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Uranium occurrences in the Cree Lake Zone, Saskatchewan, Canada

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ABSTRACT. Over 100 samples of 'pegmatite' and associated host rocks from the Cree Lake Zone of northern Saskatchewan have been studied. The degree of U and Th enrichment of the pegmatites appears to depend on the parent material of the anatectic melts produced during the Hudsonian thermotectonic event. Evidence for Archaean granulite-facies depletion of U and Th is inconclusive; however, important enrichment of U and Th in the basal Aphebian is associated with metamorphosed black shales and possibly evaporates.

NORTHERN Saskatchewan is well known as a uranium-producing area. Two groups of economic deposit are recognized—the 'vein type' of the Beaverlodge Area around Uranium City (north of Lake Athabasca in north-western Saskatchewan) and the 'unconformity type' associated with the basal of the Athabasca Formation (fig. 1). The former are at least in part older ($\simeq$ 1750 Ma) and of lower grade ($< 0.2\%$ U_3O_8) than the latter deposits ($\simeq$ 1100 Ma, $> 0.2\%$ U_3O_8). These deposits and their possible metallogeneses have been reviewed by Barbier (1974), Beck (1969, 1976), Derry (1970), Hoeve *et al.* (1980), Langford (1974, 1977), Maucher (1962), Robertson and Lattanzi (1974), Tremblay (1972), and others. Theories of origin range from hydrothermal through diagenetic to supergene. Notwithstanding these divergent opinions, most authors agree that the ultimate, or original, source of the U was the crystalline basement and that one or more processes of concentration operative over a long period of time, but in several discrete events, produced the observed concentrations of U and associated elements. This view is supported by U minerals in the deposits which indicate discrete events at 1750, 1350, 1050, and 280 Ma.

If the U was mobilized initially from basement the question is raised as to whether or not the Aphebian (Lower Proterozoic) and/or Archaean rocks presently contain evidence of a U-enriched metallogenic province. Unfortunately, few data on radioactive elements in the basement are available and maps of available airborne radiometric data do not indicate any enrichment (Stolz, pers. comm.).

This paper describes the preliminary results of work carried out on some of the numerous U occurrences, most of which are 'pegmatites'* and all of which are subeconomic, and their host rocks in the Cree Lake Zone of Archean and Aphebian basement in northern Saskatchewan.

General geology of the crystalline basement

Two review papers by Lewry and Sibbald (1979, 1980) describe the lithological, structural, and metamorphic setting of northern Saskatchewan; their conclusions are summarized below.

The Churchill Province in Saskatchewan comprises an Archaean basement overlain by Aphebian (L. Proterozoic) supracrustal rocks which were affected by the Hudsonian event ($\simeq$ 1900–1700 Ma). Four major units can be distinguished on the basis of lithological, structural, and metamorphic criteria; they are (from west to east): the Western Craton, the Cree Lake Mobile Zone, the Rottenstone Domain, and the Southeastern Complex (fig. 1). Further subdivision of these units into

* It should be noted that the term 'pegmatite' is used very loosely (grain sizes vary from 1 to 30 mm) and is defined more in terms of composition, texture, and field relations, such as evidence of anatexis, than absolute grain size.

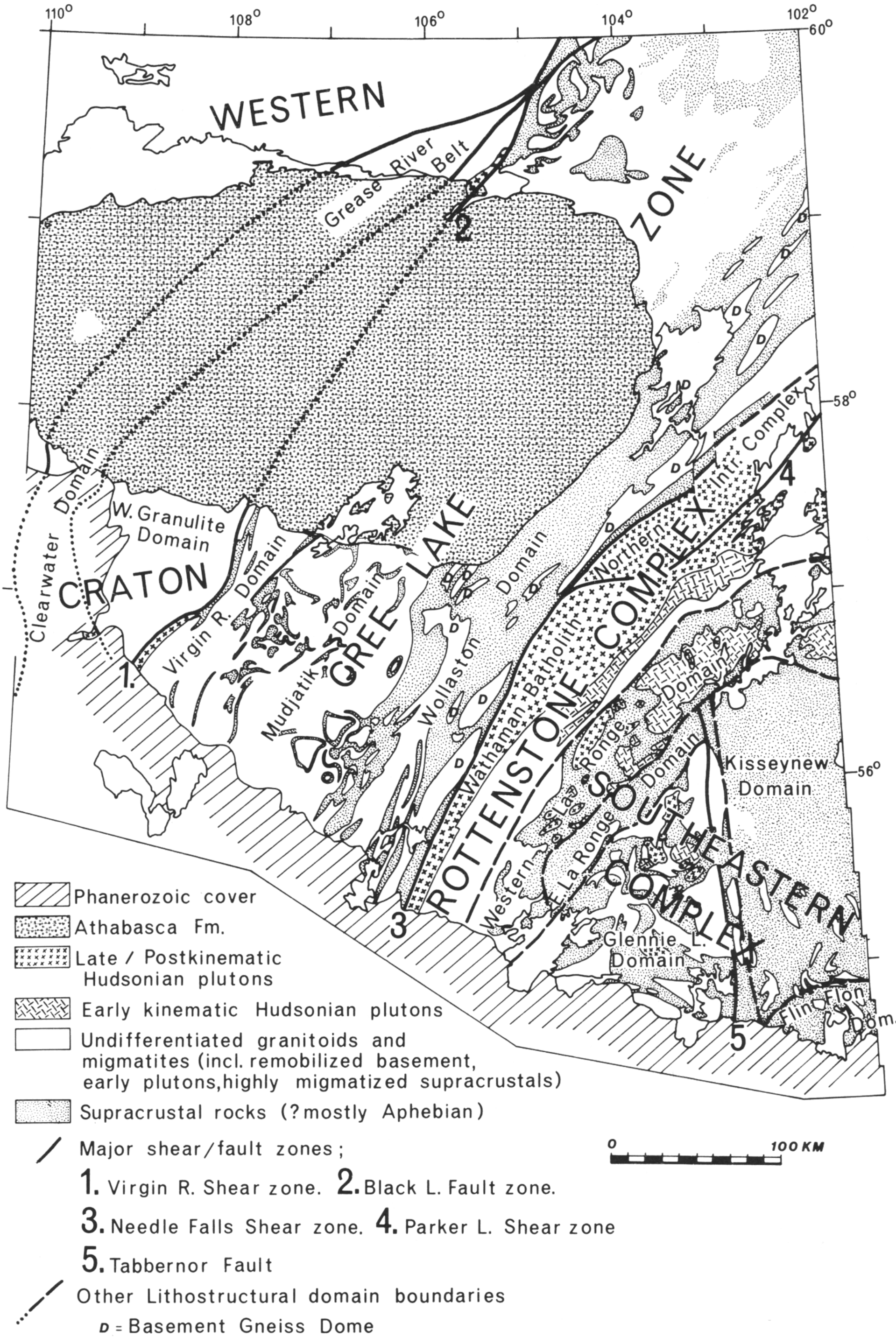

FIG. 1. Lithostructural domains in Churchill Province in Saskatchewan (after Lewry and Sibbald, 1980).

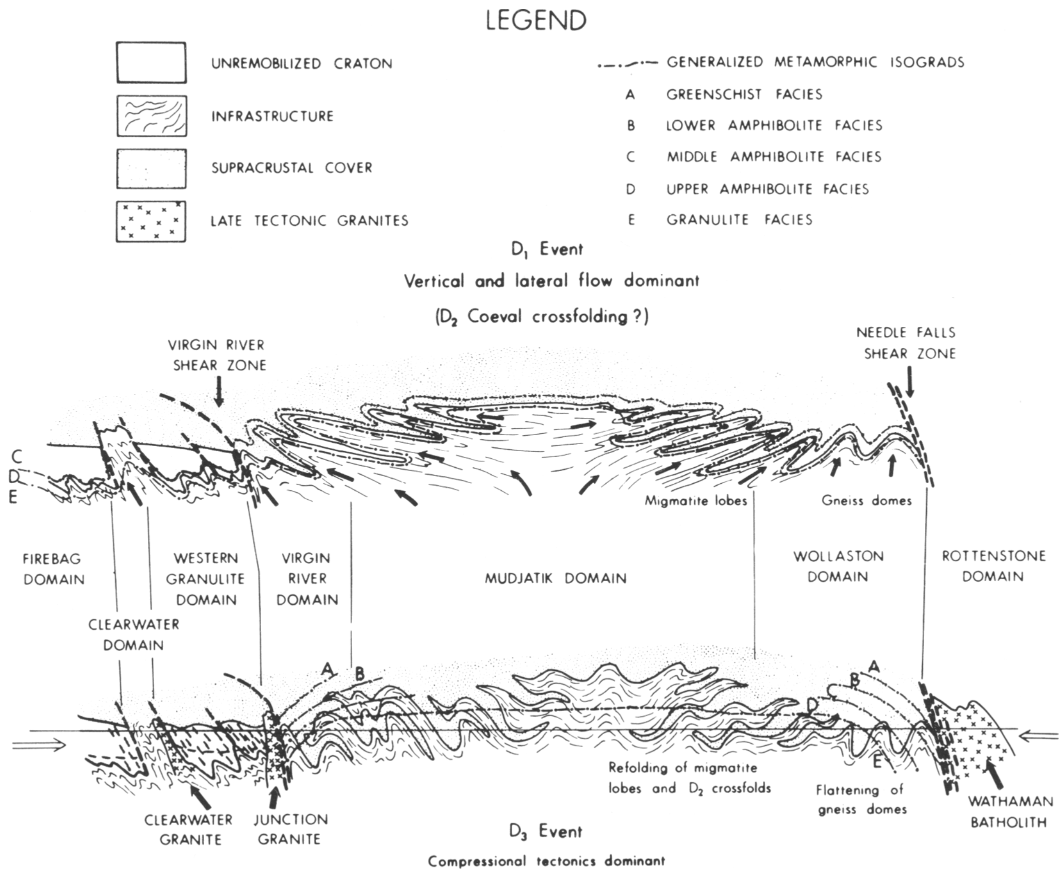

FIG. 2. Schematic NW–SE cross-section of the Cree Lake Zone south of the Athabasca Formation (after Lewry and Sibbald, 1980).

lithostructural domains of similar lithology, structure, and metamorphism is possible; see fig. 1 and the generalized crustal section in fig. 2.

The Western Craton (comprising Firebag, Clearwater, and Western Granulite Domains) is interpreted as a relatively stable cratonic foreland west of the main Hudsonian mobile belt. The area is largely Archaean with locally preserved Aphebian shelf deposits. The Archaean rocks often show limited Hudsonian reworking (retrogression) but primary Archaean metamorphic assemblages, characteristically of granulite and upper amphibolite facies, are preserved. Strong Hudsonian reworking occurs in narrow zones of intense deformation and pervasive retrogressive metamorphism at amphibolite to greenschist facies.

The Cree Lake Zone (comprising Virgin River, Mudjatik, and Wollaston Domains) is bounded to the west by the Virgin River–Black Lake Shear Zone and to the east by the Needle Falls Shear Zone. The central portion of the zone is essentially reworked Archaean comprising flat-lying migmatite lobes and rare infolded Aphebian metasediments. The cooler western (Virgin River) and eastern (Wollaston) margins consist of mantled gneiss domes with extensive envelopes of Aphebian shelf to miogeoclinal rocks. High-grade Hudsonian metamorphism and anatexis gives rise to numerous 'pegmaties', many of which are radioactive.

The Rottenstone Domain is a zone of Hudsonian plutonism dominated by the late-tectonic Wathaman Batholith ($\simeq$ 1865 Ma) which intruded earlier tonalites, granites, and injection migmatites. Pegmatites in this zone are typically non-radioactive; their origin is clearly late magmatic.

The Southeastern Complex is a predominantly eugeoclinal Aphebian sequence associated with island arc volcanics of Hudsonian age.

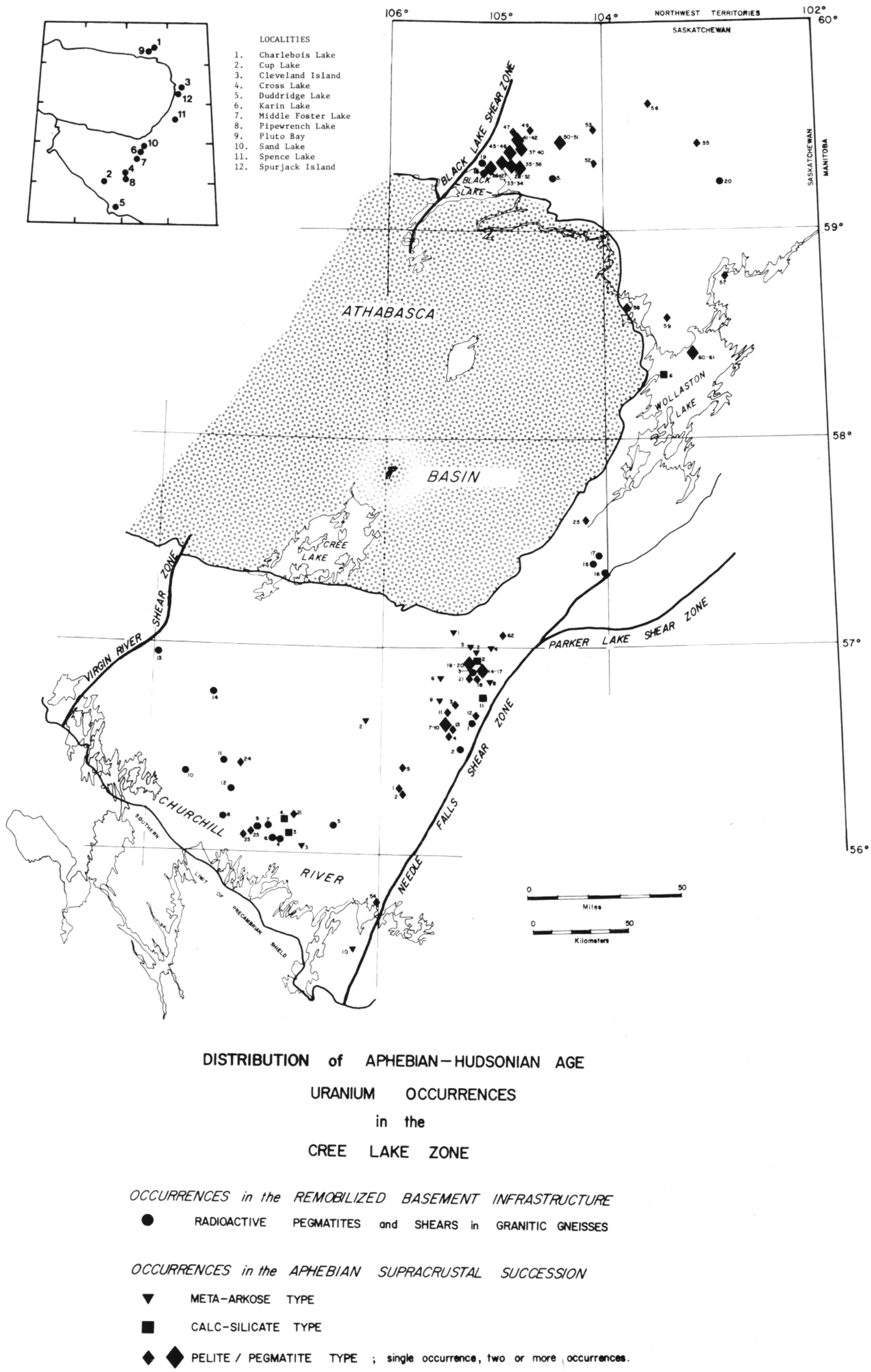

FIG. 3. Known U occurrences in the Cree Lake Zone. Inset (upper left) denotes specific deposits studied in detail.

Syngenetic uranium occurrences

Figure 3 shows the distribution of known U mineralization in the Cree Lake Zone subdivided into those within the Archaean remobilized basement and those within the Aphebian supracrustal rocks. Deposits studied in detail are indicated in the inset. The majority of occurrences lie along the cooler margins of the Cree Lake Zone providing evidence of U migration out of the granulite core towards the upper amphibolite margins or out of U-enriched Aphebian rocks overlying U-poor Archaean rocks.

The radioactive occurrences are grouped into four types: (1) those dominantly in Archaean rocks; (2) those with associated low-grade disseminated U in Aphebian meta-arkoses; (3) those with associated low-grade disseminated U in Aphebian calc-silicates; (4) those associated with Aphebian pelites and semi-pelites.

In spite of the apparently varied association, most occurrences are near to the presumed Archaean/Aphebian boundary and their frequency decreases upwards through the Aphebian. They are dominantly granitoid pegmatites (types 1 and 2), although mafic pegmatites (75% mafic minerals) composed mainly of amphibole or diopside in association with scapolite and apatite are typical of type 3. Type 4 occurrences are represented by

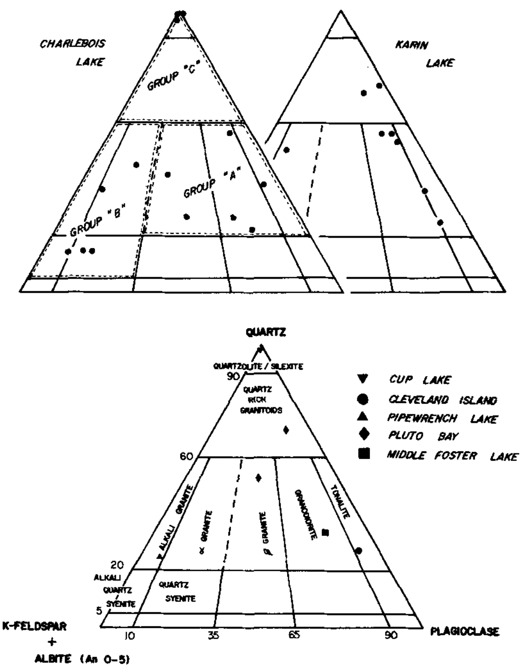

FIG. 4. Classification of granitoid pegmatites in areas studied (after Strekeisen, 1967).

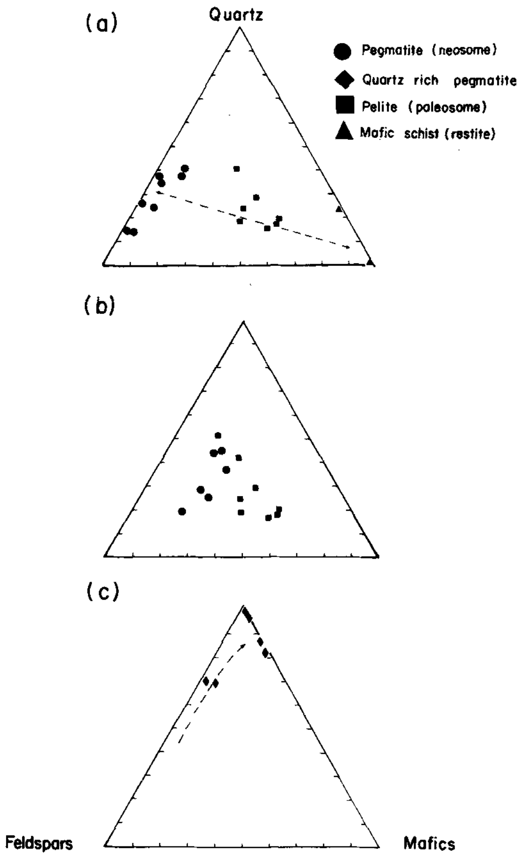

FIG. 5. Quartz–Feldspar–Mafics plots of Group A and C pegmatites and associated host rocks (pelites). According to Mehnert (1968) (*a*) represents a trend of limited partial melting (metatexis) while (*b*) is indicative of more complete melting (diatexis), (*c*) shows the disparate trend of the quartz-rich pegmatites (Group C).

disseminations of radioactive minerals in meta-arkosic and semipelitic sediments. Modally (fig. 4), the granitoid pegmatites fall into three groups, all of which may occur in close proximity to each other in the field. The groups are A—tonalites, granodiorites, β-granites; B—α-granites, quartz syenites, alkali granites; and C—quartz granites and silexites. Groups A and B are the commonest and are probably products of partial melting of the host rocks (pelites and gneisses respectively). Comparison of the pegmatites with associated host rocks on Qz-Fel-Mafic modal diagrams (fig. 5*a* and *b*), after Mehnert (1968), suggests that they were formed by partial melting or more complete melting. The schists are interpreted as restite, the larger pelitic bodies as paleosome, and the pegmatite as mobilizate or neosome. Group C pegmatites are so far removed from the central 'minimum melting zone' of fig. 4 that it is difficult to envisage a simple partial melting mode of origin. In fig. 5c the quartz-rich pegmatites form a distinct group and it is possible that they formed by a different process involving fractionation of partial melt material. The origin of mafic pegmatites (type 3) is not well understood; however, they are similar in composition and occurrence to radioactive rocks in the Bancroft area of Ontario that Robertson (1978) believes are due to 'regional metamorphic transformation of impure limestones'.

Microscope and radioluxograph work shows that the main source of radioactivity in the pegmatites is small grains (0.25–3.00 mm depending on host mineral size) of submetallic opaque material. The term 'uraninite' will be used although much of the material is metamict, rims of secondary material are observed, and initial microprobe work (Kurat, pers. comm.) has identified coffinite and other complex U silicate phases. The probe data also often give Pb values as high as 14% indicating that the mineralization has a chemical age of at least 1500 Ma. The 'uraninite' occurs predominantly in biotite and feldspar in granitic pegmatites and in amphibole and pyroxene in mafic pegmatites. Mineral separates give U and Th values up to 1500 ppm in biotite and feldspar (100 times the average values given by Wedepohl, 1969) and up to 350 and 150 respectively for diopside (over five times the average values given by Wedepohl, 1969). The lack of lattice distortion, other than undulose extinction haloes, in the host minerals suggests a syn- to post-nucleation relationship of the U phases with their host. Other minor sources of radioactivity in the pegmatites are attributed to sphene, zircon, apatite, and monazite grains.

Average U, Th, Co, and Pb values for pegmatite samples are listed in Table I (Cu, Mn, Mo, Ni, V, and Zn values show no significant variation between pegmatite types). Group A pegmatites, the commonest, exhibit a low Th/U ratio with the highest mean for U, the large standard deviation indicates erratic values (range 30–4650 ppm). In contrast, the Group B pegmatites have the highest Th/U and lowest U values while the Group C pegmatites contain high levels of all four elements. The standard deviation for the U in Group C is much smaller than that of Group A, however. The mafic pegmatites only exhibit enrichment of U. Interpretation of these limited data raises several questions. If pegmatites of Group B were produced by low degrees of partial melt and Group A represent more complete melting, then the data suggest that U and Th are mobilized only during extensive anatexis and are fixed only by such silicate phases as biotite and plagioclase.

Thus Group B pegmatites probably represent U- and Th-depleted melts from a regime in which earlier crystallization of Group A material extracted most of the U and Th although field evidence does not indicate that Group A pegmatites are invariably 'older' than Group B types.

An alternative hypothesis is that Group A and B pegmatites represent partial melt material from *different* host materials. Field evidence suggests that the Group B pegmatites are derived from (Archaean) granite gneisses and sometimes Aphebian meta-arkosic gneisses while Group A pegmatites are from (Aphebian) pelites and semipelites (richer in U and Th minerals). Anatexis of two such different parent rocks could explain the variation in the chemistry of the two pegmatite groups. Although the mechanism of formation of the mafic pegmatites is not well understood, the high U values could be derived from uraniferous Aphebian calc-silicate rocks.

The Group C pegmatites cannot be derived by a simple anatectic model and yet they contain high U and Th values similar to those of the metatectic Group A rocks. Their origin is tentatively ascribed to a volatile-enriched siliceous melt fraction from some Group A type melts.

TABLE I. *Average values (ppm) of U, Th, Co, and Pb in some Cree Lake Zone pegmatites*

	Granite pegmatites			Mafic pegmatites
	Group A	B	C	
U				
$\bar{x}$	691	68	407	404
s	963	28	141	427
n	29	6	10	4
Th				
$\bar{x}$	195	74	280	75
s	207	64	265	(92)
n	17	5	7	2
Co				
$\bar{x}$	96	68	127	22
s	20	(35)	34	(2)
n	9	2	5	2
Pb				
$\bar{x}$	80	43	138	54
s	45	(23)	36	(8)
n	9	2	5	2

$\bar{x}$ = mean. s = standard deviation (bracketed values —based on two samples—are questionable). n = number of samples.

TABLE II. *Average values of U and Th for rocks associated with radioactive pegmatites*

		U			Th		
ARCHAEAN (?) GRANITE GNEISS		*n*	$\bar{x}$	*s*	*n*	$\bar{x}$	*s*
Homogeneous granite gneiss		14	3.2	1.9	4	21.5	14.0
Hybrid granite gneiss		8	2.3	1.4	6	9.5	5.4
Marginal granite gneiss		5	6.5	0.9	5	56	17.0
Overall average		27	3.6	2.2	15	28.2	24.0
APHEBIAN							
Basal Pelite	Overall average	17	13.4	13.9	12	19.8	9.1
	Charlebois Lake	7	22.7	17.2	3	18.7	3.8
	Excluding Charlebois	10	6.9	5.7	9	20.2	10.4
Calc silicate gneiss		15	4.8	5.8	5	7.8	5.1
Amphibolite/Hb gneiss		10	0.4	0.2	3	1.3	0.6
Meta arkosic gneiss		4	1.5	0.5	2	18.0	[4.2]

U and Th values in rocks hosting pegmatites

The proposed model of granitoid pegmatite genesis involves anatexis of granitic gneisses including U- and Th-depleted Archaean rocks and supracrustal pelites and semi-pelites (U- and Th-enriched Aphebian rocks). Selected U and Th data from seventy-four samples of the various host rocks to the pegmatites are shown in Table II.

Archaean rocks. Over 70% of the Cree Lake Zone is composed of quartzo-felspathic gneisses, ranging in composition from granite to granodiorite–tonalite. In the areas sampled the gneisses fall into three groups: (1) homogeneous granite gneisses with limited compositional variations over large areas; (2) marginal granitoid gneisses which occur along the periphery of some type 1 granite gneiss domes as a white or bleached phase; and (3) hybrid gneisses, which are of extremely heterogeneous composition ranging from granite to tonalite with interlayered amphibole–biotite gneiss. Generally, these rocks exhibit upper amphibolite to granulite facies metamorphism. It is apparent from Table II that the rocks contain higher U and Th values than is typical for granulites (0.74 ppm U, Dostal and Capedri, 1978), as only two samples out of twenty-seven have U values less than 1 ppm. Levels of the two elements increase outwards from the homogeneous gneiss dome cores suggesting lateral migration of U and Th and the possibility that the enrichment of the basal Aphebian in these elements is a function of granulite-facies depletion of the Archaean. Nevertheless, the Archaean rocks are not as depleted as might be expected and U- and Th-enriched pegmatites are mostly observed in areas where biotite- and plagioclase-bearing 'parental' rocks are common.

Aphebian rocks. The majority of rocks in the sequence have average values for U and Th, but higher values characterize graphitic basal pelites (of presumed shale origin—see fig. 6), particularly in the Charlebois Lake area. These are comparable with average concentrations of U in shales and black shales elsewhere, Krauskopf (1967), Adams and Weaver (1958), Baranov *et al.* (1956), Swanson (1961), and Vine and Tourletot (1969), which range from 3.2 to 20 ppm. The high scapolite content of the calc-silicates suggests an evaporite origin for which McKelvey (1956) gives a range of 50 to 300 ppm U. The observed U values are therefore not anomalous.

The data support the interpretation that Group A and mafic pegmatites are derived from basal Aphebian pelites and calc-silicate rocks and should have relatively high U and Th values compared with Group B pegmatites, derived mainly from Archaean gneiss. Even where Group B pegmatites occur in the Aphebian sequence, they would be derived from meta-arkosic gneiss or hornblende gneiss on the basis of their compositions and would not be expected to contain high values of U and Th.

The high U and Th values in the basal Aphebian rocks may thus derive either from early Hudsonian ($\simeq$ 1900 Ma) migration of U and Th from the Archaean causing depletion, or from syngenetic concentrations of these elements in carbonaceous shales and possibly evaporites. Enrichment of U at the margins of gneiss domes supports the former hypothesis. Mn, Ni, and Zn values of the pelites are comparable with world averages for shale or black shale and provides support for models involving U-enriched sediments.

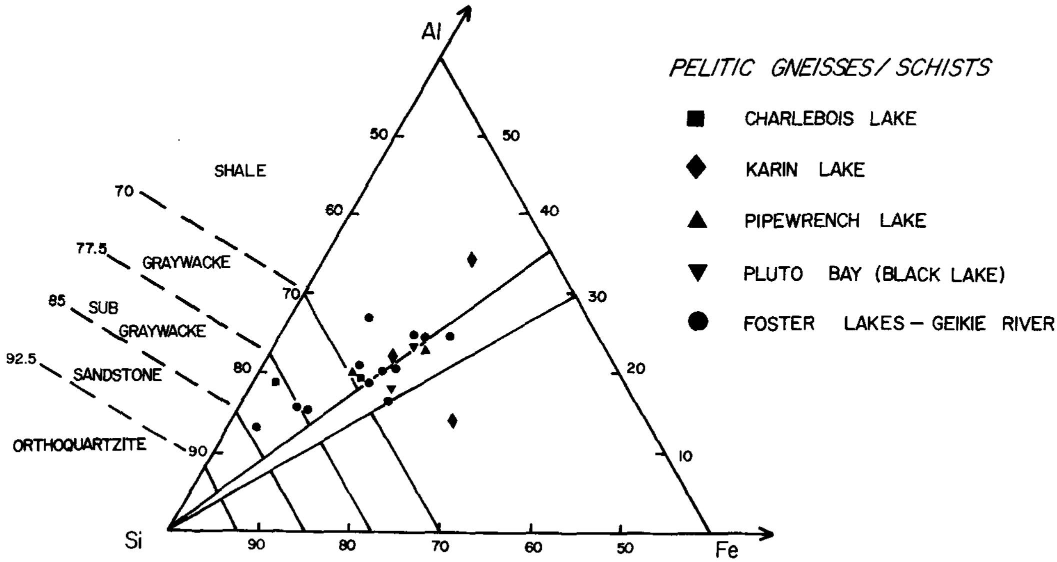

FIG. 6. Original status of pelitic gneisses and schists plotted on Moore and Dennen's (1970) Si–Al–Fe clastic sediment diagram.

Conclusions

Study of the distribution of U and Th in the Cree Lake Zone of northern Saskatchewan with particular reference to pegmatites and their host rocks indicates that four types of pegmatite can be recognized. Three of these are attributed to partial melting of different types of parental rocks—Group A from Aphebian pelitic rocks, Group B from Archaean gneisses (occasionally from Aphebian gneisses), and mafic pegmatites from Aphebian calc-silicate rocks. The fourth type, Group C, may represent a volatile-enriched siliceous melt derived by fractionation of Group A pegmatites. Thus anatectic melts reflect enrichment, of U and Th in Aphebian pelites and calc-silicates. The Archaean rocks studied are not strongly depleted in U and Th, and thus a metamorphic source for the basal Aphebian enrichment cannot be identified; however, metamorphosed black shales and evaporites could be expected to contain the observed elemental abundances as a relict primary feature. There is evidence that Archaean terrains *appear* depleted because, mineralogically, they provide an unfavourable host for U or Th.

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