Unconformity-related uranium potential: Clues from Wernecke Breccia, Yukon

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ABSTRACT

Unconformity-related uranium deposits are best known from the Athabasca Basin, Canada and the Pine Creek area of Australia. In both regions, fault-controlled mineralization is associated with a regional unconformity between Paleo- to Mesoproterozoic clastic rocks and locally carbonaceous Paleoproterozoic metasedimentary rocks. A similar scenario exists in the Wernecke and Ogilvie mountains of the Yukon where Mesoproterozoic Pinguicula Group strata unconformably overlie Paleoproterozoic Wernecke Supergroup metasedimentary rocks. Uranium occurs in veins that cut Wernecke Supergroup rocks, most notably in association with Wernecke Breccia — a large-scale Paleo- to Mesoproterozoic breccia system. Ages returned by uranium minerals are significantly younger than the ages of the host strata and may be reflecting mobilization of uranium during later tectonic and/or thermal events. The possibility that uranium occurrences in the Wernecke and Ogilvie mountains fit the unconformity model needs to be verified with further study, but is intriguing and raises the possibility that significant deposits may be found.

RÉSUMÉ

Les gisements d'uranium associés à des discordances qui sont les mieux connus sont ceux du bassin d'Athabasca au Canada et de la région de Pine Creek en Australie. Dans ces deux régions, la minéralisation déterminée par les failles est associée à une discordance régionale entre les roches clastiques du Mésoprotérozoïque et les roches métasédimentaires du Paléoprotérozoïque par endroits carbonées. On observe un scénario similaire dans les monts Wernecke–Ogilvie au Yukon où les strates du Groupe de Pinguicula du Mésoprotérozoïque reposent en discordance sur les roches métasédimentaires du Supergroupe de Wernecke (SGW) du Paléoprotérozoïque. L'uranium est présent dans des veines recoupant les roches du SGW et il est des plus remarquablement associé à la brèche de Wernecke — un grand réseau bréchique paléo- à mésoprotérozoïque. Les âges révélés par les minéraux uranifères sont significativement moindres que ceux des strates hôtes et pourraient refléter une mobilisation de l'uranium lors d'événements tectoniques et/ou thermiques ultérieurs. Des études plus poussées sont nécessaires pour vérifier la possibilité d'existence dans les monts Wernecke–Ogilvie d'occurrences d'uranium conformes au modèle de la discordance, mais elle est intrigante et évoque la possibilité de découverte de gisements importants.

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INTRODUCTION

Unconformity-type uranium deposits are the highest grade, lowest cost uranium resource in the world (e.g., Jefferson *et al*., 2003). They are best known from the Athabasca Basin, Canada and the Pine Creek area, Australia (Fig. 1; e.g., Ruzicka, 1995). The mineralization is spatially related to regional tectonic discontinuities and occurs at, or below, a regional unconformity between late Paleoproterozoic to Mesoproterozoic clastic rocks and underlying, locally carbonaceous, Paleoproterozoic metasedimentary rocks (e.g., Ruzicka, 1995; Tourigny *et al*., 2001). In a generally accepted model, uranium deposition results from the mixing of saline, oxidized, uranium-bearing basinal brines with basement-derived reduced fluid at, or near, the intersection of fault zone(s) with the unconformity (Fig. 1; e.g., Kotzer and Kyser, 1995; Ruzicka, 1995; Fayek and Kyser, 1997).

In the Wernecke and Ogilvie mountains of the Yukon, uranium is hosted by Paleoproterozoic Wernecke Supergroup metasedimentary rocks and ?Paleo- to Mesoproterozoic Wernecke Breccia that are unconformably overlain by Mesoproterozoic Pinguicula Group sedimentary rocks; the Richardson fault array, a long-lived, regional-scale fault system, is located just east of the Wernecke Mountains (Fig. 2; e.g., Abbott, 1997; Thorkelson, 2000). Brannerite and pitchblende in veins and fractures returned U-Pb ages considerably younger than those of the host strata and may be reflecting uranium mobilization during tectonic and/or thermal events (e.g., Archer *et al*., 1986). This, in turn, suggests that uranium mineralization in the Wernecke and Ogilvie mountains may fit an unconformity-type model, thereby raising the possibility that major deposits may exist in the area.

WERNECKE-OGILVIE MOUNTAINS, YUKON

GEOLOGIC SETTING

The Wernecke and Ogilvie mountains are largely underlain by Paleoproterozoic (>*ca.* 1710 Ma) rocks of the Wernecke Supergroup (e.g., Delaney, 1985; Abbott, 1997; Thorkelson, 2000). The base of the Supergroup is not exposed but is interpreted to sit on ≥1.84 Ga crystalline basement that is the westward continuation of the Canadian shield (e.g., Norris, 1997; Thorkelson, 2000; Thorkelson *et al*., 2005). A regional-scale breccia system known as Wernecke Breccia cuts the Wernecke Supergroup and hosts iron oxide-copper-gold ± uranium ± cobalt (IOCG) mineralization (e.g., Thorkelson, 2000; Hunt *et al*., 2005). Mesoproterozoic strata of the Pinguicula Group unconformably overlie Wernecke Supergroup and Wernecke Breccia (e.g., Abbott, 1997; Thorkelson, 2000).

WERNECKE SUPERGROUP

Wernecke Supergroup is approximately 13 km thick, and is made up of the Fairchild Lake, Quartet and Gillespie Lake groups (e.g., Gabrielse, 1967; Delaney, 1981; Bell, 1986a; Thorkelson, 2000). The Fairchild Lake Group forms the basal part of the Wernecke Supergroup and consists of at least a 4-km thickness of siltstone, mudstone, claystone and fine-grained sandstone, plus minor carbonate rocks and evaporites. The Quartet Group gradationally overlies the Fairchild Lake Group, is at least 5 km thick, and consists of basal black carbonaceous shale and conformably overlying, coarsening-upwards, interlayered shale, siltstone and sandstone (Delaney, 1978, 1981). The Gillespie Lake Group gradationally overlies the Quartet Group and forms the upper part of the Wernecke Supergroup. It consists dominantly of locally stromatolitic dolostone and limestone, with lesser claystone, mudstone and sandstone, and is at least 4 km thick. The Wernecke Supergroup was metamorphosed to greenschist facies and multiply deformed during the Paleoproterozoic Racklan Orogeny (e.g., Thorkelson, 2000; Brideau *et al*., 2002).

Figure 1. *(facing page) Location of unconformity-type uranium deposits in the Athabasca Basin and Pine Creek areas plus genetic models for each region. Deposits in the Athabasca Basin include: 1) Rabbit Lake, 2) Collins Bay, 3) Eagle Point, 4) Horseshoe and Raven, 5) West Bear, 6) McClean-Sue, 7) JEB, 8) Dawn Lake, 9) Midwest, 10) Cigar Lake, 11) P2 North, 12) Key Lake, 13) Cluff, Dominique-Janine and Claude, 14) Maurice Bay and 15) Fond du Lac. In the Athabasca Basin, mineralization occurs above, at, and below the regional unconformity. Deposits occur in three areas in the Pine Creek region: Alligator Rivers, South Valley and Rum Jungle; deposits include: 1) Rum Jungle Creek South, 2) Nabarlek, 3) Koongarra, 4) Ranger 1, 5) Jabiluka and 6) Coronation Hill. Mineralization is hosted in rocks below the unconformity. Modified from Ruzicka (1995).*

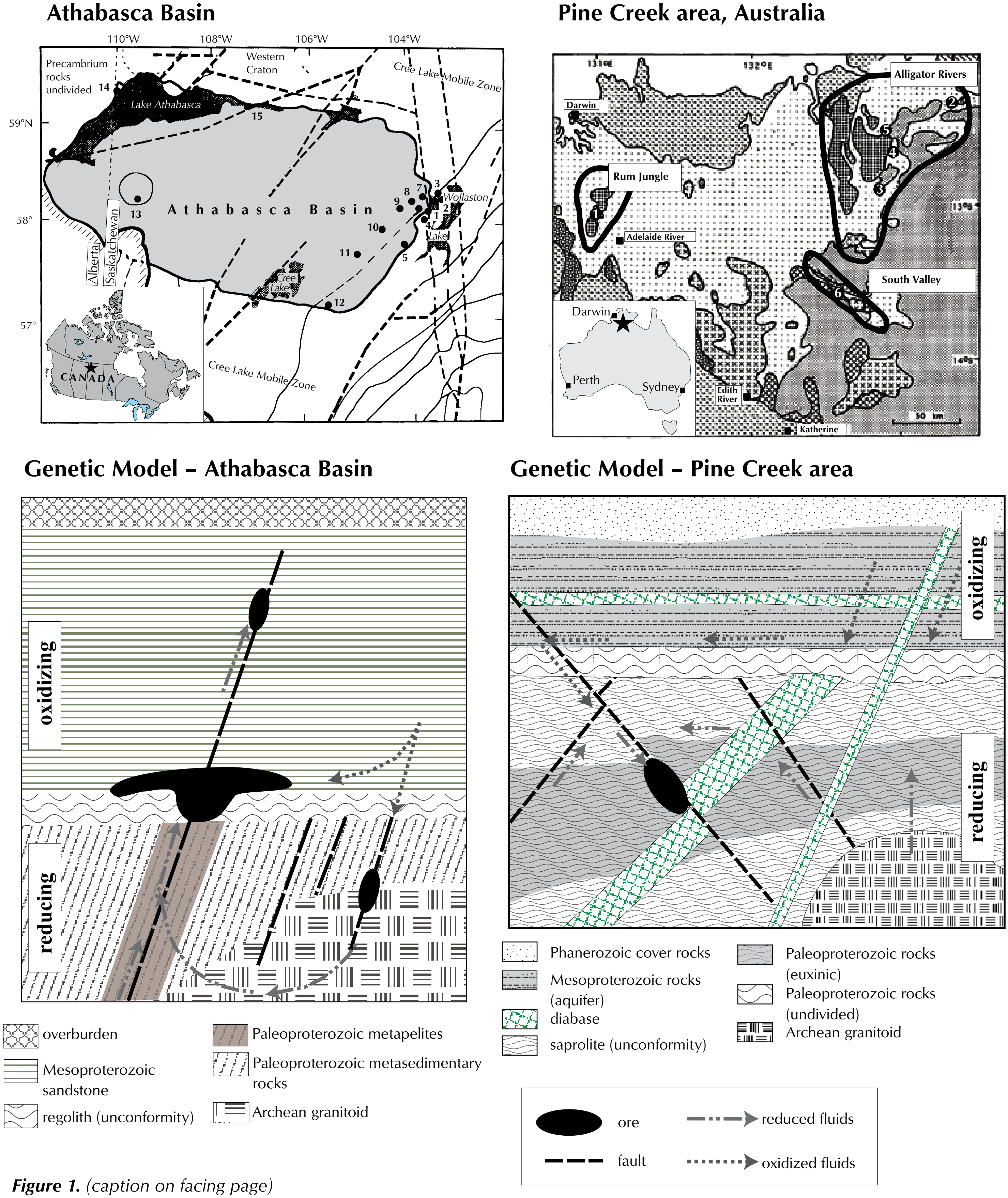

Figure 1. *(caption on facing page)*

WERNECKE BRECCIA

At least 65 bodies of Wernecke Breccia cross-cut the Wernecke Supergroup and are made up largely of clasts of the Supergroup in a matrix of rock flour and hydrothermal precipitates (dominantly quartz, feldspar, carbonate, hematite and magnetite; e.g., Thorkelson 2000; Hunt *et al.*, 2005). The breccias are spatially associated with regional-scale faults and formed in weak and/or permeable zones such as faults, fold axes and lithological contacts during the expansion of over-pressured fluids (e.g., Bell, 1978, 1986a,b; Bell and Delaney, 1977; Thorkelson, 2000; Hunt *et al.*, 2005). Iron oxide-copper (± uranium ± gold ± cobalt) minerals are disseminated and occur as veins within the breccia and surrounding Wernecke Supergroup rocks; cross-cutting relationships indicate multiple phases of brecciation and mineralization (e.g., Brookes *et al.*, 2002; Hunt *et al.*, 2002, 2005; Thorkelson *et al.*, 2003; Yukon MINFILE[2]).

PINGUICULA GROUP

The Pinguicula Group unconformably overlies Wernecke Supergroup and Wernecke Breccia, is about 3500 m thick, and has been divided from base to top into units A, B and C (e.g., Abbott, 1997; Thorkelson, 2000). Conglomerate and locally pyritic sandstone occur at the base of unit A and are overlain by shale and siltstone. The basal

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[2] *All Yukon MINFILE references are found in Deklerk and Traynor (2005).*

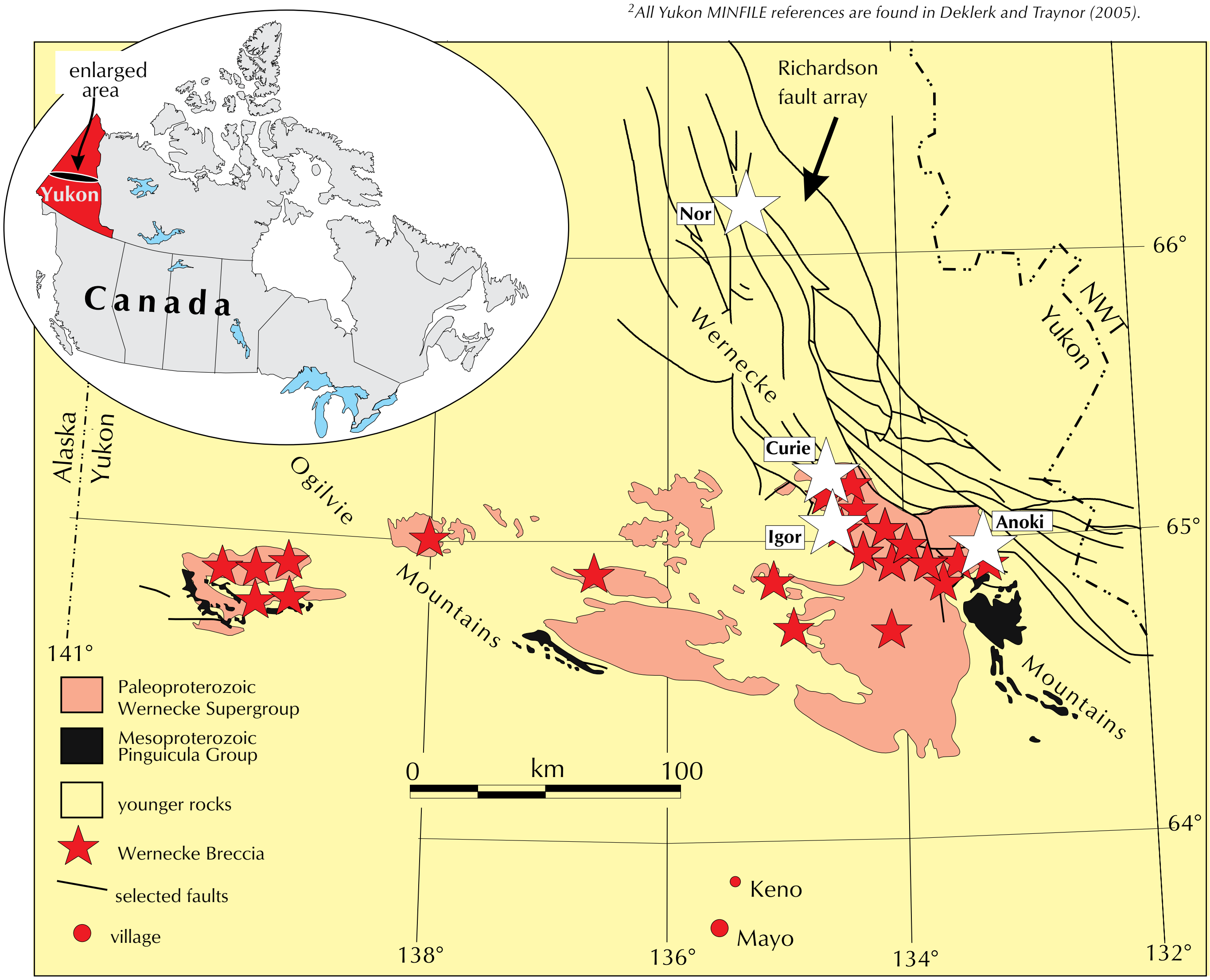

Figure 2. *Location of the Wernecke and Ogilvie mountains and the distribution of Wernecke Supergroup, Wernecke Breccia and Pinguicula Group rocks, plus the locations of the Nor, Igor and Anoki mineral occurrences (Yukon MINFILE, Deklerk and Traynor, 2005) and the Curie mineralized area.*

conglomerate is dominated by clasts of siltstone, likely derived from Wernecke Supergroup. Clasts of Wernecke Breccia are locally present. Unit B gradationally overlies Unit A and is made up of dolostone, limestone and minor siltstone. Limestone and dolostone of Unit C abruptly to gradationally overlie Unit B.

URANIUM MINERALIZATION

Uranium minerals occur in two distinct styles in the Wernecke and Ogilvie mountains: 1) disseminated in Wernecke Breccia and proximal Wernecke Supergroup strata, and 2) in veins and fractures that cut breccia and the Wernecke Supergroup (e.g., Yukon MINFILE 2005). The disseminated mineralization is likely part of the IOCG mineralizing event that is associated with the formation of Wernecke Breccia. However, the occurrence of mineralization in veins that cross-cut breccia and Wernecke Supergroup, and ages of uranium minerals that are significantly younger than the host strata, suggest later uranium mineralizing events. The ages approximately correspond to those of regional tectonic and/or thermal pulses, indicating uranium may have been mobilized by fluid flow driven by these events (Table 1). The age determinations were derived from pitchblende and brannerite, and it is possible that the U-Pb systematics have been disturbed, and therefore the resulting ages may not represent the timing of uranium mineralization. However, similar minerals were dated in the Athabasca Basin and their ages are interpreted to correspond to three main hydrothermal events, *ca.* 1500, 950 and 300 Ma, that were identified from clay and other mineral parageneses (e.g., Kotzer and Kyser, 1995; Fayek and Kyser, 1997). Transport of uranium and deposition of ore occurred during the first event. Alteration and remobilization of uranium took place during the second event. Remobilization of uranium, alteration of existing ore, and possible deposition of new ore occurred during the youngest event (e.g., Fayek and Kyser, 1997).

SOURCES OF URANIUM

Sources of uranium that could potentially be mobilized by later fluids occur in Wernecke Supergroup and in Wernecke Breccia. Elevated levels of uranium occur in some Wernecke Supergroup strata, particularly phyllite and siltstone layers in the Fairchild Lake (≤40 ppm U) and Quartet (≤18 ppm U) groups (Fig. 3; Goodfellow, 1979; Delaney, 1985). Disseminated uranium minerals occur in the matrix of Wernecke Breccia in association with IOCG mineralization (e.g., Bell and Delaney, 1977; Yukon MINFILE). Additional uranium sources could potentially be present in crystalline basement, however it is not exposed in the region, and the nature and composition of rocks underlying the Wernecke Supergroup remain unknown. Erosion of the above rocks may have contributed uranium to younger sedimentary successions; for example, clasts of Wernecke Supergroup and Wernecke Breccia occur in basal Pinguicula Group conglomerate (Thorkelson, 2000).

YUKON EXAMPLES

Wernecke Supergroup and Wernecke Breccia in the Anoki area (106C 086[3]) are unconformably overlain by basal Pinguicula Group (Fig. 2; Fig. 32 in Thorkelson, 2000). Results from rock samples collected at varying distances from the contact demonstrate that uranium is concentrated at the unconformity, i.e., U=25.7 ppm 0.2 m above and 0.3 m below the unconformity, and decreases to 4.0 ppm at 3 m below, and to 1.6 ppm at 7 m below the unconformity (Fig. 4). This pattern of enrichment suggests that uranium may have been deposited by fluid flow along the unconformity. Fracture zones from this area also contain uranium, and samples returned up to 0.6% U_3O_8 over 1 m (Stammers and Ikona, 1977). At the nearby Pterd occurrence (106C 069) pitchblende occurs in fractured Quartet Group; samples returned up to 7.67% U_3O_8 and gave $^{207}Pb/^{206}Pb$ ages of 521-469 Ma (Table 1; Archer *et al.*, 1986; Cash Minerals, 2005[4]).

The Curie area, largely underlain by Quartet Group strata and Wernecke Breccia, covers several MINFILE occurrences (106E 005, 006, 011, 028-031) that consist of disseminated and vein-style uranium mineralization (Fig. 2). Regional geochemical silt (RGS) samples from creeks draining this area returned elevated levels of uranium and rare earth elements (REE) ± silver, gold, cobalt, copper, nickel, tungsten, manganese, arsenic (Table 2; Hornbrook *et al.*, 1990) — a similar suite of elements to those enriched in unconformity-type deposits in the Athabasca Basin and Pine Creek region (e.g., Ruzicka, 1995). A boulder collected recently from a trench in the Curie area (Fig. 2) contained 54.3% U_3O_8 (Signet Minerals Inc., 2005[5]). Samples of brannerite

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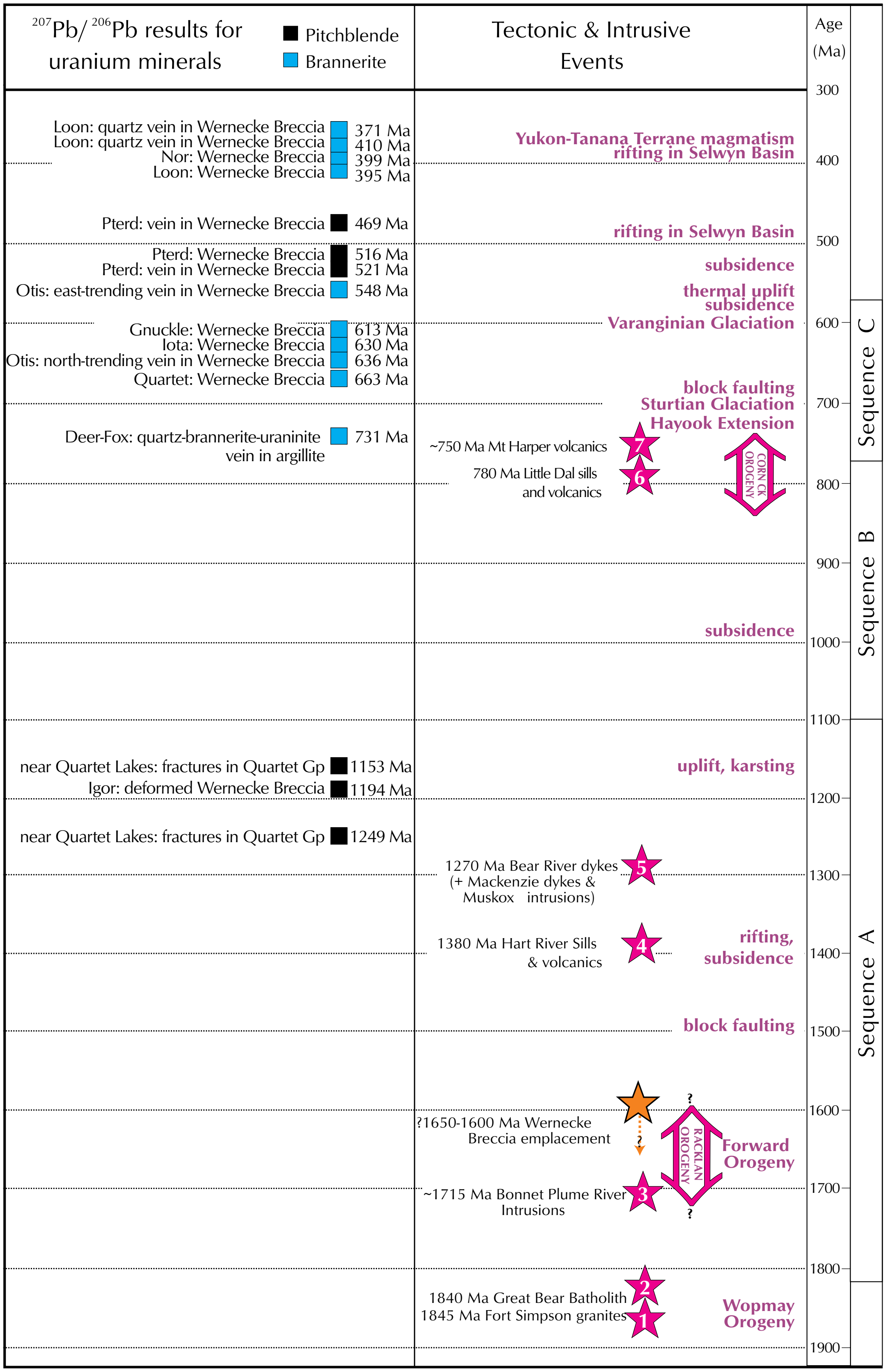
[3] *Numbers in brackets refer to Yukon MINFILE. See Yukon Geological Survey website http://www.geology.gov.yk.ca/minfile/index.html for on-line access to occurrence descriptions or Deklerk and Traynor (2005) for a published version.*

[4] *For results from Lumina (Pterd) and Igor, see Cash Minerals website http://www.cashminerals.com/s/Uranium.asp?ReportID=103562.*

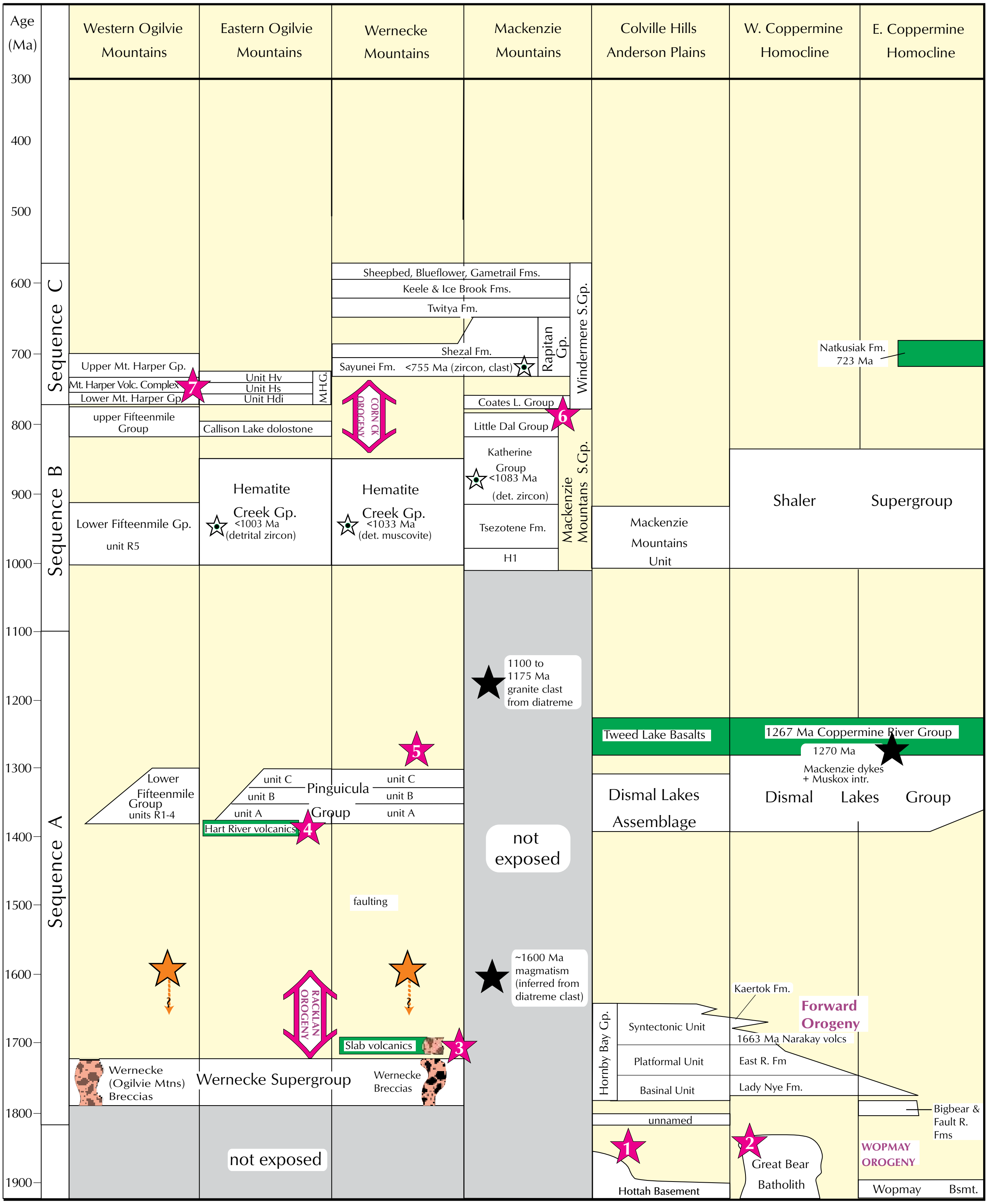
[5] *Signet Minerals Inc. News release 2005-10-26 "Signet Minerals finds 54.3% U_3O_8 in Curie grab sample."*

Table 1. *Comparison of age dates with tectonic and thermal events and suggested correlation of Proterozoic successions in the Wernecke, Ogilvie and Mackenzie mountains, and the western Arctic. Modified from Thorkelson (2000). Data in the age date column is from Archer et al. (1986). Fm = formation, Gp = Group, S.Gp = Supergroup.*



^{207}Pb/^{206}Pb results for uranium minerals ■ Pitchblende 🟦 Brannerite		Tectonic & Intrusive Events	Age (Ma)	
			300	
Loon: quartz vein in Wernecke Breccia 🟦	371 Ma			
Loon: quartz vein in Wernecke Breccia 🟦	410 Ma	Yukon-Tanana Terrane magmatism		
Nor: Wernecke Breccia 🟦	399 Ma	rifting in Selwyn Basin		
Loon: Wernecke Breccia 🟦	395 Ma		400	
Pterd: vein in Wernecke Breccia ■	469 Ma	rifting in Selwyn Basin	500	
Pterd: Wernecke Breccia ■	516 Ma			
Pterd: vein in Wernecke Breccia ■	521 Ma	subsidence		
Otis: east-trending vein in Wernecke Breccia 🟦	548 Ma	thermal uplift subsidence		Sequence C
		Varanginian Glaciation	600	
Gnuckle: Wernecke Breccia 🟦	613 Ma			
Iota: Wernecke Breccia 🟦	630 Ma			
Otis: north-trending vein in Wernecke Breccia 🟦	636 Ma			
Quartet: Wernecke Breccia 🟦	663 Ma			
		block faulting Sturtian Glaciation	700	
Deer-Fox: quartz-brannerite-uraninite vein in argillite 🟦	731 Ma	Hayook Extension ~750 Ma Mt Harper volcanics ⑦ 780 Ma Little Dal sills and volcanics ⑥ CORN CK OROGENY		
			800	Sequence B
			900	
		subsidence	1000	
			1100	Sequence A
near Quartet Lakes: fractures in Quartet Gp ■	1153 Ma	uplift, karsting		
Igor: deformed Wernecke Breccia ■	1194 Ma		1200	
near Quartet Lakes: fractures in Quartet Gp ■	1249 Ma			
		1270 Ma Bear River dykes (+ Mackenzie dykes & Muskox intrusions) ⑤	1300	
		1380 Ma Hart River Sills & volcanics ④ rifting, subsidence	1400	
		block faulting	1500	
		?1650-1600 Ma Wernecke Breccia emplacement RACKLAN OROGENY Forward Orogeny	1600	
		~1715 Ma Bonnet Plume River Intrusions ③	1700	
		1840 Ma Great Bear Batholith ② 1845 Ma Fort Simpson granites ① Wopmay Orogeny	1800	
			1900	

Table 1. *(continued)*



returned ${}^{207}Pb/{}^{206}Pb$ ages of 410-371 Ma (Table 1 – Loon; Archer *et al.*, 1986). Disseminated and vein-style uranium mineralization also occurs in Wernecke Breccia and proximal Quartet Group on the Igor prospect (106E 009). RGS samples returned elevated levels of uranium and REE ± barium, cobalt, copper, arsenic. Significant results include 0.4% U_3O_8 and 6.62% Cu over 4.32 m in drill core (Cash Minerals, 2005[5]). Pitchblende from Igor returned a ${}^{207}Pb/{}^{206}Pb$ age of 1194 Ma (Table 1; Archer *et al.*, 1986). Uranium mineralization at the Nor prospect (106L 061), which occurs about 120 km north of the main Wernecke Breccia belt, is hosted by Fairchild Lake Group and Wernecke Breccia (Fig. 2). Monazite at the Nor was dated by U-Pb at approximately 1270 Ma, whereas brannerite from the same area returned a ${}^{207}Pb/{}^{206}Pb$ age of 399 Ma (Table 1; Archer *et al.*, 1986; Parrish and Bell, 1987).

SUMMARY

Information on uranium mineralization in the Wernecke and Ogilvie mountains is not abundant, however, the available data provides tantalizing clues that suggest the mineralization may fit an unconformity-type model. The overall general geological setting is similar to that in areas (Athabasca Basin, Pine Creek region) that are known to host unconformity-associated deposits: Paleoproterozoic, locally carbonaceous, metasedimentary rocks are unconformably overlain by Mesoproterozoic clastic rocks, and the unconformity is intersected by regional-scale faults that could have acted as fluid conduits. In the Athabasca Basin, intense hydrothermal alteration is present around deposits and consists largely of clay minerals and local enrichments of potassium, magnesium, calcium, boron, uranium, nickel, cobalt, arsenic, copper and iron (e.g., Kotzer and Kyser, 1995; Fayek and Kyser, 1997). Chlorite is the dominant alteration mineral in the Pine Creek area deposits (e.g., Ruzicka, 1995). Possible unconformity-related uranium mineralization in the Wernecke and Ogilvie mountains generally occurs in, or near, bodies of Wernecke Breccia, which themselves contain IOCG (± U ± Co) mineralization and are associated with extensive potassic, sodic and carbonate

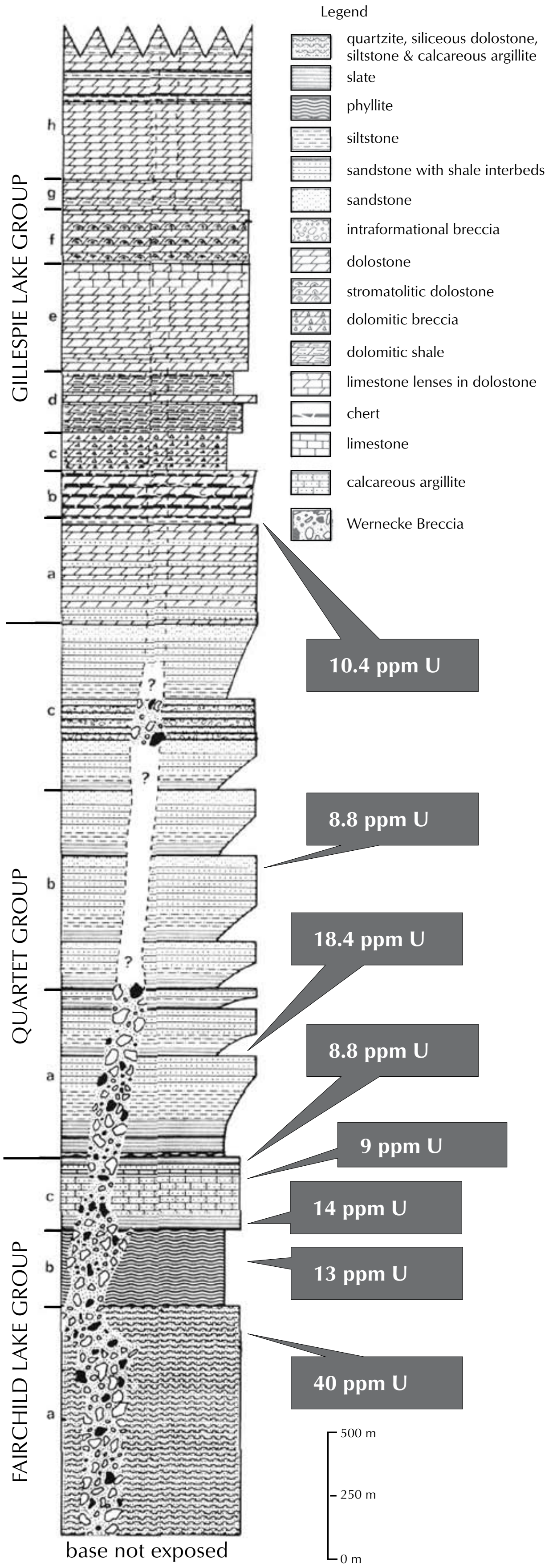


Figure 3. *Elevated levels of uranium occur in some Wernecke Supergroup strata. Unmineralized samples were analysed; figure modified from Goodfellow (1979). Results are presented in Goodfellow (1979) and Delaney (1985). Samples are described in Bell and Delaney (1977).*

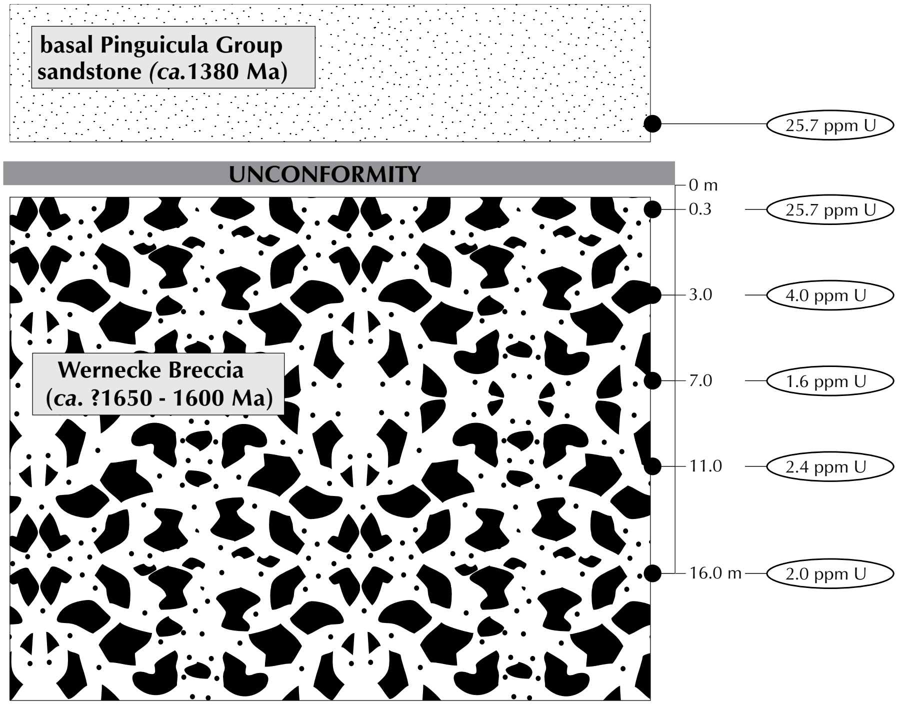


Figure 4. *Elevated levels of uranium occur in rocks collected proximal to the regional unconformity between Wernecke Supergroup – Wernecke Breccia and Pinguicula Group. Results are reported in Thorkelson (2000).*

alteration. The presence of the breccia-related alteration may make recognition of alteration related to unconformity-type uranium mineralization difficult. However, there are some hints of post-breccia alteration: for example, abundant sericite occurs at least locally at the Igor prospect and appears to overprint breccia-related alteration; at the Nor prospect, clay-altered uranium-bearing rocks were exposed in a trench at the contact between Fairchild Lake Group rocks and Wernecke Breccia.

The verification of an unconformity-type model for uranium mineralization in the Wernecke and Ogilvie mountains would be aided by geochronological studies that focussed on the identification of regional fluid flow events. Regional alteration studies that examine the unconformity and basal Pinguicula Group would also be helpful. Airborne and ground geophysical surveys, particularly gamma-ray radiometrics, have been important prospecting tools in the search for uranium in the Athabasca Basin and Pine Creek region and have led to the discovery of several deposits (e.g., Ruzicka, 1995). There is limited airborne geophysical coverage of the Ogilvie Mountains and none over the Wernecke Mountains: an airborne geophysical survey that included radiometrics could be very helpful in identifying prospective areas.

Table 2. *Selected regional geochemical survey sample results from the Curie area compared to values for the North American shelf. Data is from Hornbrook et al. (1990). All values in ppm, except Au = ppb. Analysis by INA except Cu by AAS.*

#	Au	Ce	Co	Cu	Eu	Lu	Rb	Sm	Ta	Th	U	W	Yb	As
761407	6	99.0	15	72	0.5	0.8	160	10.0	1.4	19.0	31	3.0	2	27.0
761409	11	15.5	16	153	2.0	2.0	77	15.4	0.3	9.1	224	0.5	6	14.0
763342	11	150.0	69	182	2.0	1.5	130	11.0	2.4	27.3	17	4.0	5	101.0
763347	14	130.0	35	116	2.0	1.4	130	10.1	2.1	22.7	17	3.0	4	64.9
763348	1	110.0	33	98	1.0	1.4	120	8.4	1.6	21.9	19	5.0	4	56.8
Percentile for North American Shelf														
95th	8	120	30	76	2	0.8	150	9	1.7	17	8	2	4	26
99th	20	180	56	134	3	1.2	190	14	2.8	24	16	4	5	45

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