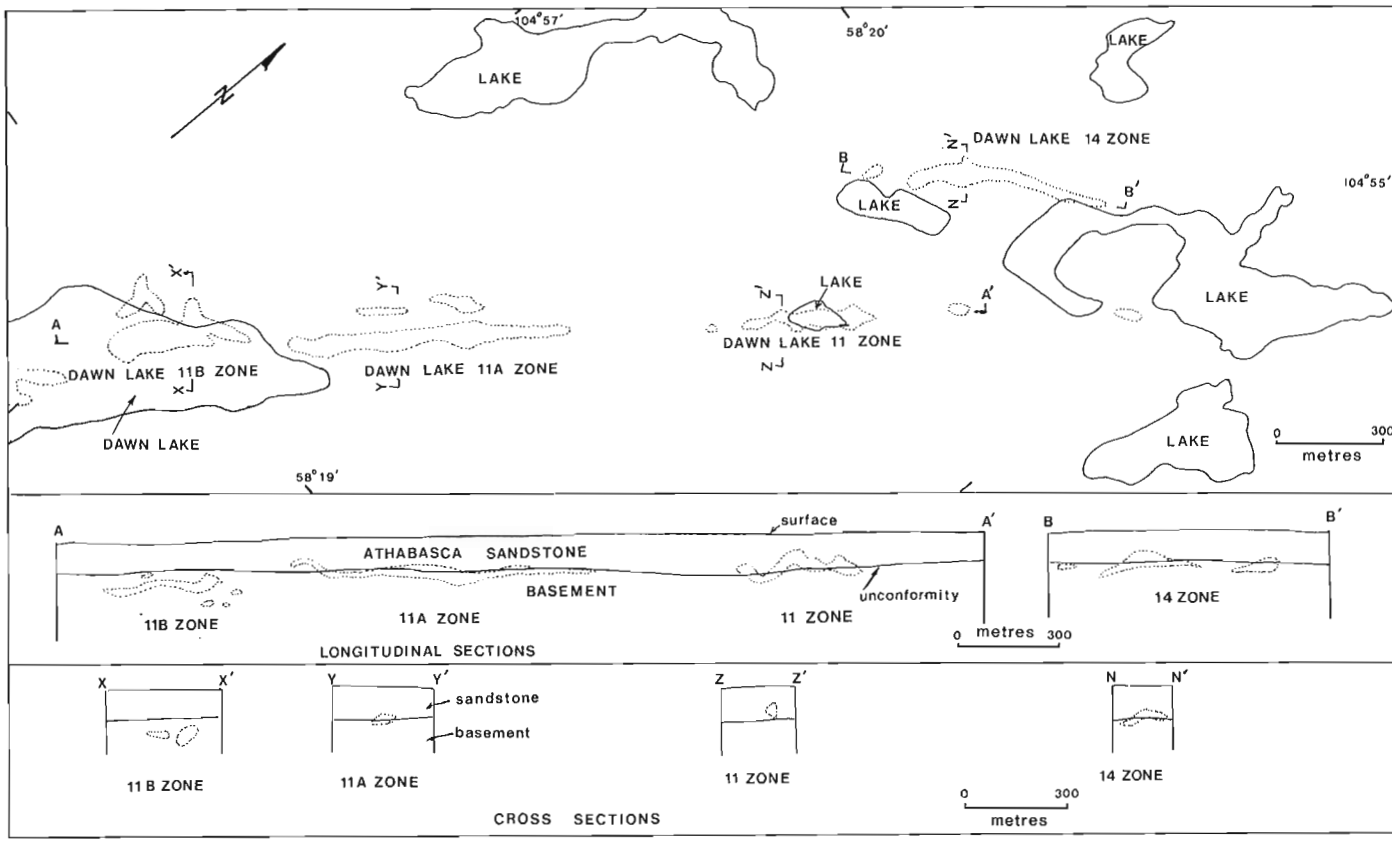

Figure 17. *Location of the Dawn Lake 11, 11 A, 11 B and 14 mineralized zones north of Dawn Lake as prepared from information supplied by Asamera Oil Corp. Ltd. in 1979. The two zones have parallel trend and comprise several mineralized areas. See Figure 4 for location of the zones relative to Rabbit Lake Mine. Ore zones not shown within the mineralized areas.*

Dawn Lake Deposits

References:

The Northern Miner, Jan. 11, Feb. 1, May 10, July 19, Nov. 1, 1979; Saskatchewan Department of Mineral Resources assessment files; Globe and Mail, Oct. 10, 1980; Asamera Oil Corp. Ltd., personal communication 1979; Clarke and Fogwill, 1981.

The Dawn Lake deposits, comprising four zones, 11, 11A, 11B and 14, are 20 km northwest of the Rabbit Lake Mine, 9 km northeast of the Midwest Lake deposit, and as much as 2 km northeast of Dawn Lake (Fig. 4, 17). Dawn Lake and other lakes to the northeast can be reached by float-equipped aircraft from Wollaston Lake village, 50 km to the east, and from La Ronge, 352 km to the south. Scheduled air flights (Norcanair) from Saskatoon reach the village twice a week. A winter road connects the property to the all-weather gravel LaRonge-Rabbit Lake Saskatchewan Highway 102-105. The property is owned by Saskatchewan Mining Development Corp. (50.75 per cent), Asamera Oil Corp. Ltd. (25 per cent), Reserve Oil and Minerals Corp. (7.5 per cent), Kelvin Energy Ltd. (3.5 per cent), E. & B Explorations Limited (6.5 per cent), S.E.R.U. Nucleaire (Canada) Ltd. (6 per cent) and Crest Resources and Exploration Corp. (0.75 per cent), with Asamera the field operator (The Northern Miner, Jan. 8, 1981, p. 1).

The property was acquired in 1976 under the Keefe Lake-Henday Lake Joint Venture. Exploration began with an airborne radiometric and magnetic survey and a seismic survey. In 1977, geochemical sampling of lake, bog and stream sediments plus prospecting and surficial geology studies were followed by airborne electromagnetic and magnetic surveys. Selected anomalous areas were tested with ground electromagnetic surveys in 1978. During 1978 and 1979, promising anomalies were drilled to basement in the 11 and 14 zones, and on extensions to the northeast and southwest. Rich mineralized rock was first encountered in the 1978 drilling program. The designations 11 zone and 14 zone (Fig. 17) refer to the drillhole numbers in which ore grades were first found. Drilling in 1979 and 1980 on the southwest extension of the 11 zone indicated two other zones, 11 A and 11 B (Fig. 17) still only partly evaluated (Globe and Mail, Oct. 10, 1980, Clarke and Fogwill, 1981, p. 20). Two additional unnamed zones were indicated by drilling in 1979 and 1980, one 8000 m north-northeast of Dawn Lake in the Mallen Lake area, the other 6000 m southwest of Dawn Lake in the Midwest Lake area. Mineralized intersections have been obtained from other parts of the property (The Northern Miner, May 10, 1979). The operators are planning a feasibility test of the bore-hole hydraulic mining method for the summer of 1982 (March 4, 1982) on one of their deposits.

The deposits occur well within the Athabasca Basin, about 18 km from the east edge. Glacial till, gravel and sand averaging 24 m in thickness blanket the area and no bedrock is exposed at the surface in the area of the mineralized zones.

The mineralized zones occur at and near the unconformity of flat lying Athabasca sandstone on steeply dipping Wollaston paragneiss at a depth of 75-115 m. However some mineralized intersections in the area of the 11 B zones are at a much greater depth, up to 135 m, entirely in basement rocks.

The Wollaston rocks consist of fine grained, grey, impure metaquartzite and metagreywacke, graphite schist and gneiss (metapelites), calcareous meta-arkose, calc-silicate rocks, coarse grained feldspathic quartzite, quartzo-feldspathic gneisses and pegmatoid rocks. These occur in steeply dipping belts trending northeasterly. A metapelite belt in contact on the west with calc-silicate rocks was traced the whole length of the area of the mineralized 11, 11 A and 11 B zones. The calc-silicate rocks were seen to incorporate in their western part much granitic and pegmatitic material. These rocks are regarded as belonging to the upper part of the Wollaston Group succession. No granitoids of possible Archean age appear to be present below the unconformity in this area (Sibbald, 1980).

Except for one or two thin conglomerate beds near the base of the succession, the Athabasca strata are entirely sandstones. The sandstone in the upper part of the succession is white, grey and buff, whereas in the basal ten metres it is multicoloured (grey, white, buff, brown, deep purple, and dark red) or white, grey, dark grey and black. Locally the sandstone near and above the unconformity is buff, porous and altered. These Athabasca sandstones are flat lying or almost so and range in thickness between 70-100 m.

Clay alteration characterizes the unconformity only locally; generally the unconformity is sharp and the underlying Wollaston rocks are unaltered. The local altered zones grade rapidly downward to fresh basement rocks, and at the unconformity include here and there thick layers or lenses of clay, which are assumed to be mainly the result of the alteration associated with the mineralization. However, Clarke and Fogwill (1981, p. 23) have reported the presence locally of paleoregolithic profiles from the area of the mineralized zones.

The 11, 11 A and 11 B zones appear to be mainly in the belt of metapelitic rocks mentioned above, near its western contact with the belt of calc-silicate rocks (Clarke and Fogwill, 1981). The 14 zone is also in metapelite. This metapelite is correlated with the other metapelite belt mentioned above repeated by folding. It is assumed to represent the northern limb of a syncline whose axis followed the calc-silicate belt between the two metapelite belts, that is between the 11, 11 A and 11 B zones in the south and the 14 zone in the north (Clarke and Fogwill, 1981).

The 11 zone is entirely in sandstone whereas the 14 zone is in sandstone at its northeast part but in basement rocks at its southwest part (Asamera Oil Corp. Ltd., personal communication). The 11 A zone is entirely at the unconformity, partly in sandstone, partly in basement rocks, and has mineralized fractures extending well above and below the unconformity. The 14 zone is entirely in basement between 5 and 20 m below the unconformity and also exhibits mineralized fractures extending to the unconformity above.

Mineralization in the basement is generally associated with intensely clay-altered rocks believed to be mainly the result of the mineralizing solutions. This mineralization is commonly at the unconformity but may occur at some distance from the unconformity down to a 5-20 m depth. Mineralization in the Athabasca succession chiefly extends no more than 10 m above the unconformity and is entirely within the multicoloured or the grey and black sandstones. In general the mineralized sandstones are not, or are only weakly, clay-altered. The most richly mineralized sandstone is dark red to reddish black, well silicified and hard. It resembles the mineralized orthoquartzite of the Stewart Island deposit on the northern rim of the Athabasca Basin.

The 11 and 14 zones are similar in shape and type of mineralization. They are elongated northeasterly parallel to the trend of the basement rocks and are made up of a bulbous core and of two narrowing tails in the direction of the zones. The 11 A zone is long and narrow, cylindrical in shape and possibly fault controlled, whereas the 11 B zone is irregular. The main uranium minerals are sooty pitchblende and coffinite in the 11, 14, and 11 A zones with some secondary uranium minerals in the 11 and 14 zones and some hard pitchblende in the 11 A zone. These minerals are disseminated throughout the rocks in the 11 and 14 zones but also occur as fracture-filling in the 11 A zone. On the other hand the 11 B zone is made up of a network of pitchblende filling fractures and of disseminations in rocks adjoining the fracture, forming irregular lenses distributed en echelon along the trend of the mineralized zone. Here the main uranium minerals are hard massive pitchblende, botryoidal pitchblende and sooty pitchblende. The mineralogy of the zone is in sharp contrast with the other zones, in which the pitchblende is mainly sooty. This hard pitchblende may be a very old pitchblende (Clarke and Fogwill, 1981). The uranium mineralization in the 11 B zone and the southern part of the 11 A zone is associated with high values of Co, Ni, Cu, and As whereas the other two zones (11 and 14) have only traces or low values of these elements with the uranium. In general hematite is a common associate of pitchblende found along fractures in fresh red basement rocks.

The 11 zone has been traced for 400 m in a northeasterly (N 30°E) direction and is 60 m wide by as much as 50 m thick. Other small local mineralized zone have been detected for 800 m on trend to the northeast of it (Fig. 17). The 11 A and 11 B zones are on its southwest extension, that is, they are between 600 and 2000 m southwest of the 11 zone. The 11 A zone is 700 m long by 15 m wide and 20 m thick. As presently known, the 11 B zone is 300 m long, 180 m wide and 20 m thick. The 14 zone is 400 m northwest of the 11 zone and parallels it. It is 600 m long by as much as 70 m wide and 22 m thick (The Northern Miner, May 10, 1979; Clarke and Fogwill, 1981). It is in general comparable in size to the 11 zone but is more continuous. Drilling for 600 m on trend to the northeast of the 14 zone failed to locate additional zones whereas three holes out of ten intersected mineralized rock along a 1500 m extension to the southwest.

Uranium metal assays from the 11 zone have been reported as 1.4 per cent over 9 m, 14.4 per cent over 3.4 m and 0.11 per cent over 2 m; and from the 14 zone, 4.2 per cent over 22 m and 0.59 per cent over one metre (The Northern Miner, January 11 and February 1, 1979). Assays of 0.13 per cent U over 1.5 m and 4.32 per cent U over 9 m were reported from the 11 B zone. It would appear that a minimum of 7700 tonnes uranium has been outlined in the Dawn Lake mineralized zones, principally the 11 B zone (The Northern Miner, January 8, 1981). This figure was raised to 8077 tonnes uranium in early 1982 (The Northern Mines, January 7, 1982).

McClean Lake Deposits

References:

The Northern Miner, November 22, 1979 and May 8, 1980; Canadian Occidental Petroleum Ltd., personal communication, 1980; Brummer et al., 1981.

The mineralized zones called herein the McClean Lake deposits are 11 km northwest of the Rabbit Lake Mine and 15 km east of the Midwest Lake deposit (Fig. 4). More specifically, the three zones, McClean North, Candy Lake and McClean South, lie between a small lake, locally named

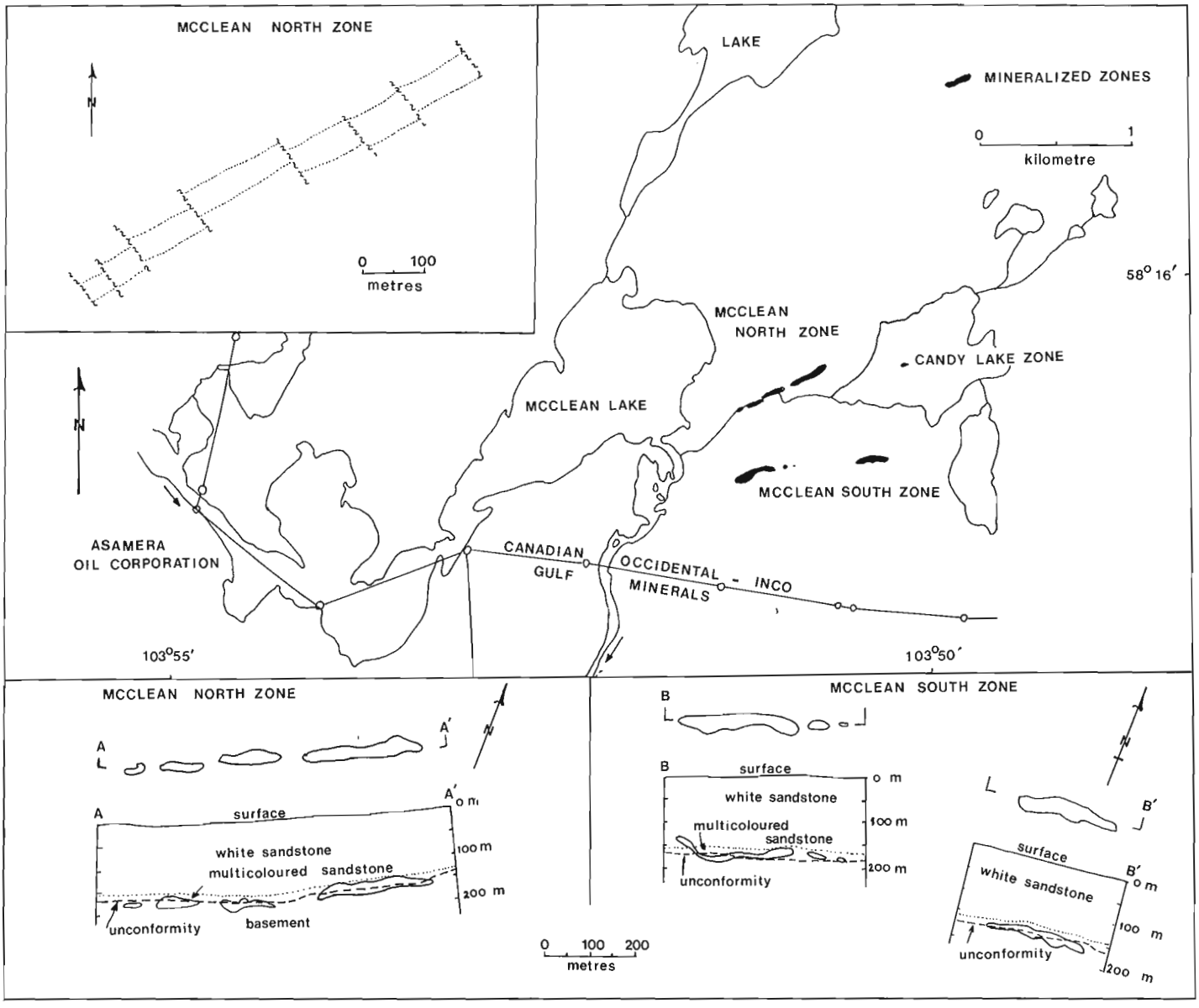

Figure 18. *Location of the McClean North and South zones and of the McClean Lake deposit east of the northern end of McClean Lake. The insert is the writer's interpretation of the faulting in the McClean North zone. Prepared from information provided by Canadian Occidental Petroleum Ltd. in 1980. For location relative to Rabbit Lake Mine see Figure 4. The thickness of mineralized zones in sections is not accurate.*

Candy Lake, and the northeast end of McClean Lake (Fig. 18). Candy Lake can be reached by float-equipped aircraft from Wollaston Lake village, 42 km to the east, and from La Ronge, 351 km to the south. A winter road connects the property to the all-weather gravel La Range-Rabbit Lake Saskatchewan Highway 102-105. The deposit is owned jointly by Canadian Occidental Petroleum Ltd. (50 per cent) and Inco Metals Co. (50 per cent) which became a partner in April 1977. Canadian Occidental is the field operator. Exploration continues on the deposit (1981).

The property was acquired by Canadian Occidental Petroleum Ltd. in August 1974. From 1975 to 1978, it was explored for uranium by several types of geological, geophysical and geochemical surveys. The first diamond-drill hole was put down in 1976 and by the end of 1978, 97 holes had been drilled to check anomalies indicated by the various surveys. Weakly mineralized core was pulled from some of these holes. Early in 1979, the McClean North zone was discovered when 12 of 14 holes intersected mineralization while drilling the southwest extension of a geophysical anomaly. The Candy Lake Zone was discovered when evaluating the McClean North Zone. It is 370 m east of the McLean North Zone and a little south of the projected extension of the North Zone. The McClean South zone is about 520 m south of McClean North Zone (Fig. 18) and was discovered in early 1980. By the end of 1980, more than 600 holes had been drilled on the property, about 400 of them in the area of the three zones. By April 1981, 178 holes had been drilled on the McClean North and 86 on the McClean South. Most holes are vertical and have penetrated basement.

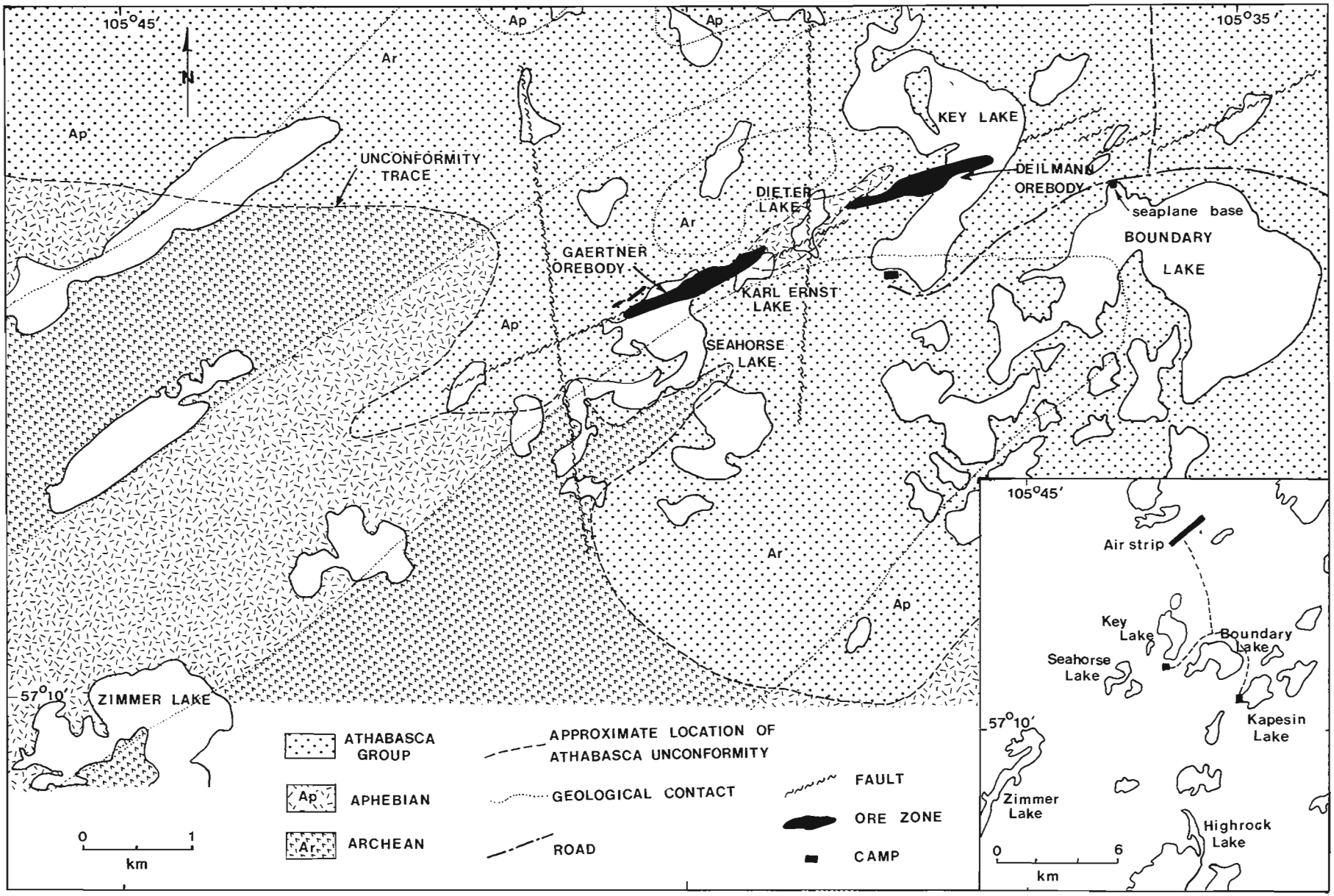

Figure 19. *Geology of the Key Lake area (from Key Lake Mining Corporation, personal communication 1979, and Gatzweiler et al., 1979).*

The mineralized zones occur at and near the unconformity of flat lying Athabasca sandstone on steeply dipping Wollaston schist and gneiss at a depth of 165 m. The deposit lies well within the Athabasca Basin, about 10 km west of the eastern edge (Fig. 4). Glacial drift of mainly drumlinoid till and eskers and as thick as 35 m blankets the area; no bedrock is exposed at the surface.

The basement rocks beneath the three zones consist of schist, gneiss and granitized rocks, derived from pelite, semipelite, massive arkose, feldspathic quartzite and amphibolite and are believed to be the basal part of the Aphebian sequence. Granitoid rocks of possibly Archean age have been reported a short distance south of McClean South zone (Sibbald, 1980). Some graphitic metapelites and meta-semipelites locally contain fine pyrite and resemble rocks known to have a few parts per million uranium and nickel in the Key Lake area. The overlying Athabasca strata comprise about 15 m of black, dark grey and multicoloured (buff, bluish grey, dark olive green, dark red and purple (sandstone succeeded by 135 m of white, buff and grey sandstone and minor shale. Most of the sandstone is coarse grained and pebbly. About one metre of white and light yellowish-green clay commonly occurs at the unconformity, developed partly within the multicoloured sandstone and partly within the basement rocks. Locally the clay can be seen to be younger than the red coloration of the basement rocks. This red coloration is assumed to be regolithic. A northwest-trending gabbro dyke is known to intrude Athabasca rocks on the property (Brummer et al., 1981).

In the McClean North Zone, mineralization has been traced by drilling for 735 m northeasterly, parallel to the assumed trend of the basement rocks, within a tested belt 1200 m long. The zone is as much as 60 m wide and 20 m thick and is made up of four narrow, sinuous well mineralized lenses. The McClean South Zone is parallel to the North Zone and comprises two lenses and and a few pods. It is within a tested belt 1000 m long. The Candy Lake Zone is made up of only one lens about 50 m long by 10 m wide (Fig. 18). The lenses resemble flattened cigars. They are each about 120-225 m long by 15-40 m wide and 7-25 m thick. From their shape and distribution they are interpreted to be bounded at their ends at least in part by transverse faults with small horizontal and vertical offsets. The lenses extend from 35 m above the unconformity to 35 m below it and the proportion of each lens above or below the unconformity is highly variable, but not one of the lenses is entirely in sandstone (Fig. 18). Some, however, are entirely in basement. The basement mineralization is always in clay-altered rocks which appear to have been the result of both regolithic and mineralizing solutions. These clay-altered areas occur generally at or near the unconformity. Some of the clay from these altered rocks was dated 1320 Ma by the ^{40}Ar-^{39}Ar method (Ontario Geoscience Seminar, Toronto, Dec. 1981) suggesting definitely that some of the clay is related to the mineralizing solutions rather than to the regolithic ones, which were active around 1632 Ma (Fahrig and Loveridge, 1981).

Pitchblende and coffinite (Brummer et al., 1981) are the main uranium minerals and are commonly associated with illite and chlorite and the following other metallic minerals: bravoite-pyrite, pararammelsbergite, nickeline, gersdorffite, safflorite, chalcopyrite, siderite, hematite and goethite. These minerals occur in four associations or facies (Brummer et al., 1981): sulphide facies (bravoite-pyrite, coffinite, pitchblende, Fe-chlorite, illite, siderite and chalcopyrite), arsenide facies (arsenides-illite, coffinite, pitchblende and minor nickeline, gersdorffite, and safflorite), bleached facies (coffinite, arsenides, illite, Mg-chlorite and minor nickeline and gersdorffite), and oxide facies (coffinite, arsenides, illite, Mg-chlorite, hematite and some goethite). The sulphide facies is found only in the sandstone, the arsenide facies in both the sandstone and the basement, and the other two facies mainly in the basement. The bleached and the oxide facies are characterized by the occurrence of clay nodules containing uranium and arsenides scattered in a clay matrix. This nodular rock constitutes the rich ore of the lenses and locally contains pockets of massive pitchblende and coffinite. The above associations or facies suggest that reducing and oxidizing conditions existed at various times during formations of the deposits. Moreover the solutions appear to have been Mg-rich when the oxidizing conditions existed since the chlorite that formed then was Mg-rich whereas the solutions must have been Fe-rich when the conditions were reducing, since the chlorite in the sulphide facies is Fe-rich. Finally there appears that must deformation in the form of expansion, dilatation and collapse took place when the conditons were oxidizing (Brummer et al., 1981). This deformation is represented in the mineralized areas by slickensiding, brecciation and fracturing of the mineralized clay-altered areas. In general the high grade areas are in the intensely clay-altered areas. Uranium metal assays from the North Zone have been reported to average 0.21 per cent and 23.6 per cent over core lengths ranging from 3-21 m (The Northern Minor, Nov. 27, 1979) with a high grade intersection of 23.7 per cent U over 10 m (The Northern Miner, May 8, 1980). One drill core from the South Zone assayed 2.46 per cent U over 6.7 m (The Northern Miner, May 8, 1980).

Reserves of 5385 tonnes of uranium in 354 000 tonnes of rock averaging 1.53 per cent U have been announced for the McClean deposits. (The Northern Miner, Jan. 1, 1981, p. 5).

Key Lake Area

The Key Lake deposits occur in a small area, about 5 km long, at the southeastern edge of the Athabasca Basin (Fig. 1), about 150 km south-southwest of the cluster of eight deposits in the Collins Bay – Michael Lake and Midwest Lake – McClean Lake areas. The Key Lake deposits are similar in many respects to those in the above two areas.

Key Lake Deposits

References:

Dahlkamp, 1978; Dahlkamp and Tan, 1977; Gatzweiler et al., 1979; Kitchner et al., 1979; Ray, 1977; Tan, 1977; Wendt et al., 1978; Saskatchewan Department of Mineral Resources assessment files; Uranerz Exploration & Mining Ltd. and Key Lake Mining Corporation, personal communication, 1979.

The Key Lake deposits are 240 km north of La Ronge (Fig. 1), and 12 km north-northwest of Highrock Lake. The deposits extend in a zone about 4 km long from Key Lake to Seahorse Lake, and the mining camp is on the south end of Key Lake less than one kilometre from the mineralized zone (Fig. 19-21). The camp can be reached by float-equipped aircraft to Boundary Lake or Kapesin Lake from La Ronge or by wheel-equipped aircraft to the company-maintained airstrip 6 km north of Key Lake and thence by 10 km of road to the mining camp. Kapesin Lake is 4 km east of Key Lake (Fig. 19). A winter road connects the camp to the all-weather gravel Saskatchewan Highway 102-105 (between La Ronge and Rabbit Lake) about 95 km to the east. An all-weather gravel road between the camp and Pinhouse Lake, about 225 km to the south-southwest, is under construction and will be completed late in 1981.

The Key Lake deposits fall within a mineral lease and four claim blocks which were part of Permit No. 1 held by Inexco Mining Co. Ltd. In 1978 Inexco sold its share of the

mineral rights and deposits to Saskatchewan Mining Development Corp. and Eldor Resources Limited (wholly owned subsidiary of Eldorado Nuclear Limited). The rights and deposits are presently held by the Saskatchewan Mining Development Corp. (50 per cent), Uranerz Exploration & Mining Ltd. (33 1/3 per cent) and Eldor Resources Limited (16 2/3 per cent). Development of the deposits for production is conducted for the joint venture by Key Lake Mining Corporation. The development permit was obtained in February 1981 and production is scheduled to begin late in 1983 or early 1984 at the rate of about 4000 tonnes uranium per year. Mining will be by open pits and the ratio of waste to ore will be around 35 to 1.

Figure 20. *Aerial view of the Key Lake area, July 1979, looking west along the trend of the ore zones; dewatering of the area was in progress. Key Lake in foreground. (GSC 203712)*

Figure 21. *Core racks at Key Lake, July 1979 (GSC 203712-K)*

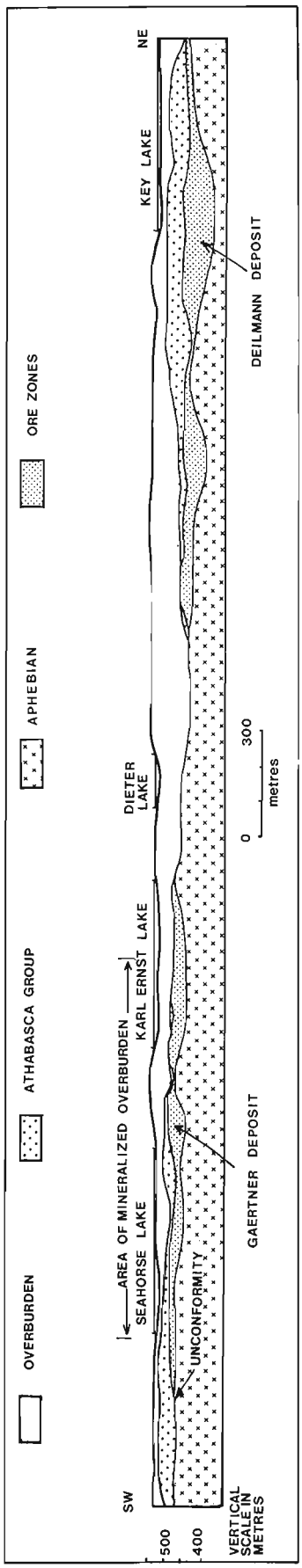

Figure 22. *Geological longitudinal section along the Gaertner and Deilmann deposits in the Key Lake area. The ore zones are elongated parallel to the trend of the section and are both in basement and Athabasca rocks at the unconformity but mainly in basement. Note the thick overburden in the Dieter Lake area above a basement inlier where some of the ore zone has been eroded. (From Key Lake Mining Corporation, 1979 and Dahlkamp and Tan, 1977).*

Exploration in the area begun in 1971 by Inexco has been continued since 1974 by Uranerz. A reconnaissance water radon survey in 1971 produced the first indication of radioactive minerals in the area when a large anomaly was found near Zimmer Lake, 8 km southwest of Key Lake (Fig. 19). Subsequently a train of high-grade mineralized boulders containing pitchblende and nickel minerals (Watkinson et al., 1975) was outlined extending northeast of Zimmer Lake. In 1973 and 1974, a geochemical survey of lake sediment and lake water yielded uranium anomalies in Zimmer and Seahorse lakes (Tan, 1977). Diamond drilling led to the discovery of the Gaertner deposit near Seahorse Lake in July 1975 and the Deilmann deposit near Key Lake in June 1976. By the end of 1979, the two deposits had been outlined, along with a few small satellite parallel mineralized zones and a sheet of mineralized glacial till and esker material above the Gaertner deposit. Glacial overburden near the Gaertner deposit is 10-60 m thick and near the Deilmann deposit 10-85 m thick. The eastern end of the Gaertner deposit subcrops below the overburden and contributed the mineralized boulders to the sheet of mineralized drift. The rolling topography in the area has a relief of less than 75 m. No rock is exposed at the surface.

The deposits occur at and near the unconformity of flat lying Athabasca sandstone on steeply dipping metasedimentary rocks of the Wollaston Lake Belt.

The basement rocks within several kilometres of the deposits comprise belts of Aphebian metasediments and domes and belts of Archean rocks (Fig. 19). The Archean rocks are pink, fine- to medium-grained, massive and gneissic granitic rocks composed mainly of quartz, microcline, oligoclase and reddish biotite (10 per cent). A K-Ar date of 1752 ± 41 Ma (Stevens et al., 1982) was obtained on the biotite, suggestive of involvement in the Hudsonian Orogeny. A Rb-Sr errorchron of 1698 ± 127 Ma (R.D. Stevens, personal communication, 1979) was obtained on seven core samples of the granitic rocks from two diamond-drill holes east of the northeastern end of the Gaertner ore body. For technical reasons only six of the samples were used in the calculation of the errorchron parameters. The age is Hudsonian but an abnormally high initial $^{87}Sr/^{86}Sr$ ratio of 0.824 ± 0.020 is cause to suspect that the rock has a complex history perhaps involving metasomatism, and that it is Archean. The age is unlikely to represent primary intrusion or the original formation of the rock.

The Aphebian metasediments comprise gneiss, schist, amphibolite, calc-silicate, migmatite and pegmatite, all at amphibolite grade. Most common near the deposits are chlorite-sericite schist, graphite-chlorite-sericite schist, biotite-plagioclase-quartz-cordierite gneiss, coarse grained garnet-quartz-feldspar-cordierite gneiss and cataclastic rocks.

Athabasca strata unconformably overlie the basement rocks. They are flat lying, 45 m thick southwest of the Gaertner deposit and 60 m thick beneath Key Lake, but between these two areas pinch out against an inlier of Aphebian metasediments (Fig. 19). The strata are mainly white quartz sandstone, with a conglomeratic base generally less than one metre thick in which the pebbles are as much as 5 cm in diameter. The sandstone consists of up to 99 per cent clear quartz grains, fairly well rounded, with white clay cement (mainly kaolinite, and some sericite and chlorite). Some sandstone approaches a quartzite; it has quartz overgrowths and is more compact than the usual sandstone. Most sandstone is porous. Some is red and dark grey to black. Mineralized sandstone is generally grey to black, and occurs at the unconformity or only a few metres above it.

The unconformity is generally sharp and readily recognized in drill core. Its surface is undulatory (Fig. 22), probably reflecting pre-Athabasca differential erosion of basement rocks and late vertical displacement along faults. Locally at the unconformity, the basement rocks are intensely altered to a white clay, probably an aggregate of kaolinite and possibly some sericite and chlorite, which is commonly believed to be a regolith as in a few places it is overlain by a few metres of red hematitic clay. However, in the areas where the rock is mineralized the alteration zone is light greenish white to light green and extends deeper along assumed faults and shear zones. In general all alteration disappears at depth greater than 35 m below the unconformity. Moreover the alteration is not always maximum at the unconformity for in some drill holes, relatively fresh rocks at the unconformity have alteration beneath them, along probable shear zones. Sandstone above the unconformity is also locally altered. It seems therefore that there are two types of alteration in this deposit: regolithic one with much kaolinite and mainly white and a late hydrothermal one, characterized by the development of abundant chlorite and sericite (locally muscovite) and light greenish white to light green. This late alteration is assumed to be related to the mineralization. A whole-rock sample of schistose and fractured, intensely clay-altered basement rocks within the Gaertner deposit 8 m below the unconformity yielded a K-Ar age of 765 ± 120 Ma (Stevens et al., 1982). The age may be that of an episode of widespread deformation involving in this area reactivation of faults which fractured and displaced the ore zone and developed slickensides along some schistose planes.

The Aphebian metasediments trend about N70°E and generally dip 60 degrees northwest. Gentle open folds trend southwesterly. Longitudinal faults are common near or within schistose graphitic layers, parallel to them; most of the faulting is pre-Athabasca but some faults cut both the Athabasca and basement rocks. A fault within the Gaertner deposit vertically offsets the unconformity as much as 40 m with the southeast side down (Fig. 23a). Faults in the Deilmann deposit apparently have much less vertical displacement (Fig. 23b). Transverse subvertical faults cut the longitudinal faults and are probably younger than the Athabasca strata.

At least 80 per cent of the mineralization is believed to be in altered Aphebian metasediments below the unconformity (Key Lake Mining Corporation, personal communication, 1980). The deposits are related to a major fault or cataclastic zone and its secondary shears, locally known as the Key Lake ore structure, to graphitic metasediments within the structure, and locally to younger schistose zones and minor breccia zones caused by late movements on the fault zone. Athabasca sandstone and the mineralized zones have been cut and offset by these younger structures (Fig. 23). The graphitic metasediments are believed to be the basal units of the Aphebian assemblage. The deposits are not generally within the graphitic rocks but rather are closely associated with them (Fig. 23); the Gaertner deposit (Fig. 23a) is below and southeast of the graphitic rocks whereas the Deilmann (Fig. 23b) is partly below, partly within and partly above and northwest of the graphitic rocks. The deposits are also closely associated with both clay alterations recognized in the area: the early white regolithic and the late light green hydrothermal chloritic sericitic one, but appear to be more specifically related to the late hydrothermal one as there is normally a strong development of chlorite and/or sericite where the ore zones are found. However, both alterations are not always mineralized.

The deposits have been traced by drilling along a strike length of almost 2.7 km (Fig. 19, 22) within a belt 600 m wide. The main deposits are as deep as 150 m; some weakly mineralized subeconomic mineralized pods below the Deilmann deposit are 280 m deep. Small satellite mineralized zones northwest and southeast of the main

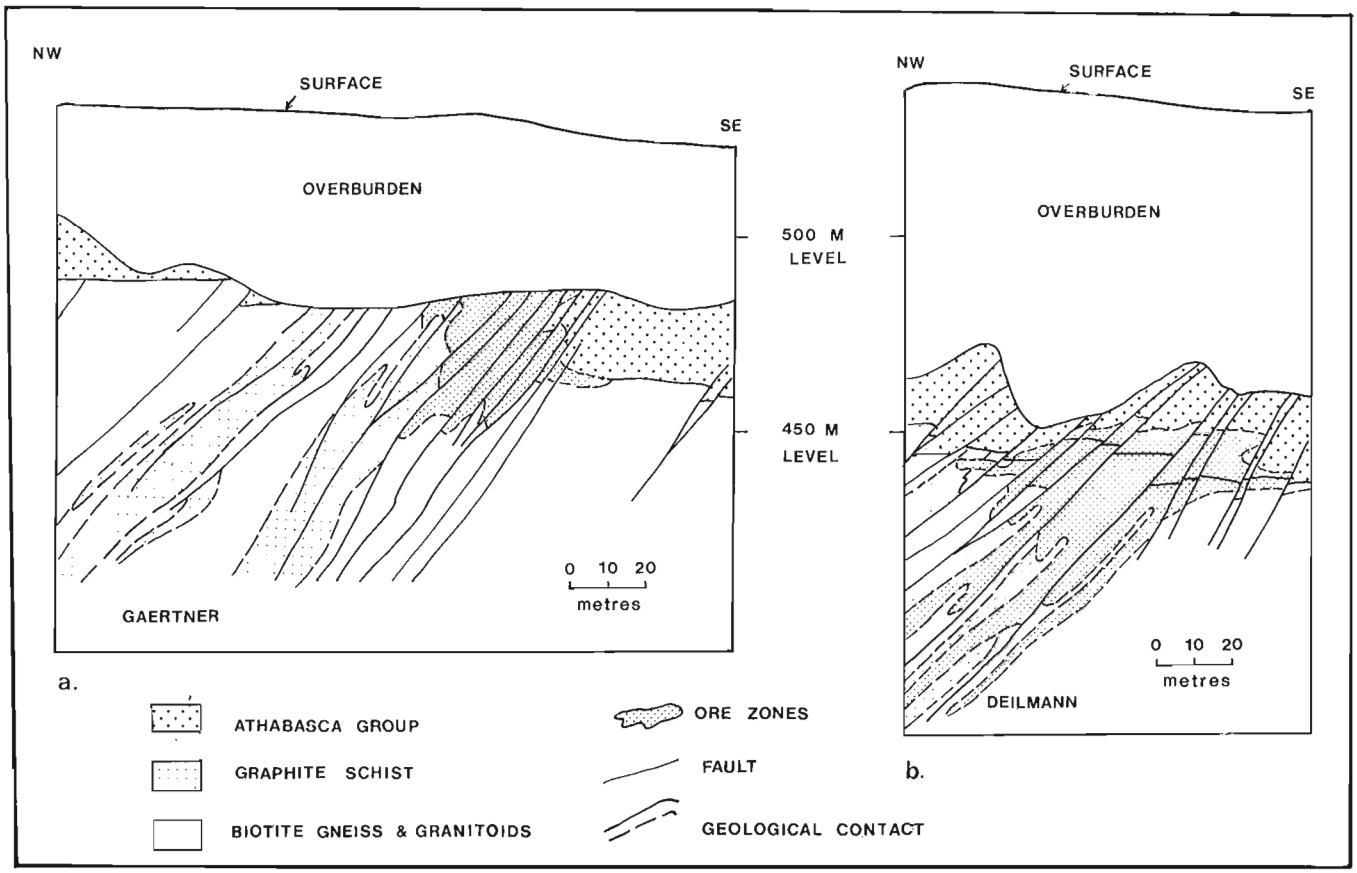

Figure 23. *Geological cross-sections through the ore zones in the Key Lake area: a, through the northeastern end of Gaertner orebody; b, through the southwestern end of Deilmann orebody. Note that the ore zones appear to occupy a zone of faults, and lie close to graphite schist (after Dahlkamp and Tan, 1977 and Gatzweiler et al., 1979).*

Gaertner deposit parallel the main deposit. Some weak subeconomic mineralization has been intersected in drillholes along the trend of the Key Lake ore structure to the southwest and northeast of the main deposits. A sheet of glacial drift "mineralized" with uraniferous boulders covers the northern half of the Gaertner deposit and extends to the southeast in the esker zone area, over an area of several thousand square metres. It varies between 1 m and 12 m in thickness, averages 3 m, and is thickest directly over the Gaertner deposit. Some of it constitutes ore. Locally, particularly in the esker zone, the mineralization appears in several lenses separated by unmineralized drift.

The mineralization is of the vein type. The ore minerals and gangue fill cracks, spaces between host rock minerals and grains, and any openings in the cataclastic rocks. They are also disseminated in the white clay-altered material. The main ore minerals are massive and sooty pitchblende and coffinite (Dahlkamp and Tan, 1977; Gatzweiler et al., 1979). In addition to uranium, these deposits commonly have high nickel and arsenic contents, locally high cobalt and relatively high molybdenum, and trace amounts of gold, silver and platinum (Key Lake Mining Corporation, personal communication, 1980). The main nickel minerals are gersdorffite, millerite and nickeline. Bravoite, rammelsbergite, pyrite, sphalerite, chalcopyrite and galena occur as accessories. The gangue minerals are chlorite, kaolinite, quartz, carbonates, sericite and epidote.

Each deposit has the shape of a flattened horizontal cigar, dipping steeply northwest, in which the downdip dimension (width) exceeds the thickness (perpendicular to downdip dimension). The Gaertner deposit is 1450 m long, 10-40 m thick and, as much as 55 m downdip (average 25 m). The larger Deilmann deposit is 1200 m long and consists of two lenses, each about 600 m long, 10-100 m thick and, in the downdip dimension, less than 80 m but locally 150 m and averaging 40 m. The two lenses are separated by weakly mineralized rock. Grades are very variable throughout the deposits, and are as high as 53.5 per cent U and 50 per cent Ni over one metre in the Gaertner deposit and 58.5 per cent U and 30 per cent Ni over one metre in the Deilmann deposit.

Estimated reserves in the Gaertner deposit are 23 150 tonnes uranium in ore averaging 2.64 per cent U, in the Deilmann deposit 46 470 tonnes uranium in ore averaging 2.19 per cent U and in the overburden 4240 tonnes uranium in ore averaging 0.5 per cent U, for a grand total of 73 860 tonnes uranium in ore averaging 1.925 per cent U (Key Lake Mining Corporation, personal communication, 1980).

The age of mineralization is related to that of the other dated deposits of the basin. Wendt et al. (1978) studied U-Pb ratios from 14 samples of pitchblende from three drillholes in the Key Lake area and concluded, using only six of the samples from two holes, that the main mineralization stage occurred 1270 Ma ago, and was followed by episodes of remobilization at 918, 270 and 100 Ma. Not dissimilar results were reported by Gatzweiler et al. (1979) on thirty-four

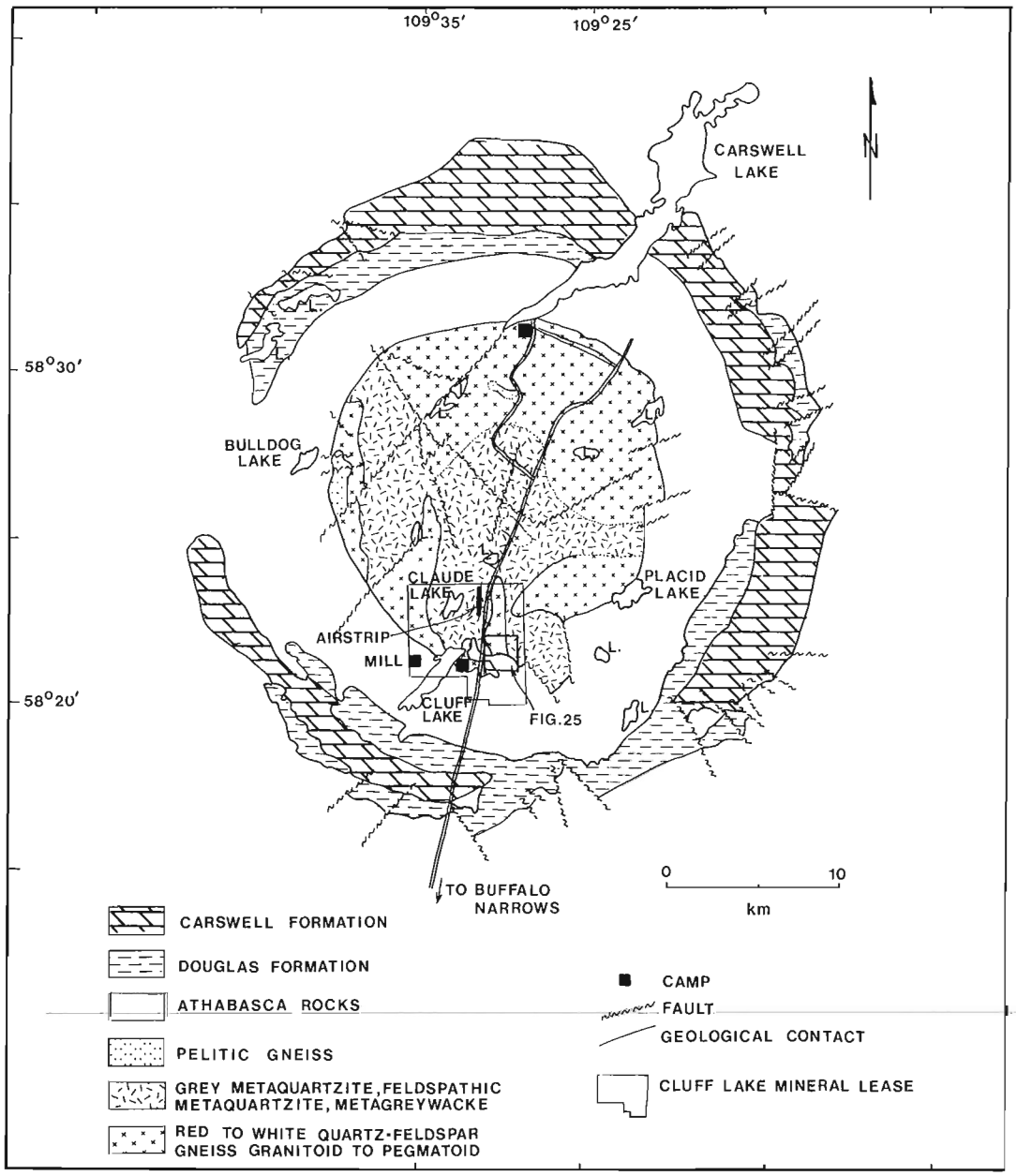

Figure 24. *Geology of the Carswell Circular Structure (compiled from information supplied by Amok Ltd., and after Harper, 1977). The deposits are in the mineral lease area and the camp at the southern end of Carswell Lake is the Amok exploration camp. The Cluff Lake mill is located west of Cluff Lake.*

samples (preliminary results only): they concluded that concentration to ore grades occurred after deposition of Athabasca strata, during Grenvillian Orogeny, and was followed by several episodes of remobilization between 1228 and 89 Ma ago.

Carswell Circular Structure

The Carswell Circular Structure lies within the Athabasca Basin about 90 km east of its western edge. It is 143 km southwest of Uranium City and 30 km east of the Alberta-Saskatchewan boundary (Fig. 1). The geology of the Carswell Structure was briefly described above in the chapter on General Geology. In a few words, the structure comprises a circular core, 18 km in diameter, of mainly granitoids, and of some quartzofeldspathic and pelitic gneiss, that has been uplifted, probably in Paleozoic time, through flat lying Athabasca strata (Fig. 24). Some of the gneisses are possibly Aphebian although most of them are assumed to be Archean. Two rings, 10 km wide, of deformed Athabasca strata surround the core. Faulted and steeply dipping to locally overturned strata characterize the rings. The outer boundary of the rings is a circular fault cut by late radial transverse faults, some of which are major. Athabasca strata outside the structure are flat lying and 1220 m thick in a nearby diamond-drill hole along the eastern edge of the structure (Fig. 2). The Cluff Lake deposits occur within the southern half of the structure and only a few minor uranium showings have been found so far in its northern half, where several widely distributed Th-bearing occurrences are reported (Harper, 1980). The structure is probably of Ordovician age (Currie, 1969).

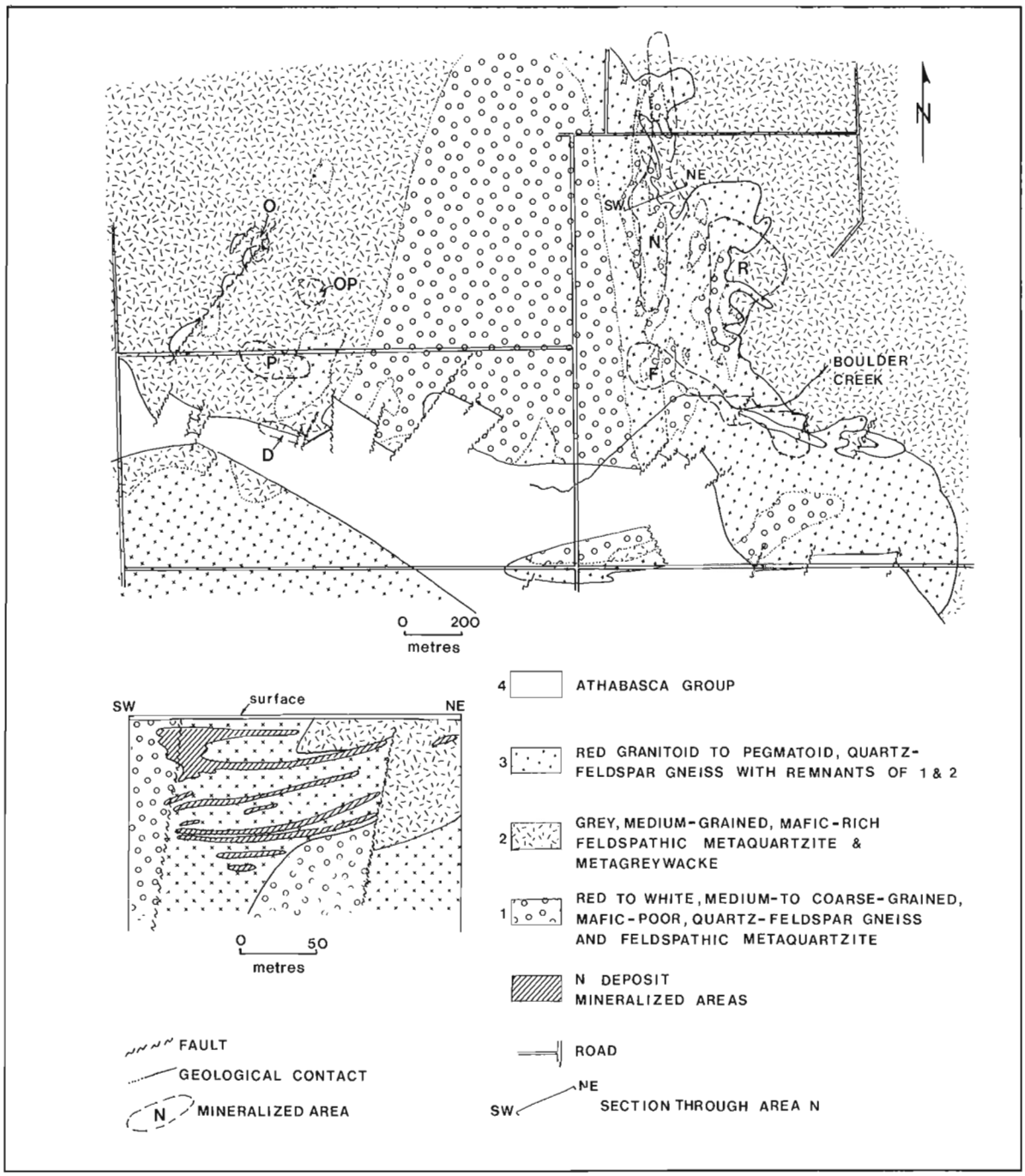

Figure 25. *Geology in the immediate area of D, N, R, F, O, P, and OP deposits northeast of Cluff Lake in the southern half of the Carswell Structure (from information supplied by Amok in 1979, and from Tapaninen, 1975). The deposits are at and near the unconformity and all are in basement rocks except the D deposit which is mainly in Athabasca siltstones. For locations see Figure 24.*

Bedrock exposure represents less than one per cent of the entire Carswell Circular Structure. Overburden is 2-10 m thick in the Cluff Lake area and appears to be thicker elsewhere in the structure. Exploration for uranium in the Carswell Structure outside the area of the Cluff Lake deposits has continued intermittently since 1971, and at present (1980) is being carried on by Amok Ltd. jointly with Numac Oil & Gas Limited, Ontario Hydro, and Saskatchewan Mining Development Corporation.

Cluff Lake Deposits

References:

Currie, 1969; Harper, 1977, 1978a, 1980; Herring, 1976; Tapaninen, 1975, 1976; Amok Ltd., personal communication, 1976 and 1978.

The Cluff Lake deposits are 330 km north of Buffalo Narrows. The all-weather gravel Saskatchewan Highway 155 connects the Cluff Lake camp at the northeast end of Cluff Lake to Buffalo Narrows and Green Lake to the south. The camp can also be reached by wheel-equipped aircraft to the

company maintained airstrip, 4 km north of the camp by road and 1 km east of Claude Lake (Fig. 24), or by float-equipped aircraft to Cluff Lake.

The known significant deposits are contained in the Cluff Lake mineral lease and are owned by Cluff Lake Mining Limited, a partnership of Amok Ltd. (80 per cent) and Saskatchewan Mining Development Corporation (20 per cent). Exploitation started in the summer of 1980 and early in 1981 attained the expected annual rate of 1550 tonnes of uranium.

The Carswell Structure was first explored by Mokta (Canada) Ltd. (now Amok Ltd.) in 1967 by an airborne radiometric survey (Amok Ltd., personal communication, 1976). Follow up ground investigations of the resulting weak anomalies in 1968 located pitchblende-bearing boulders west of the northern end of Cluff Lake. These boulders were distributed in a northeast-trending train parallel to probably the latest ice direction, and trenching and drilling at the apex of the train in 1969 intersected high grade mineralization. This was the discovery of the D deposit. Further trenching and closely spaced drilling between 1970 and 1976 (Amok Ltd., personal communication, 1976) to the north and east of the D deposit intersected and delineated the Claude, N, R, F, O, P and OP deposits and several smaller deposits and promising occurrences (Fig. 25). All these mineralized zones, including the D deposit, are within 4 km of the northeastern end of Cluff Lake. By 1980 about 3050 drillholes representing about 232 000 m of drilling had been put down to an average depth of 76 m (Amok Ltd., personal communication, 1979). Near the deposits, holes were drilled every 20 and/or 40 m along lines spaced 40 m apart. Exploration in the Cluff Lake area is continuing. A new deposit, Peter River, was discovered in 1981. It is south of Claude about half way between Claude and the northern end of Cluff Lake. Mineralization is in basement and of the vein-type.

The deposits are within the gneissic core of the Carswell Structure, near the southern contact of the core with the overlying Athabasca strata. More specifically, all but one deposit occur in the gneiss either close to the trace (subtrace) of the unconformity or where the Athabasca strata have been removed by erosion, close beneath the projected unconformity. The D deposit is partly in basement and partly in basal Athabasca rocks. Near the deposits, the basement rocks consist of much altered granites and gneisses. The gneisses are of three types: quartzofeldspathic, pelitic (bearing assemblages of garnet, cordierite, and sillimanite) and mafic, all derived from sediments, metamorphosed to the amphibolite and granulite facies, and extensively granitized and then considerably retrograded. Locally, the paragneisses contain a few beds of metamorphosed iron formation. The granites are red, coarse grained and generally have much microcline. The Athabasca succession near the deposits mainly comprises a few metres of conglomerate overlain by mature white sandstone with a white clay cement and much of it is white clay altered. Locally, some of the sandstone is dirty grey and resembles greywacke. Also here and there the succession is mainly multicoloured shales and siltstones resting directly upon the gneissic basement. This succession varies from red, white, buff, grey, and black to grey, black and dark green and is overlain by the white to buff sandstones. Gabbro dykes cut the flat lying sandstone south and outside of the Carswell Structure. They suggest that there existed igneous activities in the area after the deposition of the Athabasca rocks. They were probably associated with a thermal event affecting the whole Athabasca Basin and they have helped to make the uranium mobile. One of these dykes trends west-northwest, was not involved in the Ordovician Carswell Structure but is somewhat altered to chlorite. Although it has yielded a K-Ar whole-rock age of 949 ± 33 Ma (Wanless et al., 1979, p. 48) it probably belongs to the Mackenzie dyke swarm believed to have been intruded about 1200 Ma ago (Fahrig and Jones, 1969).

Some of the contacts between Athabasca rocks and basement gneisses are faulted but most are stratigraphic, even if locally the succession is overturned. Generally a stratigraphic contact has, on the basement side, a few metres of regolithic material, that is red to mauve and buff at the contact becoming white and green with depth. In most instances the colouring of this zone is very complex, possibly in part because of superimposed hydrothermal alteration. In addition, near the deposits the gneisses, granites and Athabasca strata are intensely and extensively altered to a light greenish-white illitic clay. In general this alteration is most intense in a narrow zone at the unconformity and along faults and shears related to the unconformity. It is also particularly pronounced in the coarse grained quartzo-feldspathic rocks of the gneissic core and in the multicoloured Athabasca sandstone and siltstone in the vicinity of the D ore body. This alteration is regarded as a later hydrothermal effect related to the uranium mineralization.

The gneisses and granites of the core are severely sheared, faulted and fractured and many of the sheared zones are possibly old mylonite zones. The Athabasca strata are also fractured and faulted particularly near the Carswell Structure core. Locally, basement rocks have been thrust, along fairly steeply dipping planes, upon fractured Athabasca strata. Radial faults especially those along the outer rim of the structure show well on air photographs; some may be old faults reactivated during the development of the Carswell Structure. Much of the Cluff Breccia and other features believed related to meteoritic impact are spatially related to some of these faults.

Mineralization in the Athabasca strata occurs as thorium-rich detrital grains in the matrix of the basal conglomerate (Herring, 1976), as rich high grade uranium-bearing zones in the carbonaceous argillite and siltstone of the multicoloured section that locally forms the base of the Athabasca succession, and locally as disseminations in the matrix of the grey to black sandstone.

Uranium mineralization in the basement rocks is richest in white clay-alteration zones along the faults and within feldspar-rich rocks at the unconformity. In detail, the deposits are of the vein type. Ore minerals coat fractures and form stringers as well as being disseminated in the altered rocks near mineralized fractures. The main ore minerals are uraninite, pitchblende, coffinite and thucholite. Finely disseminated hydrocarbon invariably accompanies the ore minerals. U-Pb and Pb-Pb isotopic studies on country rocks in the vicinity of the deposits (Gancarz, 1979) have indicated that mineralization occurred in two episodes, 1050 and 800 Ma ago with remobilization later than 234 Ma. However, alteration studies suggest that the original mineralization took place around 1200 Ma ago.

The deposits are of two types based on the assemblage of ore minerals. Those with a simple mineralogy mainly contain only uranium minerals and grade about 0.4 per cent U. Other ore elements present occur in traces or small amounts. These deposits occur entirely within basement rocks and are represented by the Claude, N, R, F, O, P and OP deposits (Fig. 25). The Peter River deposit belongs to this group. Those with a complex mineralogy contain in addition to uranium many other elements such as gold, selenium, tellurium, sulfur, lead, nickel, bismuth, copper and cobalt. These deposits are commonly of high grade and may carry a large quantity of one or two of the other elements. These appear to occur mainly in the Athabasca strata at or just above the unconformity. The D deposit represents this second type.

The D deposit is 900 m east of the northeast end of Cluff Lake (Fig. 26). It occurs in dark grey to black, thinly bedded carbonaceous argillite. This is assumed to be the base of the Athabasca succession and to rest unconformably directly upon white to red-altered, fine- to medium-grained, graphite-garnet feldspathic metaquartzite. The contact is steeply dipping, overturned and faulted, and basement rocks structurally overlie Athabasca strata (Fig. 27). The grey to black argillite is interbedded with a few thin beds of sandstone some of which are now hard, black orthoquartzite, and passes laterally through a white to light green alteration zone into a thinly bedded multicoloured siltstone and shale succession. Locally within the deposit, the grey to black argillite is altered to a sheared dark green chloritic rock which has yielded a K-Ar whole-rock age of 1128 ± 450 Ma (Wanless et al., 1979, p. 48), possibly representing the age of the chloritization. The excessively wide error limit reflects the very low potassium content of the rock (0.013 per cent), and severely limits the interpretative value of the age. This sheared chloritic rock is also altered to illitic white clay. The main ore minerals are pitchblende and uraninite, locally with thucholite. Coffinite has also been reported and there are abundant possibly radioactive hydrocarbon globules. The most abundant accessory minerals are native gold, gold tellurides, native selenium, selenides of lead, bismuth, nickel and cobalt, galena, chalcopyrite, pyrrhotite and pyrite; clausthalite and pararammelsbergite are less abundant (Harper, 1978a; Tapaninen, 1975). The ore minerals are generally fine grained and intimately mixed. According to Ruzicka (1975), based on an internal report by S. Kaiman, uraninite is paragenetically the oldest, thucolite the youngest, and pitchblende, the most abundant ore mineral, of intermediate age. The hydrocarbon is regarded by the writer as being a very late introduction. Pitchblende from the D deposit has yielded a

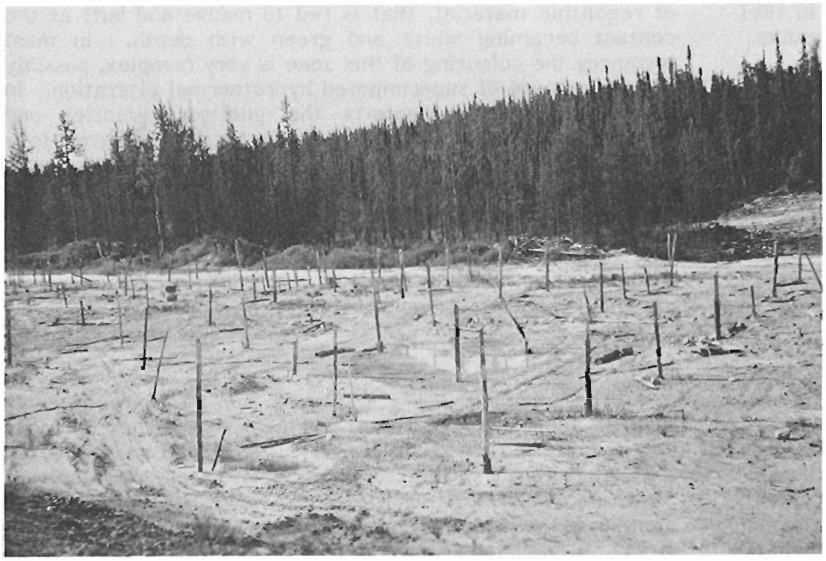

Figure 26. *Looking west along the D orebody at Cluff Lake. The area is somewhat hummocky. The vertical pickets mark the closely spaced (5 m) drilling. July 1976 (GSC 203712-G).*

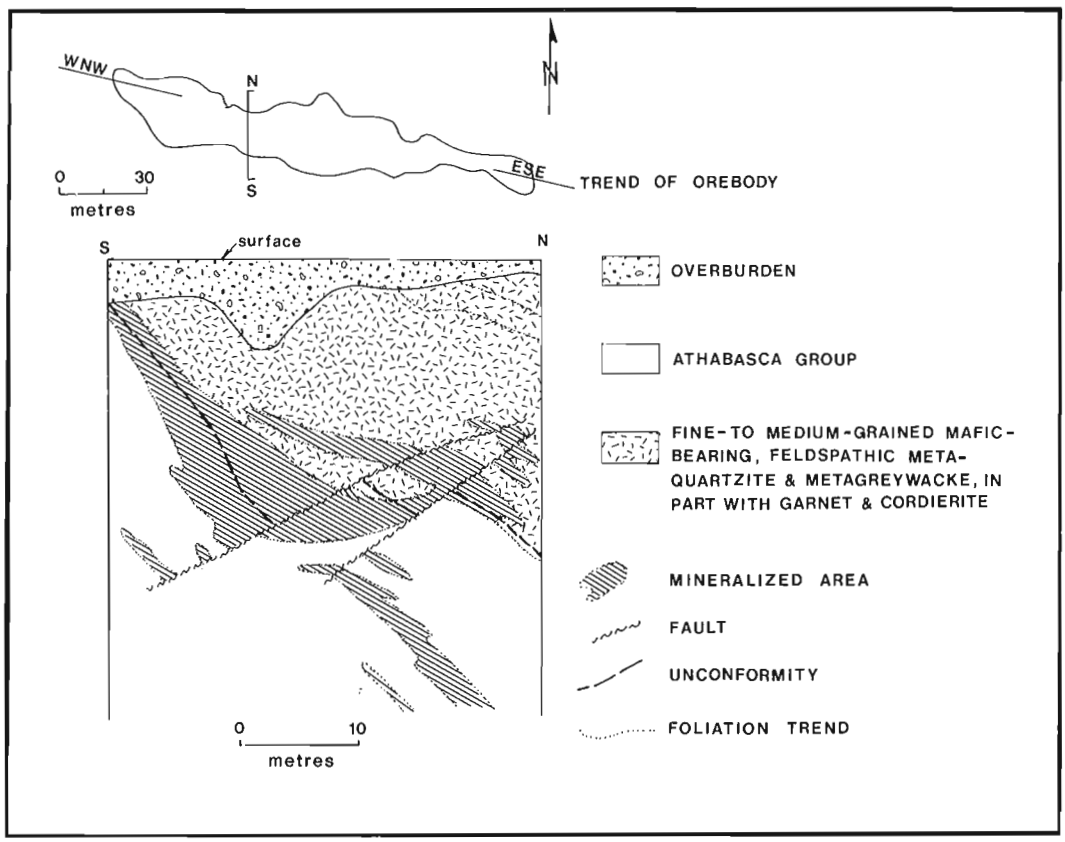

Figure 27. *D deposit, Cluff Lake. Outline of the D deposit (personal information from Amok Ltd., 1976). See Figure 25 for location. The trend, length and width of the mineralized areas in section were drawn by the author from Tapaninen (1975). Not all parts of the mineralized areas are of ore grade.*

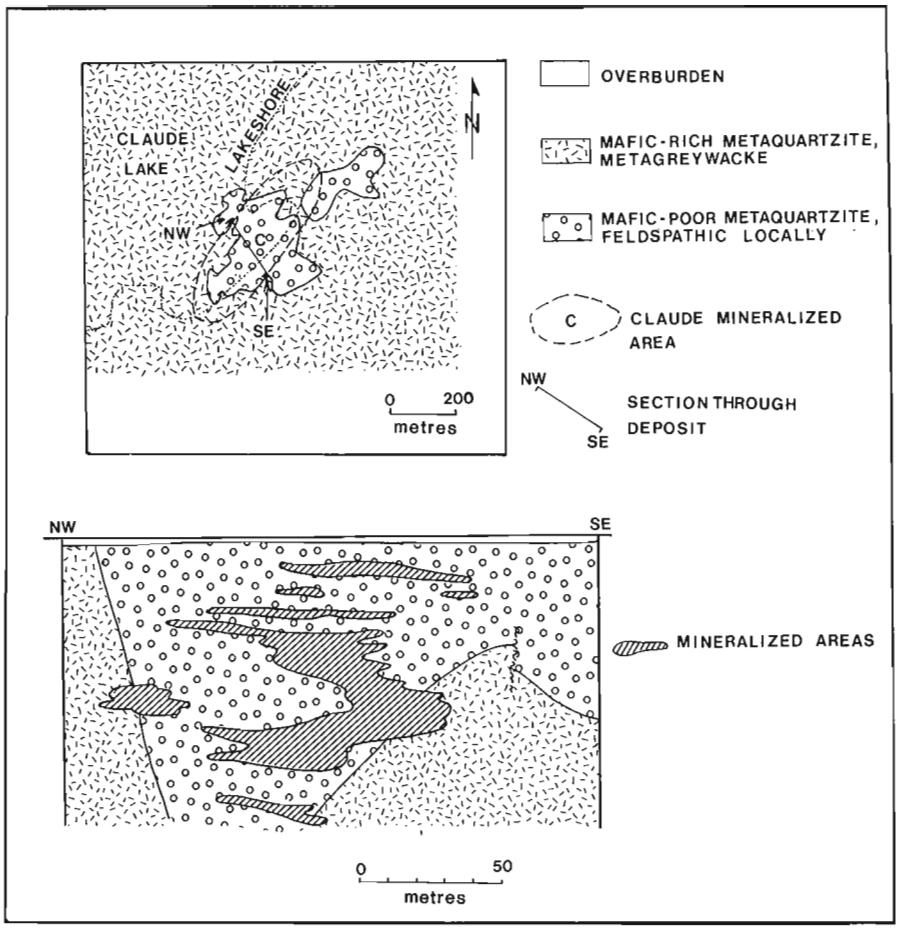

Figure 28. *Claude deposit, Cluff Lake. Outline of the deposit in plan is diagrammatic. See Figure 24 for location of deposit. The mineralization shows a relation to the areas of mafic-poor feldspathic metaquartzite. The shape, length and width of the mineralized areas in section were drawn by the author from Tapaninen (1975). Not all parts of the mineralized areas are of ore grade. Claude Lake was partly drained in 1973; the lake shore shown above is that before 1973.*

U-Pb age of 1100 Ma (Tapaninen, 1975). Most of the high grade mineralization is in the black to dark green white illitic clay altered sheared argillite and interbedded sandstone. There is also mineralization along some of the fractures and faults in basement metaquartzites structurally overlying the argillite (Fig. 27). The D deposit has the overall shape of a slightly flattened cigar which trends west-northwest, plunges about 10 degrees in that direction, and dips from 30 to 40 degrees to the north-northeast. It is 140 m long, 12 m wide and 12 m thick. It occurs between the base of the overburden and 27 m below surface; and it contains 123 000 tonnes of ore with an average grade of 4.25 per cent U for a total of 5211 tonnes of contained uranium (Bayda, 1978). Local very rich pods within the ore zone grade as much as 24.85 per cent U (Harper, 1978a). Mining of the D ore body started in the summer of 1980 and was completed by late 1981. Mining was by open pit.

All the other known deposits, the Claude, the NRF group and the OP group (Fig. 25) have almost nothing but pitchblende and coffinite as ore minerals. All are spatially related to planar shears in light coloured medium- to coarse-grained feldspathic metaquartzite. The sheared basement rocks were converted to a light greenish white clay mass. The sheared zones are almost flat lying or slope gently north passing at the edges of the mineralized zone into north-northeast-trending, steeply west-dipping faults. The intersection of these two fault systems locally gives rise to broader ore zones (Fig. 25). All these deposits, the Claude and the NRF and OP groups, are found within large low grade northerly trending mineralized areas assumed to be parallel to the major radial faults. All deposits dip gently west. All have a uranium content that increases with depth to a maximum between 25 and 40 m below surface, and then decreases gradually to a minimum at a depth of about 90 m (Amok Ltd., personal communication, 1978). It is not known whether the grade below 90 m increases again with depth in a repetitive pattern every 100 m or so as the ore zones at Beaverlodge do every 150-275 m (Eldorado Nuclear Limited, personal communication). These Cluff Lake deposits all have some graphite, hydrocarbon and accessory pyrite, marcasite, chalcopyrite, and galena, and rare uranophane. Kasolite and wulfenite were also identified by Rimsaite (1977b) who noted that the presence of these secondary lead-uranium and lead minerals suggests that very little uranium has been removed from the oxidation zone. Coffinite is generally finely distributed in the white clay-altered masses whereas the pitchblende occurs as fracture-filling and in nodules generally less than 12 cm across closely related to quartz grains. Jordesite and ilsemannite have been reported by Harper (1980) from the N deposit.

The Claude deposit is beneath the east shore of Claude Lake, and 1.9 km north of the northeast end of Cluff Lake (Fig. 24 and 28). A remnant of Athabasca rocks outcrops less than one kilometre southeast of Claude Lake. Mineralized bedrock was observed in an excavation on the east shore of Claude Lake, but there are no other mineralized outcrops in the area of the deposit. The deposit was discovered in 1971 and was outlined by drilling in 1972 with holes on a grid spaced every 20 m. Holes were drilled to a depth between 100 and 200 m. The deposit was investigated by a decline, drifts and crosscuts, 1800 m long, to the 50-ft level in 1980. It is expected that it will be mined by open pit, starting possibly in 1983.

The rock succession near the Claude deposit comprises two rock units; a grey to white, fine- to medium-grained, mafic-low feldspathic metaquartzite and a mottled, well layered, coarse grained, mafic-rich garnetiferous quartz-feldspar gneiss, the more common of the two. Each unit has a few interlayers of the other. The mafic-poor metaquartzite occurs as a lens, 1000 m long and 100 m wide, along the east shore of Claude Lake and the deposit is almost entirely in this lens. The lens trends northeast, appears to be gently folded and in the deposit area varies in thickness between 40 and 100 m and overlies mafic-rich quartz-feldspar gneiss (Fig. 28). In detail the rocks are intensely folded, fractured and faulted. Folds trend northeast and northwest. The fractures and faults trend north, north-northeast and east, and are closely spaced. The north- and north-northeast-trending faults are tight fractures, dip steeply west and define the limits of the deposit. The east-trending faults are subhorizontal planar shears that dip gently

north; they divide the Claude deposit into subhorizontal panels, and include much unaltered Cluff breccia. The planar shears are zones of intense white clay alteration and are regarded as old mylonite zones. The mineralization occurs in pods rich in organic matter and as disseminations in the clay masses within the shears. The high grade zones contain pitchblende and uraninite but the most common uranium minerals are coffinite, uranophane and other secondary uranium minerals. Graphite, pyrite, galena and molybdenite are also present. The Claude deposit is 365 m long, 140 m wide and 90 m thick and occurs within the mineralized area of Figure 28. It is elongated parallel to the trend of the lens of mafic-poor feldspar metaquartzite. Reserves of 4800 tonnes of uranium in rock with an average grade of 0.5 per cent U have been reported from the Claude deposit (Harper, 1978a).

The NRF group of deposits comprises at least five separate mineralized zones located 2.5 km east of the northeast end of Cluff Lake (Fig. 25). The N zone is the largest of the group and the F comprises three small areas. They were outlined between 1970 and 1973 by drilling every 20 m along lines spaced 25 and 50 m apart. All these mineralized zones are in basement rocks. They lie within a large low grade north trending mineralized area 1500 m long and 600 m wide, beginning about 200 m north of Athabasca rocks near the southern contact of the basement core in the Boulder Creek area.

The area was first explored in 1969 by trenching the overburden, locally to bedrock. Pitchblende-bearing boulders were found and pitchblende with organic material was observed in outcrops (Amok Ltd., personal communication, 1978). Subsequently about 700 holes were drilled to explore the mineralization and outline and evaluate these deposits.

The NRF group of deposits is located along a contact zone between fine- to medium-grained, mafic-rich granoblastic quartz-feldspar gneiss, to the east, and medium- to coarse-grained, mafic-poor feldspathic metaquartzite and coarse grained granitoid rocks, to the west (Fig. 25). The contact is very irregular, trends generally north-northwest, dips steeply west and consists of a zone of mixed rocks including those above plus some chloritized quartz-feldspar gneiss or amphibolite and metapelite. The mineralization is concentrated within the contact zone where the rocks are intensely faulted, fractured and intensely white clay-altered. As in the Claude deposit, two systems of faults and fractures trending north and north-northeast, with steep west dips and a system of subhorizontal planar shears trending east and dipping gently north were recognized. The shears are regarded as intensely white clay-altered old mylonite zones. The mineralization is within these clay zones in pods of massive and nodular pitchblende, as disseminations of pitchblende and coffinite and as pitchblende and organic matter filling fractures. Graphite is common with the mineralization. Accessory minerals include pyrite, marcasite, chalcopyrite, galena and locally some native gold. Uraninite was reported from one of the holes. Where the planar shears intersect steeply dipping faults, the mineralized zones are larger and their grade higher (Amok Ltd., personal communication, 1978). The N zone is 1200 m long in a north direction, 250 m wide and 100 m thick. The R zone is 600 m long in a north direction, 250 m wide and 100 m thick. The NRF zones have calculated reserves of 5000 tonnes of uranium in rock with an average grade of 0.35 per cent U (Harper, 1978a).

The OP group of deposits includes the O, P and OP zones and is within a mineralized area 500 m long north-south and 250 m wide east-west, beginning about 200 m north of the D deposit (Fig. 25) or one kilometre northeast of the northeast end of Cluff Lake. Three separate zones were outlined to a depth of 100 m in this low grade mineralized area. Their reserves have been calculated at 1800 tonnes uranium in rock with an average grade of 0.65 per cent U (Harper, 1978a). About 350 holes were drilled to assess this area. The zones occur in well layered fine- to medium-grained, mafic-rich quartz-feldspar gneiss containing variably sized bodies of mafic-poor coarse grained feldspathic metaquartzite. Most of the mineralization is associated with the feldspathic metaquartzite. In general the rocks are much altered to light greenish white clay. The mineralization is also of the fracture filling type. In 1981 a decline and several drifts and crosscuts, 1500 m long, were done to evaluate the deposits at a 50 m depth.

In summary, about 2 788 500 tonnes of ore have been outlined from the mineralized zones of the Cluff Lake area (Harper, 1978a).

Maurice Bay Area

The Maurice Bay area is on the northwestern rim of the Athabasca Basin (Fig. 1) some 380 km from the Collins Bay-Michael Lake area, and serves to emphasize how widespread uranium deposits related to unconformity are within the basin area.

Maurice Bay Deposit

References:

Harper, 1978b, 1979; Lehnert-Thiel and Kretschmar, 1979a, b; Mellinger, 1979, 1980; Uranerz Exploration & Mining Ltd., personal communication, 1978; Lehnert-Thiel et al., 1981.

The Maurice Bay deposit is near the northwestern shore of Lake Athabasca, 77 km west-southwest of Uranium City (Fig. 1). The deposit is 3 km west of the lakeshore and 5 km east of the Saskatchewan-Alberta boundary (Fig. 29). The exploration camp is on the south side of Maurice Bay and is normally reached by float-equipped aircraft from Uranium City. There is no road to the property. The deposit is jointly owned by Saskatchewan Mining Development Corp. (50 per cent), Uranerz Exploration & Mining Ltd. (25 per cent) and Eldor Resources Limited (25 per cent). Uranerz is the field operator.

Exploration for uranium by Uranerz Exploration & Mining Ltd. during 1974 and 1975 in Athabasca strata west of Lake Athabasca in Saskatchewan and Alberta resulted in the discovery of several radioactive boulders, some of which were found to contain pitchblende. In 1977 the probable apex of a major radioactive boulder train slightly north of Griffiths Creek in Saskatchewan was drilled and high grade mineralization was encountered in what is now called the Maurice Bay deposit Main Zone. This was the discovery of the Maurice Bay deposit. Drilling continued during 1977-79 when about 1000 holes were put down to an average depth of about 100 m. Exploration is still continuing. The Maurice Bay deposit as now known comprises three mineralized zones: the Main Zone which includes the discovery deposit, the A Zone and the B Zone as well as some mineralized drill intersections outside these zones. The three zones were drilled every 10 or 20 m along lines spaced 25 m apart. At time of writing (1981), the grade and tonnage are still insufficient to warrant production.

The deposit underlies a lowland of muskeg and peat bog (Fig. 30) a short distance from Lake Athabasca, and bedrock exposures are sparse to lacking. Overburden of clay and glacial drift is about 20 m thick. A trench excavated to bedrock southwest of the deposit near the position of the unconformity trace on surface has exposed a mineralized fracture in both basement and Athabasca sandstone. The mineralization probably subcrops at the west end of the Main Zone where a small inlier of basement rocks surrounded by

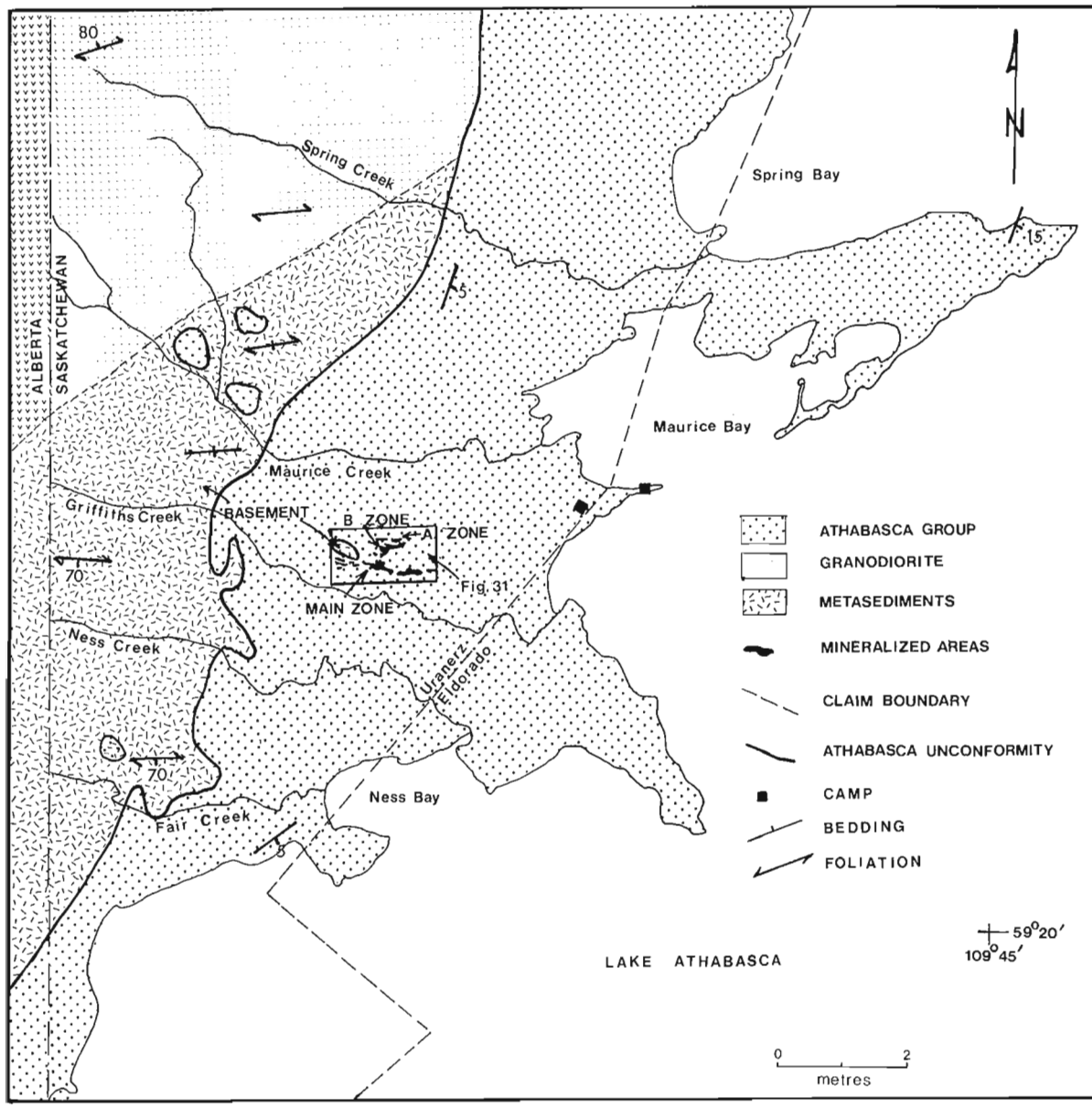

Figure 29 *(above). Geology of the Maurice Bay area (after Harper, 1978b and Uranerz Exploration & Mining Ltd., personal communication, 1978). Note the inlier of basement rocks at the western end of the Main Zone and the southeasterly trend of the Main Zone parallel to the length of the inlier.*

Figure 30

Looking southwest across the eastern end of the Maurice Bay deposit, June 1978. (GSC 203712-J)

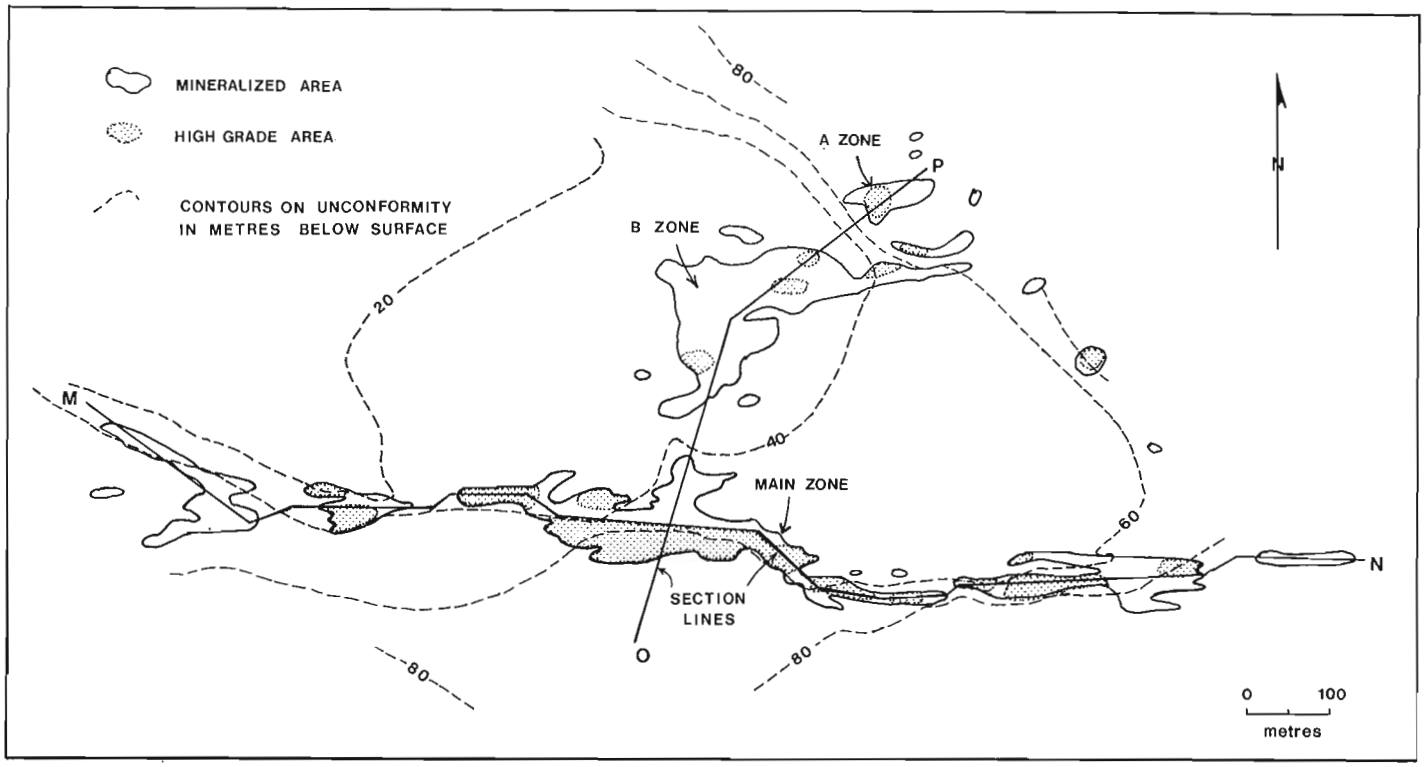

Figure 31. Map of the mineralized zones, the Main, B and A zones in the Maurice Bay deposit. Not all zones are of ore grade. The Main Zone was the first zone to be discovered in the Maurice Bay area and is the most important (from Uranerz Exploration & Mining Ltd., personal communication, 1978, and after Lehnert-Thiel and Kretschmar, 1979a, b). See Figure 29 for location.

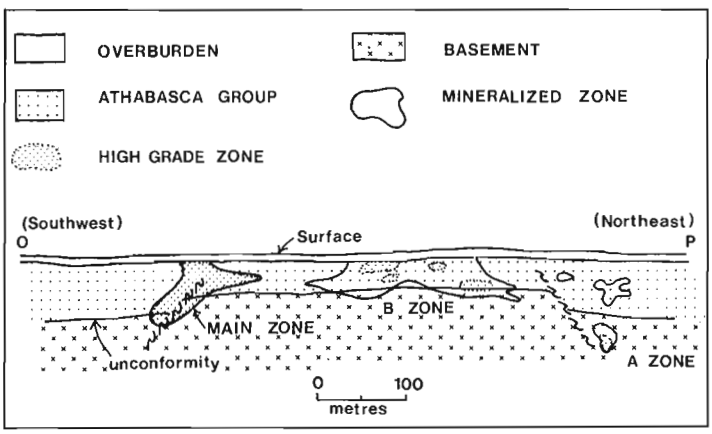

Figure 32. Cross-section of the Main, B and A zones of the Maurice Bay deposit along line OP of Figure 31. The Main Zone contains the highest tonnage and grade (from Uranerz Exploration & Mining Ltd., personal information 1978-79, and after Lehnert-Thiel and Kretschmar, 1979a, b, and Harper, 1979).

Athabasca rocks has been outlined by drilling (Fig. 29), and this mineralization was probably the source of the radioactive boulders near Griffiths Creek.

Uranium mineralization with very little or no white clay alteration occurs within the Athabasca sandstone along and above the unconformity and within the basement rocks, especially along and near faults. The basement rocks are probably of Archean age with locally possibly some of Aphebian age, all deformed and metamorphosed during the Hudsonian Orogeny. They are now mainly granitized metasediments and coarse grained gneisses, some with a little graphite, and are regarded as forming the western extension of the Tazin Belt north of Lake Athabasca. The deposit is within the Athabasca Basin, less than 3 km east of its western edge. The Athabasca rocks near the deposit are flat lying or dip a few degrees southeast and vary in thickness from zero at the basement inlier in the west to more than 60 m in the east. Basal conglomerate as much as 4 m thick is overlain by a few metres of thinly interbedded multicoloured sandstone and siltstone – red, buff, grey, dark grey, black and green (rare) – which in turn is sharply overlain by mainly white quartz sandstone with a white clay cement. Most mineralization in the Athabasca strata is within the multicoloured sandstone and siltstone.

In the deposit area the unconformity at the base of the Athabasca strata is sharp with generally little associated white clay alteration, which is generally so abundant in the area of the deposits south of the Lake. However it is common to observe here slight induration and silicification of the overlying sandstones and intense red to light green coloration in the basement rocks. Some of these silicified sandstones are hard and black and resemble the orthoquartzite of the Stewart Island deposit. Generally the red colour of the basement rocks gradually passes downward into a light green alteration which becomes less evident farther downward until it disappears into chloritic (retrogressed) basement rocks. This downward change from red to light green alteration is assumed to be regolithic, and is superimposed on the older dark green chloritic retrogressed alteration. The white clay alteration noted only rarely here, and believed to be related to the mineralization in the deposits south of the lake, is also here younger than all the

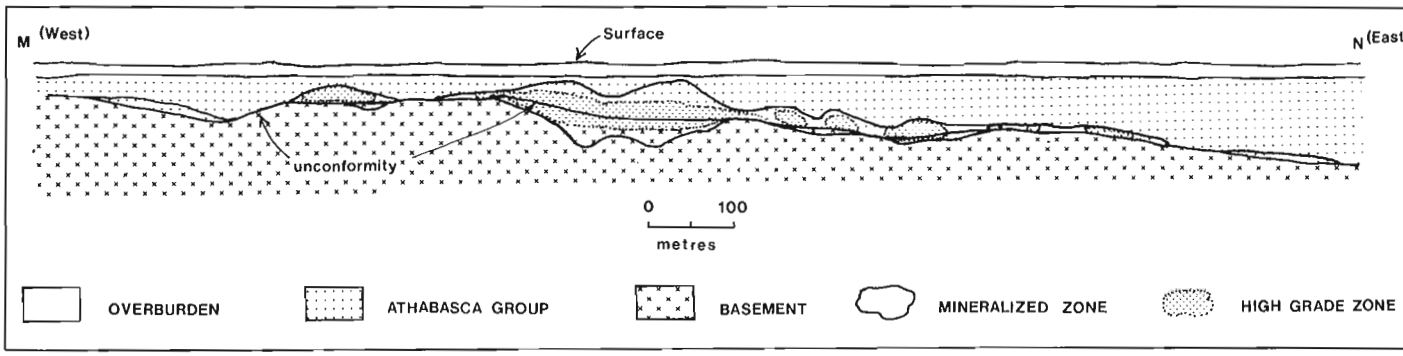

Figure 33. *Longitudinal section of the Main Zone of the Maurice Bay deposit along line MN of Figure 31 (from Uranerz Exploration & Mining Ltd., personal communication, 1978, and after Lehnert-Thiel and Kretschmar, 1979a, b). The rich core is in the thickest section of the zone.*

other alterations. A sample of a somewhat white clay-altered basement rock from the Main Zone yielded a whole-rock age of 1541 ± 40 Ma by the K-Ar method (Stevens et al., 1982). The age appears to reflect the time of weathering of the basement before burial by Athabasca sediments, i.e. to date the time of the regolithic alteration and not that of the white clay alteration related to the mineralization.

The unconformity surface dips gently southeasterly, basinward, and is characterized by domelike highs and ridges separated by valleys, the lows, which trend southeast (Fig. 31). The flanks of a typical high slope 45 degrees to the southwest and to the northeast. Relief is as much as 50 m. The pattern resembles a block faulted terrane and/or stream-channelled region in which the streams may have been controlled by pre-Athabasca faults. One high is marked by the inlier near the west end of the Main Zone (Fig. 29, 32), and possibly another one (not shown on Figure 31) lies 550 m to the northeast of the Main Zone (Uranerz Exploration & Mining Ltd., personal communication, 1978).

Sooty to hard lustrous pitchblende is the main ore mineral, along with minor secondary uranium oxides. Other minerals are hematite, quartz, sericite, pyrite and chlorite. Pitchblende fills fractures, is disseminated within the matrix of the sandstone and siltstone and within basement rocks, and occurs as aggregates or pods within these rocks. Where these rocks are mineralized, particularly the basement rocks, they are often slightly white clay altered. Mineralized sandstones and siltstones are generally dark grey to black, green and dark red and some are silicified, well indurated, and resemble the black orthoquartzite of the Stewart Island deposit. In general hematite is a common associate of pitchblende. The deposit is considered monomineralic (Lehnert-Thiel et al., 1981).

The mineralization is thought to be related to the presumed faults that bound the basement highs and cut the sandstone cover, and to the unconformity and related secondary fractures.

The Main Zone is on the south flank of an east trending basement high. The less significant A and B zones (Fig. 31) may be the northward extension of the Main Zone. The rich core of the Main Zone is usually referred to as the Maurice Bay deposit, whose reserves as quoted in Table 1, are 577 tonnes uranium in rock with an average grade of less than 0.42 per cent U (Lehnert-Thiel and Kretschmar, 1979b). The Main Zone has been traced for 1500 m in an east-west direction; its width varies irregularly from zero to 100 m and its thickness from zero to 35 m (Fig. 32, 33). The rich core is 300 m long, 45 m wide and 10 m thick. The rest of the Main Zone is thinner (average 4 m), generally of lower grade and the mineralization is discontinuous and erratic. About 80 per cent of the mineralization in this zone is in sandstone (Uranerz Exploration & Mining Ltd., personal communication, 1978). The zone trends and plunges about 5 degrees south-easterly parallel to the unconformity (Fig. 31). Its dip, however, is 45° south. The B Zone, north of the Main Zone, lies across the top of the ridge (the high on the unconformity). The mineralization there is almost entirely in the Athabasca rocks (Fig. 32). The A zone lies on the north flank of the high, a few metres deeper than the Main Zone. Unlike the Main and B zones, the A Zone is entirely in the basement. It is along a fault within strongly silicified and mylonitized granitic rock that resembles certain host rocks also much silicified and mylonitized at the Eldorado Fay-Ace-Verna mine at Beaverlodge, Saskatchewan (Tremblay, 1972). These similarities suggests that this mineralization (A Zone) may represent a much older mineralization than that of the other two zones. The mineralization in the A and B zones is in general discontinuous, erratic and of low grade, although some high grade intersections have been reported (Harper, 1979, p. 104), e.g. 2.5 per cent U over 13 m in the A Zone and 0.42 per cent U over 7 m in the B Zone.

Northern Rim of Athabasca Basin

Along the northern rim of the Athabasca Basin between Maurice Bay on Lake Athabasca and Black Lake east of Lake Athabasca, a distance of 246 km, are two widely separated small uranium deposits (Fig. 1, 2). These are the Stewart Island and Fond-du-Lac deposits. They differ significantly from other uranium deposits in the Athabasca Basin in that they are entirely or almost entirely in Athabasca sandstones, now in part a dark red to black orthoquartzite, at some distance above the sub-Athabasca unconformity.

Stewart Island Deposit

References:

Beck, 1969; assessment files of Saskatchewan Department of Mineral Resources; Anonymous, 1981.

Stewart Island is one of several islands in the northern part of Lake Athabasca south of Crackingstone Peninsula (Fig. 34). The deposit is on the south shore of the island about 32 km southwest of Uranium City and 6.4 km south of the pit at the closed Gunnar uranium Mine. The deposit can be reached only by boat or float-equipped aircraft.

The deposit was discovered in 1955 by two independent prospectors and soon after was optioned separately to two different exploration companies, Frobisher Ltd. and Pipelines and Petroleum Ltd. (Beck, 1969). A long legal dispute over ownership ensued, at the end of which Pipelines and Petroleum Ltd. was the confirmed owner. In 1959-60, Scurry-Rainbow Oil Limited, formerly Pipelines and Petroleum Ltd., drilled 25 holes for a total of 1509 m of core.

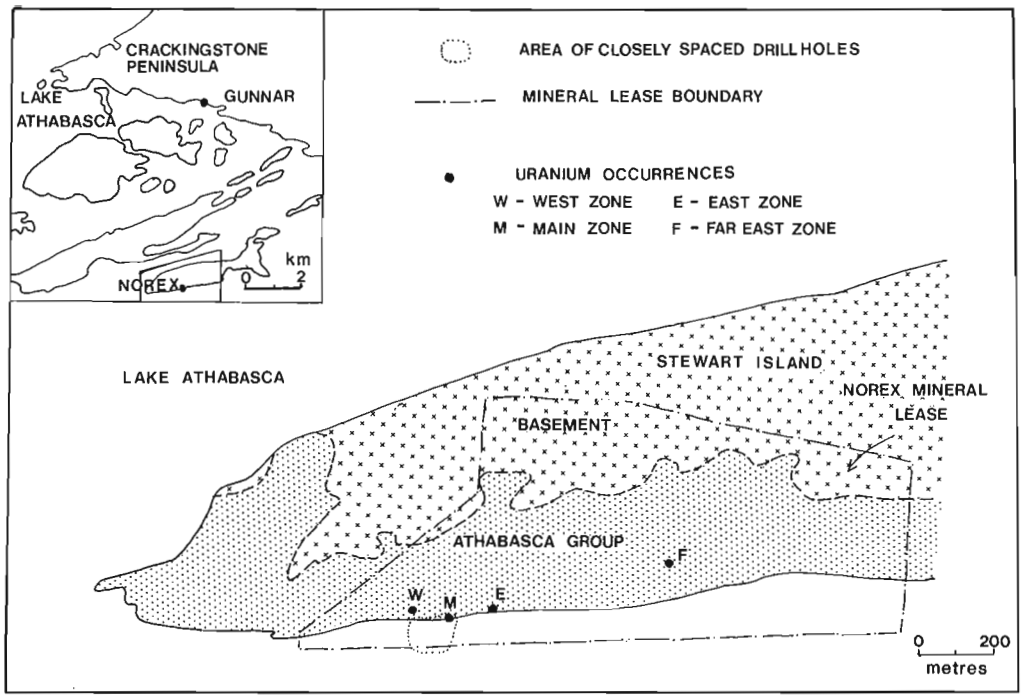

Figure 34

Geological map of the western part of Stewart Island showing the location of the radioactive occurrences on the Norex Mineral lease and the area of closely spaced drillholes.

In 1960 the property reverted to the prospectors. In 1964, it was acquired by Norex Uranium Ltd. as a mineral lease to which 36 claims were added soon after. Norex in 1967-68 mapped the geology of the property at a scale of 1:500, dug some trenches, and drilled 67 holes totalling 2176.5 m. At present (1981), the property is owned jointly by Norex Resources Ltd. (formerly Norex Uranium Ltd.) Saskatachewan Mining Development Corporation and Eldorado Nuclear Ltd. Eldorado is the field operator but no exploration plans have been announced.

The mineralization is in Athabasca rocks which near the deposits are 60 m thick and lie unconformably upon deformed white quartzite, a probable correlative of the Tazin Group. The rocks of the Athabasca succession are gently south-dipping; the unconformity is exposed along the axis of the western end of the island, from 200 to 300 m north of the south shore (Fig. 34). Beneath the deposit, the basal 21 m of the Athabasca succession consists of unmineralized dark red sandstone, mudstone, siltstone and conglomerate. This is succeeded by mainly white sandstone with a white clay cement interbedded with a few thin beds of shale. The mineralized sandstone is within the white sandstone about 35 m above the basal red hematized strata. Two sets of steeply dipping to vertical fractures and faults cut the sandstones, one trending northwest and the other between east-northeast and east.

The only ore mineral is pitchblende. The pitchblende is disseminated in the matrix of the sandstone and coats fracture surfaces where it is associated with some hematite and quartz. Mineralized sandstone is red, grey, black, and quartzitic, and the matrix of the sandstone is black or grey and is composed of fine grained carbonate and chlorite with pitchblende. No white clay alteration was observed here although some was reported near the deposit (Anonymous, 1981).

Radioactive sandstone has been found in four outcrop areas, which are referred to as the Main, West, East and Far East zones (Fig. 34). Radioactive sandstone boulders have been found along 1600 m of beach on the south shore of Stewart Island. Because some of the boulders contain magnetite, it is possible that many of the boulders were not derived from these mineralized zones.

The Main Zone outcrops near the low water line and consists of a lenticular body of mineralized sandstone, 15.3 m long, 9.2 m wide and 4.6 m thick, within and concordant to flat lying sandstone. A 2.6 m channel sample across the outcrop contained 0.89 per cent U (Beck, 1969). Drill core contained 0.25 and 0.54 per cent U over 5.7 and 6.7 m respectively. Calculated reserves are 2324 tonnes of rock grading 0.396 per cent U. Drilling to the west and south, 30 m from the Main Zone, located two small masses of 3 m thick mineralized sandstone each 4.6 and 6 m in diameter.

The West Zone is 92 m west of the Main Zone, while the East and Far East zones are 122 and 610 m east of the Main Zone. In each zone outcropping sandstone is red to dark red and quartzitic, with radioactivity several times background. Radioactivity seems confined to fractures and to wall rocks of the fractures. Drilling of each zone showed that the mineralization does not extend to depth. No assays on these zones are known.

Fahrig reported ages on the pitchblende from this deposit as varying between 646 and 418 Ma (Fahrig, 1961, p. 33). Two other ages (318 and 24 ma) were reported (Anonymous, 1981).

Fond-du-Lac Deposit

References:

Homeniuk et al., 1980; assessment files of Saskatchewan Department of Mineral Resources; Eldorado Nuclear Limited, personal communication, 1979-80.

The Fond-du-Lac deposit is on the south shore of Lake Athabasca (Fig. 35) about 2 km south-southeast of the village of Fond-du-Lac, which is on the north shore of the Lake. The deposit can be reached only by boat or float-equipped aircraft. It is owned jointly by Famok Limited and Eldorado Nuclear Limited. Eldorado is the field operator.

An airborne radiometric survey was conducted by Mokta (Canada) Ltd. (now Amok Ltd.) for Famok Ltd. in 1967 and anomalies were found in 1968 to have been caused by a large field of more than one thousand radioactive sandstone boulders. This field is 8 to 10 km long, one kilometre wide

and trends N 60°-70°E about parallel to the ice direction. Further prospecting and some drilling by Famok Ltd. in 1974 outlined a small deposit within Athabasca sandstone. Since 1976, Eldorado Nuclear Limited has continued surface exploration and drilling. In 1977-78, about 350 holes were drilled every 10 m along lines 20 m apart. The known deposit is small and no plans for exploitation have been announced.

The deposit lies within the Athabasca Basin, 0.5 km south of the north rim (Fig. 1). Near the deposit, 35 m of Athabasca strata unconformably overlie basement and are in turn covered by 10 m of glacial and recent overburden. The basement consists of meta-arkose and metapelite of granulite facies, now mainly quartzofeldspathic gneiss, quartz-biotite gneiss and pelitic schist, some with traces of graphite and up to 5 per cent pyrite. These rocks resemble the rocks exposed on the north shore of Lake Athabasca (Baer, 1968). The unconformity is generally sharp and flat or dips less than 2 degrees south. The basement rocks at the unconformity are generally altered to a hematitic red that decreases in intensity downward into a light green chloritic alteration, that has been assumed at Maurice Bay to be regolithic. There is also a dark green chloritic retrogressive alteration. A similar alteration was described from Cluff Lake (Harper, 1978a) and Beaverlodge (Tremblay, 1972). It occurs also at Maurice Bay. A weak white-clay alteration was noted locally at the unconformity and it may be related to the mineralization . The overlying Athabasca strata consist mainly of subhorizontal sandstone with minor conglomerate and siltstone. The sandstone is generally buff, massive, fine grained and well sorted; some is grey to black and some rarely is red. Carbonate (siderite) is abundant locally in the sandstone.

All but a small part of the mineralization is within Athabasca strata and furthermore, most of it is not at the unconformity (Homenuik et al., 1980) as most Athabasca Basin deposits are, but nevertheless is within 35 m of it. The mineralized zone subcrops at its western end below the drift cover and this portion of the deposit is probably the source of the mineralized boulder field. Mineralized sandstone is red, buff and grey white. Near the base and toward the centre of the mineralized zone it is dark red and silicified and much resembles the orthoquartzite of the Stewart Island deposit. This part is also in part carbonate-bearing. Toward the edge of the zone, the sandstone is grey to white, porous and much white clay altered, and contains rare carbon buttons. The mineralized zone (Fig. 35) comprises a high grade core 390 m long, ranging from 10 to 40 m wide and averaging 22 m, and as much as 30 m thick but averaging 10 m, surrounded by an irregularly shaped aureole of low grade mineralization of similar length and locally as wide as 350 m (Homenuik et al., 1980). The mineralization of the core does not appear to favour a particular section of the Athabasca succession whereas the low grade aureole is roughly conformable to a coarse grained crossbedded sandstone section. Pitchblende is the main ore mineral and is usually associated with quartz, hematite, limonite (goethite) and carbonate (siderite). It occurs as grains interstitial to the other sandstone grains, as coatings on and as inclusions in some other grains (carbonate and goethite) and as veins. The veins fill steeply dipping fractures less than 1 mm wide, mainly in the core of the deposit, and form a stockwood that trends N50°E. Some coffinite is present and pyrite was noted. The weak mineralization in the basement is interpreted by the writer as supergene. Preliminary results (Eldorado Nuclear Limited, personal communication, 1980) indicate reserves in the order of 385 tonnes uranium in rock with an average grade of less than 0.21 per cent U. The initial uranium deposition took place 1100-1200 Ma ago with remobilization at 215 Ma and 80 Ma (Homeniuk et al., 1980).

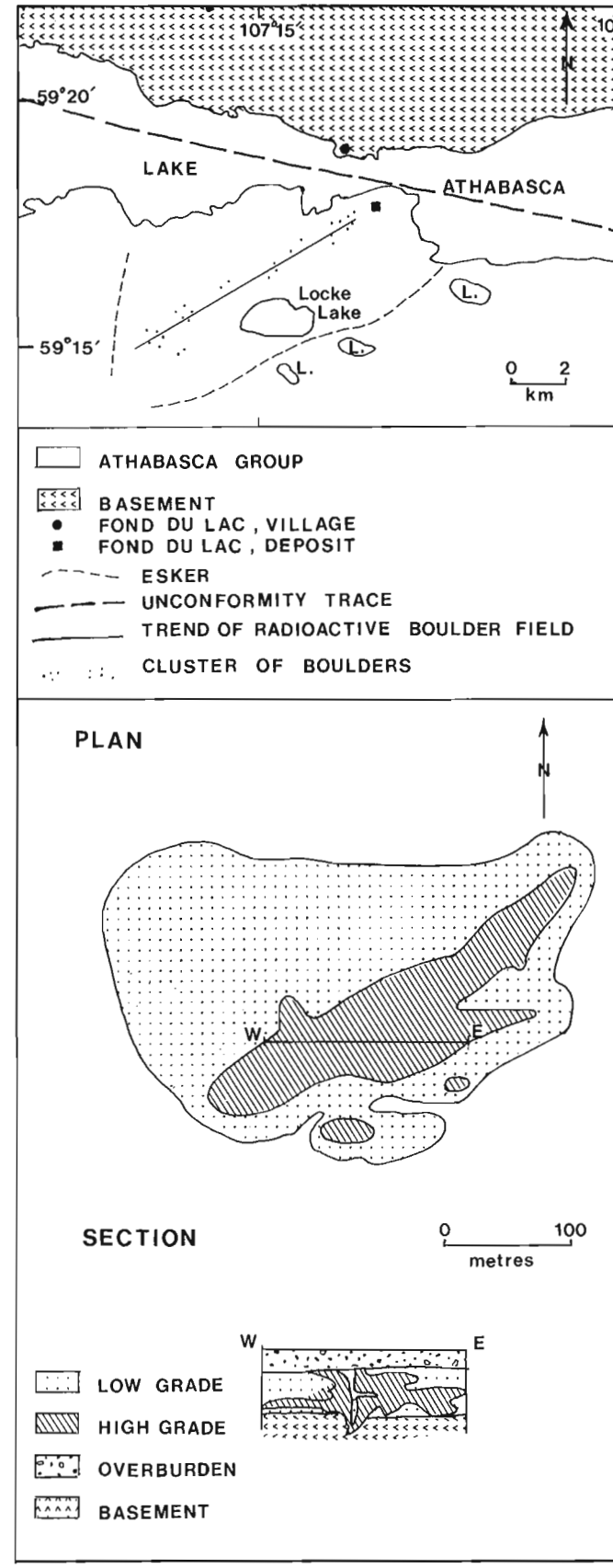

Figure 35. *Fond-du-Lac deposit (Homenuik et al., 1980 and Eldorado Nuclear Limited, personal information, 1980). Position of section through the deposit was assumed by the writer. Width of high grade position part is diagrammatic.*

Table 5. Characteristics of the uranium deposits associated with the Athabasca Basin. None of these deposits except possibly the Stewart Island and the Cluff Lake Claude deposits outcrop

Deposit	Cover		Mineralization in overburden		Unconformity		Faults			Host Rocks		Basement Rocks	
	Over-burden Thickness	Athab. Rocks m	Basement Boulders	Athab. Boulders	well defined	obscure by alteration	well developed	weakly developed	Pre Athabasca	Post Athabasca	in basement	in Athabasca	Type	Age
1.[1] Rabbit Lake	15	none	X		eroded		X		X	X	Q,C,G,F		M	Ap
2A. Collins Bay A	6	2	X		X	X	X		X	X	F,G		M	Ap
2B. Collins Bay B	16	20		X	X		X		X	X	G,C	Sm	Gr	Ar & Ap
3. Raven & Horseshoe	18	none	X		eroded			X	?	X	Q,G		M	Ap
4. West Bear	12	20			X	X		X	?	X	G	Sb	M	Ap
5. Midwest Lake	20	200		X		X		X	?	X	G,C,Q	Sm + Sb	Gr	Ap & Ar
6. Dawn Lake	18	112			X			?	?		G,C	Sb	M	Ap
7. McClean Lake	15	165			X	X		?	X	?	Q,G	Sm	M	Ap
8. Key Lake	80	45-60	X			X	X		X	X	G	Sb	Gr	Ap & Ar
9A. Cluff Lake D	2	a few m	X	X	X		X		?	X	Q,C	P	M	Ar
9B. Cluff Lake Claude		none	X		eroded		X		X	?	Q,F		M	Ar
9C. Cluff Lake NRF	to	a few m over F only	X	X	eroded in part		X		X	X	Q,F	Sb	Gr	Ar
9D. Cluff Lake OP	10	none	X		eroded		X		X	?	F,Q		Gr	Ar
10. Maurice Bay	20	0-60		X	X			?	?	X	F	Sm	Gr	Ar
11. Stewart Island	none	60	X	X	X			X		X		Sb	T	Ar
12. Fond-du-Lac	10	35		X	X					?		Sm	Gr	Ar

[1] These numbers correspond to the deposit numbers on Figure 1.

Q = Quartzite, feldspathic quartzite
C = calc-silicate rocks
G = gneiss, graphitic
F = qtz. feldspar granitoid
S = sandstone
m = multicoloured
b = black

P = pelite
M = metasedimentary
Gr = granitoid and metasedimentary
T = Tazin Quartzite
Ap = Aphebian
Ar = Archean

Table 5 (cont.)

	Alteration						Localization of mineralization			Associated elements		Tonnes of contained U	Average grade in % U	Date Age Ma	of Discovery	Owners
	Regolithic		Silicified		Argillic											
	strong	weak	strong	weak	strong	weak	at unconf.	below U	above U	major	minor					
1.	X			X	X			X			V,Mo,Cu	15 400	0.36	1281 ± 11	1968	Gulf, Uranerz
2A.	X				X		X	X		Ni,As	Au,Ag,Pb	>15 400	?	?	1971	Gulf
2B.		X			X		X		X	Ni,As			?	1238	1977	Gulf
3.		X			X			X			Cu		?	?	1972,1974	Gulf
4.	X					X	X	X	X		Ag,Ni,Pb	425	0.34	?	1977	Gulf,Noranda,SMDC
5.	X				X		X	X	X	Ni,As Co	Ag,Pb	21 500	1.06	?	1978	Esso,Numac & Bow Valley Industries
6.		X	X			X	X	?	X	?	?	>7700	?	?	1978	Asamera,SMDC,SERU, Kelvin, Crest R.
7.		X			X	X	X	X	X	Ni	?	5385	1.53	?	1979	CanOxy, Inco
8.	X				X		X	X	X	Ni,Co, As		73 860	1.925	1228 ±	1975,1976	SMDC,Uranerz,Eldor R.
9A.	X			X	X		X	X	X	Au,Te, Se	Co,No,	5211	4.25	1100	1969	Amok, SMDC
											Bi,Pb	4800	0.5		1970	Amok, SMDC
9B.	X				X			X			Mo,Pb	5000	0.35	1050		Amok, SMDC
9C.	X				X			X			Cu,Pb,Au			and	to	
9D.	X				X			X			Cu	1800	0.65	800	1976	Amok, SMDC
10.		X	X			X	X		X			577	<0.42	?	1977	SMDC,Uranerz,Eldor
11.		X	X						X			9	0.40	646	1955	Norex R. Ltd.
12.		X	X						X			385	<0.21	1100-1200	1974	Amok&Eldorado N.

CHARACTERISTICS OF THE DEPOSITS

It is obvious from the description presented above that the unconformity-type uranium deposits of the Athabasca Basin have much in common. However they also display some differences. These characteristics are described in the following pages, firstly those common to all or most deposits and secondly those which differ from one deposit to some other (Table 5). Examples are used to emphasize the similarities and the differences.

Common Features

Features common to all or most deposits are as follows:

1. All deposits when found were covered with glacial and Recent overburden, from a few metres to 90 m thick, and some (Rabbit Lake, Collins Bay A and B zones, Midwest Lake Main Zone, Key Lake Gaertner and Deilmann and Cluff Lake Claude) were entirely or partly covered by several metres of lake water.
2. Most deposits do not subcrop beneath the overburden. Where the Athabasca rocks have been eroded down to the unconformity, the deposits may subcrop beneath the overburden as the south end of the Rabbit Lake orebody, the northeastern part of the Gaertner deposit at Key Lake, parts of the Collins Bay A and B zones, some deposits at Cluff Lake and the western end of the Maurice Bay deposit. Erratics and detritus from the eroded mineralized zone rocks yielded radioactive boulder trains which were detected by airborne and ground scintillometers and spectrometers, prospectors and geochemical surveys.
3. Most deposits are spatially related to the unconformity at the base of the Athabasca strata. All are within 40 m above and 100 m below the unconformity. Furthermore, of apparent significance, many deposits are localized where relief on the unconformity is pronounced and alteration intense. The relief is due to post-Athabasca faulting, and/or pre-Athabasca differential erosion. The alteration appears to be twofold: mainly a regolithic, pre-Athabasca weathering product characterized by kaolinite and possibly some sericite and chlorite, and a later, hydrothermal product possibly related to the time of the main uranium concentration and characterized by abundant chlorite and sericite. This late alteration is called here white to light green argillization.
4. Most deposits are closely associated with faults. The mineralized zones occur within and near faults, mainly reverse faults and thrusts, and are elongated parallel to them. Most of these faults which offset the unconformity appear to be reactivated older faults because in the basement they follow strongly schistose zones which are locally mylonitic and/or brecciated, such as graphitic schist and gneiss. Most of the Cluff Lake deposits and the Collins Bay, Key Lake and Midwest Lake deposits are associated with faults. Probably the Rabbit Lake deposit is also. All these faults trend east-northeast and north-northeast.
5. Stratigraphically the deposits do not appear to be restricted to a specific rock unit in basement rocks or to a particular stratigraphic level within the Athabasca strata except that in the Athabasca rocks they are generally within the first 40 m of the Athabasca succession immediately above the unconformity and within any one deposit are restricted to a particular bed or group of beds within these first 40 m. Basement host rocks are either Archean or Aphebian; those near the eastern margin of the Athabasca Basin are mainly Aphebian metasediments of the Wollaston Lake Belt whereas those at Cluff Lake and along the northern margin of the basin are regarded as chiefly Archean. In addition, those within the Wollaston Lake Belt appear to belong entirely to the basal units of the Aphebian succession.
6. Basement host rocks generally contain graphite, feldspar, and/or carbonate and some are calc-silicate rocks, as at Key Lake, Rabbit Lake, Collins Bay, Dawn Lake, Cluff Lake and Midwest Lake. Even those deposits found only or mainly in Athabasca strata are generally above graphitic basement rocks, as at Collins Bay and in part at Maurice Bay. Mineralized Athabasca strata are dark grey and black or multicoloured (dark green, brown, shades of red, grey, white and buff). The dark grey, black and green sandstones contain relatively more sulphur (Table 3) and probably also some carbonaceous and bituminous matter.
7. All deposits are closely associated with host rock alteration, a white to light green argillization, presumed to be hydrothermal and to be genetically related to the main uranium concentration. These altered host rocks are characterized by much sericite and/or chlorite. This alteration is widespread and has affected both basement and cover rocks to various intensities (Brummer et al., 1981). It is most intensely developed at the unconformity and along crosscutting faults above and below the unconformity. Most altered are coarse grained basement rocks rich in feldspar, particularly those already altered to clay material by weathering, and Athabasca sandstones at the unconformity, within and along fault zones and along some sandstone beds higher in the succession adjacent to faults. Gabbro dykes within the alteration zone have been altered to serpentine. The K-Ar whole rock age of this alteration product is about 1260 Ma (Table 4, average of five determinations). This alteration is very strong in the area surrounding the Gaertner and Deilmann deposits at Key Lake, the Rabbit Lake deposit at Rabbit Lake, the Collins Bay A zone and part of the Collins Bay B zone at Collins Bay, most deposits at Cluff Lake, and the Main Zone at Midwest Lake. It is also well developed but not as conspicuous in all the other deposits except those along the northern rim of the Athabasca Basin.

   Conversion of sandstone to quartzite by silicification is common in most deposits along the northern edge of the Athabasca Basin, in the Cluff Lake D deposit, and locally in the Dawn Lake area and is probably a diagenetic alteration developed before the argillic alteration described above. This quartzite in the Cluff Lake D deposit was observed to be slightly affected by the argillic alteration.

The third type of alteration is regolithic. Although most of its products resemble those of the argillic alteration, because of their fine grained clay like appearance and white colour the difference is clear at least in their modes of occurrence; the regolithic products have been recognized or assumed in the vicinity of all deposits along the unconformity, are restricted to basement rocks, and are crosscut by the argillic alteration products. Nevertheless the clay products of regolithic alteration and those of argillization associated with the mineralization are in places distinguished only with difficulty and uncertainty because of their fine grained nature and their white or light coloured and clay-like appearance. Noteworthy is that sericite characteristic of argillization is commonly slightly coarser grained and a bit greener than that assumed to be produced by the pre-Athabasca weathering. Finally it is possible that some of the clay is not an alteration product but was brought to the site in colloid form as physical clay particles.

8. Mineralization in the basement is entirely in white clay-altered rocks, mainly along and in faults and fractures, and that in the sandstone is partly in white clay-altered rock and partly in dark grey and black to multicoloured sandstones always with an abundant clay matrix or cement. Most mineralization at Key Lake is in white clay-altered basement rocks, that at Collins Bay B Zone is in multicoloured Athabasca strata and in white clay altered rocks (probably basement), that at Collins Bay A Zone is in clay-altered regolith and that at Maurice Bay is in multicoloured sandstones. The deposits at Cluff Lake are all in clay-altered basement rocks except for the 'D' orebody which is in argillized Athabasca pelite (a rock unit at the base of the Athabasca succession at Cluff Lake).

9. Most deposits are linear and/or cigar shaped. Their longer dimension generally parallels the intersection of a pre-Athabasca basement fault with the unconformity. For example, the Key Lake Gaertner and Deilmann deposits are each more than one kilometre long but they are only about 70 m wide and 40 m thick. In general most deposits are less than 40 m thick, but some have roots extending downward along mineralized white clay-altered fault zones as much as 150 m below the unconformity. These root-like mineralized zones are also elongated parallel to the intersection of the fault and unconformity.

   In Athabasca cover rocks the mineralized zones are elongate within bedding planes of the sandstone and parallel to the intersection of the fault that cut both basement and cover rocks and the unconformity. The texture, grain size and composition of the Athabasca strata, plus porosity and intensity of fracturing, seem to determine the width and thickness of the deposits.

10. Most deposits are characterized by relatively small zones or pods of high grade material (up to 30 per cent U) within a more extensive lower grade mineralized area (Figure 8).

11. Many deposits contain several other metals and semimetals in addition to uranium. Some of these elements are locally as abundant as uranium itself and some deposits are truly polymetallic. The elements most commonly found in some abundance are: nickel, cobalt, arsenic, selenium, tellurium, gold, vanadium, molybdenum, copper, lead and silver. The Gaertner deposit at Key Lake contains as much nickel as uranium. Gold is abundant in the Cluff Lake D orebody, nickel, silver and some gold in the Collins Bay A Zone, cobalt and nickel locally in the Midwest Lake deposit, cobalt locally in the Key Lake deposits, molybdenum at Rabbit Lake and locally at Key Lake and vanadium in the Rabbit Lake orebody. On the other hand, some deposits like Maurice Bay and Cluff Lake NRF, Claude, and OP have very little other than trace amounts of such elements.

12. Mineralogy of the deposits reflects the variety of elements present and varies from simple to complex. Deposits with uranium and little else have a simple mineralogy, as for example, the deposits at Maurice Bay, Rabbit Lake and some at Cluff Lake. In contrast, those with an abundance of other elements in addition to uranium have a complex mineralogy. Thus the Key Lake deposits contain pitchblende, coffinite, several selenides, tellurides and sulfides, and abundant bituminous material. Carbonates are rare except where host rocks include carbonate-bearing calc-silicate rocks, as at Rabbit Lake and in part at Key Lake.

13. Age of the main episode of mineralization appears to be similar in all deposits (Table 4), i.e. about 1281 ± 11 Ma (Cumming and Rimsaite, 1979), judging from the many radiometric ages on paragenetically early uranium minerals from several deposits and on clay alteration minerals (about 1260 Ma, average of five K-An ages) related to the mineralization (Table 4). All deposits show radiometric evidence of much uranium remobilization, as demonstrated by such ages as 918, 270 and 100 Ma (Wendt et al., 1978).

14. Temperature of the main episode of mineralization was determined to be less than 300°C from the exsolution of pentlandite in pyrrhotite (Dahlkamp, 1978), the local occurrence of tetragonal uraninite (Dahlkamp, 1978), and from fluid inclusions and isotopic studies (Pagel, 1975a, b). Depth of formation was calculated to be less than 5 km (Pagel, 1975a).

Differing Features

Features making some deposits different from others are:

1. Most of the major known uranium deposits in the Athabasca Basin occur in its southeastern part, where basement rocks are mainly Aphebian metasediments of the Wollaston Lake Belt. Those in the western two thirds of the basin and along the northern rim are in an area where the basement rocks are predominantly Archean or assumed to be Archean. Relative to the rest of the basin, the deposits in the southeastern part are more numerous, more closely spaced and contain a much greater tonnage of uranium metal. It can thus be inferred that the uranium content of the source rock in the southeast corner of the basin was higher and that the collecting fluids were more effective. It probably also indicate that the volume of source rocks available to the collecting fluids was greater and that the host rocks in the mineralized zone of today had more pronounced reducing conditions. All these observations support the obvious conclusion that the part of the Athabasca Basin underlain by Aphebian metasediments is the most likely place to more uranium deposits (Burrill and Davies, 1979). Nevertheless, if it is assumed that the basement rocks beneath and near the northwestern two thirds of the basin yielded the uranium now found in the Athabasca deposits of that part of the basin and that this basement includes rocks similar to those of the Beaverlodge area north of the basin, which there are regarded to be the source rocks as well as the host rocks (Tremblay, 1978b) for the large Eldorado Fay-Ace-Verna vein deposits, then the northwestern two thirds of the basin has a good potential for additional uranium deposits. Moreover some Aphebian rocks still unrecognized and unmapped may be present with the Archean rocks in that part of the basin and may have been also as important uranium source rocks as the Aphbeian rocks of the southeast part were. So although the basement rocks in the northwestern two thirds may differ or appear to differ from those in the southeast, they appear also to have a good potential.

2. That the deposits are concentrated along and close to the unconformity probably indicates that the unconformity was the pathway for uranium-rich circulating solutions and the site of reducing conditions causing deposition. The deposits are found a few metres above and below (mainly below) the unconformity, in the lower 40 m of Athabasca strata and along fractures in basement rocks as deep as 100 m below the unconformity. It appears that the colour of Athabasca rocks just above the unconformity can be used to predict where most uranium is concentrated in relation to the unconformity. If the mineralized sandstone at the unconformity is mainly dark grey and black to white, it appears that most uranium will be in the basement. On the other hand if the mineralized sandstone at the unconformity is multicoloured, the deposit will be either entirely in the sandstone or in both the sandstone and the basement, not in the basement alone. White, grey, dark grey and black sandstones occur just above the unconformity in the deposits at Key Lake, in the area north of the Main Zone at Midwest Lake, and in some parts of the Collins Bay area, whereas multicoloured sandstones occur in the Main Zone at Maurice Bay, the Main Zone at Midwest Lake, the Collins Bay B Zone and the McClean North Zone.

3. Some differences in elemental content exist (a) between deposits at the unconformity and those well above and well below the unconformity, and (b) between groups of deposits in different parts of the Athabasca Basin. The deposits at the unconformity generally are much richer in uranium and have a greater variety and more of, other elements such as nickel, cobalt, arsenic, selenium, gold, etc., than the deposits well above and well below the unconformity. There are also locally a few high grade zones along fault zones in either sandstone or basement a short distance above or below the unconformity which are also rich in the same elements. These zones may be displaced basement rock blocks that were formerly at the unconformity. Uranium is the only abundant element in the deposits above the unconformity along the northern margin of the basin that is at Maurice Bay, Stewart Island and Fond-du-Lac and also in the deposits below the unconformity as at Raven and Horsehoe and most of Cluff Lake area. Examples of deposits with a multi-elemental association at the unconformity are the Cluff Lake D orebody, Key Lake, Midwest Lake Main Zone and parts of the McLean deposit.

   The multi-elemental deposits also differ amongst themselves. The Cluff Lake D body has much selenium, tellurium, gold and bituminous material whereas the deposits in the area extending from Key Lake to Collins Bay including Midwest Lake Main Zone, parts of the McClean deposits and possibly also some of the Dawn Lake deposits have much nickel, cobalt and arsenic. Molybdenum, vanadium and some copper is characteristic of the Rabbit Lake deposit which may be related to the type of deposit at Duddridge Lake and Burbidge Lake in the Wollaston Lake Belt east and south of the Athabasca Basin (Tremblay, 1978a).

4. A correlation is apparent between the elemental content of the deposits and the probable source rocks for the elements, that is, the nearby basement rock or rocks from which the uranium and accompanying elements were extracted by circulating waters. The source rocks for the deposits in the area from Key Lake, Midwest Lake and Collins Bay were probably the lower members of the Aphebian metasedimentary succession of the Wollaston Lake Belt whereas those for the Rabbit Lake, Raven and Horseshoe deposits were probably much higher up in the Aphebian succession within the same belt. Appreciable amounts of nickel, cobalt and uranium are known to occur in the basal phyllites of the Wollaston Lake Belt (Dahlkamp, 1978, p. 1444 and personal communication) and small molybdenum-copper(?)-uranium occurrences have been described from rocks higher up in the succession east of Rabbit Lake (Sibbald et al., 1977). Moreover, the source rocks for the deposits along the northern margin of the Athabasca Basin and those at Cluff Lake were probably Archean rocks of the kind found north of Lake Athabasca. Such Archean rocks in the Beaverlodge area have a relatively high uranium content and were regarded as the source of the uranium in the veins of the Eldorado mine at Beaverlodge (Tremblay, 1970, 1972, 1978b). These veins contain, in addition to uranium, appreciable amounts of titanium (0.4 per cent average of core samples) as brannerite, rutile and octahedrite and of vanadium (0.7 per cent average of mill samples) probably as nolanite (Robinson, 1955 and Eldorado Nuclear Limited, personal communication). Although these elements have not been found in the northern and western Athabasca deposits they may be present there, but probably not in comparable quantities because the Athabasca deposits are smaller, have a different origin and have a different time of formation. Molybdenum has been found in some deposits at Cluff Lake and is believed to be present at Beaverlodge because of the association of elements there. All these deposits (Athabasca and Beaverlodge) have no, or very little, Ni, Co, Ag. In view of the above, the writer feels that these Athabasca deposits and those of Beaverlodge are related through their source rocks. Furthermore, there is a second type of uranium deposit in the Beaverlodge area, which has nickel, cobalt, gold, selenium and tellurium in noticeable quantities, e.g. Consolidated Nicholson Mines Limited (Robinson, 1955). In the vicinity of this second type of uranium deposit there are others, such as the Box Mine west of Neiman Bay on Lake Athabasca, which have mainly gold. The Box Mine was a gold producer about 1942. The Cluff Lake D orebody contains gold, tellurium, selenium, cobalt, nickel, etc., so may be derived from source rocks similar to those of the Nicholson and Box Mines and deposits in their vicinity.

5. The Athabasca host rocks were very important (#2 above) in controlling the quantity of uranium precipitated and the site of deposition. Moreover all deposits along the southern and southeastern margin of the Athabasca Basin are associated with large concentrations of phyllosilicates formed by alteration of the original minerals of the host rocks to sericite or illite, chlorite and clay minerals, such as kaolinite and dickite. These clay masses occur at the unconformity and along major fault zones in the Athabasca and basement rocks, and these masses contain the high grades of uranium, nickel, cobalt and other elements. Where clay alteration is weak or missing, uranium mineralization is of low grade and generally lacks accompanying elements such as nickel, cobalt, gold, silver and arsenic. For example, the deposits along the northern margin of the basin have no major clay alteration, are small and of generally low grade and lack other elements, except in insignificant trace amounts. Similarly, where quartz-rich sandstone with little (generally less than 20 per cent) clay matrix is mineralized, the grade is generally low and a significant content of other elements, is lacking except again those areas along fault zones that have much clay and which may be rich in uranium and accompanying elements.

In summary deposit to deposit differences in uranium grades (Tables 1 and 5), in grades of accompanying metals (number 11 of the section on 'Common Features') if any, in sites of deposition (Table 5) and possibly also in tonnage of uranium (Table 1, 5) are regarded as being accounted for by differences in source and host rocks. However, this does not imply that where there is abundant clay alteration and phyllosilicates there is necessarily also important or significant mineralization.

SUBTYPES OF ATHABASCA DEPOSITS

The following five subtypes of unconformity-type deposits are recognized mainly by elemental associations among the deposits described above:

1. Rabbit Lake, Raven and Horseshoe. These have small amounts of copper, molybdenum and vanadium and locally much carbonate. They appear to resemble chemically the known deposits of the Wollaston Lake Belt, which have the source elemental association (Sibbald et al., 1977; Tremblay, 1978a) and which are also sediment-hosted uranium deposits.
2. Key Lake, Midwest Lake, Collins Bay A and B zones, McClean North and South zones, Dawn Lake 11 A and 11 B zones and possibly also West Bear. These all have local important concentrations of nickel, cobalt, silver and arsenic.
3. Cluff Lake D zone. This is a high grade deposit with much gold, selenium and tellurium and appears to resemble chemically the small deposits with complex mineralogy in the Beaverlodge area north of Athabasca Basin (Robinson, 1955).
4. Cluff Lake Claude, NRF and OP zones. These have almost nothing but uranium and chemically they appear to resemble the large Fay-Ace-Verna deposits of Eldorado Nuclear Limited at Beaverlodge (Tremblay, 1978b) north of the Athabasca Basin and have similar source and host rocks.
5. Maurice Bay, Fond-du-Lac and Stewart Island (northern rim of the Athabasca Basin) and Dawn Lake 11 and 14 zones. Silicification of the Athabasca sandstone is one of their main characteristic and they have only uranium.

CONDITIONS REQUIRED TO PRODUCE A DEPOSIT

The conditions outlined below are those regarded by the writer as essential to the formation of significant deposits of the Athabasca unconformity-type in the Athabasca Basin. They are features common to all the deposits found at the unconformity.

1. Several types of uranium-bearing source rocks should occur at the periphery and in the basement of the Athabasca Basin and the uranium in them should be in leachable form. Uranium-bearing rocks are known to occur north, east and south of the basin and uraninite has been identified locally in some. Uranium content varies between a few ppm (up to 20) in phyllites and metapelites at the base of the Wollaston Lake belt succession and several hundred ppm (up to 430) in pegmatites, granite masses and calc-silicate rocks within the Wollaston Lake Belt. North of the basin the uranium occurs as pitchblende in veins and as discrete uraninite crystals in pegmatites and granites enriched in uranium and also as uraninite and brannerite in metasedimentary remnants in granitized rocks.
2. The Athabasca unconformity is critical as almost all deposits are close to, or at least within a few tens of metres of, the unconformity. Some deposits, like Rabbit Lake and those at Cluff Lake, are in basement rocks a short distance below the projected level of the unconformity before erosion removed all Athabasca strata and some basement rocks. Others like the Stewart Island and Fond-du-Lac deposits in Athabasca rocks are a short distance above the unconformity.
3. An irregular unconformity surface is important. The relief is probably due to pre-Athabasca differential erosion of basement rocks or post-Athabasca faulting, or both.
4. The presence of major faults is also important. These faults are old basement faults of major importance that trend north to east and have been reactivated after the deposition of Athabasca rocks. These faults are usually marked by some brecciation and shearing of the Athabasca rocks and are associated with graphite, talc, micas and clay in the basement and locally (Key Lake, Collins Bay and Maurice Bay) in the Athabasca strata. Some faults, such as the Rabbit Lake Fault, even displace the ore zones, suggesting very late movement.
5. The development of much clay is essential. Clay in the form of sericite, chlorite, possibly talc, and clay minerals (mainly kaolinite, dickite, illite) is developed mainly at the unconformity, along major faults and other secondary fractures in basement and sandstones, and along bedding planes in the Athabasca strata. Much of that clay is regolithic but a late clay development in the form of chlorite and/or sericite is assumed to accompany the mineralizing process.
6. The most favourable host rock in the basement is a coarse grained feldspar-rich quartz-feldspar granitoid or gneiss. The high feldspar content facilitates clay development. The most favourable host rock in the Athabasca succession is black and dark grey sandstone at and near the unconformity.
7. The presence of rocks with reducing agents required to precipitate uranium from solutions is essential. In the basement such rocks are graphite-bearing gneisses and schists and carbonate-bearing calc-silicate rocks. In the Athabasca succession they are carbonaceous, bituminous and locally pyrite-bearing grey to black sandstones.

GENESIS OF THE DEPOSITS

Several models have been presented to explain the origin of the Athabasca unconformity-type uranium deposits.

The occurrence of economic deposits in Precambrian sandstone in Gabon, Africa, led Mokta (Canada) Ltd. to explore the Carswell Structure and the Fond-du-Lac area in the western and northern part of the Athabasca Basin in 1967. Gulf Minerals Canada Limited explored the Rabbit Lake area at the eastern edge of the Basin about the same time. After the Rabbit Lake discovery (1968), Knipping (1974), impressed by the supergene origin proposed by Barbier (1974) for vein deposits in France, suggested a similar origin for the Rabbit Lake deposit, i.e. that near surface groundwater circulated through Athabasca sandstone and along the unconformity and deposited uranium in the clay-altered rocks at the unconformity. Langford (1977, 1978) extended the supergene origin to all the deposits related to the Athabasca unconformity and even to the vein deposits of the Beaverlodge-type in the Uranium City area

north of the basin. He assumed that they formed on basement rocks in the same way as the Australian calcrete deposits, were later covered by Athabasca strata, and then were modified by diagenetic processes. Both Knipping and Langford assumed that the uranium was released by weathering from basement rocks exposed to the east of the basin and was carried in solution in fluvial water. Langford favoured pre-Athabasca mineralization while Knipping favoured post-Athabasca mineralization. McMillan (1977) also supported a supergene origin.

A hydrothermal origin was proposed for the deposits by Little (1974), Morton (1977) and Munday (1979). In this model, uraniferous solutions, assumed to be deep seated, moved upward through the basement rocks and deposited the uranium at the unconformity. For Morton, the hot solutions were generated by metamorphic processes and he assumed that Grenville thermal effects were probably responsible for the circulation of the solutions. Diabase dykes found cutting the Athabasca strata in many places in the basin, were held as evidence of the thermal effects at about 1200 Ma. Morton assumed that the deep seated uranium solutions derived their uranium from basement protores of Hudsonian age.

A diagenetic-hydrothermal origin was proposed for the Rabbit Lake deposit as early as 1976 by Hoeve and Sibbald (1976). Two years later, they (Hoeve and Sibbald, 1978b) applied the same model to all deposits related to the Athabasca unconformity. They believed that the uranium-bearing solutions were produced by diagenesis of Athabasca sediments and that the uranium was derived entirely from those sediments. A year later they classed the Athabasca deposits as a special variety of the sandstone-type (Hoeve et al., 1979). Clark (1979) assumed a similar origin (diagenetic-hydrothermal) except that he favoured both basement and Athabasca strata as the source of the uranium. Pagel et al. (1979) supported this model but assumed that basement rocks were the source of the uranium.

Dahlkamp (1978) believed like Langford that most of the Key Lake deposits were formed by basement weathering and concentration of uranium before deposition of Athabasca sediments and that after deposition of the Athabasca sediments the uranium was remobilized by diagenesis and hydrothermal activity, but that the shape and position of the deposits were changed very little. Kitchner et al. (1979) in their description of the Key Lake deposits assumed that most of the uranium was derived from the basement rock and was deposited after deposition of the Athabasca sediments.

The writer supports a model in which the genetic history of the deposits commences very early in the geological development of the Precambrian rocks of northern Saskatchewan and in which several stages of uranium concentration were required to produce significant deposits (Pagel et al., 1979; de Carle, 1981). In this sense the deposits are polygenetic. The following stages have been recognized.

1. Sedimentation stage. The first stage of uranium concentration took place when uranium was deposited as a relatively rich component of Archean and Aphebian sediments. Archean metapelites and metaquartzites of the Beaverlodge area north of the Athabasca Basin and Aphebian metapelites of the Wollaston Lake Belt east of the basin have high uranium contents compared to world values of 3.7 ppm for shales and 0.45 ppm for sandstone (Turekian and Wedepohl, 1961). The Fay Complex metapelites and metaquartzites of the Beaverlodge area average 4.6 and 3.0 ppm uranium respectively (Tremblay, 1970; Tables II, IV, and VII) and the metapelites of the Wollaston Lake Belt contain up to 20 ppm uranium (Dahlkamp, 1978, p. 1444 and personal communication).
2. Anatectic stage. Uranium was further concentrated during metamorphism and granitization of the Archean and Aphebian rocks. Aggregates of uraninite and monazite reflecting this process (Ruhlmann, 1980, p. 242) occur in metasedimentary remnants in granitized rocks and granites so are the concentrations of brannerite in the Fay Complex of the Fay-Ace-Verna deposits at Beaverlodge. Some pegmatites and granites contain as much as 430 ppm uranium (Eldorado Nuclear Limited and Saskatchewan Mining Development Corp., personal communication).
3. Lateritic stage. The next stage of uranium concentration occurred during removal by lateritic weathering and erosion of several hundred metres of Archean and Aphebian rocks and the development of lateritic material. The paleolatitude of deposition of the Athabasca Basin was about 39° North as calculated by Fahrig et al. (1978) from paleomagnetic studies, that is within a desert belt. This uranium-bearing lateritic material (Table 3 – regolithic clay) occurring on the regionally smooth sub-Athabasca unconformity is assumed to have resembled present day surficial iron and manganese deposits or the calcrete of Langford (1978). Uranium concentrations in the lateritic material were probably fairly extensive in some localities but their grade must have been low. Five core samples (5 cm long) of brown to red regolithic clay assayed 0.0 to 0.055 per cent U, averaging 0.033 per cent U. However, it is not known how much of this uranium deposited with the regolith and how much was later. The lateritic regolith was covered by Athabasca sediments and preserved from erosion. Under such a model, the uranium probably came almost entirely from nearby basement rocks.
4. Athabasca depositional stage. The presence of uranium (up to 200 ppm) with apatite and fluorapatite (Ramaekers, 1980) in some sections of the Wolverine Point Formation (Table 2) suggests that there was some uranium concentration during the deposition of the Athabasca rocks. The small deposits (Stewart Island and Fond-du-Lac) along the northern rim of the basin may represent in part such primary concentration. Their present position within the Athabasca succession and the basin seems to indicate, however, that very little uranium now in the deposits at the unconformity was derived from this source, that is, the Athabasca rocks.
5. Groundwater mobilization stage. This stage is later than the deposition of the Athabasca sandstone and probably took place when the chlorite and sericite alteration enveloping the deposits was formed around 1260 Ma ago (average of 5 whole-rock K-Ar ages on core samples rich in sericite, Table 4). Two processes produced the deposits and governed their size, shape and site. In the first, uranium was dissolved and carried by circulating groundwater from several source rocks: mainly from the lateritic regolith at and below the unconformity, and less so from the metamorphic and granitized Aphebian and Archean rocks and uraniferous anatectic granites and pegmatites of the basement, and uraniferous beds within the Athabasca strata. In the second, uranium was deposited along and near the unconformity within the lateritic regolith and along fault zones in both basement and Athabasca strata. This most important stage is responsible for producing the present orebodies from submarginal and 'geochemically interesting' concentrations of uranium.

6. Later groundwater remobilization stage. Continued passage of groundwater through part or all of a deposit redissolved and redeposited some uranium. Thus, the shape of the deposit and distribution of uranium grades were changed slightly. Uranium probably was moved along permeable sandstone beds outward from the deposit and along fault zones. Such 'leakage' produced radioactive sandstone well above the main deposit, enhancing opportunities for its detection through radioactive boulder trains and geochemical and geophysical anomalies. In general, however, it appears that once an economic deposit was formed it was not disturbed very much by this late and continued or repeated process.

Undoubtedly, stage 5, groundwater mobilization, is the heart of the model. It is argued that a rise in geothermal gradient gave rise to mobilization and concentration of the uranium. Evidence of conditions that might have generated higher temperatures along the unconformity are:

a. As much as 1500 m of Athabasca strata now bury the unconformity and it is expected that if the thickness was greater, the thermal gradient and temperature would also have increased. Pagel (1975a, b) estimated from studies of fluid inclusions in quartz overgrowths on detrital quartz grains at the base of the Athabasca succession that the thickness could have been three times as much in the Carswell Structure area:

b. There was some generation of heat along faults by friction during movement. The latter is likely but difficult to estimate as we do not know the frequency of faulting and fracturing, though faults and fractures are common and abundant:

c. Intrusion of gabbro dykes as a thermal effect related to a much broader thermal event associated with the Grenville Orogeny about 1200 Ma ago must have introduced some heat and

d. radioactive heat from the uranium may have raised the temperature a degree or so. It is argued that in general this rise in temperature was enough to energize a circulating system that could extract the uranium, carry it in solution and lock it in the clay at the unconformity while solutions continued making more clay or bringing it in colloid form as physical clay particles. Fluid inclusions in quartz and carbonates and stable isotope (H, C and O) studies suggest a temperature of formation of about 200°C for these deposits (Pagel, 1975a, b, 1977; Pagel et al., 1979).

The circulation paths of the uraniferous solutions were numerous. The main ones were the unconformity, the bedding planes and permeable beds in the Athabasca strata, the faults and fractures in basement and Athabasca rocks, and the zones of clay alteration in all rock types and particularly those at the unconformity that have a high sericite and chlorite content because the development of these minerals make these zones more porous as observed in mining pits and in cores. Precipitation of uranium was probably caused by a redox reaction in which uranium-rich solutions in the oxidized state came in contact with reducing agents such as graphite-bearing rocks, carbonaceous sandstone, calc-silicates, and mafic-rich rocks, all altered in part or entirely to clay, sericite and chlorite. These clays with chlorite and micaceous minerals seem to have acted as a catalyst in the precipitation of the uranium and to have captured and fixed the uranium. Rimsaite's findings (1978a) at Rabbit Lake and the experimental work of Giblin (1979) support the adsorptive character of such a clay.

Concentrations of uranium in sandstone well above the unconformity, perhaps more than 40 m, such as those along the northern rim of the Basin cannot be readily explained by the above sequence of stages, except as a leakage from an unconformity related deposit that is either still undiscovered or was destroyed during the later groundwater remobilization stage. However the evidence of the "leakage" process is not apparent in the vicinity of these deposits, although the date on Stewart Island pitchblende (418 Ma) seems to support it. Moreover, these deposits in the sandstone do not seem to represent concentration of uranium-bearing minerals in the heavy mineral fraction of the sedimentary succession. Then, it is possible that they represent in part a roll front type of deposit.

The presence of basement rocks with in nickel, cobalt, silver, gold and arsenic near deposits in which such elements occur (unpublished industrial data) suggests that the metals of these deposits were derived from the nearby basement rocks. On the other hand, Hoeve et al. (1979) have assumed that the above elements and uranium were present in sufficient quantity in the heavy mineral fraction of the Athabasca rocks to be the source of these elements and the uranium. Such a source is not regarded here as significant or likely because (a) the Athabasca rocks consist mainly of very clean quartz sandstones, as shown by their chemical compositions (Table 3), and their heavy mineral content is regarded as too low to account for the large quantities of some of these elements (particularly nickel, cobalt and gold) in some deposits, and (b) if these elements were derived from the heavy mineral fraction of the Athabasca strata, it would be expected that titanium, and vanadium would also be present in relatively large amounts as nickel and cobalt are. These elements are fairly abundant in the Beaverlodge deposits (Robinson, 1955; Tremblay, 1970) and it is known that their assumed source rocks were also relatively rich in titanium and vanadium (Tremblay, 1970, 1972). Clark (1979) from a different point of view suggested that the gabbro dykes that cut the Athabasca rocks could be the source of these elements. But these dykes are too few, too small, and too scattered throughout the basin to be an effective source. In fact, most gabbro dykes, both observed and interpreted from geophysical surveys, are far from the main known deposits. However, these dykes may be the indication of an important thermal event taking place where the uranium deposits were formed.

EXPLORATION

The following remarks are a brief outline of the approach to uranium exploration in the Athabasca Basin.

Outcrops are absent or rare in the Athabasca Basin and overburden is generally more than five metres thick. The simplest method to determine the presence of mineralization in the rocks below the overburden is to search for evidence of mineralization in the overburden. That is to search for mineralized rock fragments and a boulder train, or for broad uranium geochemical anomalies in surface water, soil and fine sized fraction in overburden materials, or for radiometric anomalies on radioactive overburden. Airborne and ground methods can be used. This is the first exploration approach. Negative results do not rule out the presence of mineralization at depth; overburden may be too thick or the deposit may not subcrop at the base of the overburden.

Since all located economic deposits have been found at the unconformity and since most of them are long cigar-shaped bodies, their presence may be indicated by pathfinder elements in a broad halo around the mineralized zones. Such a halo could be very extensive, particularly if the indicator elements have moved in a gaseous state. The halo may be elongated if controlled partly by fault and fracture systems

within and surrounding the deposits. Arsenic, boron, mercury, helium and radon may be useful pathfinders, especially in materials showing signs of clay alteration. Negative results may indicate that no deposit is nearby but any indications even if very small may be significant.

Since most deposits appear to be related to irregularities of the unconformity surface caused mainly by faults, isopach maps of the unconformity would help to locate the irregularities and major faults. And if prepared from drilling and various geophysical data they could also provide information on the nature and trend of the basement rocks, on the location and trend of the zones of clay alteration, and on the location of significant secondary faults.

BIBLIOGRAPHY

Alcock, F.J.
1936: Geology of Lake Athabasca Region, Saskatchewan; Geological Survey of Canada, Memoir 196, 41 p.

Allman, N.J.
1980: Gulf Minerals is looking beyond Rabbit Lake; The Northern Miner, August 21, 1980, p. C12.

Anonymous
1981: The Stewart Island Uranium Showing; in Canadian Institute of Mining and Metallurgy, Geology Division Uranium Field Excursion Guidebook, Sept. 8-13.

Armstrong, R.L.
1978: Pre-Cenozoic Phanerozoic time scale – computer file of critical dates and consequences of new and in-progress decay-constant revisions; in Contributions to the Geologic Time Scale, ed. G.V. Cohee, M.F. Glaessner and H.D. Hedberg; American Association of Petroleum Geologists, Studies in Geology no. 6, p. 73-91.

Baer, A.J.
1968: The Precambrian geology of the Fond-du-Lac map-area (74/O), Saskatchewan; Geological Survey of Canada, Paper 68-61, 17 p.

Barbier, M.J.
1974: Continental Weathering as a Possible Origin of Vein-type Uranium Deposits; Mineral Deposita (Berlin) 9, 271-288, by Springer-Verlag.

Bayda, E.D. Justice
1978: Cluff Lake Board of Enquiry, Government of Saskatchewan, Regina, Saskatchewan.

Beck, L.S.
1969: Uranium deposits of the Athabasca Region, Saskatchewan; Saskatchewan Department of Mineral Resources, Report 126.

1977: Changing ideas on metallogenesis of Saskatchewan's uranium deposits; Canadian Mining Journal, v. 98, p. 49-51.

Brummer, J.J., Saracoglu, N., Wallis, R.H., and Golightly, J.P.
1981: McClean Uranium Deposits Saskatchewan, Part 2, Geology; in Canadian Institute of Mining and Metallurgy & Geology Division Uranium Field Excursion Guidebook, Sept. 8-13.

Burrill, G.H.R. and Davies, J.C.
1979: Criteria to be considered in establishing exploration priorities in the Athabasca Basin; Canadian Mining and Metallurgy Winnipeg Meeting, Manitoba, September, v. 72, Abstract.

Burwash, R.A., Baadsgaard, H., and Peterman, Z.E.
1962: Precambrian K-Ar dates from the Western Canada sedimentary basin; Journal of Geophysical Research, v. 67, p. 1617-1625.

Canada Wide Mines Ltd.
1981: The Midwest Uranium Deposit; in Canadian Institute of Mining and Metallurgy Geology Division Uranium Field Excursion Guidebook, Sept. 8-13.

Carino, A.B.
1979: Uranium Recovery at the Rabbit Lake operation of Gulf Minerals Canada Limited; Canadian Mining and Metallurgical Bulletin; v. 72, no. 506, p. 162-166.

Christie, R.L.
1979: Phosphorite in sedimentary basins of Western Canada; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 253-258.

1980: Paleolatitudes and Potential for Phosphorite deposition in Canada; in Current Research, Part B, Geological Survey of Canada, Paper 80-1B, p. 241-248.

Clark, L.A.
1979: Uranium Ore genesis and Exploration in Saskatchewan; American Institute of Mining Engineering Annual Meeting, New Orleans, Louisiana; February, Extended Abstract.

1980: Uranium Deposits of Northern Saskatchewan; Oilweek, v. 31, p. 24.

Clark, L.A. and Burrill, G.H.R.
1979: Uranium Ore genesis in Saskatchewan and Comparisons with Australian Deposits; Canadian Mining and Metallurgy, Winnipeg Meeting, Manitoba, September, v. 72, Abstract.

Clark, R.J.McH., Homenuik, L.A., and Bonnar, R.
1980: Uranium Metallogeny in the Athabasca Basin and a Comparison with other Canadian Proterozoic Basins; Canadian Mining and Metallurgy, Toronto Meeting, Ontario, March, v. 73, Abstract.

Clarke, P.J. and Fogwill, W.D.
1981: Geology of the Asamera Dawn Lake Uranium Deposits Athabasca Basin, Northern Saskatchewn; in Canadian Institute of Mining and Metallurgy Geology Division Uranium Field Excursion Guidebook, Sept. 8-13.

Cumming, G.L. and Rimsaite, J.
1979: Isotopic studies of lead-depleted pitchblende, secondary radioactive minerals and sulphides from the Rabbit Lake uranium deposit, Saskatchewan; Canadian Journal of Earth Sciences, v. 16, p. 1702-1715.

Currie, K.L.
1969: Geological Notes on the Carswell Circular Structure, Saskatchewan (74K); Geological Survey of Canada, Paper 67-32, 60 p.

Dahlkamp, F.J.
1978: Geological Appraisal of the Key Lake U-Ni Deposits, Northern Saskatchewan; Economic Geology, v. 73, p. 1430-1449.

Dahlkamp, Franz J. and Tan, B.
1977: Geology and mineralogy of the Key Lake U-Ni deposits, northern Saskatchewan, Canada; in Geology, Mining, and Extraction Processing of Uraniumed. M.J. Jones; London, Institute of Mining and Metallurgy, p. 145-158.

David, Peter P.
1981: Stabilized dune ridges in northern Saskatchewan; Canadian Journal of Earth Sciences, v. 18, p. 288-310.

Davies, J.C.
1979: Uranium Exploration in Saskatchewan as a Function of Genetic Modelling; Canadian Mining and Metallurgy, Montreal Meeting, Quebec, April, v. 72, Abstract.

de Carle, Arthur L.
1981: Geology of the Key Lake Deposits – are overview; in Canadian Institute of Mining and Metallurgy Geology Division Uranium Field Excursion Guidebook, Sept. 8-13.

Dunning, N. and Parslow, G.R.
1979: Preliminary report on the geochemistry and geology of the Rabbit Lake area, northern Saskatchewan; in Proceedings of a Symposium on Uranium Exploration Techniques, ed. G.R. Parslow; Saskatchewan Geological Society, Special Publication No. 4, p. 257-280.

Fahrig, W.F.
1961: The geology of the Athabasca Formation; Geological Survey of Canada, Bulletin 68, 41 p.

Fahrig, W.F. and Jones, D.L.
1969: Paleomagnetic evidence for the extent of Mackenzie igneous event; Canadian Journal of Earth Sciences, v. 6, no. 4, pt. 1, p. 679-688.

Fahrig, W.F. and Loveridge, W.D.
1981: Rb-Sr isochron age of weathered pre-Athabasca Formation basement gneiss, northern Saskatchewan; in Rb-Sr and U-Pb Isotopic Age Studies, Report 4; in Current Research, Part C, Geological Survey of Canada, Paper 81-1C, p. 127-129.

Fahrig, W.F. and Wanless, R.K.
1963: Age and significance of diabase dyke swarms of the Canadian Shield; Nature, v. 200, p. 934-937.

Fahrig, W.F., Christie, K.W., and Freda, G.
1978: The Paleolatitude and Paleomagnetic age of the Athabasca Formation, Northern Saskatchewan; in Current Research, Part C, Geological Survey of Canada, Paper 78-1C, p. 1-6.

Farstad, J.
1979: The Discovery of the Midwest Lake Uranium Deposit, Saskatchewan; Prospectors and Developers Association, Toronto Meeting, March. Abstract.

Finch, W.I.
1967: Geology of epigenetic uranium deposits in sandstones in the United States; United States Geological Survey, Professional Paper 538.

Fish, R.
1979a: The Key Lake Development: Battling sand and water; Canadian Mining Journal, August, v. 100, p. 26-29.

1979b: Midwest Lake may go underground despite grade; Canadian Mining Journal, August, v. 100, p. 32-37.

1979c: Gulf plans mining to year 2000 at Wollaston; Canadian Mining Journal, August, v. 100, p. 41-45.

Gancarz, A.J.
1979: Chronology of the Cluff Lake Uranium Deposit, Saskatchewan, Canada; International Uranium Symposium on the Pine Creek geosyncline, N.W. Australia, June; Extended Abstracts.

Gatzweiler, R., Lehnert-Thiel, K., Clasen, D., Tan, B., Voultsidis, V., Strnad, J.G., and Rich, J.
1979: The Key Uranium-nickel deposits; Canadian Mining and Metallurgical Bulletin, v. 72, p. 73-79.

Giblin, Angela
1979: Experiments on the role of Clay adsorption in genesis of uranium ores; International Uranium Symposium on the Pine Creek geosyncline, N.W. Australia, June; Extended Abstracts.

Godfrey, John D. and Langenberg, C. Willem
1977: Metamorphism in the Precambrian Shield of northeastern Alberta, Contribution ser. no. 807, Geology Division, Alberta Research Council.

Harper, C.T.
1977: Uranium metallogenetic studies III: Cluff Lake; in Summary of Investigations 1977, Saskatchewan Geological Survey, p. 136-146.

1978a: The Geology of the Cluff Lake Uranium Deposits; Canadian Mining and Metallurgical Bulletin, v. 71, p. 68-78.

1978b: Uranium Metallogenic Studies; Maurice Bay; in Summary of Investigations, 1978; Saskatchewan Geological Survey, Miscellaneous Report 78-10, p. 74-83.

1979: Uranium Metallogenic Studies: Maurice Bay Area, Geology and Mineralization; in Summary of Investigations, 1979; Saskatchewan Geological Survey, Miscellaneous Report 79-10, p. 96-106.

1980: Uranium Metallogenic Studies: Cluff Lake Area; in Summary of Investigations, 1980; Saskatchewan Geology Survey, Miscellaneous Report 80-4, p. 36-43.

Herring, B.F.
1976: The metamorphism and Alteration of the Basement rocks in the Carswell Circular Structure, Saskatchewan; unpublished M.Sc. thesis, University of British Columbia, Vancouver.

Hoeve, J.
1977: Uranium metallogenetic studies II: Rabbit Lake: Mineralogy and geochemistry; in Summary of Investigations 1977; Saskatchewan Geological Survey, p. 124-135.

1978a: Uranium metallogenetic studies: Rabbit Lake: Mineralogy and geochemistry; in Summary of Investigations 1978; Saskatchewan Geological Survey, Miscellaneous Report 78-10, p. 61-65.

1978b: Uranium concentration related to the sub-Athabasca unconformity, northern Saskatchewan; in Uranium Deposits: their Mineralogy and Origin; ed. M.M. Kimberly; Short Course, Mineralogical Association of Canada, University of Toronto, p. 475-484.

1979: Uranium metallogenesis and its significance to exploration in the Athabasca Basin; in Proceedings of Symposium on Uranium Exploration Techniques, ed. G.R. parslow, Saskatchewan Geological Society, Special Publication no. 4, p. 161-188.

Hoeve, J. and Sibbald, T.I.I.
1976: The Rabbit Lake Uranium Mine; in Proceedings of a symposium on Uranium in Saskatchewan, ed. C.E. Dunn, Saskatchewan Geological Society, Special Publication no. 3, p. 331-354.

Hoeve, J. and Sibbald, T.I.I. (cont.)
1978a: Mineralogy and geological settings of unconformity-type uranium deposits in northern Saskatchewan; in Uranium Deposits: their Mineralogy and Origined. M.M. Kimberly; Short course, Mineralogical Association of Canada, University of Toronto, p. 457-474.

1978b: On the genesis of Rabbit Lake and other unconformity type uranium deposits in northern Saskatchewan, Canada; Economic Geology, v. 73, no. 8, p. 1450-1473.

Hoeve, J., Sibbald, T.I.I., and Ramaekers, P.
1979: Athabasca Basin Unconformity-type Uranium Deposits: a special class of sandstone-type deposits?; International Uranium Symposium on the Pine Creek geosyncline, N.W. Australia, June; Extended Abstracts.

Homeniuk, L.A., Bonnar, R., and Clark, R.J.McH.
1980: The Fond-du-Lac Uranium Deposit, Saskatchewan; Canadian Mining and Metallurgy, Toronto Meeting, Ontario, April, v. 73, Abstract.

Innes, M.J.S.
1964: Recent advances in meteorite crater research at the Dommion Observatory, Ottawa, Canada; Meteorics, v. 2, p. 219-249.

Jones, B.
1980: The Geology of the Collins Bay Uranium Deposit, Saskatchewan; Canadian Mining and Metallurgical Bulletin, v. 73, no. 818, p. 84-90.

Kermeen, J.S.
1955: A study of some uranium mineralization in Athabasca sandstone near Stony Rapids, Northern Saskatchewan, Canada; unpublished M.Sc. thesis, University of Saskatchewan.

Kirwan, L.D.
1979a: The Discovery of the Midwest Lake Uranium Deposit; in Proceedings of Symposium on Uranium Exploration Techniques, ed. G.R. Parslow, Saskatchewan Geological Society, Special Publication no. 4, p. 59-79.

1979b: Case History of the Midwest Lake Uranium Discovery, Saskatchewan; Canadian Mining and Metallurgy, Montreal Meeting, Quebec, April, Abstract.

Kitchner, G., Lehnert-Thiel, K., Rich, J., and Strnad, J.G.
1979: Key Lake and Jabiluka: Models for Lower Proterozoic uranium Deposition; International Uranium Symposium of the Pine Creek geosyncline, N.W. Australia, June; Extended Abstracts.

Knipping, H.D.
1974: The concepts of supergene versus hypogene emplacement of uranium at Rabbit Lake, Saskatchewan, Canada; in Formation of Uranium Deposits, International Atomic Energy Agency, Vienna, p. 531-548.

Lang, A.H.
1952: Uranium Orebodies. How can more be found in Canada?; Canadian Mining Journal, v. 73, June.

Lang, A.H., Griffith, J.W., and Steacy, H.R.
1962: Canadian deposits of uranium and thorium; Geological Survey of Canada, Economic Geology ser. no. 16, Second Edition, 324 p.

Langford, F.F.
1977: Surficial origin of North American pitchblende and related uranium deposits; American Association of Petroleum Geologists Bulletin, v. 61, no. 1, p. 28-42.

1978: Origin of Unconformity-type Pitchblende deposits in the Athabasca Basin of Saskatchewan; in Uranium Deposits: their Mineralogy and Origin, ed. M.M. Kimberly, Short Course, Mineralogical Association of Canada, University of Toronto, p. 485-499.

Lehnert-Thiel, K. and Kretschmar, W.
1979a: The Discovery of the Maurice Bay Uranium Deposit and Exploration Case History; Canadian Mining and Metallurgy, Winnipeg Meeting, Manitoba, September, Abstract.

1979b: The Geology of the Maurice Bay Deposit; Canadian Mining and Metallurgy, Winnipeg Meeting, Manitoba, September, Abstract.

Lehnert-Thiel, K., Kretschmar, W., and Petura, J.
1981: The Geology of the Maurice Bay Uranium Deposit; in Canadian Institute of Mining and Metallurgy Geology Division Uranium Field Excursion Guidebook, Sept. 8-13.

Lerand, M.M.
1970: Athabasca Formation Rumpel Lake stratigraphic test, Lithologic description; Geological Survey of Canada, Open File Report 668, January, 1980.

Lewry, J.F. and Sibbald, T.I.I.
1977: Variations in lithology and tectonometamorphic relationships in the Precambrian basement of Northern Saskatchewan; Canadian Journal of Earth Sciences, v. 14, no. 6, p. 1453-1467.

1979: A review of the Pre-Athabasca basement geology in northern Saskatchewan; in Proceedings of Symposium on Uranium Exploration Techniques, ed. G.R. Parslow, Saskatchewan Geological Society, Special Publication no. 4, p. 19-58.

Little, H.W.
1974: Uranium in Canada; in Report of Activities, Part A, Geological Survey of Canada, Paper 74-1A, p. 137-139.

Mason, J.D.
1979: Visit to some Saskatchewan Uranium Deposits provided Scintillating Experience on Canadian Mining and Metallurgy Tour; The Reporter, Canadian Mining and Metallurgy, July.

McMillan, R.H.
1977: Metallogenesis of Canadian Uranium Deposits: a review; a talk presented to the London Institute of Minerals and Metallurgy, London, England.

1978: Genetic Aspects & Classification of Important Canadian Uranium Deposits; Canadian Mining and Metallurgical Bulletin, v. 71, p. 61-67.

Mellinger, M.
1979: Uranium Metallogenetic Studies: Maurice Bay Deposit, Geology and Petrography; in Summary of Investigations, 1979; Saskatchewan Geological Survey, Miscellaneous Report 79-10, p. 107-109.

1980: Uranium Metallogenic Studies: Maurice Bay Deposit, in Summary of Investigations, 1980; Saskatchewan Geological Survey, Miscellaneous Report 80-4, p. 89-92.

Moreau, M., Poughon, A., Puibaraud, Y., and Sanselme, H.
1966: L'uranium et les granites; Chronique des mines et de la recherche minière, Paris, no. 350, p. 47-51.

Morton, R.D.
1977: The western and northern Australian uranium deposits – exploration guides or exploration deterrents for Saskatchewan?; in Proceedings of a Symposium on Uranium in Saskatchewan, ed. C.E. Dunn, Saskatchewan Geological Society, Special Publication no. 3, p. 211-255.

Munday, R.J.
1979: Uranium mineralization in northern Saskatchewan; Canadian Mining and Metallurgical Bulletin, v. 72, April, p. 102-111.

Pagel, Maurice
1975a: Cadre géologique de gisements d'uranium dans la structure Carswell (Saskatchewan-Canada): Etude des phases fluides; Thèse de Docteur de Spécialité (3e cycle), Université de Nancy.

1975b: Determination des conditions physico-chimiques de la silicification diagénétique des grés Athabasca (Canada) au moyen des inclusions fluides; Academic des Sciences, Comptes Rendus Hebdomaires des Sciences, Series D, Sciences Naturelles, Paris, v. 280, p. 2301-2304.

1977: Microthermometry and chemical analysis of fluid inclusions from the Rabbit Lake uranium deposit, Saskatchewan, Canada; Institution of Mining and Metallurgy (London) Transactions, Section B, Applied Earth Science, v. 86, p. B157-B1558.

Pagel, M. and Openshaw, R.F.
1979: The paleolatitude and paleomagnetic age of the Athabasca Formation, Northern Saskatchewan: Discussion; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 419.

Pagel, M., Poty, B., and Sheppard, S.M.F.
1979: Contribution to some Saskatchewan Uranium Deposits mainly from fluid inclusions and Isotopic Data; International Symposium on the Pine Creek geosyncline, N.W. Australia, June; Extended Abstracts.

Ramaekers, Paul
1979a: Geology of the Middle Proterozoic Basins in the Athabasca area; Abstract of a talk given to Petro-Canada, Calgary, April 6.

1979b: Stratigraphy, Sedimentology, and Structural Geology of the Middle Proterozoic Basins in the Athabasca Area, Saskatchewan, Canada and their Bearing on uranium mineralization; International Uranium Symposium on the Pine Creek geosyncline, N.W. Australia, June; Extended abstracts.

1979c: The paleolatitude and paleomagnetic age of the Athabasca Formation northern Saskatchewan, Discussion; in Current Research, Part C, Geological Survey of Canada, Paper 79-1C, p. 117-118.

1979d: Stratigraphy of the Athabasca Basin; in Summary of Investigations 1979, Saskatchewan, Geological Survey, Miscellaneous Report 79-10, p. 154-160.

1980: Stratigraphy and Tectonic History of the Athabasca Group (Helikian) of Northern Saskatchewan; in Summary of Investigations, 1980; Saskatchewan Geological Survey, Miscellaneous Report 80-4.

Ramaekers, P. and Hartling, A.A.
1979: Structural geology and Intrusive Events of the Athabasca Basins and their Bearings on Uranium mineralization; in Proccedings of a Symposium on Uranium Exploration Techniques, ed. G.R. Parslow, Saskatchewan Geological Society, Special Publication no. 4, p. 221-234.

Ray, G.E.
1977: The geology of the Highrock Lake-Key Lake vicinity; Saskatchewan Geological Survey, Report 197, 29 p.

Rimsaite, J.Y.H.
1977a: Mineral assemblage at the Rabbit Lake Uranium deposit, Saskatchewan; a preliminary report; in Report of Activities, Part B, Geological Survey of Canada, Paper 77-1B, p. 235-246.

1977b: Occurrences of rare secondary U- and Pb-bearing mineral aggregates in uranium deposits, northern Saskatchewan; in Report of Activities, Part C, Geological Survey of Canada, Paper 77-1C, p. 95-97.

1978a: Layer silicates and clays in the Rabbit Lake uranium deposit, Saskatchewan; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 303-315.

1978b: Application of mineralogy to the study of multistage uranium mineralization in remobilized uranium deposits, Saskatchewan; in Uranium Deposits: their Mineralogy and Origin, ed. M.M. Kimberly; Short Course, Mineralogical Asociation of Canada, University of Toronto, p. 403-430.

1979: Petrology of basement rocks at the Rabbit Lake deposit and Progressive alteration of pitchblende in an oxidation zone of uranium deposits in Saskatchewan; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 281-299.

Robertson, P.B. and Grieve, R.A.F.
1975: Impact Structures in Canada: their recognition and characteristics; Journal of Royal Astronomical Society, Canada, v. 69, p. 1-21.

Robinson, S.C.
1955: Mineralogy of Uranium Deposits, Goldfields, Saskatchewan; Geological Survey of Canada, Bulletin 31, 128 p.

Ruhlmann, F.
1980: Qulques exemples de relation uranium-titane; Bulletin de Mineralogie, v. 103, p. 240-244.

Ruzicka, V.
1975: Some metallogenic features of the "D" uranium deposit at Cluff Lake, Saskatchewan; in Report of Activities, Part C, Geological Survey of Canada, Paper 75-1C, p. 279-283.

Schreiner, B.T.
1979: Reconnaissance Quaternary Geology Mapping, Northeastern Shield; Summary of Investigations, Saskatchewan Geological Survey, Miscellaneous Report 79-10.

Sibbald, T.I.I.
1976: Uranium metallogenetic studies, I: Rabbit Lake; in Summary of Investigations 1976; Saskatchewan Geological Survey, p. 115-123.

1977: Uranium Metallogenic Studies, I: Rabbit Lake, Geology; in Summary of Investigations 1977; Saskatchewan, Geological Survey p. 111-123.

Sibbald, T.I.I. (cont.)
1978: Uranium Metallogenetic Studies, Rabbit Lake: Geology; in Summary of Investigations 1978, Saskatchewan Geological Survey, Miscellaneous Report 78-10, p. 56-60.

1980: Geological Map, NEA/IAEA Athabasca Basin Test Area; in Summary of Investigations 1980, Saskatchewan Geological Survey Miscellaneous Report 80-4.

Sibbald, T.I.I., Munday, R.J.C., and Lewry, J.F.
1977: The geological setting of uranium mineralization in northern Saskatchewan; in Proceedings of a Symposium on Uranium in Saskatchewan, ed. C.E. Dunn, Saskatchewan Geological Society, Special Publication no. 3, p. 51-98.

Steiger, R.H. and Jager, E., compilers
1977: Subcommission on Geochronology: convention on the use of decay constants in geo- and cosmochronology; Earth and Planetary Science Letters, v. 36, no. 3, p. 359-362.

Stevens, R.D., Delabio, R.N., and Lachance, G.N.
1982: Age determinations and geological studies, K-Ar isotopic ages, Report 15; Geological Survey of Canada, Paper 81-2, p. 34-35.

Tan, B.
1977: Geochemical Case history in the Key Lake area; Proceedings of a Symposium on in Uranium in Saskatchewan, ed. C.E. Dunn, Saskatchewan Geological Society, Special Publication no. 3, p. 323-330.

Tapaninen, K.
1975: Geology and metallogenesis of the Carswell area uranium deposits; Canadian Institute of Mining and Metallurgy, Edmonton Meeting, Alberta.

1976: Cluff Lake; in Uranium Deposits of Northern Saskatchewan, Field trip A-1 guide book, ed. C.M. Trigg and G.N. Woolett, Geological Association of Canada and Mineralogical Association of Canada.

Tremblay, L.P.
1961: Wind striation in northern Alberta and Saskatchewan, Canada; Geological Society of America Bulletin, v. 72, p. 1561-1564, October.

1970: The significance of uranium in quartzite in the Beaverlodge area, Saskatchewan; Canadian Journal of Earth Sciences, v. 7, p. 280-305.

1972: Geology of the Beaverlodge mining area, Saskatchewan; Canada Geological Survey, Memoir 367, 265 p.

Tremblay, L.P. (cont.)
1978a: Uranium subprovinces and types of uranium deposits in the Precambrian rocks of Saskatchewan; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 427-435.

1978b: Geologic setting of the Beaverlodge-type of vein-uranium deposit and its comparison to that of the unconformity-type; in Uranium Deposits: their Mineralogy and Origin; ed. M.M. Kimberly, Short Course, Mineralogical Association of Canada, University of Toronto, p. 431-456.

1978c: Notes on possibilities for additional uranium deposits in Saskatchewan; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 437-439.

Turekian, K.K. and Wedepohl, K.H.
1961: Distribution of the elements in some major units of the earth's crust; Geological Society of America Bulletin, v. 72, p. 175-191.

Wallis, R.H.
1971: The geology of the Hidden Bay area, Saskatchewan; Saskatchewan Geological Survey, Report 137, 75 p.

Wanless, R.D., Stevens, R.D., Lachance, G.R., and Delabio, R.N.
1979: Age determinations and geological studies, K-Ar isotopic ages, Report 14; Geological Survey of Canada, Paper 79-2.

Wanless, R.D., Stevens, R.D., Lachance, G.R., and Edmonds, C.M.
1968: Age determinations and geological studies, K-Ar isotopic ages, Report 8; Geological Survey of Canada, Paper 67-2, pt. A, 141 p.

Watkinson, D.H., Heslop, J.B., and Ewert, W.D.
1975: Nickel sulphide-arsenide Assemblages associated with uranium mineralization, Zimmer Lake area, Northern Saskatchewan; Canadian Mineralogist, v. 13, p. 198-204.

Wendt, I., Hohndorf, A., Lenz, H., and Voultsidis, V.
1978: Radiometric age determination on samples of Key Lake Uranium Deposit; United States Geological Survey, Open File Report 78-701.

Wray, E.M., Ayres, D.E., and Ibrahim, H.
1982: Geology of the Midwest Uranium Deposit, Northern Saskatchewan; Canadian Mining and Metallurgy Regina Meeting, Saskatchewan, September, 1981.

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