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ONTARIO GEOLOGICAL SURVEY

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Huronian Geology and the Blind River Uranium Deposits

by

James A. Robertson

1983

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E.G. Pye, Director
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ABSTRACT

In the Blind River area Proterozoic clastic and sedimentary rocks and minor volcanic rocks (The Huronian Supergroup) uncomformably overlie and trangress northwards over dominantly granitic Archean terrane (2 500+ million years) and are intruded by Nipissing Diabase (2115 million years). Later deformation and metamorphic events are recognized. The developing depositional basin was controlled by the incipient Great Lakes Tectonic Zone marginal to the Algoman Craton.

The Matinenda Formation (basal Huronian) comprises northwards derived fluvial arkose,quartzite, and pyritic, uraniferous oligomictic conglomerate which contains some 2/3 of Canada's uranium resources. Production to date 98.3 thousand tonnes U average recovered grade 0.1% U. The remaining resources are at

lower grades. Some thorium and yttrium have been produced. Minor amounts of gold reflect the paucity in the source area. Gold is better-developed in the Huronian north of Sudbury reflecting the local source area.

The conglomerate beds lie in southeasterly-striking zones controlled by basement topography down sedimentation from uraniferous Archean granite. Uraninite textures, the distribution of monazite, and local enrichment by reworking indicate a syngenetic, probably placer, origin of the mineralisation. "Brannerite" has formed by solution of uranium from the margins of the uraninite grains and redeposition on the original titaniferous minerals. Penecontemporaneous volcanics may have been a source for sulphur in some of the pyrite and of trace amounts of Co Ni and Au. Some pyrite may be detrital, some may be authigenic and some introduced.

Drab coloured rocks, uranium and sulphide mineralisation, the presence of hydrocarbon (Thucholite) and a post-Archean regolith formed under reducing conditions have been cited as evidence of an early Precambrian reducing environment extended to the atmosphere. Sedimentary features indicating fast-flowing water and possibly a cold climate imply that the uraninite would be exposed to whatever oxygen was present in the atmosphere under conditions which would inhibit complete solution. In the upper Huronian, red beds and in the Lorrain Formation a monazite-iron oxide assemblage and copper mineralisation indicate more oxidising conditions.

Similar uranium deposits occur at Agnew Lake and in the basal Huronian north of Sudbury there are minor uranium and gold values.

Provenance, lack of complete oxidation, transportation and depositional processes, redistribution during diagenesis and possibly low grade metamorphism, and the lack of post-depositional destructive processes are the dominant factors in the formation and preservation of the ores. The modified placer theory of genesis is well entrenched and an exploration model for such deposits throughout the world is well-documented.

Research continues on mineralogy and textures of the ores, detailed sedimentology of the ores and their host rocks, with particular emphasis on: provenance area, the influence of early Precambrian mineralization patterns on the mineralization present in the Huronian both in space and in time.Fluvial sedimentation and diagenesis. Expansion and reopening of the mines of the Elliot Lake camp should facilitate further studies.

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Huronian Geology and the Blind River Uranium Deposits

by

James A. Robertson[1]

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[1] Policy Advisor, Mineral Resources Branch,
Ontario Ministry of Natural Resources,
Queen's Park, Toronto

Any opinions expressed in this paper do not necessarily express the view of the Ontario Geological Survey.

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INTRODUCTION

The Blind River uraniferous pyritic quartz pebble conglomerates were first identified in 1949 and since 1953, when their commercial importance was realised, the activities of mining companies, Ontario and Federal Government Geologists and of research workers in the universities have given rise to a large body of literature and other data, including comparison with other major uranium deposits.

The paper addresses the present knowledge of the deposits themselves with emphasis on the regional setting. It draws on earlier review papers, particularly Card et al 1972, Frarey 1977, Robertson, J.A. 1969a, 1976b, 1981a,b, Roscoe, 1969, Young, 1981 which provide extensive references to the earlier literature, and notes more recent papers. The entire area has been mapped in detail by the Geological Survey of Canada and the Ontario

Geological Survey. For references to individual maps and reports these authorities should be consulted. The region is covered by O.G.S. compilation maps at one inch to four miles (Giblin, et al (1979) and Card and Lumbers (1977). (Other papers in this volume are addressed to the economic history of the camp, and to specific aspects of the individual ore bodies or mines).

REGIONAL GEOLOGY

Blind River (fig.1) lies on the North Shore of Lake Huron, halfway between Sudbury and Sault Ste. Marie. The town of Elliot Lake, built to service the uranium mines, lies 20 miles northeast of Blind River. The names Blind River and Elliot Lake are both used for the deposits.

The region lies on the boundary between the Southern and Superior Provinces of the Canadian Shield. The Superior Province (Goodwin et al, 1972) comprises

Archean rocks that were affected by the Kenoran Orogeny(2,600 m.y. (million years)), and the Southern Province (Card et al, 1972) includes Proterozoic rocks affected by the Penokean Orogeny with a metamorphic culmination at 1,950 m.y. and the Hudsonian(?) orogeny with late orogenic granitic rocks at 1,750 m.y.). The Blind River-Elliot Lake area lies at the margin both of early Proterozoic sedimentation and of the mid-Proterozoic metamorphism: (Card et al 1972, Card 1978a,b). The Blind River area is contiguous with the "Original Huronian area" defined by Murray and Logan (1863) and recently remapped by Frarey (1977) and is now recognised as providing the principal reference section for the Huronian Supergroup (Robertson et al 1969 a,b). Regional mapping was undertaken by Collins (1925, 1933) and this formed the basis of all future work including the exploration of the Blind River camp.

To the west, equivalents of the Huronian Supergroup have been recognised in Michigan (Cannon, 1981) and in scattered areas of the Wyoming province (Young, 1973c, Roscoe, 1981, Houston and Karlstrom, 1979).

To the east, the Huronian has been traced to Sudbury and southeast to Killarney (Card (1978b), Frarey *in press*) and northeast to Cobalt-Noranda area with possible equivalent in the Otish Mountains. Whilst uranium mineralization is known at several localities production has only been achieved in the Blind River-Elliot Lake camp including Agnew Lake.

Table 1 is a Table of Formations using the momenclature recommended by the Federal-Provincial Committee on Huronian Stratigraphy (Robertson J.A.*et al*(1969), and table 2 permits comparison with schemes used in publications prior to 1969. Table 3 provides a synopsis of stratigraphy and its relation to mineralization. Uranium ores of the Blind River camp only occur in the Matinenda Formation. Table 2 also indicates the approximate absolute ages of the rock units. The data have been recompiled by Stockwell (1982) and where appropriate Rb-Sr ages have been recalculated using decay constant λ = 1.42.

The bedrock of the area falls into three broad uits, the distribution of which is shown on figure 2. These are (1) the Archean basement, consisting of Keewatin-type greenstone, Algoman granite, and minor mafic intrusives, (2) the Huronian sedimentary and metasedimentary rocks, with local mafic volcanics, and (3) Post-Huronian intrusive rocks, comprising the Nipissing Diabase sills, post-Nipissing Diabase Dikes, the Cutler Granite, the Croker Island Complex, and late Precambrian olivine diabase (Figure 5).

In the Elliot Lake-Blind River area, the Huronian Supergroup has been gently folded into westward-plunging folds, and the metamorphic grade is low. To the south and east, folding is severe and the metamorphic grade reaches the amphibolite facies; post-Huronian granite (Card, 1978a) occurs locally (Card *et al*. 1972; J.A. Robertson 1967.

ARCHEAN (EARLY PRECAMBRIAN)

The Lower Precambrian in the Blind River-Elliot Lake area has been subdivided into: Keewatin-type metavolcanics and metasediments, including minor cherty iron formations; pink to grey gneissic granitic rocks with abundant inclusions of Keewatin-type rocks; and massive, moderately radioactive, red quartz-monzonite see Fig. 2. The massive red quartz-monzonite has been recorded from a number of localities (J.A. Robertson 1976b, 1981b) and airborne gamma-ray spectrometry has confirmed that much of the terrain north and northwest of the Elliot Lake area contains anomalous amounts of uranium (Darnley and Grasty 1971; Richardson *et al.* 1975). Figure 5 shows the general correlation between anomalous uranium content and red quartz monzonite (red granite on Figure 5).

Charbonneau (1982) has shown that the granitic rocks of the Elliot Lake area contain approximately 4 times the ground equivalent uranium derived from the airborne data. Rb-Sr isotope studies show that these red granitic rocks are little contaminated by pre-existing crustal rocks.

The author believes that these massive red quartz-monzonite bodies and related pegmatite (now eroded) were the source material for the Elliot Lake uranium deposits. J.P. McDowell (1957),p.35) proposed that the source area lay 210 to 400 km west-northwest of Thessalon in the Montreal River-Lake Superior area, which is characterized by low-grade uraniferous pegmatite and Late Precambrian pitchblende occurrences. (J. Robertson 1981b, J. Robertson and Gould 1981, 1982).

After the Early Precambrian (Kenoran) orogenesis, the area was peneplaned and local topography was controlled by basement lithology and structure. (Fig. 6).

Throughout the Blind River area partially weathered zones (regolith) have been preserved under the Huronian-Archean unconformity and, particularly, over the granitic rocks. As the actual contact is approached, the plagioclase feldspar grains of the granitic rocks become yellow, owing to the development of sericite, and the ferromagnesian minerals disappear; the granitic texture is preserved by the quartz and microcline crystals. This material passes into an unsorted aggregate of partly corroded quartz and microcline grains in a yellow-green matrix of sericite. Rarely, angular fragments of vein quartz and patches of less-altered granite may be present. This material is overlain by sorted sericitic arkose, in which bedding and crossbedding are generally visible. At Pronto Mine the ore bed overlies the regolith, J. Robertson 1970 and this volume p.

Poorly-developed regolith has also been postulated over Archean volcanic rocks (Rice 1958).

Fig 5. derived from analyses by Pienaar (1963) and J. Robertson (1960 and later) illustrates the compositional relationship of the regolith to the parent granitic rock showing.

1. Silica is constant, and a slight gain in alumina.

2. Zirconia is constant, reflecting stability of zircon.

3. Total iron shows marked loss; ferric iron is lost more completely than ferrous.

4. Magnesia and manganese have been partially lost.

5. Lime and strontium and soda have been markedly reduced.

6. Potash, rubidium, and water (+) are strongly increased.

These observations reflect (1) the destruction of the plagioclase and the removal of the soluble constituents, (2) the stability of the potassic feldspars (microcline), and (3) the formation of hydrated clay minerals represented by sericite. The trace elements follow the major elements in the pairs: Mn-Mg, Rb-K, and Sr-Ca.

Total iron has been lost, suggesting that Fe_2O_3 has been converted to F_e0 and removed by leaching. Such reduction may have been owing to the exclusion of the iron from the atmosphere by overlying material or to an atmosphere deficient in oxygen.

Roscoe and Steacy (1958,p.4-5) studied the distribution of uranium and thorium in two series of saprolite (regolith) samples from the Quirke Lake area of Township 144. They stated, "Both show uranium to be about one-third less in the most altered samples than in the freshest granite. One shows a proportional loss of thorium which is only slightly less than the loss of uranium. The other shows a net gain of thorium".

As regolithic material contributed to the formation of the uraniferous, pyritiferous, oligomictic conglomerates of the basal Lower Huronian, the presence in the regolith of F_eO (ferrous iron) and the persistence of uranium normally soluble in an oxidizing environment are of interest, whatever the cause of reduction.

Many authors, for example Roscoe (1969, 1973) and D. S. Robertson (1974), have suggested that this and/or other features of the uraniferous sequences implies a reducing atmosphere. Similar conditions elsewhere in the world during the later Archean or at the Archean-Proterozoic boundary are similarly considered to suggest a reducing (anoxygenic) atmosphere which presumably provided a chronological control on the Blind River type of uranium deposits (D. Robertson et al 1978; Roscoe 1973; Smith 1974). E. Dimroth and M.M. Kimberley (1976) have concluded from a study of the distribution of sedimentary carbon, sulphur, uranium, and iron that it is not necessary to invoke an oxygen-deficient atmosphere. Grandstaff (1974, 1980, and Gay and Grandstaff (1980) as part of studies on uraninite kinetics analysed serial samples from regolith profiles and noted that in the uppermost portion of the regolith Fe_2O_3 was enriched relative to FeO indicating that minor amounts of oxygen might have been available at the regolith surface. Astronomical evidence has been obtained indicating that early planetary atmospheres were not necessarily reducing but that oxidized components were present (Henderson-Sellars *et al* 1980).

PROTEROZOIC (MIDDLE AND UPPER PRECAMBRIAN

Huronian Supergroup

The Huronian Supergroup unconformably overlies the Archean rocks. The classical descriptions were given in Logan (1863) and Collins (1925). Recent work has resulted in several revisions of Huronian stratigraphy (Robertson J.A. *et al* 1969), including the recognition of the cyclical nature of much of the sequence and the presence of mafic volcanic rocks near the base of the sequence at many localities (Roscoe, 1969; Robertson, J.A. 1971b).

ELLIOT LAKE GROUP

The lowermost group of the Huronian is the Elliot Lake Group, comprising the Matinenda and McKim Formations and local predominately mafic volcanic assemblages. In the Blind River-Sault Ste. Marie area a basal quartzitic unit lying between the Thessalon volcanics and the Archean has been given formational status, (Frarey 1967, 1977) and named the Livingstone Creek Formation.

MATINENDA FORMATION

The Matinenda Formation is the host formation for all commerical uranium deposits found in the eastern Southern Province.

The thickness of the Matinenda Formation increased from 0 at the north shore of Quirke Lake through 600 ft (180 m) near Elliot Lake to 700 ft (210 m) on the north side of the Murray Fault at the Pronto Mine. Superimposed on the regional pattern are the effects of basement highs and lows. The formation has not been recognized south of the Murray Fault east of Algoma, but it underlies Lake Huron west of Blind River. As northward overlap is pronounced (fig. 4) the ore-beds at Nordic are older than those at Quirke. If the northward overlap were not disrupted by basement highs, the ore beds at Pronto, would be older again (D. S. Robertson, 1974) but in the absence of continuous marker horizons this cannot be proved.

To the east of Pronto Mine the formation is locally missing along the flanks of a regional basement high. It is present north of Spanish and again near Massey where it is interbedded with the Salmay Lake Volcanics (J. Robertson 1976a,b). In May and Shakespeare, the combined assemblage attains 1000 feet (300 m) and in Hyman Township in the Agnew Lake enclave the Matinenda Formation is 700 feet (200 m) but is missing to the west. To the east of Agnew Lake it thickens to 2000 feet (600 m) in eastern Hyman and Drury Townships passing laterally into the Stobie and McKim Formations of the Sudbury area (Card, 1978b). Only locally can Matinenda lithologies (with very minor uranium bearing conglomerate) be recognised in the Sudbury, South Lake Wanapitei area.

In the Elliot Lake area the distribution and facies of the Matinenda Formation is profoundly influenced by the underlying geology which may be either Archean basement or Huronian Volcanics. The rock types present are sericitic arkose, generally greenish in colour, grey to buff feldspathic quartzite, pyritic uraniferous quartz pebble conglomerate and polymictic conglomerate. The uraniferous quartz pebble conglomerate reefs are largely confined to the arkose sequences which in turn are confined to the basin margin and depressions in the Pre-Matinenda surface.

Roscoe, (1981) modifing earlier work (Roscoe, 1969, Pienaar, 1963) within the Quirke Syncline divided the formation into members see fig.6: 1) The Ryan member (the Nordic and Pardee-Pecors mineralised zones of J. Robertson, (1976b, 1981a,b) and fig.12: 2) the Stinson member which comprises a lower conglomeratic member characterized by volcanic fragments derived from early Huronian volcanics and an upper grey feldspathic quartzite and 3) On the north limb of the Quirke Syncline overlying the Stinson but overlapping on to the basement is the Manfred member - the Quirke mineralised zone of J. Robertson (1976b, 1981a,b and fig. 12).

Studies on cross-bedding style and direction McDowell(1957), Pienaar (1963), Roscoe (1968), J. Robertson (1960 et seq), indicate northwest-southeast transportation reflecting basement topography. Studies on pebble size and orientation (Pienaar (1963) Theis (1979)) show similar trends which can be correlated with heavy mineral distribution, and thorium analyses. Uranium analysis trends are less clear but reflect redistribution during diagenisis. Similar information for the south limb is less well-documented and modern research must await reopening of the mines.

Rupert et al (1972), and recent workers on sedimentation have indicated that long-shore currents may have reworked deposits laid down by the predominantly fluvial southeasterly currents.

D. S. Robertson has suggested that deltaic processes rather than braided stream systems were dominant. Comparison with the more-clearly deltaic portions of the Rand deposits (Skinner 1981, Minter 1981) including the presence at Elliot Lake of only extremely localised hydrocarbon facies indicates that deltaic fans have not yet been unequivocably recognised in the Elliot Lake camp.

In the western part of the Quirke Syncline diamond drilling has revealed a diffuse mineralized zone, (the Moon Lake zone of Robertson 1976b, 1981a,b, Fig.12: and the Keelor member of Roscoe, 1981). This member clearly overlies the Dollyberry Volcanics and may also overlie the Stinson member. The Stinson and possibly the Manfred members grade vertically and laterally into the McKim Formation which is present only in the eastern portion of the south limb of the Quirke Syncline.

When Huronian volcanics were identified in the Quirke Syncline (Robertson J.A., 1971b) it was postulated that quartzite units with minor uraniferous conglomerate underlying the Dollyberry Lake Volcanics were Matinenda equivalent and Roscoe (1968, 1981) placed them in his Ryan member. Bennett (1978, 1981) however has correlated ~~them~~ an upper uraniferous sequence with the basal Thessalon Formation and a lower sandstone sequence with the Livingstone Creek Formation recognizing a regolith and a sedimentation gap between them; Bennett considers that the uraniferous Matinenda Formation overlies the volcanic sequence uncomformably.

It should also be noted that to the east of Nordic Mine J. Robertson identified Huronian volcanic rocks (correlated with the Dollyberry-Thessalon Volcanics by Bennett, 1981) under the Ryan Member (Fig.). Robertson (1971b) and Bottrill (1971) would possibly correlate these unnamed volcanics with the Salmay Lake Volcanics of the south limb of the Chiblow Anticline. These authors and several company geologists have also identified Ryan member overlying southern extensions of the Dollyberry Lake Volcanic.

More detailed work and re-examination of drill core if it is still available, is required to further elucidate the relationship of the members of the Matinenda and McKim Formations. The Matinenda Formation outside the Quirke Syncline is less amenable to stratigraphic subdivision.Round the nose of the Chiblow Anticline it is markedly radioactive (J.Robertson 1976b, 1981a,b and Fig.4) but the only deposit found was the original discovery at the Pronto Mine which is located on the flank of a regional basement high. Between Spanish and the

Sudbury area the Matinenda Formation is intermittently recognised. It is the host formation for the Agnew Lake Deposit, J. Robertson (1976b) and Card (1978b) indicate that in this area the Matinenda and the Huronian Volcanics interdigitate.

Ruzicka (1979, 1981) has reported that thucholite is present in the scattered uranium bearing quartz pebble conglomerates near Massey.

McKIM FORMATION

The McKim Formation comprising metagreywacke, quartzites and argillites is well exposed in the Sudbury-Espanola area (Card 1976, 1978b, Roscoe 1969). It is less well exposed between Espanola and Pronto Mine with metamorphosed rocks present south of the Muray Fault and unmetamorphosed rocks to the north

(J. Robertson 1970, 1976a). McKim Formation argillaceous rocks are found on the south limb of the Quirke Syncline between Elliot Lake and Whiskey

Lake (Roscoe 1969, J. Robertson 1961, 1962) where drill hole data indicates a maximum of 250 feet but dies out rapidly to the north and to the west-northwest. McKim Formation is not recognised in the area west of Blind River mapped by Frarey, (1977).

In the type area near Sudbury, the Formation is some 6000-8000 feet (1800-2600 meters) thick and comprises thickly-bedded greywackes characterised by partial or in some cases complete Bouma cycles. Although metamorphosed, primary structures such as bedding, graded bedding, planaar and convolute laminations, flame structures, ball and pillow structure, and cross-bedding are generally well preserved. Westwards the arenaceous component increases, the formation thins and the turbidites are distal rather than proximal. The formation also thins eastwards toward the Grenville Front and southward toward Manitoulin Island. Intercalation of volcanic rocks and Matinenda Formation is observed in the central and eastern area (Massey to Grenville Front), (Card, 1978b, J. Robertson, 1976a). In the west central area and in parts of the Elliot Lake area if the Ramsay Lake Formation is missing it may be difficult to place the contact between the McKim and the Pecors Formations - normally the latter has more turbidite features and the former more argillite. Both J. Robertson (1969a) and Card (1978b) have related the distribution and facies changes of the McKim Formation to the hinge zones or incipient faulting at the margin of the Huronian sedimentaiton basin or what is now called the Great Lakes Tectonic Zone. In the southern Elliot Lake Espanola, Sudbury area the formation is weakly to strongly metamorphosed and distribution of minerals such as staurolite garnet, and chloritoid can be readily mapped demonstrating the nodal metamorphism described by Card, 1964, 1978a.

VOLCANIC ROCKS

In the Blind River area (fig.2) mafic volcanic rocks are found at Thessalon, Dollyberry Lake, near Nordic Mine, Pater Mine, and in the vicinity of Massey. One outcrop at Pronto Mine may be a Post Archean agglomerate (J. Robertson 1970). Thick volcanic assemblages have also been recognised northeast of Sault Ste. Marie and were named Thessalon Formation (Frarey 1967, 1977). Bennett 1978 has correlated all the volcanic rocks and minor intercolated arkose and radioactive conglomerate from Elliot Lake to Sault Ste. Marie with the Thessalon Formation of Frarey. Local underlying grey sandstones and polymitic conglomerate, ~~both polymictic and oligomictic~~, are placed in the Livingstone Creek Formation of Frarey (1967). Bennett restricts the Matinenda Formation to arkosic rocks which overlie the volcanics uncomformably. Characteristically the rocks are massive and dark green to black and only locally show feldspar phenocrysts and amygdules. Ropey texture and flow-top breccias are recognised, and pillows are very rare or absent: these features and locally preserved regolith indicate a subaerial environment. Pillows have been observed in the upper part of the Thessalon Formation in Duncan Township (Bennett, 1978, 1981), suggesting transition to submarine deposition. Locally at Thessalon, Dollyberry Lake and Massey, but better developed at Sudbury (the Copper Cliff Rhyolite) intermediate or felsic flows are found. So far, attempts to date these suggest a date of about 2,400 m.y. (Fairbairn and others, 1969), but a reliable isochron or zircon (Pb) age needs to be established. J. A. Robertson (1969a) has pointed out the close spatial relations to two major fault zones, the Murray and the Flack, which are also zones of marked change in sedimentation and expressions of the boundary of the developing Great Lakes, Tectonic zone. Symons and O'Leary (1978) studied the paleomagnetism of the Thessalon Volcanics and on the basic of a primary age of 2375 ± 75my concluded that resetting had taken place at 2040 ± 50my. They further concluded that the volcanics had been extruded at a latitude of 35° indicating that the contemporaneous uranium deposits were formed in a warm temperate climate. However, further work (Stupavsky and Symons in press, Symons personal communication) based on the Dollyberry volcanics indicates evidence for two post extrusion remagnetisations at 2215 ± 60 my and 1900± 100my and the conclusions concerning the original latitude of the volcanics and the deduction concerning the uranium deposits have been withdrawn. Innes (1974, 1975) has studied the volcanic rocks between Sudbury, and Massey which are pillowed, interlayered with arkose and conglomerate rocks of Matinenda type. Locally interlayered sediment hosts layered sulphide deposits. The Massey Copper belt is related to the gabbro-anorthosite the Salmay Lake, the Pater volcanics are in the metamorphic zone south of the Murray Fault but show an affinity to the Salmay Lake volcanics (Robertson J.A. 1970, Bennett 1978). The Pater copper deposit lies in a silicified shear zone which transects the Pater volcanics (see also Pearson 1977). These data and limited work on the rocks at Massey (J.Robertson, 1976a) and Dollyberry Lake(J.A. Robertson), show the rocks are subalkaline tholeiites and host iron and copper sulphides; some units are Mugearites or Hawaiites (Bennett, 1978, 1981). Between Massey and Sudbury, layered gabbro-anorthosite instrusive bodies are found cutting Archean rocks; these are probably part of the same igneous cycle as the volcanic rocks and have similar chemical affinities (Card 1978b, J. Robertson 1976a).Bennett (personal communication 1982) has been unable to confirm a postulated unconformity on top of the gabbro-anorthosite complexes.

The known uranium ore bodies are marginal to the volcanic piles, which may have physically controlled the depositional currents in the same way as the topographic highs reflecting basement geology. (J. Robertson 1976b, 1981a,b, Roscoe, 1981).

Emanations from the volcanism may also have contributed sulphur to convert detrital magnetite to pyrite in the sediments (J. Robertson 1971b). Ross (1981) has further postulated that trace amounts of gold and elements such as Cu,Ni,Co in the pyrite of the ores may reflect volcanogenic derivation.

HOUGH LAKE GROUP

The Hough Lake Group comprises the Ramsay Lake Formation, polymictic paraconglomerate; the Pecors Formation, argillite; and the Mississagi Formation, quartzite.

RAMSAY LAKE FORMATION

The Ramsay Lake conglomerate consists of pebbles and cobbles of grey granite, quartz, and mafic igneous rocks scattered in a dark grey greywacke-to-quartzite matrix characterised by large grains of smokey quartz and pyrite. The lithology indicates mass transportation and an association with graded greywackes with dropped clasts suggests ice rather than mud flow as the transportation medium, (J. Robertson 1968a, 1976b, Card 1978b, Young, 1970). A crude bedding, particularly in the south, the presence of mud cracks and ripple marks on the upper surface, and crossbedding in quartzite or greywacke lenses indicate deposition in shallow water.

On the North Shore of Quirke Lake the Ramsay Lake Formation rests directly on basement (J. Robertson, 1961 1968a), but in the Quirke, Denison, and Panel Mines it truncates the uraniferous horizons in the Matinenda Formation and is both slightly radioactive and potassic. Ross, (1981) indicates that the reworked material is also enriched in pyrite and in gold. Elsewhere where the Ramsay Lake Formation truncates arkose; the basal part of the formation is both lighter in colour and more potassic than the upper part, reflecting incorporation of material from the Matinenda Formation.

The formation thickens from 0-15 ft (0-4.5 m) at northernmost outcrops to more than a thousand feet (300 meters) in the Espanola-Sudbury area (Card _et al_, 1972). The Ramsay Lake Formation indicates that the general climate was cold and that the uranium mineralization was syngenetic.

PECORS FORMATION

The Ramsay Lake Formation is followed conformably by the Pecors Formation, which comprises a sequence of argillites in the Quirke Lake-Elliot Lake area, or argillites, siltstones, and quartzites on the south limb of the Chiblow Anticline, and of siltstones and argillaceous quartzite where found to the south of the Murray Fault. The transition zone from the Ramsay Lake conglomerate comprises argillite, which may include varvite with dropped clasts (J. Robertson, 1968a), but locally a quartzite bed may be present. The argillites are frequently ripple marked. On the south limb of the Chiblow Anticline and south of the Murray Fault, ripple marks, microcrossbedding, and slumpage structures are characteristic. (J. Robertson 1976a). Some beds contain partial Bouma units and are possibly distal turbidites.

The thickness ranges from 100 ft (30 m) at Quirke Lake (J. Robertson, 1961, 1968a) to about 1,000 ft (300 m) south of the Murray Fault (J. Robertson, 1976a), but the formation may be missing over well-developed basement highs, and its thickness is markedly reduced over the crest of the Chiblow Anticline. This reduction is in sedimentation thickness and not due to folding. On the flank of a basement high running from Chiblow Lake to the Cutler-Massey area some of the argillaceous beds of the Pecors Formation are moderately radioactive (J. Robertson, 1976a, p.46). From Massey to Sudbury the Pecors Formation is up to 3000 feet thick but in the northern fringe may be missing. In the most southerly sequences greywackes showing Buoma cycles and slumpage features are common (Card 1978b).

Away from the central Huronian area the lower Huronian stratigraphy is less clear cut. Argillaceous rocks at the base of the Huronian in the Cobalt Embayment are generally included in the Mississagi Formation but may be correlative in part with the Pecors and Ramsay Lake Formations (Long 1977 1978, 1981). Similarly to the west the Aweres Formation, also correlated with the Mississagi (Frarey 1977), may also include a correlative of the Pecors.

MISSISSAGI FORMATION

The Mississagi Formation consists of greenish arkose on the north limb of the Quirke Syncline. This passes upwards and southwards into well-bedded grey quartzite, but adjacent to basement highs the yellow-green colour and increased feldspar content are again characteristic. Thickness ranges from 600 ft (180 m)at Quirke Lake to 1,500 ft (460 m) near Elliot Lake (J. Robertson, 1961, 1968a) and to 2,700 ft (820 m) on the south limb of the Chiblow Anticline as exposed both north and south of the Murray Fault at Blind River (J. Robertson, 1964). Current direction was from the northwest, and the influence of basement topography was much diminished. Scour and fill structures are common in the arkosic quartzites and planar in the grey quartzite.

Along the north limb of the Quirke Syncline and again adjacent to the Chiblow-Cutler basement high the yellow-green arkosic phase is characterised by radioactivity. Uranium and thorium, as well as potassium, is revealed by -ray spectrometry (Darnley and Grasty, 1971). In the northern section thin pyritic quartz-pebble bands, carrying trace uranium and thorium mineralization, are found (J. Robertson, 1963).

As noted in the Sudbury and Cobalt-Embayment areas, the Mississagi Formation shows pronounced facies changes. In the latter area (where it was formerly known as the Wanapitei quartzite) sedimentation cycles with pronounced cleaning upwards diagnostic of marine deposition (Palonen 1973 Card 1978) are found. Sedimentation directions are mixed reflecting introduction of material from both sides of the Sudbury regional high (Card et al 1972, Card 1978b, Long 1978). In the latter area mixed lithologies are present and include quartzite, argillaceous quartzite, oligomictic and polymictic conglomerate, and argillite possibly representing flood plain deposits adjacent to a braided stream system. Several of these lithologies carry uranium mineralisation and gold has been recorded (Meyn

1979, Meyn and Matthews 1980).

At the west end of the Huronian belt similar impure quartzites are found in the Aweres Formation (Frarey 1977) but there is less evidence of mineralisation.

The marked facies changes in the Mississagi Formation account for the differing descriptions and interpretations of the formation. Further study will doubtless lead to recognition of members based on lithology, sedimentation and facies studies. Apart from individual Provincial and Federal Township and map-area reoprts, the principal regional discussions of the formation are given by Palonen 1973 and Long 1978.

McDowell, 1957 (fluvial) and Pienaar 1963 (near shore deltaic). Farery and Roscoe, (1970) favoured flucial deposition but Pettijohn 1970 on general grounds, Card (1978b) and Palonen (1973), based on their experience of the Sudbury-Espanola area, favoured regressive marine cycles

Long's reconstruction (1977) interprets northwesterly to northerly derivation from granitic terrane in the central to western Huronian, northwesterly derivation from a granite-greenstone terrane in the Cobalt Embayment and mixing of the two systems in the Sudbury-Espanola wedge. In the latter area Card (1970) and Palonen (1973) would further involve marine deposition. J. Robertson (1976b, 1981a,b) noted the influence of basement particularly when granitic on the composition and mineralisation of the formation.

QUIRKE LAKE GROUP

The Quirke Lake Group comprises: polymictic paraconglomerate of the Bruce Formation; carbonate and siltstone of the Espanola Formation; and quartzite of the Serpent Formation.

BRUCE FORMATION

The Mississagi Formation is overlain disconformably by the Bruce Formation - a conglomerate that consists of boulders of white granite and greenstone in a partly sorted, slightly pyritic, siliceous greywacke matrix. The Bruce Formation is probably a tillite that has been subjected to some sorting. Locally, dropped clasts have been seen in varvite lenses (J. Robertson 1964, 1971b, Card 1978b). The conglomerate can be traced throughout the entire district. In the Elliot Lake area unit is generally less than 200 ft (60 m) thick (fig. 4) missing in places, and elsewhere there are channels of boulder conglomerate up to several hundred feet in thickness.

The close similarity to the Ramsay Lake Formation should be noted (table 1). Like the latter it was formed by glacial and fluvioglacial processes (J. Robertson 1971b, 1976b, 1981a,b, Young, 1970).

The matrix is more siliceous and is characterised by more pyrite and the lime and soda contents (Fig.8) are greater than in the Ramsay Lake Formation. Where metamorphosed, the pyrite is replaced by pyrrhotite, and the formation has a magnetic expression. The basal part of the formation contains reworked material from the underlying Mississagi Formation, but to the south and east the contact is sharp and non-erosional (Card 1978b). In the Agnew Lake area the features resemble the Elliot Lake sequence. In the Espanola belt the unit is better bedded, contains quartzite layers and reaches a maximum thickness of 1500 feet (450 meters) but thins eastwards toward the Grenville Front. Further south the formation is again thinner and is locally missing.

To the west (Frarey, 1977), the formation is less well-developed than in Elliot Lake and variations in lithology and thickness are ascribed to local conditions. The massive sparse conglomerate and the increasing marine character to the southeast remain the dominant features

ESPANOLA FORMATION

In the Blind River area the Espanola Formation consists of three units: a lower unit, characterized by limestone, a middle unit, characterized by mudstone and greywacke, and an upper unit having a marked development of ferruginous dolomite. Near Espanola an upper crossbedded quartzite member is present (Card, 1976, 1978b).

The limestone member consists of thinly interbedded cream-coloured limestone and siltstone. Differential weathering and small scale folding (in part tectonic and in part soft sediment slumpage) give the rock a spectacular appearance. Where the unit is complete, the thickness is generally 100 ft (30 m).

The siltstone and dolomite members can be distinguished from each other only by the brown-weathering ferruginous dolomite bands in the latter. Both members are characterized by intraformational breccias, siltstone and congolmerate dikes and sills, mudcracks, ripple marks, flame structures, ball and pillow structures and penecontemporaneous faults (Collins 1925, J. Robertson 1968a, 1971b, Eisbacher 1970, Card 1978b, Young 1973b, 1981). These features indicate shallow-water deposition, possibly tidal flats and incipient tectonic disturbance. Young, 1973b, 1981 interprets the formation as shallow water to tidal post-glacial marine with minor turbidite and in the south a prograding fluvial member not deposited in the north. In the Agnew Lake area the unit is 700 feet (200 m) thick, thickening southwards to between 1000 and 2000 feet (300 - 600 metres) and thinning eastwards to the Grenville Front. Depositional structure, slumpage and diagenitic features are common (Card 1978b). Metamorphic and deformational features such as development of scapolite and flowage pinch and swell features are common (Card 1978b, J. Robertson 1976a). The conglomerate dikes at Espanola are world-famous.

In the area to the west mapped by Frarey (1977) the Espanola Formation has much the same character as in the Elliot Lake area but reaches a slightly greater maximum thickness 600 feet (180 m). Frarey (1977) emphasised the usefulness of the unique lithology as a marker horizon in mapping (and drilling). Occasional quartzite beds, which are more common to the northwest, show crossbedding that is indicative of a northwesterly derivation. Where complete, in the Quirke Syncline, the thickness of the siltstone member is 300-400 ft (90-120 m) and that of the dolomite member is 150 ft (45 m).

This unit is of considerable interest, as it represents an early carbonate. The presence of carbonate and of iron suggests that the environment contained some free oxygen.

SERPENT FORMATION

The Espanola Formation is overlain by the Serpent Formation, a white feldspathic quartzite with conglomerate sections and minor siltstone

The quartzite is strongly crossbedded and generally calcareous. Crossbedding, and lithology and thickness changes in individual members, again indicate derivation from the northwest. Ripple marks, mudcracks, and windblown grains, indicate shallow-water conditions the environment being fluvial subaerial to shallow marine (Young 1981, Young *et al* 1977).

In contradistinction to the earlier arkosic units of the Elliot Lake area the dominant feldspar in the Serpent Formation is oligoclase indicating derivation from the grey granitic terrane.

J. Robertson, (1976a, 1977) in the Cutler-Espanola area and Card (1976, 1978b) in the Espanola-Sudbury area described similar variation in thickness up to 5,000 feet (1,500 meters). The formation comprises a lower feldspathic sandstone with minor carbonate and siltstone and an upper quartzite unit thicker bedded and with less carbonate and siltstone: polymictic lag conglomerates are present and a wide variety of bedding and crossbedding styles.

Rapid changes in thickness are a reflection both of the depositional basin and of post-depositional folding and erosion prior to or during early deposition of the overlying Gowganda Formation. Long (1978) postulated a distal braided stream environment with eolian influence and suggested that discontinuous calcarceous siltstones were playa or sabka deposits. To the west at Bruce Mines and Ophir (Frarey, 1967) describes limited exposure of

Serpent Formation but elsewhere the Serpent was either not deposited or removed by erosion. Where present thickness reaches a maximum of 800 feet (240 m) and lithology resembles the Quirke Lake sequence.

COBALT GROUP

The Quirke Lake Group is overlain unconformably by the Cobalt Group, which, in the Blind River-Elliot Lake area, consists of the Gowganda Formation, the Lorrain Formation, the Gordon Lake Formation, and the Bar River Formation.

GOWGANDA FORMATION

Within the map area (fig.2), the Gowganda Formation rests on all formations between the Mississagi and the Serpent; in the Mount Lake and Kirkpatrick Lake area, north of the Flack Lake Fault (J. Robertson, 1971b; Siemiatkowska 1981), it rests on the Archean basement. Locally, the contact can be seen truncating the bedding of the underlying formations and consolidated or partly consolidated fragments of the underlying rocks are found in the lowermost beds of the Gowganda Formation (Pienaar 1963, J. Robertson 1961, 1963b); elsewhere, the contact is a "soft-sediment" contact, (Frarey 1977) and in yet other localities it is a knife-sharp contact.

The Gowganda Formation is a heterogeneous assemblage of conglomerate, greywacke, quartziete, and argillite. These rock types are found throughout the sequence, although the lower part is characterized by boulder conglomerate, in which red granitic clasts predominate and the upper is characterised by quartzite and argillite. This two-fold division is particularly pronounced in the vicinity of Cobalt where R. Thomson (1957) proposed that the two units be ascribed formational status and be named the Coleman Formation and the Firstbrook Formation. The Federal-Provincial Committee on Huronian Stratigraphy (J. Robertson _et al_ 1969) decided that the term Gowganda Formation should be retained on a regional basis and therefore that the Coleman and Firstbrook units were more properly members. Wood (1973) further discussed upper Huronian Stratigraphy and pointed out that however difficult the division may be to map throughout the southern Province it did mark the middle unit of a Huronian cycle which comprised the two Gowganda units and the overlying Lorrain Formation. In the lower Huronian such cycles had been used to define the Groups. Wood suggested that the lower Gowganda be called Gowganda Formation, the upper Gowganda be renamed LcCloche Formation and that the Cobalt Group be restricted to the 3-gold cycle and the Bar River and Gordon Lake Formations be placed in a new group, the Flack Lake Group. Whilst recognising the principle behind the suggestion most recent pulbicaitons have continued to use traditional nomenclature for the upper Huronian. Within the Quirke Syncline, the Gowganda Formation is about 1,700 ft (510 m) thick

(Robertson, 1963a). To the west, in areas mapped by Frarey (1977), it is at least 3,000 ft. (900 m thick). To the north near Mount Lake, the formation lies on basement rocks and is less than 500 ft (150 m) thick (Wood, 1975). To the south in the La Cloche Syncline, the Gowganda Formation is some 4,200 ft (1,260 m) thick (J. Robertson, 1976a) at La Cloche Lake and in the Willisville-Espanola area (Casshyap, 1966, 1968, Card 1978b). The conglomerate matrix is fine grained, chloritic, and characterised by high soda content relative to the lower Huronian polymictic conglomerate (fig. 8). Detailed sedimentological and stratigraphic accounts of the southern facies of the Gowganda Formation are given by Casshyap 1966, 1968 and Card, 1978b. Frarey, 1977 gives similar attention to the western area emphasising the soft-sediment contact with the Serpent Formation, the variable lithology including para-conglomerate and varved argillites with dropstones and slumpage features particularly in the upper well-bedded sequence.

The origin of the Gowganda Formation has been much discussed. Dense boulder conglomerates, quartzites, and argillites were definitely water laid; varved conglomerates and greywackes probably formed under conditions characterized by alternate freezing and thawing, although some authorities would ascribe these rocks to turbidity currents; and sparse boulder conglomerates with a disrupted greywacke matrix may be either tillites or mudflow deposits. Slumpage breccias are characteristic of the upper Gowganda Formation, Frarey, 1977, Meyn, 1973, Young, 1981. Ovenshine (1965) has described the structures of the Gowganda Formation of the Elliot Lake-Blind River area and has endorsed a glacial environment, particularly on the basis of numerous dropped clasts in graded greywackes. In the southeast part of the area shown in figure 2 and in the areas to the east mapped by Card (1978b) and Casshyap (1966, 1968), a marine rater than a continental glacial environment is indicted (Lindsey, 1966). Some clasts are striated, but J.A. Robertson (1971a) has questioned the use of this feature as a criterion for glacial action by Lindsay et al, 1970 and suggests that the striae are due to postdepositional tectonism, as described by Bielenstein and Eisbacher (1969). Striated pavement beneath the formation has been reported by Cooke (1922) and Schenk (1965). The latter has been re-examined and considered to be tectonic. Of particular interest is the presence of iron oxide in the Gowganda Formation. The arkosic quartzites are red to pink in colour, reflecting the preservation of hematitic dust in the feldspar and interstitial material. Some thicker beds of argillite or siltstone contain magnetite and anomalies corresponding to zones of such material can be traced on regional magnetic maps. (J. Robertson 1963a, 1976a). No significant uranium anomalies have been identified, but scattered thorium and potassium values (Richardson et al, 1975) reflect the granitic content of the conglomeratic lower portion of the formation. The lack of a preserved regolith at the Archean surface (J. Robertson 1971b; Wood, 1970) may indicate oxidizing rather than the reducing conditions that prevailed during the deposition of older lower Huronian sediments elsewhere in the district (J. Robertson, 1969a, 1976b, 1981a,b; Roscoe, 1969; Wood, 1970).

LORRAIN FORMATION

The Lorrain Formation conformably overlies the Gowganda Formation. In the Flack Lake area several units have been mapped within the Lorrain Formation in the following ascending stratigraphic order: (1) pink ferruginous quartzite and minor siltstone, (2) coarse grained green arkose, (3) pink coarse hematitic arkose with radioactive (thorium:uranium >10:1) quartz-pebble conglomerates (J. Robertson, 1971); (4) interbedded pink and buff quartzite and, in a few places, greenish quartzite (quartz-chert-jasper pebble bands are characteristic of the upper part of this member), (5) massive white quartzite, with quartz-chert-jasper pebble bands in the lower part. Sericite, kaolinite, pyrophyllite, and diaspore are found replacing feldspar in upper unit (2) and (3) and in the nonfeldspathic beds of members (3) (4) and (5) (Chandler et al, 1969 J. Robertson 1971b) and indicate the onset of warm rather than frigid conditions (Wood, 1973, Young, 1970). Crossbedding is common in the Lorrain Formation in the Flack Lake-Mount Lake-Rawhide Lake area but is variable; southwesterly current direcitons have been interpreted by Hadley (1969) and by the writer. North of Bruce Mines, Hadley (1969) deduced southeaserly current directions. The same members can be recognized and traced in the La Cloche Lake-Whitefish Falls area (Card, 1976, 1978a; Chandler, 1969, J. Robertson, 1976a) but the individual members are both thicker and finer grained indicting deposition further from source. The basal member is transitional from the underlying Gowganda Formation (J. Robertson 1976a) and some workers have placed the base of the Lorrain at the base of the arkose (Wood 1973). The formation is up to 8000 feet (2 500 m _ thick in the La Cloche Syncline (Card 1976, 1978b) where it has been strongly folded, foliated, and somewhat metamorphosed; the clay minerals are represented by kyanite and andalusite the margins of which may show retrograde metamorphism to kaolinite (Church, 1967; Chandler, 1969; J. Robertson, 1976a.

GORDON LAKE FORMATION

The Lorrain Formation is overlain, apparently conformably, by the Gordon Lake Formation (Frarey 1967, 1977) a 1,000 ft (300 m) sequence of well-bedded siltstone, argillite chertstone, and fine - to medium-grained sandstone. There are three members: (1) a lower member comprising reddish sandstone and siltstone with chert anhydrite and gypsum nodules (and salt casts?), (2) a middle member of dark green siltstone, argillite and minor sandstone, and (3) an upper member of reddish siltstone, argillite, and chert (Eisbacher and Bielenstein, 1969; Bottrill, 1970; J. Robertson, 1971b, Wood, 1973). The middle member tends to form a scarp in the Flack Lake area that corresponds to a moderate magnetic anomaly (J. Robertson, 1971b). . Current ripples, microcrossbedding, slumpage structures, and desiccation cracks indicate deposition in very shallow water (Young, 1969; J. Robertson, 1971b, Wood, 1975). In the axial zone of the La Cloche Syncline the Gordon Lake Formation also, coincides with a magnetic anomaly (J. Robertson, 1976a Card, 1978b. These rocks though deformed are characterised by slumpage structures - flame casts and ball and pillow structures, starved ripples and dewatering structures.

Gordon Lake Formation has been recognised, but is poorly-exposed, in fault blocks in the south central portion of the Cobalt Embayment, Meyn (1973), Card et al (1972), Wood (1979). A threefold subdivision is possible; a basal buff to red quartzite and arkose, a middle thin-bedded sandstone and yellowgreen mudstones and upper white sandstone and greenish mudstone. The middle unit is characterised by ripple marks, sandstone dikes, intraformational breccia and chert nodules.

Young (1981), concluded that the Gordon Lake Formation formed in a stable shallow-water low-energy environment such as a muddy tidal flat. Frarey, (1977) considered the environment marine to littoral possibly lagoonal

BAR RIVER FORMATION

In the Flack Lake area, the Gordon Lake Formation is overlain by the Bar River Formation, (named by Frarey 1967, 1977 for Gordon Lake northwest of Bruce Mines) which comprises at least 1,200-1,500 ft

(360-450 m) of massive to well-bedded orthoquartzite, generally crossbedded and ripple marked (J. Robertson, 1971b, Eisbacher and Bielenstein, 1969). At Gordon Lake the formation is about 1000 ft (300 m) thick and comprises massive white quartzite with structure either lacking or obscured.

At Flack Lake mudcracks and desication features are common particularly in finer grained sandstones and intercalated siltstone bands. One unit is characterized by thin bedding and feruginous siltstone and quartzite. The iron has been partly redistributed, and small-scale solution depositional fronts adjacent to joints and fractures are frequent.Some ripple-marked surfaces at this horizon are covered with segmented, tapering sinuous structures of possible organic origin. Young (1967) and Hofmann (1967) initially favoured metazoans (worms) as the organism involved, but Donaldson (1967) suggested that the structure represents the infilling of desiccation cracks in algal mats. In the same area there are many rather similar structures that are undoubtedly desiccation features. The desiccation features of the Gordon Lake Formation (Young, 1969; J. Robertson, 1969b) are so similar to the most organic-looking structures of the Bar River Formation that the organic nature of the latter remains in doubt. Hofmann (1971) after detailed studies on Flack Lake and similar material from the Lorrain Formation at Desbarats (Frarey 1977) concluded that the structures were inorganic and related to dewatering processes. Wood (1970 recorded oolites in the ferruginous rocks, and their presence along with the many primary structures indicated deposition in very shallow water. In the ferruginous rocks Bottrill (1970, personal communication) has observed pyrite and in polished section has identified the major iron mineral as maghemite rather than hematite.

Card (1978b) describes some 3000 feet (900 m) of white orthoquartzite and femiginous sandstone-siltstone in the eastern North Channel of Georgian Bay with upward coarsening cycles and abundant but variable crossbedding and other sedimentation features.

Bar River Formation (Meyn 1973) Card et al (1972) and Wood (1979) has been recognised, but is poorly exposed, in fault blocks in the south-central portion of the Cobalt-Embayment where it is represented by rippled and cross bedded white to pink sandstone. The conditions of deposition, sedimentation, climate and state of atmospheric oxidation represented by the upper Huronian rocks are discussed in more detail by Wood (1973).

The Bar River of the Flack Lake area is considered to be a beach or aeolian deposit whereas shallow marine processes operated in the southerly facies Card (1978b) Young (1973c, 1981).

SUMMARY OF HURONIAN

The Huronian rocks of the area thus comprise thick sequences of clastic sediments and minor tholeiitic basalts. The sediments were derived from the adjacent Archean Craton and were deposited as migrating diachronous facies with cyclical rejuvenation. The Huronian is subdivided into four groups, an initial eugeosynclinal group with volcanics and turbidites as well as the uranium bearing quartz-pebble conglomerate - arkose sequences, at the margin of the developing Great Lakes Tectonic Zone(Sims et al 1980); two groups each representing a cycle initiated by tillite and followed by coarsening upward sequences and a fourth group which represents a third cycle followed by an upper sequence of beach and tidal fluvial deposits. In the upper group there is evidence of post-depositional solution and migration of iron and trace amounts of uranium.

The depositional basin extended east-west and deepened towards the southeast. The distribution of volcanic rocks and marked changes in thickness and facies of sedimentary units were controlled by hinge zones, which later became regional fault zones. Minor changes in composition of similar rock types are due to shifts in provenance and to the efficacy of weathering and winnowing processes. Radioactivity and heavy minerals are characteristic of quartz-pebble conglomerates in the fluviatile near-shore facies. In the lower Huronian the association is of uranium and sulphides, predominantly pyrite and in the upper Huronian it is of thorium and iron oxides. Glacial deposits are characteristic of the lower and middle Huronian, whilst the uppermost Huronian comprising beach, tidal flat and fluvial deposits was apparently deposited in a dry and hot environment. Figure 8 illustrates the alkali content of the matrices of the Huronian polymictic paraconglomerates; in figure 9 three compositional ratios for Huronian argillaceous rocks are shown. Of particular interest in figure 8 is the variation in maturity of the paraconglomerate matrices, which decreases towards the Gowganda Formation, the marked increase in soda, and, in the lower part of the paraconglomerate sequences, the incorporation of potassic material from the underlying arenite. Figure 9 shows an increase in ferric/ferrous iron ratio in the argillaceous rocks, reflecting change in general oxidation conditions; an increase in the SiO_2/Al_2O_3 ratio, reflecting increased efficacy of chemical weathering in the upper Huronian; and variations in the Na_2O/K_2O ratio, reflecting changes in provenance from a granitic to a granodioritic-greenstone terrane. The arenaceous rocks show similar changes in provenance and efficacy of of chemical weathering. The role of oxidation is apparent in the frequency of red beds from the Gowganda Formation upwards contrasted to the total lack of red beds in the lower formations. Roscoe (1973) placed the oxyatmoversion point within the Gowganda Formation although J. Robertson has pointed out that the Huronian bears evidence of free oxygen at least as early as the Espanola Formation.The excellent exposure of and access to the Huronian make the area ideal for teaching and research. The more significant outcrops are described and located in field guides, Card and J. Robertson (1972) J. Robertson & Card (1972), J. Robertson (1978a), Frarey, Card & J. Robertson (1979) and Bennett (1981).

Post Huronian Events

The North Shore of Lake Huron has been subjected to a long history of Middle and Late Precambrian structural deformation, igneous and metamorphic events. These are summarised below and the principal elements are shown on fig.2:

1) Vulcanism and early tectonism accompanied the

deposition of the Huronian;

2) A period of mild metamorphism and deformation and intrusion of granitic rocks near Sudbury preceeded the Nipissing diabase (J. Robertson 1972)and constitute Stockwell's (1982) Blezzardian event;

3) Intrusion of the Nipissing Diabase 2115 my;

4) The Sudbury event - intrusion of the Sudbury nickel irruptive possibly due to metenite impact;

5) Deformation and metamorphism locally attaining amphibolite facies, of the Penokean Orogeny peaking at about 1900 my;

6) Later granite intrusion (the Cutler 1750 my and Grenville Front granites - the Hudsonian Orogeny, and

7) Various post orogenic felsic and mafic intrusions.

(Cannon 1970, Card et al (1972), Card (1978a), Van Schmus (1965, 1976), papers in Young (1973a)).

Earlier authors used the terms Penokean and Hudsonian interchangeably, some recognised the sequence of events but only named the two major events.

Late Precambrian diabase dikes intruding radioactive Archean granite remobilised uranium resulting in small pitchblende deposits particularly in the Theano Pt. - Montreal River area north of Sault Ste. Marie (J. Robertson, 1981b) approximating to the source area for the Huronian as postulated by McDowell(1957).

These events had no genetic relationship to the Blind River uranium deposits. The Nipissing Diabase (2155 - MY Van Schmus (1965) recalculated Stockwell (1982) served to define a minimum age for Huronian Sedimentation, however dating of the Murray-Creighton granite at Sudbury further defines this at 2165 my (Stockwell 1982).

The Nipissing Diabase has associated with it a variety of metaliferous deposits showing regional zonation corresponding to the regional Archean metal zonation (Card and Pattison (1973), Innes and Colvine (1979). Uranium is not characteristic of the assemblage although occurrences have been reported as for example, at Flack Lake and at Sowerby (J. Robertson and Gould, 1982). Ruzicka 1979) has reported minor occurrences near Cobalt.

Alteration (albitization, chloritization, and carbonatization) associated with dikes or sills has locally afected the uranium deposits, which were clearly in place prior to the intrusion (J. Robertson, 1968a, 1970, repeated in this volume). Deformation and metamorphism of that part of the Blind River area in which uranium ores are found has been minimal and thus a factor in the preservation of the ore boides. Age data on minerals, reflects some resetting of the decay clocks at times corresponding to known peaks of regional metamorphism or thermal events rather than episodic introduction of more uranium (Roscoe, 1969).

THE URANIUM DEPOSITS

Uranium and thorium-uranium deposits are found in conglomerates at a number of localties in the Blind River-Elliot Lake and Agnew Lake areas, as well as throughout the Huronian belt (J. Robertson, 1968b, J. Robertson and Gould 1981, 1982 Thomson, 1960). Similar mineralisation has been discovered in Black Hills, S. Dakota and in the Medecine Bow and Sierra Madre Mountains of Wyoming (Karlstrom *et al* (1981), Houston and Karlstrom (1979)Roscoe (1981). In Canada deposits at Sakami Lake, Otish Mountains and Montgomery Lake,

D. Robertson (1974), Roscoe (1981)) also bear similarities in style and setting to the Blind River Deposits. The studies on the Rand, Blind River and Jacobina (Brazil) have formed the basis for definition of the uranium (gold) bearing quartz-pebble comglomerate class of ore deposits. The most significant recent publications with extensive bibliographies are, Armstrong (1981), Button and Adams (1981), Houston and Karlstrom (1979) and Pretorius (1981).

Distribution or Uranium Ore Deposits - Blind River-Elliot Lake

The workable uranium deposits of the Blind River camp are found as quartz-pebble pyritic conglomerate interbedded with conglomeratic to barren arkosic quartzite beds in zones controlled by basement topography (fig.12). In the Quirke Syncline the relation of the uraniferous conglomerates to granite-greenstone contact areas and valleys over softer zones in the greenstone belt is clearly demonstrated (fig.12) The Pronto deposit is located on granitic basement on the flank of a regional basement high. (For a description of the Pronto Deposit see J. Robertson, this volume).

The ore zones strike northwest-southeast and are controlled by basement structures. The Quirke zone (the largest in the area) is 32,000 ft. (9,600 m) long and from 6,000 ft (1,800 m) to 9,000 ft (2,700 m) wide, and the Nordic zone is 19,000 ft (5,700 m) long and from 4,400 ft. (1,320 m) to 6,000 ft (1,800 m) wide (J. Robertson, 1967, 1968a). The Pronto deposit (J. Robertson, 1970) and the unworked zones are of smaller dimensions.

At Quirke No. 1 the main ore reef is approximately 30 m (100 ft) above basement and is approximately 3.5 m (12 ft) thick. Toward the east the ore zone is truncated by an unconformity at the base of the Ramsay Lake conglomerate.

At Quirke No. 2 and Denison, the best ore development is in the Denison Reef some 30 m (100 ft) below the Quirke Reef. The Denison Reef normally comprises two conglomerate zones each

1.8-3.6 m (6-12 ft) thick separated by barren arkose 0.6-2.4 m (2-8 ft) thick. Throughout much of the Denison Mine, ore grade was sufficient to permit mining of both comglomerate beds and the intervening quartzite as one unit using large-scale equipment and trackless haulage. Other conglomerate beds 0.6-3 m (2-10 ft) thick separated by quartzite beds 3.6-6 m (12-20 ft) thick are known on both the Quirke and Denison properties. At Stanrock Mine another reef was found under the Denison Reef in the southeastern part of the mine. The en-echelon pattern with the oldest reef to the southeast conforms to the regional overlap pattern. The nomenclatures used in the various mines of the Quirke zone and their stratigraphic relations are illustrated schematically in Table 4.

At the Nordic Mine the main ore bed comprised conglomerate or conglomerate with quartzite over a width of 3 m (10 ft) with a grade of 2.5 lbs U_3O_8 per short ton (1.25 kg per metric ton). Locally another reef lower in the sequence, the Lacnor Reef, was mined where grade attained 2.0 lbs U_3O_8 per short ton (1 kg per metric ton). In the eastern part of the mine a third reef, the Pardee Reef, attains one grade, 2.3 lbs U_3O_8 per short ton (1.15 kg per metric ton) over 5 ft (1.5 m). This reef extends eastward over a basement ridge into the Pardee and Pecors mineralized zones (fig.12). These reefs extend down rake to the Stanleigh Mine where original operations were largely carried out over the Lacnor and Nordic Reefs. The Stanleigh Mine is being prepared for renewed production in 1983. Ore reefs are currently named lower, middle and upper. Resources are indicated primarily in the middle and upper reefs. As with the Quirke zone, other reefs of conglomerate of submarginal grade or minor extent are known.

Five types of boundary to the ore beds are known:

1. Outcrop of the conglomerate bed.

2. Wedging due to contact with either regional or local basement "highs". To the west of Quirke No. 1 the "basement" may be the edge of a pile of Huronian volcanics rather than Archean.

3. Lateral thinning of conglomerate and thickening of the intervening quartzite beds accompanied by drop in grade of the radioactive units. This is probably the typical boundary and the definition is arbitrary.

4. Removal by erosion subsequent to deposition, as for example in Quirke, Denison, and Panel, where there is an unconformity at the base of the Ramsay Lake conglomerate. Where material from conglomerates of the Matinenda Formation has has been incorporated in the Ramsay Lake conglomerate, the latter contains anomalous but

minor amounts of uranium radioactivity.

5. Fault contact. Locally, areas were not mined either because of unfavourable mining conditions caused by faults, extensive fracturing, or diabase dikes or because of unfavourable milling conditions caused by albite, chlorite, or carbonate alteration.

Some of these relationships are illustrated in figure 11, a cross section through the New Quirke (Quirke No. 2) Mine of Rio Algom Ltd.

Cobalt Embayment

That part of the Southern Province lying north of Sudbury is known as the Cobalt Embayment Fig.13 Lower Huronian rocks are intermittently exposed in the southern portion of the Cobalt Embayment but are largely concealed by Nipissing Diabase and upper Huronian rocks. The regional geology has been discussed by Thomson (1960) Meyn (1973, 1979 and Meyn and Matthews (1980). Precise stratigraphic correlation with Blind River is unclear, but rocks equivalent to the Mississagi Formation are present. At the base of these, wherever exposed, there are anomalous concentrations of uranium Fig.13 and, at some localities, gold in conglomerates and uranium in argillaceous quartzites. Long (1977, 1978b, 1981) based on Peters, (1969) has suggested that these rocks may be the equivalent of the Pecors and Ramsay Lake Formations of the Elliot Lake area. Early descriptions of the conglomerates (Thomson, 1960; Meyn, 1973; J. Robertson, 1968b) compared these rocks with the Blind River oligomictic conglomerates. On closer examination, however, this comparison is simplistic. Many of the conglomerates are polymictic, containing fragments of granite, greenstone, and iron-formation sparsely distributed in an argillaceous quartzite matrix. Many of the so-called quartz pebbles are actually quartzite of unknown provenance or iron-formation similar to that of nearby Archean greenstone belts. At least two showings contained trace amounts of gold (J. Robertson, 1968b Robertson and Gould 1982).

Meyn 1979 and Meyn and Matthews 1980 resampled 13 showings north of Lake Wanapitei and reported U ranging from 1 to 8200ppm, Au 2 to 800 ppb and Th 10 to 1640ppm. The three high values were all from one showing. Meyn and Matthews (1980) also reported on the heavy mineral associtation and identified the uraniferous minerals as "brannerite", uraninite and coffinite. They suggested a fluviatile environment (braided) stream but indicated some of the uranium could have been transported in solution. The deposits were modified by later events.

The provenance for the Huronian includes many auriferous greenstone belts. Studies by the Ontario Geological Survey (Innes & Colvine (1979), Wood (1980), Colvine (1981)) on mineral zonation in the Superior Province and its persistance in time have led to the concept that gold mineralisation may be found in fluvial deposits in the younger Huronian Formations. Similarly the fiords or river systems preserved as north trending tongues of Gowganda Formation (Card and Lumbers 1977, Giblin et al 1979 may contain hidden placer deposits of gold and uranium in lower Huronian rocks. Whilst less well-known, similar conditions may exist at the west end of the Huronian belt where gold is again present in the hinterland.

Long (1981) has further studied the sedimentation of the gold-uranium-bearing sequence and postulated a braided river fluvial system with some lake and pond deposits. Gold content is variable but highest averages were obtained in medium grained sandstone 57 ppb, fine sandstone 47 ppb and conglomerate 56 ppb. The gold which is related to pyrite was considered to be derived from the greenstone of the Abitibi belt of the Superior Province.

Agnew Lake Area

Stratiform uranium deposits in basal Huronian rocks also occur at Agnew Lake (see Figure 2, Figure 13; Little, et al 1972). The Agnew Lake deposit (Fig. 14) lies in an embayment in the Huronian Archean contact and possibly lies at or near the mouth of an ancient river system. The deposit was brought into production using an in situ bacterial leaching of broken ore and surface leaching of the excess broken ore. Due to unsatisfactory recovery rates, mining operations ceased early in 1980: leaching of broken material continued as long as this was economically feasible. The ore comprises gritty oligomictic conglomerate interbedded with arkose in a metamorphosed quartzite-argillite-conglomerate sequence which is probably equivalent to the Matinenda Formation of the Elliot Lake area. Pebbles at Agnew Lake are smaller and sparser, and pyrite is less conspicuous. The ratio of thorium to uranium is generally higher than at Elliot Lake, reflecting the presence of substantial uranothorite and monazite. Post-Huronian deformation has been considerably greater, resulting in steeper dips, more pronounced cleavage, and stretching of pebbles.

H. W. Little, et al (1972) quoted company estimates of the reserves to be 8000 short tons U_3O_8 in material grading 1.88 lbs of U_3O_8 per short ton. Production 1977 through 1981 was approximately 671 tonnes U and is expected to terminate late 1982 or 1983.

The cleavage, near vertical dips and metamict minerals have enhanced the leaching process. Cross-faluting hindered the development of large stopes that had been planned originally. The passage of leaching fluids through the broken ore in the stopes was not as predicted and inability to control breakage of the ore in the larger stopes led to solution rates being considerably less than required to maintain feed to the extraction plant.

Lithology and Mineralogy of Uranium Ore Deposits

The typical ore-bearing conglomerates of the Matinenda Formation consist of well-rounded, well-sorted quartz pebbles or cobbles in a matrix of quartz feldspar, and sericite and have an average pyrite content of 15 percent. Monazite and zircon are characteristic heavy minerals. "Brannerite" and uraninite are found in the matrix. Thucholite is found locally and may line fissures in the ore beds. The ore minerals are "brannerite", uraninite, and monazite (J. Robertson, 1960 and later; Roscoe, 1959a,b, 1969 ~~and later~~; Pienaar, 1963; Roscoe and

Steacy 1958; Robinson 1982).

Thucholite is present in the ore but is also in fractures as a postore secondary mineral. The interest in hydrocarbon at the Rand (Hallbauer 1975, 1981, Pretorius 1966, 1975 & 1981) prompted Ruzicka (Ruzicka and Steacy 1976, Ruzicka 1981)to initiate comparative studies on Blind River material.

Gummites (soddyite and uranophane) are rare, but Rice (1958) stated that they form a significant proportion of the ore mineralization at the Spanish American Mine. Uranothorite has also been identified (Roscoe and Steacy, 1958, p.14) and Patchett (1960) identified coffinite in altered material from the Nordic Mine.

Pyrite is the commonest sulphide mineral; it usually constitutes 10-15 percent of the matrix, but it may rarely be as much as 30 percent. Pyrite is concentrated in the matrix, and only rarely is there indication of replacement or fracture filling in the quartz pebbles. Individual grains may be rounded ("buckshot" pyrite) or subhedral to massive. R. G. Arnold (1954) suggested that the pyrite formed by sulphidization of detrital magnetite, and he described grains showing cores rich in leucoxene that he considered to have developed from ilmenite exsolved from the original magnetite. Bottrill (1971) and J. Robertson (1971b) have suggested that the sulphur required was derived from the lower Huronian volcanic rocks. Pienaar (1963), in a trace-element study, could not distinguish between the pyrite of the ore beds and the pyrite found in other rocks of the district.

Kimberley et al (1980) have indicated that Co/Ni ratios are characteristic of volcanic rocks. Ross (1981) suggested that the gold present in the ores was confined to the pyrite and was probably introduced in fluids derived from volcanism.

In distinction to the Rand (Pretorius 1966, 1975, 1981) and Jacobina (Gross 1968), gold is a very minor component of the Blind River ores (see also papers in Armstrong, 1981). Early statements indicated that gold was lacking or present only in erratic traces. Mining companies do notroutinely assay for gold. However, Boyle, (1979) indicatd that in the samples available to him gold was typically 0.09ppm largely contained in pyrite bearing 0.64ppm. Ross (1981) obtained values in the range 5 to 987 ppb with individual reefs averaging 73 to 117 ppb and reworked (reef at the base of the Ramsay Lake conglomerate attaining 400ppb). Although a wide variety of other sulphides and heavy minerals has been identified, it should be stressed that these occur in very small quantities. J. A. Robertson (1976b) provided a list of these and of the appropriate references.

There has been much discussion and description of the main minerals in the ore, mainly from polished-section work but more recently electron microscopy studies have been undertaken. The similarity to the gold- and uranium-bearing bankets of the Witwatersrand (Ramdohr, 1958 Pretorius 1966, 1975, 1981), radioactive conglomerate at Jacobina in Brazil (Gross, 1968), and some deposits in Australia and Russia has been stressed in the literature (Davidson, 1957; Derry, 1960; Armstrong, 1981; Button and Adams, 1981, Houston & Karlstrom, 1979).The major ore mineral at the Pronto Mine and in the Quirke Mine A Reef (Theis, 1973 Thorpe 1963) is "brannerite", first described from the area by Nuffield (1954). Although some relatively fresh material has been observed (Rice, 1958), "brannerite" is typically found as ovoid and red-brown to black grains in the metamict state showing bladed rutile surrounded by a uranium oxide and rare-earth oxides, the two-phase uranium-titanium compound of Pienaar (1963). Pienaar (1963) , Roscoe (1969), and D. Robertson and Steenland (1960) suggested that the rounding is due to transportation and that the material is detrital. Ramdohr (1957) has suggested that the "brannerite" rather than decomposing is authigenic and has proposed the "Pronto Reaction,"

$$UO_2+2-3TiO_2=UTiO_{2-3}O6-8$$

which he held took place during metamorphism. Experimental efforts to reproduce this reaction indicate that it takes place at temperatures in excess of those to which the rocks have been subjected (Gruner, 1959 p. 1315; Patchett, 1959). The "brannerite" generally contains small inclusions of pyrrhotite and of radiogenic galena (Thorpe, 1963, p. 39). Table 5 (from J. Robertson, 1968a) lists the published partial analyses of "brannerite" from the Blind River area along with the regional value selected by Thorpe.

Ferris and Ruud (1971) and Theis (1973) have concluded that Blind River "brannerite", and the brannerite or uraniferous leucoxene of the Rand, formed at low temperatures during diagenesis as a result of uranium migrating from uraninite to decomposing ilmenite.

Uraninite is the second most important mineral at Pronto and apparently the most important in the Nordic zone and in the C Reef at Quirke Mine (Theis, 1973). Generally it occurs as black subhedral grains approximately 1 mm across. Ramdohr (1958) and D.S. Robertson (1962a, b, 1974) have described rounded grains. Derry (1960) and Thorpe (1963) have both selected 6 percent as the regional value of ThO_2 content. Table 6 (from J. Robertson, 1968a) summarizes the early published data on Blind River uraninite, since confirmed by Grandstaff (1974).

This corresponds to the composition of pegmatitic rather than hydrothermal uraninite. The rounding and thorium content may indicate a detrital origin. Davidson (1957, 1965) has used the general lack of uraninite in modern placers and geochemical principles along with the Lyellian concept of uniformitarianism (actualism) as argument against the detrital origin of uraninite.

Roscoe (1959b) has described the monazites from the Blind River ores and has pointed out that monazite can contain considerable uranium and is, therefore, one of the ore minerals. Grains are normally rounded to subangular and less than 0.3 mm in diameter. Grey varieties of monazite are strongly radioactive, may contain uranothorite or thorite (Roscoe, 1959b; Patchett, 1959), and have pyrite inclusions. Table 7 (from J. Robertson, 1968a) gives Roscoe's (1959b) uranium-thorium analyses of monazites and the values selected by Thorpe (1963).

Roscoe has shown (1959a,b) that the uranium-thorium ratios in monazite are comparable to that of the basement. The lateral variation in the ore-mineral and uranium-thorium ratios, as studied by Roscoe (1959a,b), D.S. Robertson (1962a,b ,1974), J.A. Robertson (1968a), and Thorpe (1963), are best explained by the relative stability of monazite during transportation (elaborated on with respect to Denison and Quirke by Theis 1973). Monazite is the chief radioactive mineral in the occurrences in the Lorrain Formation.

Production

Between 1955 and 1981 the Blind River-Elliot Lake camp has produced 98.3 thousand tonnes of uranium from 99.5 million tonnes of ore milled for average recovered grade of 0.099% uranium. (Derived from J. Robertson 1968b, J. Robertson and Gould 1982, Runnalls 1981 and Company Annual Reports).

Minor amounts of thorium and yttrium, details of which are not in the public realm, have also been produced. In addition the Agnew Lake mine, using a leaching process, in the years 1977-1981 produced some 670 tonnes uranium. Maximum production from the camp was obtained in 1959 when some 9345 tonnes were produced. In 1981, Rio Algom produced from the Quirke and Panel mines 1658 tonnes uranium from 3,428,000 tonnes ore (.078% U recovered) and Denison produced 1824 tonnes uranium from 2,788,000 tonnes ore (0.065% U recovered).

As mining progresses grade of the ore will continue to drop. Part of the recent expansions undertaken at Elliot Lake were to maintain output in face of declining ore grades and part to enable the companies to meet their long term contracts with Ontario Hydro. For details on the history of the camp see Runnalls 1981 and the paper by _________ in this volume.

Reserves and Resources

Given the bedded nature of the deposits and the extent of diamond drilling, the resourcesof the camp have been known since the late 1950's and have generally been quoted as approximately 400 thousand to 500 thousand tonnes uranium e.g. Griffith and Roscoe 1964. Only minor change have been made in resource data reflecting production, mine development, and economic factors influencing the classification of known mineralisation.

In 1975 the writer confirmed that reasonably assured resources comprised 200,000 short tons U_3O_8(154,000 tonnes U) with perhaps as much again in estimated additional resources. It was noted that the reserves also contained 100,000 short tons of recoverable ThO_2. A more detailed discussion of thorium resources is given in OECD 1981.

Aggregated information on Canadian uranium resources has been compiled and published by the Uranium

Resource Appraisal Group (URAG) Energy Mines and Resources Canada of EMR and the Ontario information has been discussed by Robertson, 1981b. The most detailed published breakdown on Ontario Resources (predominantly the Elliot Lake camp) is that given to the Porter Commission: measured 49,000 tonnes U; indicated 75,000 tonnes; inferred 246,000 tonnes U; and prognosticated 182,000 tonnes U at prices < $156/K$_g$ U (1978).

The 1980 URAG report indicates Ontario Resources Measured + Indicated + Inferred as 361,000 tonnes U and prognosticated as 169 000 tU at prices of up to $200/K$_g$U(1980). The drop particularly in prognosticated resource reflects the increasing pressure of rising cost. The well publicised spot price has dropped further (17.00 $US/lb U_3O_8 Sept. 1982) and readjustment in resources and decrease in the totals may be anticipated.

Quartz pebble conglomerate of Lower Proterozoic age make up 15% of the world's reasonably assured resources and 20% of Estimated Additional Resources as of January 1, 1981. (OECD, 1981) the total resource being approximately equally divided between Blind River and the Rand.

ORIGIN OF THE URANIUM DEPOSITS OF BLIND RIVER TYPE

The following discussion is largely taken from earlier summaries by the author (J. Robertson, 1967b 1968a, 1969a, 1981a,b).

Uranium and thorium mineralization occurs at a number of localities throughout the world in quartz-pebble conglomerates bearing appreciable pyrite and, especially at the Witwatersrand in South Africa, gold in the matrix. The origin of these conglomerates has been much debated. The similarity of the deposits at Blind River to one or another of several of the well-known deposits at Witwatersrand, South Africa, and Jacobina, Brazil, have been pointed out by Davidson (1957, 1965), Derry (1960, 1961), Joubin (1960), and Gross (1968). Davidson also mentions similar deposits in Australia and Russia. This characteristic assemblage and its distribution is the major theme of Armstrong, 1981 the papers from a 1965 workshop which in time sparked development of the quartz-pebble conglomerate model and intensified work on the Wyoming Precambrian (Button and Adams, 1981; Karlstrom *et al* 1981; Houston and Karlstrom 1979).(For comparison of Blind River and Wyoming settings see Figures 15 and 16). The relation to major unconformities, particularly those marking the Proterozoic-Archean boundary, has been emphasized (Derry, 1961).

In the Blind River camp this unconformity can be placed at 2,500 m.y. ago; it is clear that the conditions did not persist beyond a minimum of 2,165 m.y. ago and that the period 2,500-2,300 m.y. ago seems the most favourable.

Bateman (1955, p.371), Joubin and James_(1957), Davidson 1957, p. 668), and Heinrich (1958) have cited as evidence of a hydrothermal origin the supposedly high uranium-to-thorium ratios, the high titanium-to-iron ratio, and the association of titanium, cobalt, nickel, thorium and uranium in a deposit carrying the characteristic minerals gold, brannerite, uraninite, and pyrite. Patchett (1960), after detailed study of only three samples from the Nordic Mine, regarded the ores as epigenetic. Joubin (1954_ suggested the "Keweenawan" diabase [Nipissing diabase] as a source but in a later paper (1960) admitted that mining evidence clearly indicted that the diabase postdated the uranium mineralization. Davidson (1957) suggested that the post-Huronian granite lying to the southeast at Cutler was the probable source.

In 1965, Davidson (1965) returned to the question of the origin of banket ore bodies and considerably modified his earlier views. The revised hypothesis may be summarized as follows:

1. Deposition of molasse-type sediments in deep basins with conglomerate near the basal unconformity.

2. Leaching of the metal content (for Blind River uranium and thorium) by groundwater.

3. Prolonged series of intrastratal migration, allowing mineralized groundwater to sink to the lowest permeable horizons, the oligomictic conglomerate beds, where the metals would be reprecipitated.

4. The thermal energy for cycling groundwater would be derived from postsedimentation intrusions.

Abraham (1953) and McDowell (1957) regarded the ores as fossil placer deposits. Pienaar (1963) and Roscoe (1969, 1981) have also indicated a preference for a placer origin. D. S. Robertson(1962a, b) and later Theis 1973 assembled data, particularly on uranium/thorium ratios, that is suggestive of a placer origin. Holmes (1957) suggested that the ores were of syngenetic (placer) origin but were modified by later events; the enunciation of the modified placer theory.

Derry (1960) has suggested a syngenetic origin for the uranium mineralization but has raised the possibility that the uranium was largely carried in solution and reprecipitated in gravel banks by bacterial agencies. Joubin (1960) published similar ideas but did not include bacterial precipitation. Other conglomerates in the district, for example, the Matinenda polymictic conglomerate and the Ramsay Lake, Bruce, and Cobalt conglomerates, do not carry markedly high uranium values, although all, particularly the Bruce, carry pyrite and pyrrhotite. An exception to this occurs when such a conglomerate unconformably overlies the uranium-bearing sequence or lies on the basement.

The sericitic matrix of the ore-bearing conglomerates is similar to the sericitic paleosoil developed on the Archean-Huronian unconformably and was probably derived from the regolith; there is no reason to suppose that it was produced by the passage of hydrothermal solutions. Uraniferous oligomictic pebble conglomerates and a green arkose sequence are characteristic of whichever part of the Huronian overlies the basement in the area of the North Shore of Lake Huron, and these rocks show a progressive northward overlap. Significant thicknesses and grades of uranium mineralisation have so far been found only in the Matinenda Formation.

Quartz veins and other evidence of intense hydrothermal activity are not conspicuous in the rocks of the area and bear no sympathetic relation to the uranium deposits. Where found, the associated mineralization is of copper and other sulphide minerals. Within the Blind River-Elliot Lake camp, there is no indication that either the Nipissing or the olivine-diabase intrusions are a possible source of major radioactive mineralization. Locally ores were subjected to intense local alteration (J. Robertson, 1968a, 1970 repeated this volume) and all rocks of the region suffered sulphide mineralization at the time of intrusion of the Nipissing diabase. Wanless and Traill (1956) using lead isotope dataobtained an average age of 1,300 million years for ores from Algom Quirke and 623 million for ores from Pronto. Stieff et al 1956 obtained discordant Paleozoic ages with some indication of an earlier

2000 my mineralisation. In the Sixth Commonwealth Mining and Metallurgical Congress guide (CIMM 1957) it was concluded the Pronto ores being closer to the Cutler batholith had been more greatly affected at that time. Roscoe 1969 compiled the available isotopic data on various mineral in the Blind River ores and concluded that the data is compatible with the primary age of 2.5 billion years and modification (resetting) reflecting the later tectonic, metamorphic and thermal events, the effect of which increase from north to south as the Penokean Fold Belt is approached. Episodic introduction of uranium mineralisation was not indicated Stockwell (1982) P.50 whilst preferring the explanations of CIMM Guide (1957) and Roscoe (1969), however, considers that further work is desirable to settle the isotopic data and its interpretation.The overall distribution of beds and the behaviour of thickness and grades are more consistently explained by the modified placer hypothesis, which the author has suported (J. Robertson, 1960 and later). Mineragraphic studies of Ferris and Ruud (1971) and Theis (1973) and the electron microscope studies of Robinson (1982) have added cogent additional support to the modified placer hypothesis. Robinson (1982) has pointed to the lack of apatite in the ores although it is ubiquitous in the source granites (J. Robertson 1960) and to partial solution of monazite grain margins and has suggested that phosphate complexing may have played a major role in the solution of the uraninite.

The modified placer hypothesis proposes that the deposits were derived from cratonised Archean terrain to the north and northwest, transported by rapidly moving water, and deposited in a near shore fluviatile environment under cold, low oxygen conditions about 2500 my ago. Mafic volcanic rocks were simultaneously accumulating in the basin. The basin location was controlled by the incipient Great

Lakes Tectonic Zone (Sims et al 1980). The equivalent units see Figs. 15 and 16. In Wyoming bear a similar relationship to the McMullen-Nash Creek shear zone which like the Great Lakes Tectonic Zone marks an Archean plate boundary Houston and Karlstron 1979; Karlstrom et al 1981; Button and Adams, 1981. The uranium deposits were later subjected to diagenesis and to minor alteration during subsequent intrusive, metamorphic, and tectonic events, but were not subjected to either erosion or leaching.

The foregoing genetic hypothesis has led the author to a systems-analysis approach to resource-potential and exploration-potential assessment. The geological factors (parameters) inherent in source, transportation, deposition, modification, and preservation have been identified and their efficacy assessed. This systems approach has been developed and expanded in part of the work of the Federal-Provincial Resource Appraisal Group (Ruzicka 1977a,b). As a further aid to stratigraphic and economic studies in the Elliot Lake camp, all drill logs in the files of the Ontario Government have been abstracted in standard format and nonmenclature, and a computer file has been created. A manual file of public data and location maps is also available. (Leahy 1973).

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Where a writer has published preliminary maps, summary of field work, preliminary reports, etc. or where thesis research work has resulted in publication the publication now readily available has normally been given as the reference.

On at least two separate occasions the proceedings of workshops were not finally published (or in the case of some authors had been published elsewhere) until several years after the material had been widely disseminated and had already infludenced other workers. Thus reference dates do not necessarily reflect first dissemination of results. Further it may be commented that recent papers contain numerous photographs of structures and textures much analytical data and quantified sedimentological data.

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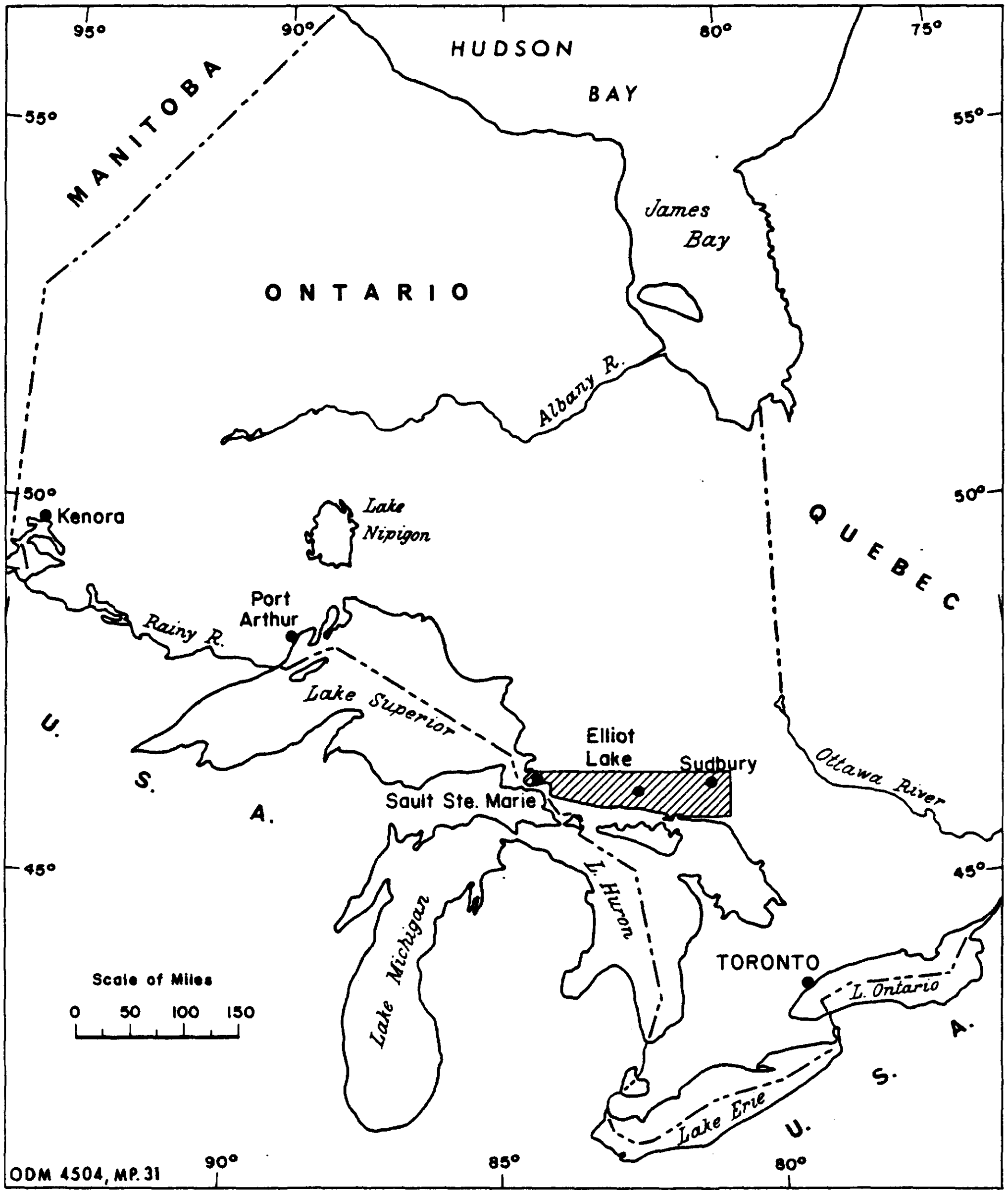


Figure 1. Location of the Blind River - Elliot Lake area

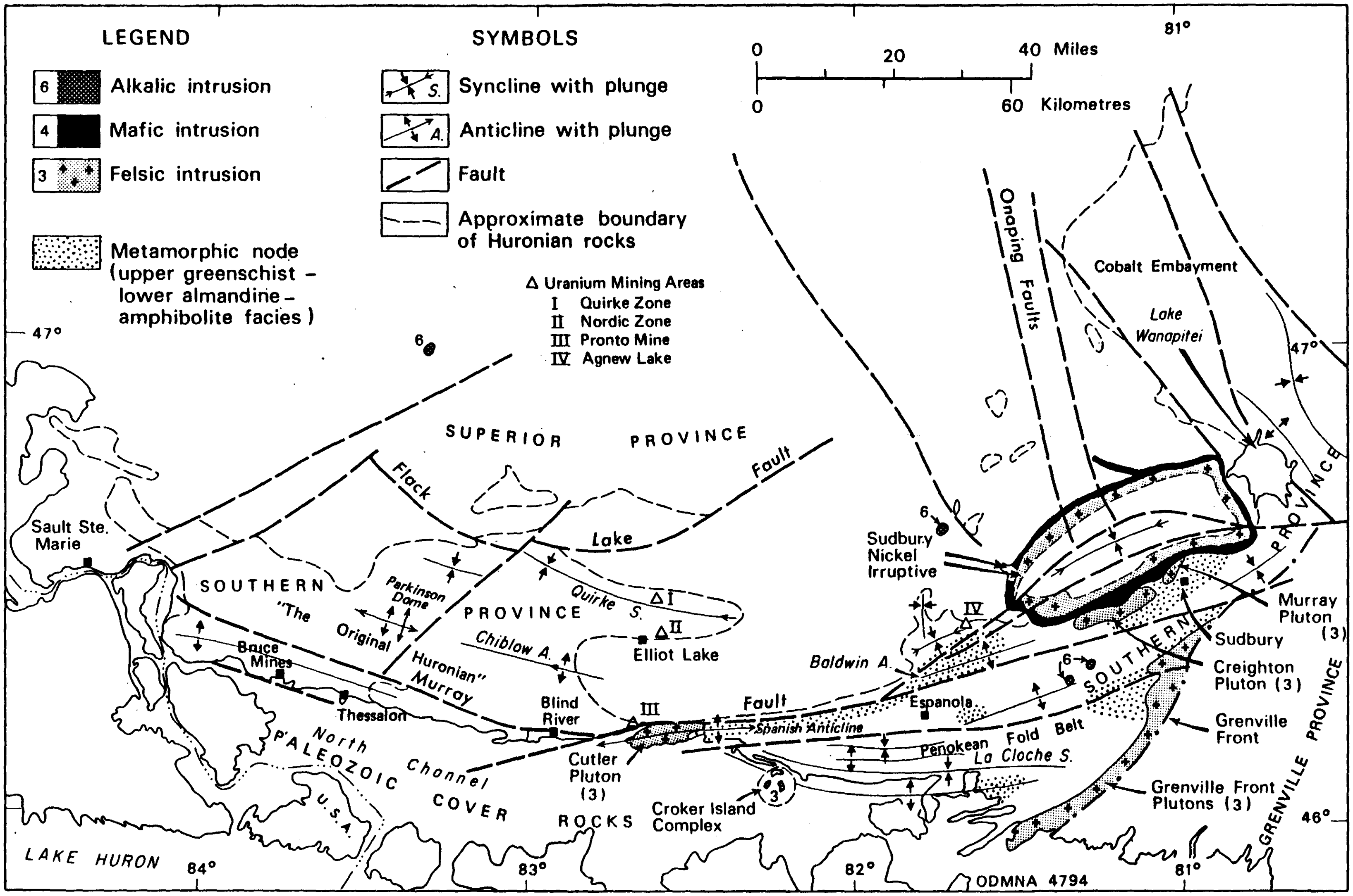


Figure 2. Eastern Southern Province - Structural Elements and Uranium-mining area, after Frary, Card, Robertson, 1979.

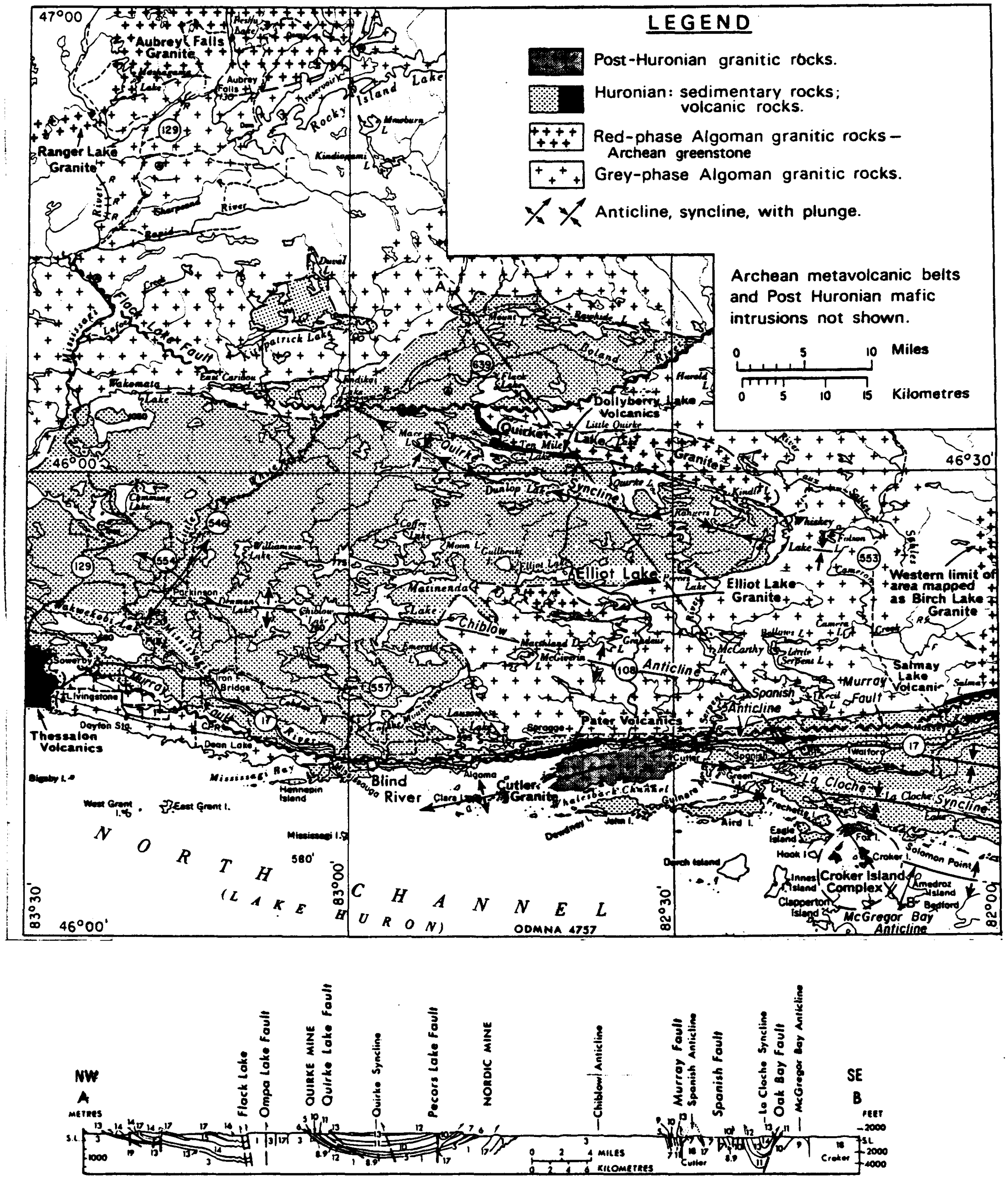


Figure 3. Generalized geologic map of the Blind River-Elliot Lake area, with schematic cross-section.

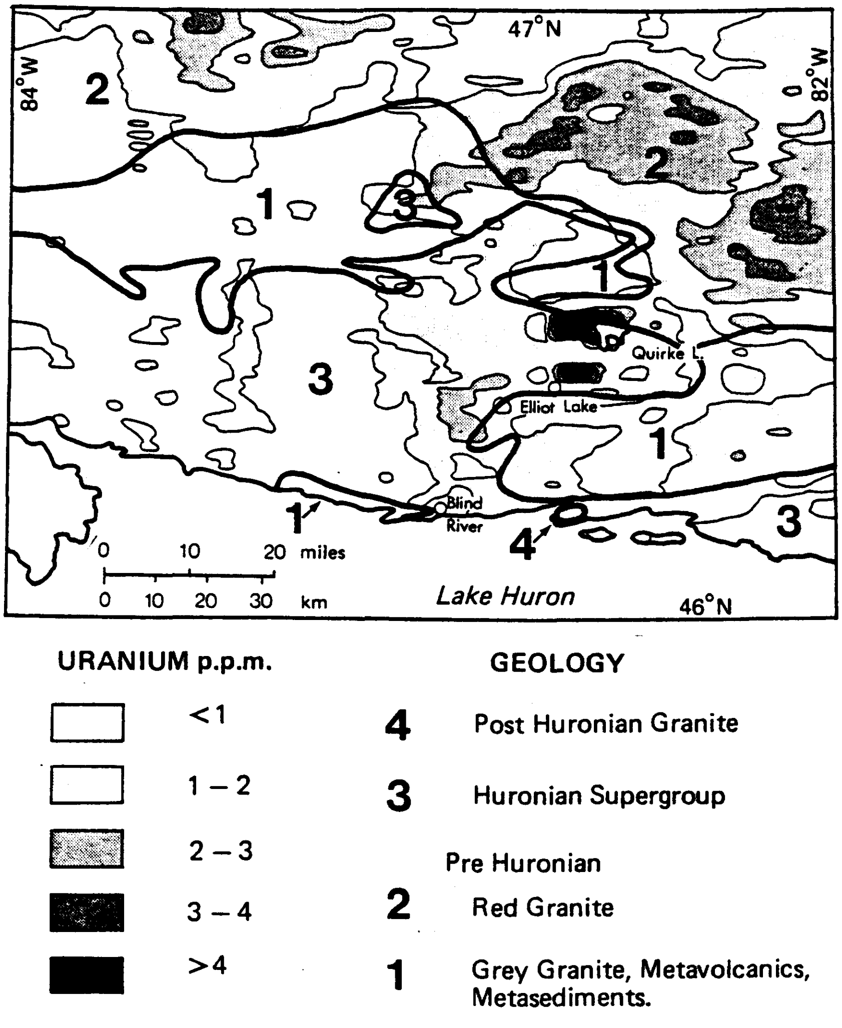


Figure 4. Uranium distribution in the Blind River area, airborne gamma ray spectrometry after K.A. Richardson, P.G. Killen and R.W. Charbonneau (1974).

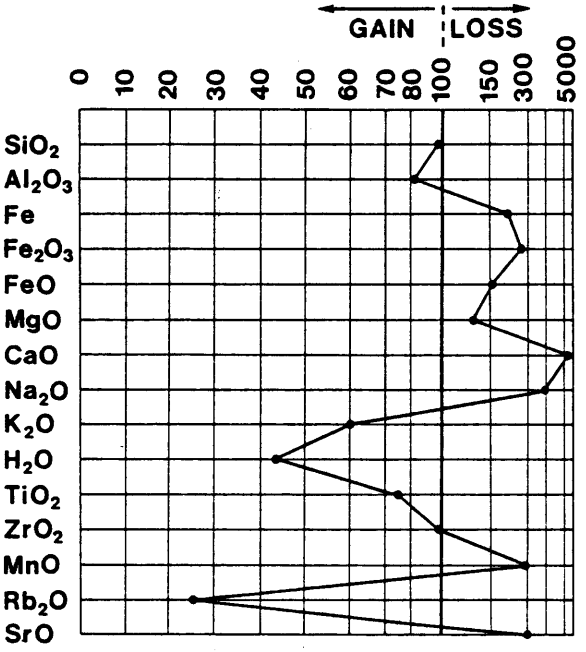


Figure 5. Formation of granitic regolith.

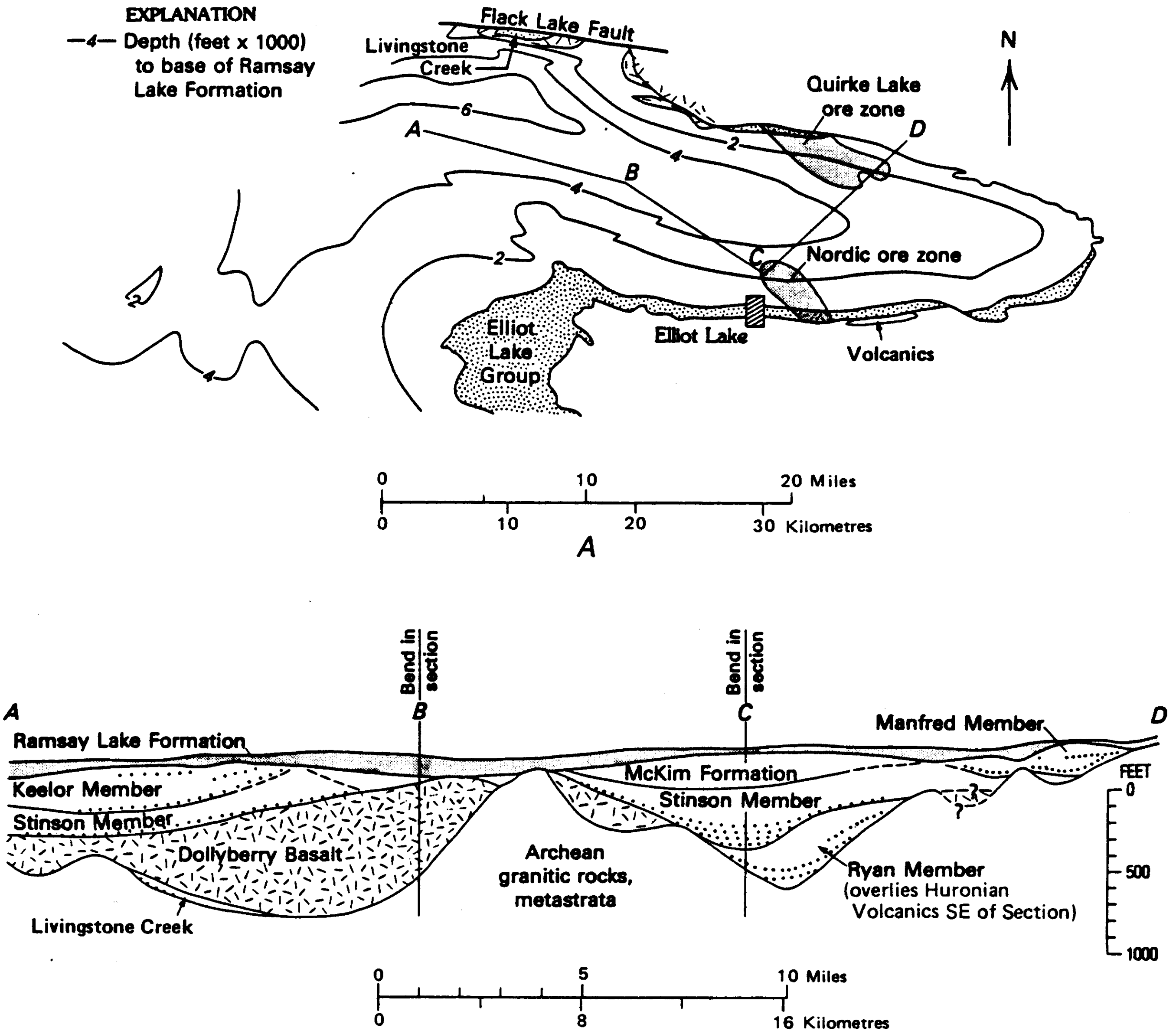


FIGURE 6 – Stratigraphic relations in Elliot Lake Group near Elliot Lake. *A*, Map showing outcrops of Elliot Lake Group and depth to the base of the Ramsay Lake Formation. *B*, Schematic cross section near Elliot Lake showing relations among arenaceous members of the Matinenda Formation, Dollyberry basalt, and McKim Formation in the Elliot Lake Group.

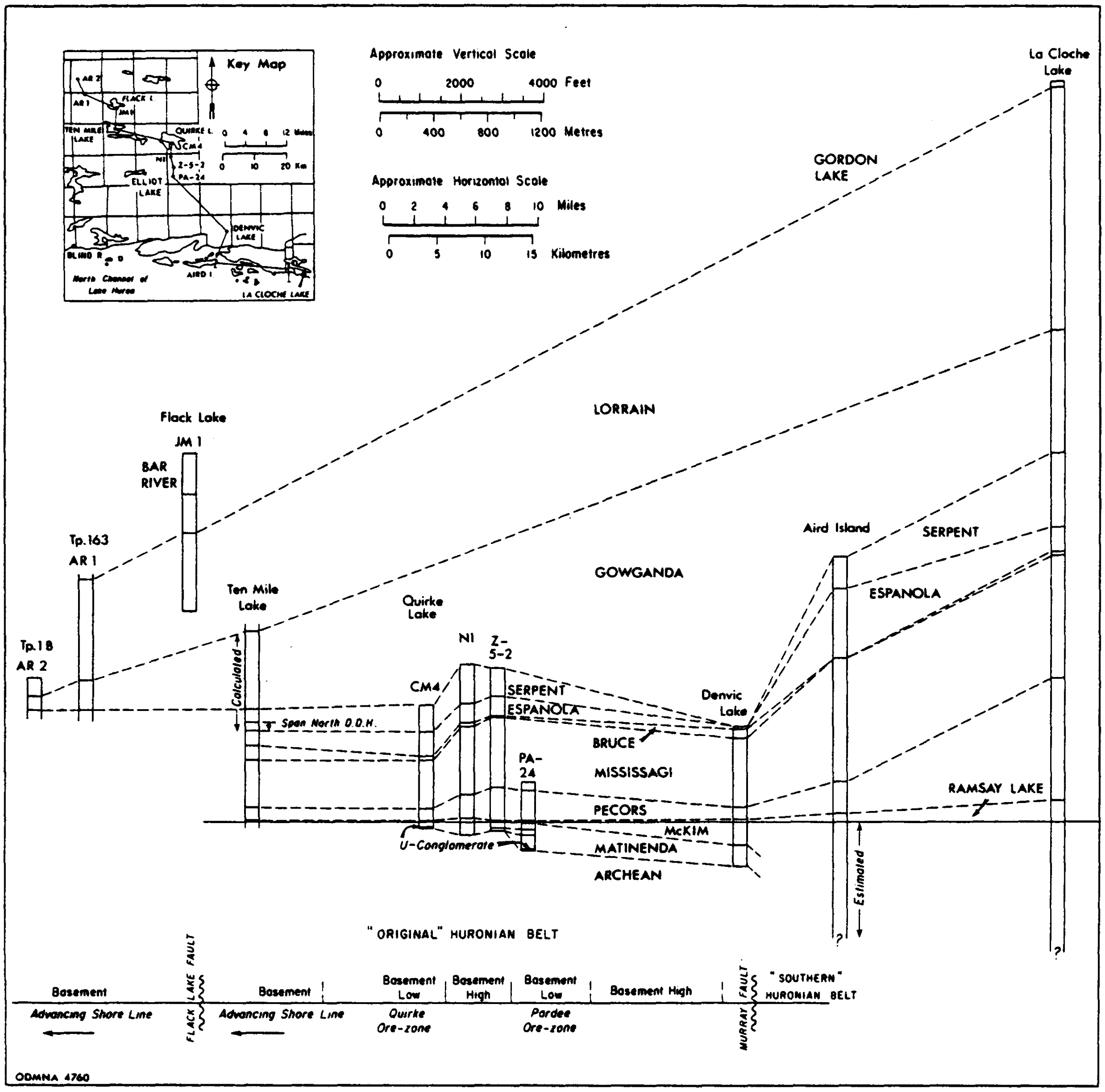


Figure 7. Lateral variation of the Huronian Supergroup, Elliot Lake Area.

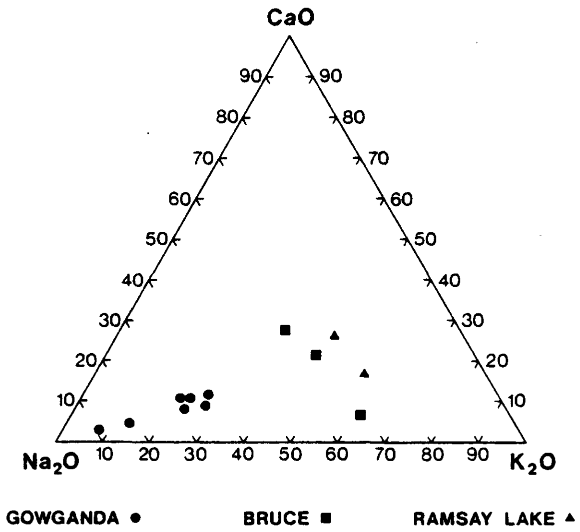


Figure 8. Alkalic content, Huronian polymitic conglomerates.

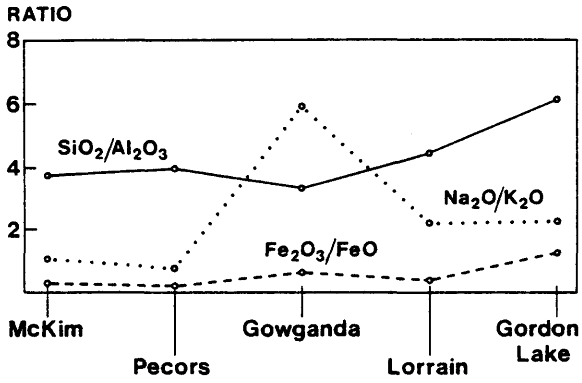


Figure 9. Silica/alumina, ferric iron/ ferrous iron, and soda/potash ratios for Huronian argillaceous rocks.

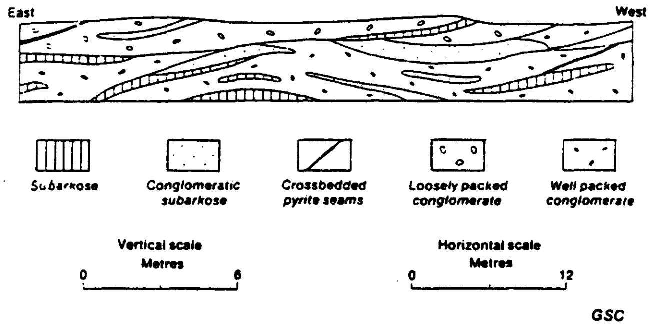


Figure 10. Intricate lensing within ore conglomerate (from Pienaar 1963, p. 64).

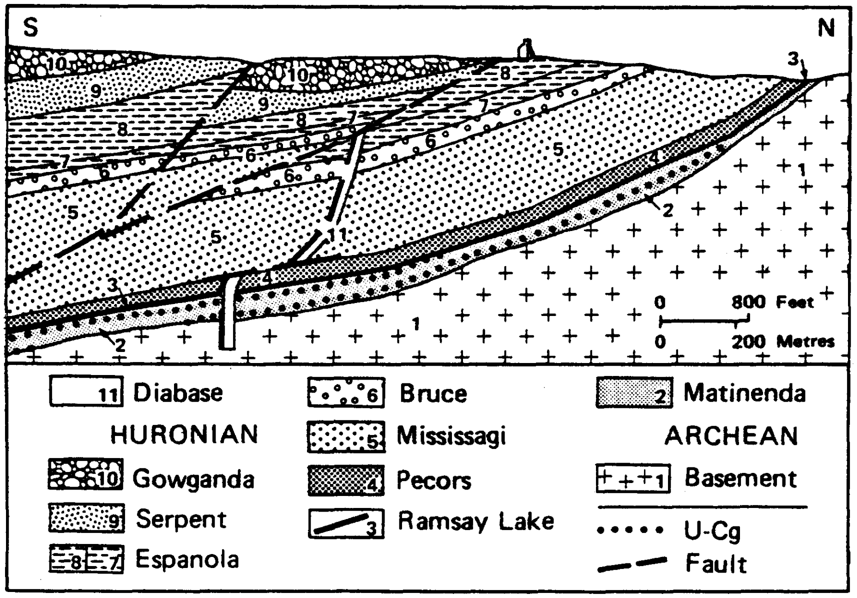


Figure 11. Cross-section New Quirke Mine (after Rio Algom Mines Limited and J.A. Robertson,1976)

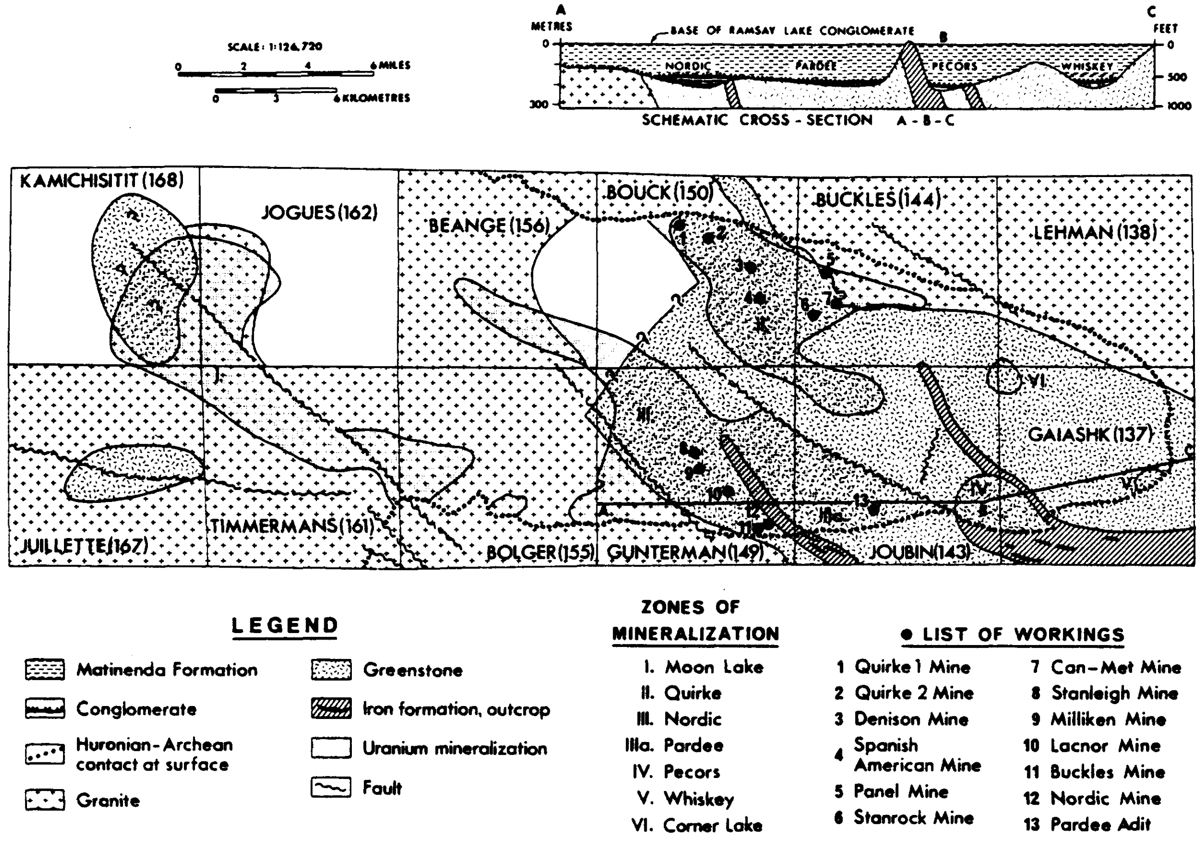


Figure 12. Uranium deposits in Quirke Syncline - Elliot Lake area.

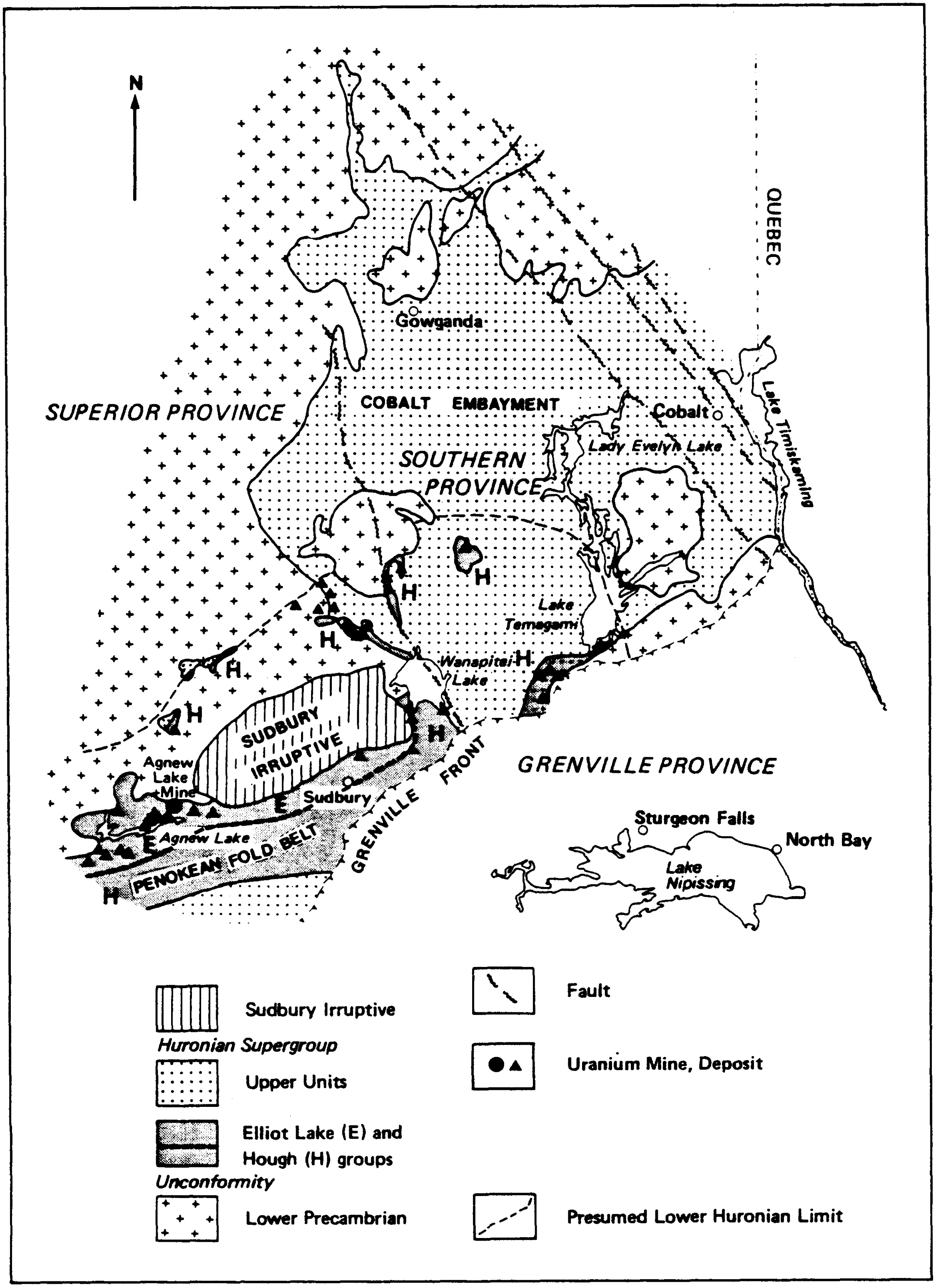


Figure 13. Uranium deposits - Cobalt Embayment and Agnew Lake areas.

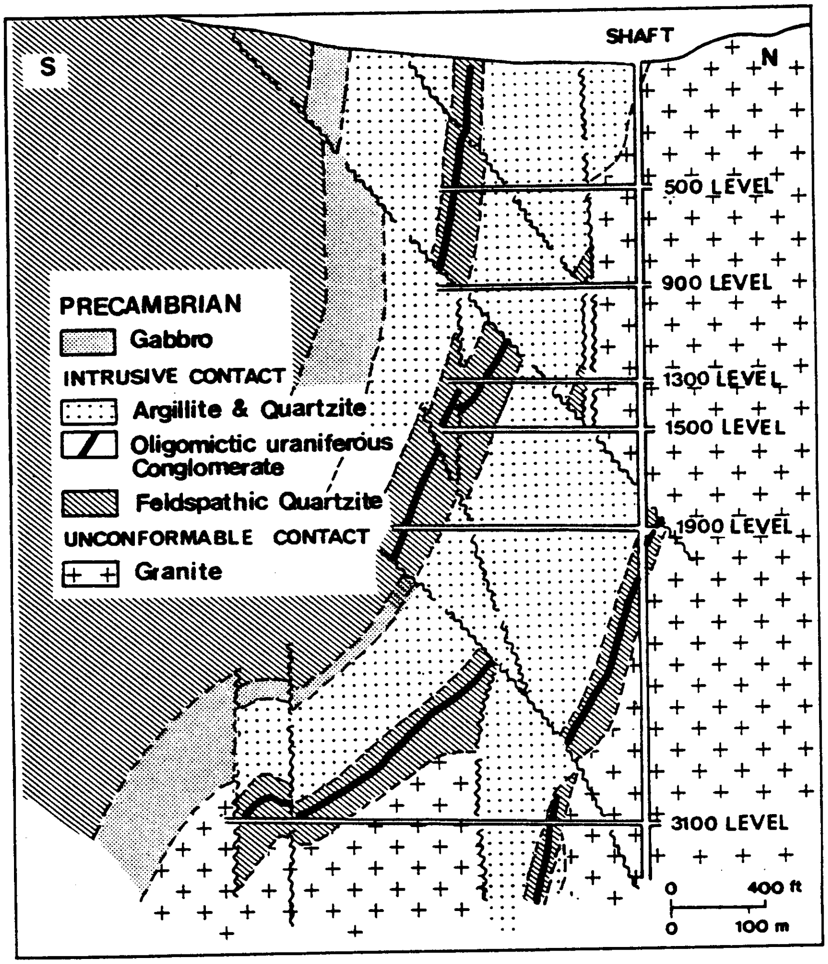
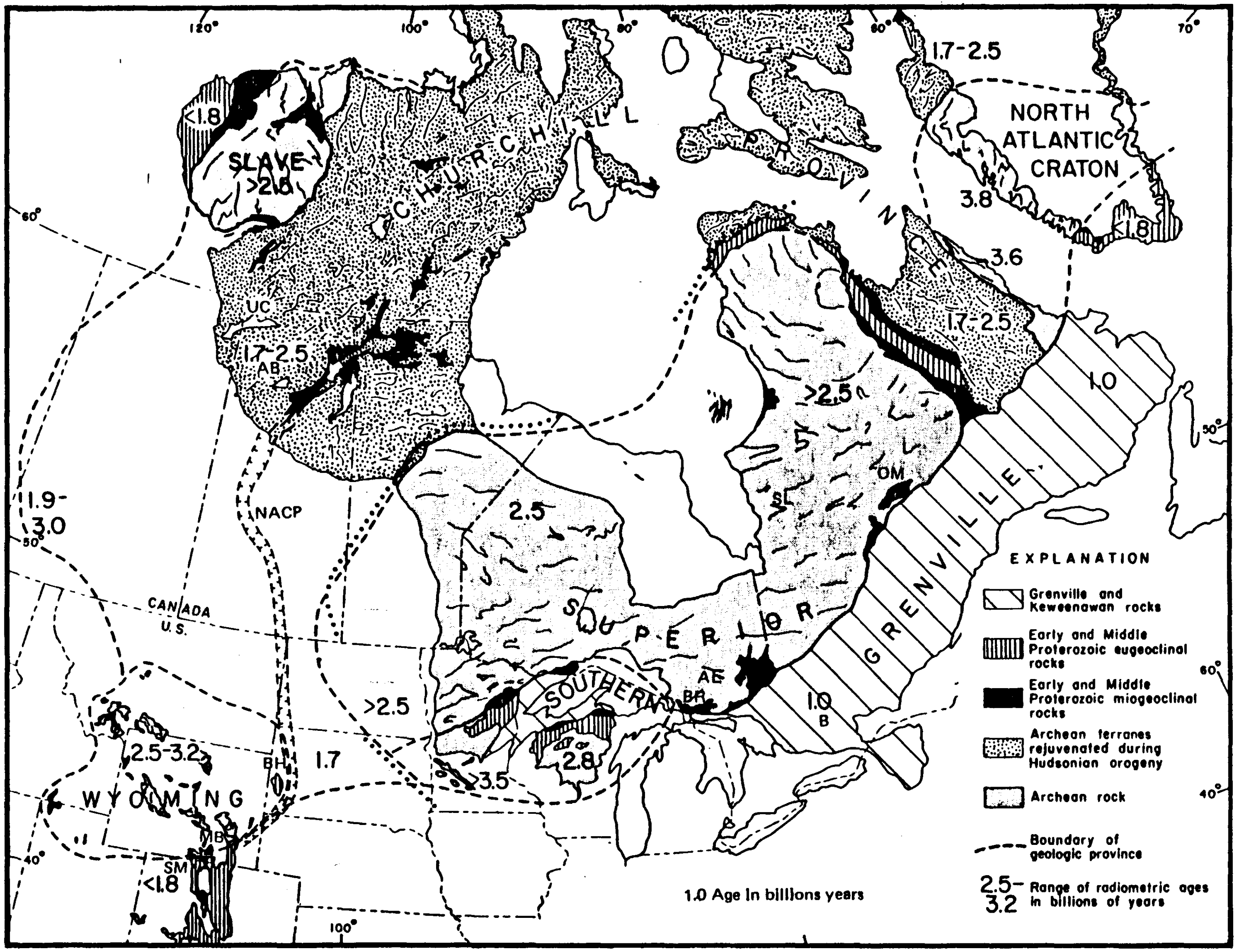


Figure 14. Cross section Agnew Lake Mines Limited after D.S. Robertson (1964).



NACP – North Atlantic Central Plains conductivity anomaly
UC – Uranium City
AB – Athabasca Basin
BH – Black Hills
SM – Sierra Madre
MB – Medecine Bow
BR – Blind River
AL – Agnew Lake
B – Bancroft
OM – Otish Mauntains
SL – Sakami Lake

Figure 15. Geology of the Archean Nucleus of North America.

FIGURE 16: STRATIGRAPHIC SUCCESSION OF THE SIERRA MADRE AND MEDICINE BOW AREAS IN WYOMING COMPARED TO THAT OF THE HURONIAN SUPERGROUP IN ONTARIO (FROM HOUSTON AND KARLSTROM 1979)

SIERRA MADRE WYOMING After Graff (1978)					MEDICINE BOW MOUNTAINS WYOMING After Karlstrom and Houston (1979a, 1979b)			HURONIAN SUPERGROUP ONTARIO CANADA Robertson (this paper) and after Roscoe 1969			
YOUNGER IGNEOUS AND METAMORPHIC ROCKS					Sugar Loaf Qtzite.	Sandstone		COBALT GROUP	Bar River Fm.	Sandstone	Fluvial—beach
					Lookout Schist	Mudstone, Siltstone			Gordon Lake Fm.	Siltstone Sandstone	Tidal flat
					Medicine Peak	Sandstone, Qtz-pebble cgl.	Shallow Marine		Lorrain Fm.	Sandstone Qtz-pebble cgl.	Fluvial—near-shore R
====== SHEAR ZONE ======					Heart Fm.	Sandstone Siltstone Sandstone	Marine?				
LIBBY CR. GP.		Slaughter-house Fm.	Dolomite Phyllite	Carbonate bank	Headquarters Schist	Shale Arkose Paraconglomerate	Glacio-marine		Gowganda Fm.	Graywacke Siltstone Sandstone Paraconglomerate	Glacial, glacial-marine
DEEP LAKE GROUP	CYCLE 4	Copperton Qtzite	Sandstone	Shallow Marine	Rock Knoll Fm.	Conglomerate Sandstone Shale	Shallow marine	QUIRKE LAKE G.P.	Serpent Fm.	Sandstone	Fluvial, shallow marine
		Vagner Fm.	Sandstone Shale Limestone Paraconglomerate	Glacio-marine	Vagner Fm.	Shale Limestone Paraconglomerate	Glacio-marine		Espanola Fm.	Dolomite Limestone Sandstone	Fluvial, lagoonal—marine
									Bruce Fm	Paraconglomerate	Glacial—glacial-marine
	CYCLE 3	Cascade Qtzite	Arkose Sandstone	Fluvial	Cascade Qtzite	Pebbly arkose Pebbly sandstone	Fluvial	HOUGH LAKE G.P.	Mississagi Fm.	Sandstone	Fluvial—shallow marine (R)
									Pecors Fm.	Siltstone	Shallow marine—turbidite
		Campbell Lake Fm.	Sandstone Shale Paraconglomerate	Glacial?	Campbell Lake Fm.	Shale Paraconglomerate	Glacial		Ramsay Lake Fm.	Paraconglomerate	Glacial—glacial-marine
	CYCLE 2	Singer Peak Fm.	Sandstone Shale	Marine	Lindsey Qtzite	Sandstone	Fluvial	ELLIOT LAKE G.P.	McKim Fm.	Siltstone	Shallow marine—turbidite
		Magnolia Fm.	Sandstone Qtz-granule ss. Qtz-pebble cgl	Fluvial R	Magnolia Fm.	Qtz-granule ss. Qtz-pebble cgl	Fluvial R		Matinenda Fm.	Sandstone Qtz-pebble cgl	Fluvial—deltaic R ore
PHANTOM LAKE SUITE	CYCLE 1	Silver Lake Conglomerate	Graywacke Boulder cgl.	Marine?	Upper Phantom Lake Metamorphic Suite	Paraconglomerate Basalt	Subaerial		Thessalon Fm.	Basal Sandstone	Subaerial Fluvial R
		Spring Lake Volcanics	Flows, tuffs	Subaerial-shallow marine		Micaceous ss.	Shallow marine		Livingstone Creek Fm.	Subarkose cgl.	Fluvial
		Upper Jack Creek Fm.	Shale, sandstone Paraconglomerate Qtz-pebble cgl	Shallow marine Fluvial R		Argillite Fine gr. ss. Qtz-pebble cgl.	Marine Fluvial R				
		Lower Jack Creek Fm.	Sandstone Paraconglomerate Shale, flows, tuffs Graywacke	Subaerial, fluvial, and shallow marine	Lower Phantom Lake Metamorphic Suite	Volcano-clastic Graywackes, flows and tuffs	Subaerial?	?			
ARCHEAN METASEDIMENTS, GNEISSES, AND GRANITE											

R–radioactive mineralization In conglomerate

TABLE 1. FORMATIONS FOR THE BLIND RIVER-ELLIOT LAKE AREA

Unit	Dominant lithology	Age (million years)
Phanerozoic		
Cenozoic		
Pleistocene and Recent	Sand, gravel, till	
Unconformity		
Paleozoic		
Ordovician (20)[4]	Limestone	
Precambrian		
Proterozoic		
Keweenawan Supergroup		
Sudbury dikes (19)	Olivine diabase	1 225
Intrusive contact		
Mount Lake Dike[1]	Quartz diabase	
Lamprophyre	Lamprophyre	1 385
Intrusive contact with Nipissing Diabase		
Hudsonian		
Croker Island Complex (18)	Gabbro, granite	1 460
Cutler Batholith	Granite	1 750
Intrusive contact		
Penokean		
Nipissing (17)	Quartz diabase, diorite	2 115
Intrusive Contact		
Murray-Creighton[2]	Granite	2 165
Intrusive contact		
Huronian Supergroup		
Cobalt Group		
Bar River (16)	Quartzite	
Gordon Lake (15)	Siltstone, sandstone	
Lorrain (14)	Quartzite, conglomerate arkose	
Gowganda (13)	Conglomerate, greywacke, quartzite	
Unconformity-disconformity		
Quirke Lake Group		
Serpent (12)	Quartzite	
Espanola (11)	Limestone, siltstone	
Bruce (11)	Conglomerate	
Local disconformity		
Hough Lake Group		
Mississagi (10)	Quartzite	
Pecors (9)	Argillite	
Ramsay Lake (8)	Conglomerate	
Local disconformity		
Elliot Lake Group[3]		
McKim (7)	Argillite	
Matinenda (5)	Quartzite, with or without uranium-conglomerate Conglomerate Arkose, with or without uranium-conglomerate	
Thessalon-Dollyberry Lake[3]	Mafic volcanics, minor felsic volcanics, sedimentary rocks	
Livingstone Creek	Quartzite, minor conglomerate	
Unconformity		
Archean	Regolith	
Late Archean intrusives	Diabase, gabbro-anorthosite	2 500 (?)
Intrusive contact		
Kenoran (Algoman) (3)	Granite	2 600+
Intrusive contact		
Early Archean intrusives	Gabbro	
Intrusive contact		
Keewatin (1)	Volcanic and sedimentary	

[1] Mount Lake Dike may be 1795 m.y. old, relationship to lamprophyre not known

[2] There are no Murray-Creighton Granitic Rocks represented in the Elliot Lake area, however, age determinations provide a closer upper limit on the Huronian Supergroup than those from the Nipissing Diabase.

[3] Volcanic rocks are found locally in the Elliot Lake Group (6); each occurrence has been given its own name; age about 2400 m.y. Units to south and east may be distinct from the Thessalon-Dollyberry Formations, and related to gabbro-anorthosite intrusions.

[4] Codes keyed to fig. 2 are in parentheses, Geologic ages given are from a variety of sources, recalculated Stockwell 1982.

TABLE 2. – SYSTEMS OF HURONIAN STRATIGRAPHIC NOMENCLATURE

COLLINS (1925)		ROBERTSON (1967a)		ROSCOE (1960)		ROBERTSON AND OTHERS (1969)	
Cobalt Series	Upper White Q[1]	Cobalt Group	Bar River	Cobalt Group	Upper White Q[1]	Cobalt Group	Bar River
	Banded Cherty		Gordon Lake		Banded Cherty		Gordon Lake
	Lorrain		Lorrain		Lorrain		Lorrain
	Gowganda		Gowganda		Gowganda		Gowganda
Bruce Series	Serpent	Bruce Group	Serpent	Quirke Lake Group	Serpent	Quirke Lake Group	Serpent
	Espanola		Espanola		Espanola		Espanola
	Bruce		Bruce		Bruce		Bruce
	Mississagi		Upper Mississagi	Hough Group	Mississagi	Hough Lake Group	Mississagi
			Middle Mississagi argillite		Pecors		Pecors
	(Ramsay Lake)		Conglomerate		Whiskey		Ramsay Lake
	Granites		Lower Mississagi argillite	Elliot Group	Nordic	Elliot Lake Group[2]	McKim
Archean Sudbury Series	McKim		Quartzite		Matinenda		Matinenda
		Archean	Algoman	Archean		Archean	
	Schist Complex		Keewatin				

[1] Q equals Quartzite

[2] Volcanic rocks are found locally in the Elliot Lake group: Livingstone Creek Formation locally underlies volcanic rocks.

TABLE 3 SUMMARY OF HURONIAN STRATIGRAPHY IN THE BLIND RIVER-ELLIOT LAKE AREA.[1]

Group	Formation	Lithology	Thickness (in feet)[2,3]	Depositional Environment[3]	Source	Mineralization
Cobalt	Bar River	Quartzite	At least 1 000 — Flack Lake; at least 4 000 — Willisville	Coastal—beach	Source north but currents variable	
	Gordon Lake	Siltstone, sandstone	1 000 — Flack Lake; 3 000 Willisville	Tidal flat		
	Lorrain	Quartzite, conglomerate, arkose	2 000 — 6 000	Fluvial to near shore	North-northwest	Th (U)[4] in north Cu
	Gowganda	Conglomerate, greywacke, quartzite, siltstone	500 — 4 200	Glacial in north; glacial-marine in south	North-northwest	
Quirke Lake	Serpent	Quartzite	0 — 1 100	Fluvial	Northwest	
	Espanola	Limestone, dolostone, siltstone	0 — 1500	Fluvial, lagoonal—marine	Northwest	U trace in Victoria Tp. Cu in limestone against diabase
	Bruce	Conglomerate	0 — 200	Glacial, glacial-marine	North?	
Hough Lake	Mississagi	Quartzite	0 — 3 000+	Fluvial—shallow marine	West-northwest in west; north in southeast	U-Th near basement highs
	Pecors	Argillite	40 — 1 000+	Shallow water—turbidite	North-northwest	Traces U near basement highs
	Ramsay Lake	Conglomerate	5 — 200	Glacial—glacial-marine	Northwest?	Traces U where unconformable on Matinenda Formation
Elliot Lake	McKim	Argillite—greywacke	0 — 2 500+	Shallow water, turbidite to S.E.	Northwest	Traces U near basement highs
	Matinenda	Quartzite, arkose, conglomerate	0 — 700+	Fluvial—deltaic	Northwest	U-Th-Rare Earths in conglomerate in basement lows [5]
	Volcanic rocks	Andesite—basalt (felsic volcanic rocks)	Local piles	Subaerial	Flack Lake F. Murray F.	U-Th in conglomerate interbeds
	Livingstone Creek	Subarkose, conglomerate	0 — 1 000+	Fluvial	Unknown?	

[1] Table derived from Robertson 1970, Fralick and Miall 1981.

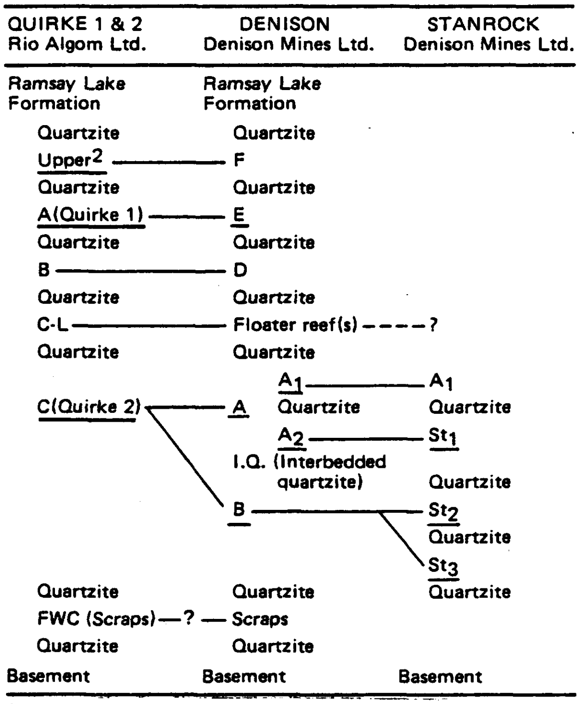
[2] To convert to metres, multiply by 0.3048

[3] Deeper water facies are found in the Espanola wedge to the S.E.

[4] Abbreviations: Cu — Copper, Th — Thorium, U — Uranium, F — Fault

[5] All U-deposits of commercial importance in the Blind River-Elliot Lake area are in the Matinenda Formation.

TABLE 4 CORRELATION OF QUARTZ-PEBBLE CONGLOMERATE REEFS, QUIRKE ZONE.[1]



QUIRKE 1 & 2 Rio Algom Ltd.	DENISON Denison Mines Ltd.	STANROCK Denison Mines Ltd.
Ramsay Lake Formation	Ramsay Lake Formation	
Quartzite	Quartzite	
Upper[2]	F	
Quartzite	Quartzite	
A(Quirke 1)	E	
Quartzite	Quartzite	
B	D	
Quartzite	Quartzite	
C-L	Floater reef(s) – – – –	?
Quartzite	Quartzite	
	A_1	A_1
C(Quirke 2)	A Quartzite	Quartzite
	A_2	St_1
	I.Q. (Interbedded quartzite)	Quartzite
	B	St_2
		Quartzite
		St_3
Quartzite	Quartzite	Quartzite
FWC (Scraps) —? —	Scraps	
Quartzite	Quartzite	
Basement	Basement	Basement

[1] Modified from Robertson 1976.

[2] Underlined beds have given rise to production

TABLE 5 - Uranium, thorium, and titanium contents
in percent, of Blind River brannerite

Mine	Author	Colour	Comments	U_3O_8 ratio	T_hO_2	TiO_2	U_3O/ThO_2
Others than Blind River	Thorpe (1963)	-----------		40-52	0.3-.15	32-40	40-52
Nordic	Patchett (1960)	Reddish brown	Altered	32.6	2.6	30.3	12.5
Do	do	Darker	More glassy, less altered	32.2	1.8	30.5	17.9
Denison	Roscoe (1959a)	Black		41	6.1	20	6.7
Do	do	Dark brown		36	1.8	30	20.0
Quirke	do	do		24	1.7	37	14
Do	do	Brown		20	2.2	30	9.1
Do	do	Cream		6	1.2	27	5.0
Can-Met	Pienaar (1963)	Veinlet material					
Regional	Thorpe (1963)			30	2.3	30	13

Theis 1979 has further studied the "brannerite" and has classified it as follows:

Type 1 - Composite variable proportions of quartz rutile, anatase, uraninite, galena and rarely pyrrhotite with a typical lath textrue and a zoning of the brannerite phase.

Type 2 - Similar to the uranium phase of type 1, unzoned, red-brown to black in colour, with little or no rutile present and a cheesy texture.

Type 3 - A single zoned grain with high niobium.

The compositions of the "Brannerite phase" are similar to those of the "other than Blind River" given by Thorpe (above) but the composition of the composite grains would be extremely variable and would have no mineralogical meaning.

Robinson (1982) has recognised additional types of Ti-U aggregate but types 1 and 2 of Theis are numerically the only significant ones.

TABLE 6 Uranium and thorium contents in Blind River uraninite

Mine	Author	U_3O_8	ThO_2	$U_3O_8ThO_2$
Denison	Pienaar (1963)	48.4	5.6	8.65
Do	do	39.0	7.2	5.4
Do	do	55.5	5.4	10.3
Nordic	Patchett(1960)	55.25	6.25	8.85
Quirke	Wanless & Traill (1956)	51.7	4.1	12.6
Pronto	do	57.0	5.12	11.1
Nordic	Roscoe (1959a)	64	6.3	10.15
Denison	do	60	5.9	10.2
Panel	Thorpe (1963)	29.6	[1]3.84	[1]7.7
Regional	do	60	6	10
[1]Contaminated?				
Nordic	Grandstaff 1980	65.3	6.2	10.05
Quirke/Denison,	Theis 1979	65	6.5	10

TABLE 7 - Analyses of Blind River monazites

	Roscoe (1969b)				Thorpe (1963	
	1	2	3	4	Range	Average
Colour	Orange	Yellow	Grey	Grey	-----	-----
ThO_2	5.9	3.9	6.7	5.9	5.6 -6.2	5.6
U_3O_8	.31	.95	1.65	2.9	1 -2	1.4
U_3O_8/ThO_2	.0525	.244	.246	.492	.18-.32	.25