Geochemistry of the Archean Kam Group, Yellowknife Greenstone Belt, Slave Province, Canada

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ABSTRACT

The geochemistry and isotope systematics of Archean greenstone belts provide important constraints on the origin of the volcanic rocks and tectonic models for the evolution of Archean cratons. The Kam Group is a ~10-km-thick pile of submarine, tholeiitic mafic, and subordinate felsic volcanic rocks erupted between 2712 and 2701 Ma that forms the bulk of the Yellowknife greenstone belt in the dominantly granite-metasedimentary Slave Province. Mafic rocks range from Normal-mid-ocean range basalt-like basalts to slightly light-rare-earth-element-enriched (LREE-enriched) but Nb-depleted basaltic andesites and andesites, whereas dacitic to rhyodacitic felsic rocks are strongly LREE-enriched and highly depleted in Nb. The ε^T_{Nd} range from +5 to −3 in the mafic to intermediate rocks and from 0 to −5.5 in the felsic rocks. The ε^T_{Nd} decreases with increasing La/Sm, SiO_2 and decreasing Nb/La, suggesting that as the mafic magmas evolved they were contaminated by older basement rocks. Gneissic granitoids >2.9 Ga in age, found at the base of the Kam Group, have ε^T_{Nd} between −6 and −9 and are excellent candidates for the contaminant. The geochemical and isotopic data, combined with the submarine eruptive setting and field evidence for existing continental basement, support a continental margin rift model for the Kam Group. Similar geochemical-isotopic studies are required on other Slave greenstone belts in order to test evolutionary models for the Slave Province.

Introduction

The field relationships and geochemistry of volcanic, plutonic, and sedimentary rocks in Archean greenstone belts retain a record of their tectonic setting. On the basis of modern plate tectonic models, the geochemical signatures of ancient volcanic rocks have been used to distinguish between continental, oceanic (spreading center, oceanic plateau, seamount), back-arc, or volcanic arc origins for greenstone belts in Canada and worldwide (e.g., Condie and Baragar 1974). The Yellowknife Volcanic Belt is one of several small greenstone belts exposed in the southern part of the dominantly granitic-metasedimentary Slave Province, Northwest Territories, Canada (fig. 1). This greenstone belt is extremely well preserved, has well-exposed contact relationships, and has suffered only low-grade greenschist facies metamorphism, such that geochemistry can be used to resolve stratigraphic and tectonic problems within the belt. The Yellowknife Volcanic Belt has been mapped in considerable detail, has been the subject of major and trace element geochemical studies, and is well dated by modern U-Pb zircon techniques. Nevertheless, only a handful of neodymium (Nd) isotopic analyses exist for volcanic and plutonic rocks in the Yellowknife area (e.g., Dudás 1989; Davis and Hegner 1992).

Radiogenic isotopic data, in unison with field observations and major and trace element geochemistry, have the potential to distinguish between different tectonic scenarios for the origin of the volcanic rocks and to discern whether or not the volcanic rocks were erupted through an existing basement complex. This article presents the results of a geochemical and Nd isotopic study of approximately 60 volcanic and intrusive rocks of the ca. 2.7-Ga Kam Group, which forms the bulk of the Yellowknife Volcanic Belt, as well as rocks interpreted to be part of the basement complex to the greenstone belt.

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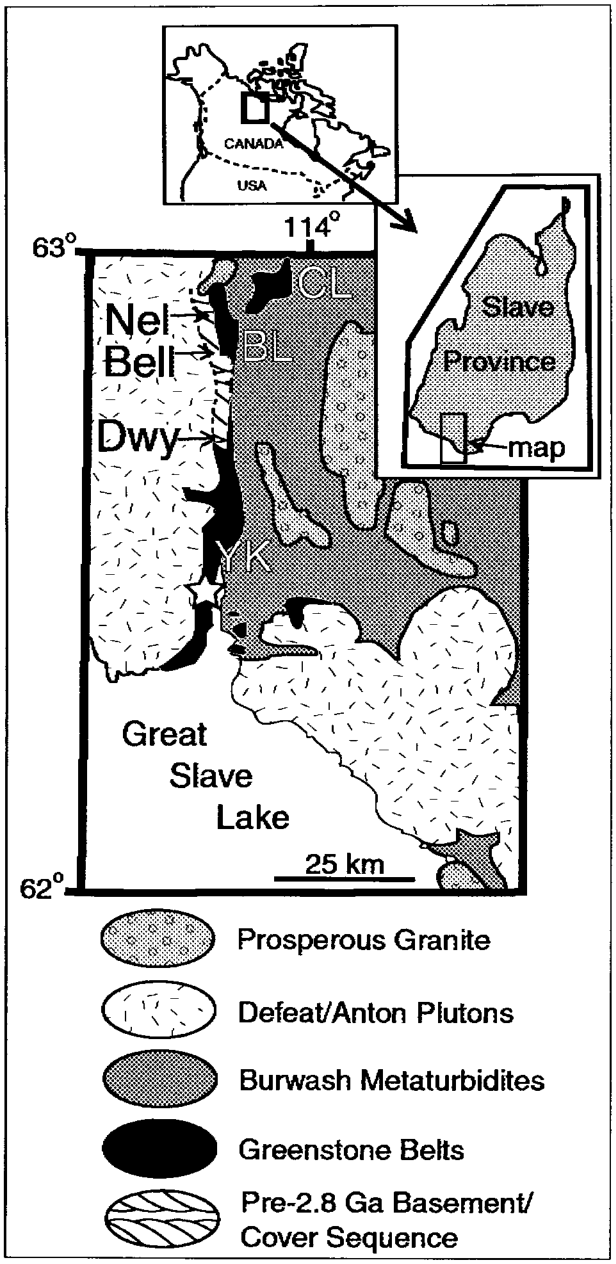

Figure 1. Simplified geological map of the southern Slave Province around Yellowknife (*star*). *Dwy* = Dwyer Lake, *Bell* = Bell Lake, *Nel* = Nelson Lake. Greenstone belt labels are *CL* = Clan Lake complex, *BL* = Bell Lake, *YK* = Yellowknife Volcanic Belt. The distribution of the basement/cover sequence is from Bleeker and Ketchum (1998). *Inset top*, location of Slave Province in the northern Canadian Shield. *Inset right*, outline of the Slave Province, northern Canada. Box indicates area of geological map.

Regional Geological Setting

The Yellowknife Volcanic Belt (YVB) is one of several Archean greenstone belts exposed in the southern Slave Province (fig. 1). The belt has been subdivided into two groups, the dominantly mafic tholeiitic Kam Group and the unconformably overlying, more felsic-dominated Banting Group (figs. 2, 3) (Helmstaedt and Padgham 1986). Precise (±1–4 m.yr.) U-Pb zircon crystallization ages from Kam Group felsic volcanic rocks range from 2712 to 2701 Ma, although some cherty felsic tuffs of the lower Kam Group include inherited zircons as old as 2820 Ma (Isachsen 1992). Banting Group crystallization ages are ~2660 Ma (Isachsen 1992). The metavolcanic supracrustal package forms a steeply dipping homocline, such that the stratigraphic "way-up" is to the southeast. The rocks are metamorphosed to greenschist grade, but metamorphic grade increases to amphibolite in proximity to younger intrusions. The belt was subsequently dismembered by Proterozoic faulting into four major blocks (Helmstaedt and Padgham 1986).

To the west, the YVB is intruded by the Western Plutonic Complex, which includes, from south to north, the Defeat Plutonic Suite, the Duckfish Granite, and the Anton Complex (figs. 1, 2) (Henderson 1985). Precise U-Pb zircon ages from these granitoids range from 2608 to 2641 Ma (Henderson 1985; Henderson et al. 1987; Dudás et al. 1990; van Breeman et al. 1992). Much of the Anton Complex is intrusive into the YVB and the underlying gneissic basement/cover group in the Dwyer Lake area and may be an early deformed part of the Defeat Suite (Helmstaedt and Padgham 1986; MacLachlan and Helmstaedt 1995). To the east, the YVB is conformably overlain by the Burwash and Walsh Formations, a thick pile of greywacke and mudstone turbidites thought to be basin-fill sediments (figs. 1–3) (Henderson 1985; Helmstaedt and Padgham 1986). The Kam and Banting Groups are unconformably overlain by the conglomerates and sandstones of the Jackson Lake Formation (Henderson and Brown 1966; Helmstaedt and Padgham 1986).

Basement rocks to the YVB that have been recognized include metasedimentary, metavolcanic, and plutonic rocks exposed in the area around Dwyer Lake, Bell Lake, and Nelson Lake at the north end of the belt (figs. 1, 3) (Helmstaedt and Padgham 1986; Isachsen 1992; MacLachlan and Helmstaedt 1993; Isachsen and Bowring 1997; Bleeker and Ketchum 1998). Originally termed the Dwyer Formation or Dwyer Group (Helmstaedt and Padgham 1986), these rocks have been split

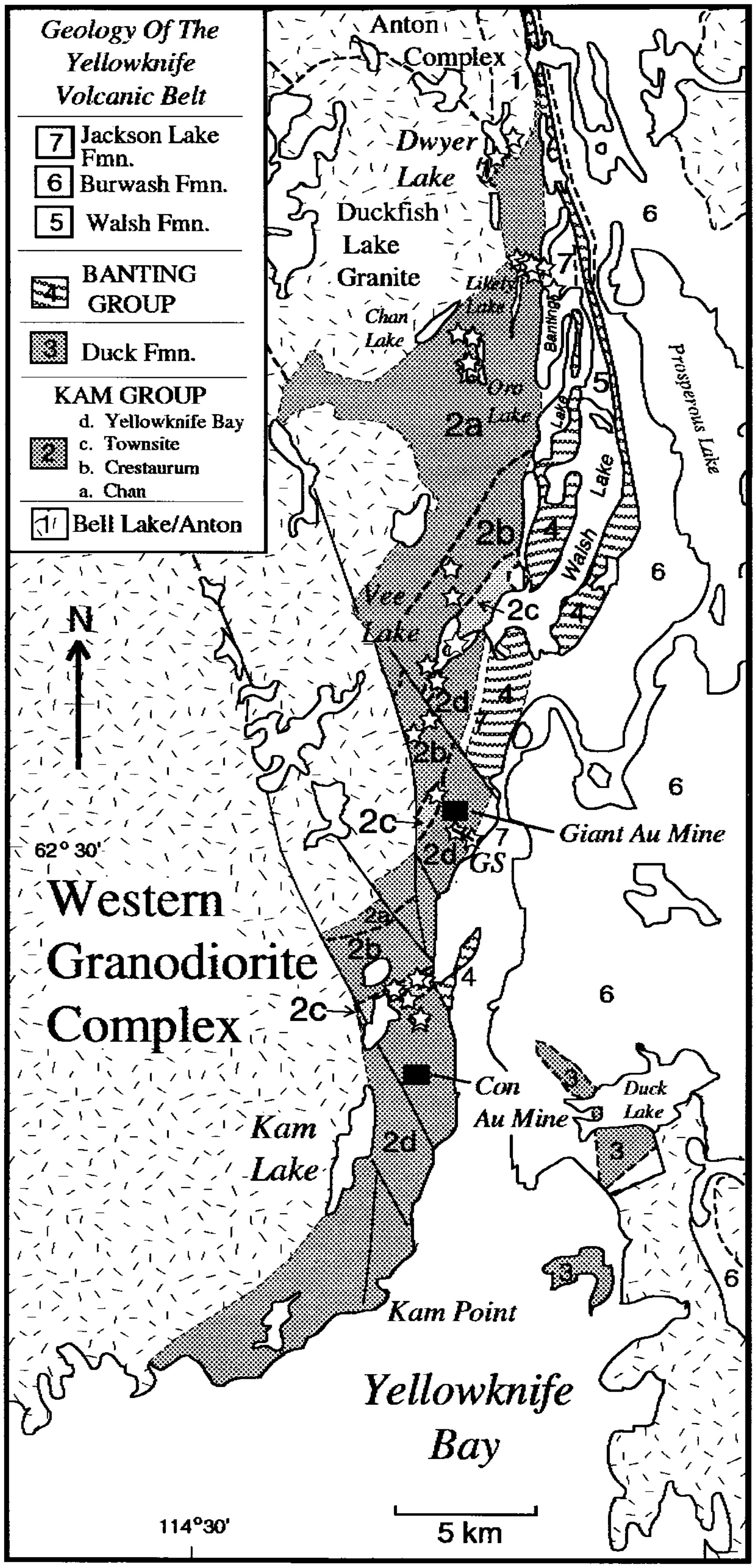

Figure 2. Simplified geological map of the Yellowknife Volcanic Belt (Padgham 1987*b*). Anton Complex and Bell Lake Group are discontinuous north of Dwyer Lake. Stars indicate sampling locations. Thin solid lines are Proterozoic faults.

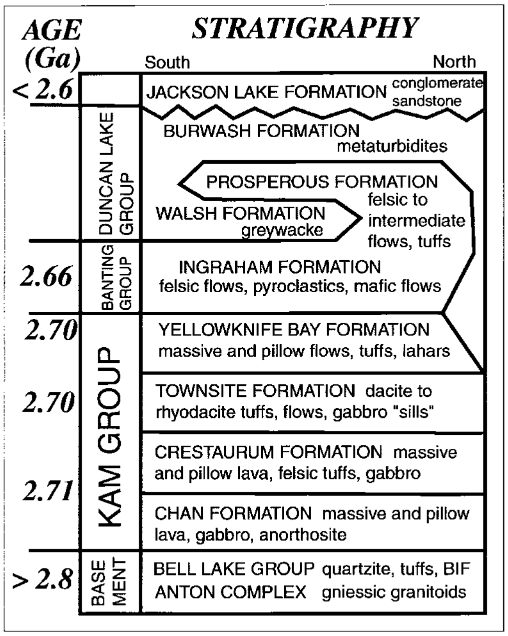

Figure 3. Stratigraphy and U-Pb zircon ages of the Yellowknife Volcanic Belt in the southern and northern parts of Yellowknife Bay (Helmstaedt and Padgham 1986; Isachsen 1992).

into two groups: gneissic plutonic rocks with U-Pb zircon ages >2.93 Ga found along the eastern margin of the plutonic Anton Complex and the overlying quartzites, metarhyolite, and banded iron formation that are >2.8 Ga in age, termed the Bell Lake Group (Isachsen and Bowring 1997). From this point forward, the term "Anton Complex" will apply only to gneissic granitoids along the eastern margin of the Anton Complex interpreted to be basement to the YVB. Amphibolite dikes in the Bell Lake Group, related to the synvolcanic dikes in the overlying Chan Formation, imply that the volcanic rocks of the Chan Formation were fed through and deposited over the Bell Lake Group (MacLachlan and Helmstaedt 1995). Further evidence for older basement rocks beneath the YVB comes from xenoliths of tonalitic gneiss in a diatreme at the Con mine south of Yellowknife, which have discordant U-Pb zircon ages of 3040–3300 Ma (Nikic et al. 1980).

The YVB stratigraphic sequence of Mesoarchean gneissic basement, a cover group consisting of post-2.93-Ga quartzites, banded iron formation, and minor metavolcanic rocks, and an overlying ca. 2.7 Ga greenstone belt, is proposed to be present throughout the central Slave Province (Bleeker and Ketchum 1998). Regional Pb (sulfides) and Nd (plutons) isotopic studies of the Slave Province have demonstrated that the western Slave (including the YVB) is underlain by basement rocks >2.8 Ga in age, whereas the eastern Slave lacks such an ancient basement (Bowring et al. 1989; Dudás 1989; Davis and Hegner 1992; Thorpe et al. 1992).

Geology and Geochemistry of the Kam Group

The YVB has been the subject of field and geochemical studies that define the basic geochemical characteristics of the belt (Jenner et al. 1981; Goodwin 1988; Cunningham and Lambert 1989; MacLachlan and Helmstaedt 1995). The ~10-km-thick Kam Group is divided into four conformable formations, which are, from base to top, the Chan, Crestaurum, Townsite, and Yellowknife Bay Formations (fig. 2) (Helmstaedt and Padgham 1986; Padgham 1987*b*). All but the Townsite Formation are composed dominantly of mafic volcanic rocks and sills with a tholeiitic differentiation trend.

The Chan Formation is the thickest (6–7 km) of the four formations of the Kam Group. The Chan Formation is composed entirely of basaltic lavas, dikes, and sills and lacks conformable felsic volcanic rocks. The base of the Chan Formation includes a dike and sill complex that is interpreted to be a sheeted dike complex, similar to those seen in Phanerozoic ophiolites (Helmstaedt et al. 1986).

The overlying Crestaurum Formation is composed largely of pillow basalt and massive mafic flows and sills but includes several thin, cherty, felsic tuffaceous units that are dacitic to rhyodacitic in composition (Henderson and Brown 1966; Helmstaedt and Padgham 1986). The Chan-Crestaurum contact is defined by the Ranney tuff and chert, which have complex zircon systematics, and the zircons are interpreted to have been derived from older basement rocks (Isachsen 1992). Another widespread tuffaceous unit above the Ranney tuff, the Cemetery tuffs, includes dominantly volcanic zircons with U-Pb ages between 2707 ± 2 and 2714 ± 8 Ma (Isachsen 1992).

The Townsite Formation, interpreted to be displaced by younger faults into (from south to north) the Niven, Brock, and Vee Lake members, is composed of dacitic to rhyolitic flows, tuffs, and breccias that are intruded by gabbroic sills (Henderson and Brown 1966; Helmstaedt and Padgham 1986). Although the Brock and Vee Lake members have similar ages of 2703 ± 2 and 2705 ± 3 Ma, respectively, zircons from the felsic rocks of the Niven member are more complex and yield ages between 2683 ± 5 and 2726 ± 2 Ma (Henderson et al. 1987; Isachsen 1992). Although the most concordant Pb-

Pb age from a small zircon population is 2702 ± 1 Ma, which is within error of the Vee Lake and Brock Pb-Pb ages, it is possible that portions of the Niven member are younger (ca. 2684 Ma). Ongoing detailed investigations of the field relationships in the Townsite Formation suggest that there are many generations of mafic and felsic rocks, some of which are intrusive and may postdate volcanic rocks in the Townsite Formation (e.g., Finnigan 1998).

The Yellowknife Bay Formation is, like the Crestaurum Formation, dominated by pillow basalts, massive flows and sills, and several cherty tuffaceous units. Contrasts in bedding orientation suggest that the rocks of the Chan Formation at the northern end of the YVB were undergoing uplift and erosion during the deposition of the Yellowknife Bay Formation (Padgham 1987*b*). Near the top of this formation is a distinctive reversely graded, conglomeratic, interflow sediment named the Bode Tuff, which includes rounded clasts of rhyodacite porphyry (Henderson and Brown 1966). Two U-Pb zircon analyses of boulders from the Bode Tuff and two analyses of cherty tuffs in the area of Kam Point yield consistent ages of 2704 ± 1, 2701 ± 3, 2702 ± 1, and 2701 ± 1 Ma for the upper Yellowknife Bay Formation (Isachsen 1992). The prolific gold-bearing shear zones in the Yellowknife area are hosted in the Yellowknife Bay Formation.

Very little isotopic work has been done in the YVB. Two basaltic rocks from the Chan Formation have ε_{Nd}^{2700} of +1.5 (MacLachlan and Helmstaedt 1995). Basalts (sample locations unknown) from the Kam Group and the Clan Lake Complex (northeast of Bell Lake; fig. 1) are reported to have ε_{Nd} of −0.4 to −2.1 (at 2.6 Ga), suggesting that they are not derived purely from Archean depleted upper mantle (Dudás 1989). A regional study of basement gneisses and volcanic, sedimentary, and plutonic rocks of the southern Slave Province has determined that mafic to intermediate volcanic rocks of the YVB have low ε_{Nd}^{T}, interpreted to result from contamination by pre-2.8-Ga basement (Yamashita et al. 1998). Isotopic and geochemical work in other greenstone belts from the southern Slave Province has shown that the basaltic rocks are mostly tholeiitic, mantle-derived magmas that have assimilated older crustal components, but that some calc-alkaline assemblages commonly having positive ε_{Nd}^{T} are also present (Lambert et al. 1992; Dostal and Corcoran 1998; Yamashita et al. 1998).

Sampling and Analytical Methods

Volcanic rocks from all four formations in the Kam Group were collected in 1996, 1997, and 1998, supplemented by additional samples from the Chan Formation at Oro and Dwyer Lakes (MacLachlan and Helmstaedt 1993). Many of the felsic volcanic rock samples were collected from the same locations as those sampled for U-Pb zircon geochronology (Isachsen 1992). Included is a suite of samples from the Giant Section (GS in fig. 2), one of which is a rhyodacite cobble from the Bode Tuff, the prominent interflow sedimentary unit near the top of the Yellowknife Bay Formation (Padgham 1987*a*; Falck 1990). A sample of a felsic metavolcanic unit from the Bell Lake Group at Dwyer Lake (Dwyer Metarhyolite, dated by Isachsen 1992) was obtained from K. MacLachlan. Potential basement granitoids of the Anton Complex were sampled at Dwyer, Bell, and Nelson Lakes to the north, in many cases from previously dated outcrops (Isachsen 1992; Isachsen and Bowring 1997). The sample locations are listed in table 1 and indicated in figure 3.

The volcanic and plutonic rocks were slabbed, crushed in a Chipmunk jaw crusher, and then ground to a fine powder in an agate ring mill. A split of each powdered sample was sent to the Ontario Geological Survey Geochemical Laboratory in Sudbury for major and trace analysis (table 1). Major elements were analyzed by fused-disc XRF with loss-on-ignition (LOI) determined as volatile loss at 1000°C; S and CO_2 by combustion; Ba, Cr, Zr, Y, Nb, Sr, and Rb by pressed-pellet XRF; Co, Cu, Ni, Sc, V, and Zn by ICP-OES; and the rare earth elements Th, U, Hf, and Ta by acid-digestion ICP-MS. Nb and Rb contents were also determined by ICP-MS to take advantage of the lower detection limits for these elements compared with XRF, and the two methods agree to within 2 and 1 ppm, respectively. The precision of the data was estimated using results for international standard rocks, duplicate runs of several samples, and blind standards included in the sample set.

Nd isotopic analyses were performed on the crushed powders. Between 100 and 200 mg of sample were spiked with a mixed ^{149}Sm-^{148}Nd spike and then dissolved in Savillex Teflon beakers. Nd and Sm were separated following standard cation exchange techniques (Cousens 1996). Total procedural blanks for Nd are <400 pg and are insignificant. The $^{147}Sm/^{144}Nd$ ratios are reproducible to 1%. Samples were loaded with 1N HNO_3 on one side of a Re double filament and run in a Finnigan MAT261 thermal ionization mass spectrometer at temperatures of 1780°–1820°C. Isotope ratios were normalized to $^{146}Nd/^{144}Nd = 0.72190$. Analyses of the USGS standard BCR-1 yielded Nd = 29.02 ppm, Sm = 6.68 ppm, and $^{143}Nd/^{144}Nd = 0.512668 \pm 20$

Table 1. Representative Major and Trace Element Analyses, Kam Group and Basement Rocks

	RL-1	K92-94[a]	40869	YK-28	YK-17	YK-13	YK-6	YK-7	GS-4	GS-18	Precision (%)
Group or formation	Anton	Bell Lake group	Chan	Crestaurum	Crestaurum	Townsite-Niven	Townsite-Niven	Yellowknife Bay	Yellowknife Bay	Yellowknife Bay	
Rock type	Granite	"Metarhyolite"	Pillow basalt	Basalt	Cherty tuff	Gabbro	Felsic tuff	Pillow basalt	Basalt	Bode tuff boulder	
Latitude	62°50.40′	62°41.02′	62°39.34′	62°31.38′	62°32.00′	62° 27.54′	62°27.43′	62°27.00′	62°29.95′	62°29.95′	…
Longitude	114°19.55′	114°19.40′	114°17.90′	114°21.95′	114°21.63′	114°22.51′	114°22.14′	114°22.34′	114°20.60′	114°20.60′	…
SiO_2 (wt %)	75.44	62.34	48.71	47.00	63.57	48.41	68.01	49.72	52.20	70.22	.3
TiO_2	.32	.83	.84	2.18	.95	.80	.66	1.15	1.46	.38	.5
Al_2O_3	14.02	15.96	15.10	13.87	13.45	14.89	13.95	14.41	17.65	12.89	.4
Fe_2O_3	.58	6.02	12.31	15.27	9.08	14.18	4.98	15.04	9.79	1.06	.5
MnO	.01	.16	.21	.21	.09	.19	.08	.24	.20	.05	.4
MgO	.43	1.98	7.33	5.94	2.85	7.93	.85	5.67	3.85	.71	.5
CaO	.06	4.04	10.08	9.03	1.76	10.43	6.10	8.42	2.14	4.05	.9
Na_2O	.32	7.19	1.65	2.41	1.08	1.99	2.62	3.65	5.91	.70	.9
K_2O	6.37	.56	.21	.86	2.94	.34	1.25	.06	1.21	4.33	1.6
P_2O_5	.04	.17	.06	.29	.14	.05	.21	.09	.16	.11	3.3
LOI[b]	1.52	.90	2.74	2.63	2.78	.63	1.17	.72	3.18	4.70	1.0
S	.01	…	.06	.06	.47	.02	.01	.09	.10	.03	.9
CO_2	.05	…	.12	.80	.36	.10	.36	.22	.72	2.80	1.0
H_2O[c]	1.47	.90	2.62	1.83	2.42	.53	.81	.50	2.46	1.90	…
Total	99.11	100.15	99.24	99.69	98.69	99.84	99.88	99.17	97.75	99.20	…
Nb (ppm)	10	11	4	7	9	2	13	4	5	5	1
Zr	176	185	59	183	231	50	271	77	110	130	1
Y	7	27	24	56	27	19	40	27	24	10	3
Sr	55	53	103	65	29	113	237	68	34	20	3
Rb	194	31	16	20	96	9	65	7	22	130	2
Ba	750	57	52	150	526	127	301	70	630	410	7
Cr	19	12	201	153	7	273	6	188	140	6	2
Co	5	19	50	36	15	44	8	51	40	…	2
Cu	5	…	…	123	29	60	18	142	88	…	3
Ni	9	10	145	88	13	134	5	89	73	…	1
Sc	3	…	29	29	13	31	9	36	27	4	1
V	18	155	250	369	99	238	36	323	240	34	1
Zn	19	…	…	109	172	88	68	115	130	15	1
La	51.40	30	3.17	12.29	24.51	2.30	44.73	2.76	9.50	14.22	.8
Ce	99.77	73	7.95	30.14	51.53	6.08	91.33	8.38	21.01	28.97	1.1
Pr	10.65	…	1.19	4.41	6.01	.97	10.69	1.37	2.67	3.29	.8
Nd	33.77	27	6.42	20.76	21.91	5.06	38.53	6.94	11.74	12.20	1.7
Sm	5.04	…	1.96	6.03	4.46	1.72	7.75	2.45	3.22	2.39	2.0
Eu	.73	…	.85	2.24	1.36	.67	1.63	.83	1.05	.73	2.4
Tb	.35	…	.49	1.39	.71	.43	1.18	.63	.59	.29	1.4
Gd	2.94	…	2.71	8.41	4.58	2.44	7.55	3.41	3.30	2.05	1.3
Dy	1.29	…	3.36	8.98	4.38	2.86	6.83	4.30	3.97	1.47	1.1
Ho	.21	…	.73	1.94	.94	.63	1.39	.96	.83	.29	1.5
Er	.51	…	2.20	5.57	2.77	1.82	3.92	2.75	2.44	.71	2.2
Tm	.07	…	.31	.83	.42	.28	.58	.41	.38	.11	2.2
Yb	.46	…	2.04	5.23	2.87	1.77	3.73	2.50	2.27	.62	2.4
Lu	.08	…	.27	.81	.46	.29	.58	.37	.33	.09	.6
Th	33.89	13.8	.37	2.29	11.52	.29	18.55	.48	1.87	5.20	3.5
U	3.48	2.9	.11	.57	3.26	.05	5.33	.12	.58	1.42	1.7
Hf	5.00	…	.70	3.80	5.90	.80	6.40	1.00	2.63	3.19	4.7
Ta	.65	…	.14	.62	.88	.14	1.11	.22	…	…	5.9
Nb (ICP-MS)	…	…	2.11	…	…	…	…	…	4.69	4.22	1.0

Note. Major elements in weight %, trace element in weight parts per million. Precision of analyses expressed as a percentage of the value of each oxide or element, based on duplicate analyses. For a complete data set, contact *The Journal of Geology*'s editorial office.

[a] All elements analyzed by XRF at University of Ottawa.

[b] LOI = weight loss on heating at 1000°C, equivalent to total volatiles.

[c] H_2O calculated as difference between LOI and CO_2.

($n = 4$). Twenty-two runs of the La Jolla standard averaged $^{143}Nd/^{144}Nd = 0.511877 \pm 18$ (2σ, September 1996–May 1998). The isotopic data are listed in table 2. Initial ε^{T}_{Nd} values are calculated using available U-Pb zircon ages, with the exception of the granitoids (Isachsen 1992). Granitoids that predate Kam volcanism are potential contaminants of Kam magmas, and thus ε_{Nd} values at 2700 Ma are of greatest interest. Epsilon values at time T are calculated using the following relation:

$$\varepsilon^{T}_{Nd} = [({}^{143}Nd/{}^{144}Nd^{T}_{sample} / {}^{143}Nd/{}^{144}Nd^{T}_{CHUR}) - 1] \times 10{,}000,$$

where CHUR is the Chondrite Uniform Reservoir and T is generally the time the rock was formed. The uncertainty in the initial ε_{Nd} values is ± 0.8 epsilon unit, based on the analysis of duplicate samples. At 2.7 Ga, depleted upper mantle is thought to have had an ε_{Nd} between +2.5 and +3.0 (Machado et al. 1986; DePaolo 1988).

Petrography of the Volcanic and Plutonic Rocks

Although primary minerals are rarely preserved in the mafic volcanic rocks of the Kam Group, primary structures and textures are generally well preserved (Helmstaedt et al. 1986). In thin sections, mafic rocks of the YVB are altered to an assemblage of chlorite, amphibole, and variably albitized plagioclase feldspar, with minor epidote. In some samples, secondary carbonate is visible both filling fractures and disseminated in the groundmass. Most of the pillow lavas are aphyric or include trace amounts of olivine or plagioclase phenocrysts. Felsic volcanic rocks are commonly feldspar or quartz-feldspar porphyritic with a fine-grain matrix. Rarely, biotite is also present. Secondary carbonate in the groundmass is common. The cherty tuff horizons in the Kam Group usually are very quartz rich with rare quartz or feldspar phenocrysts. The Cemetery Tuff (Crestaurum Formation) commonly includes crystal tuffs, with lozenges of quartz-feldspar porphyry, interbedded with finely laminated cherty tuffs.

Gneissic granitoids from the Anton Complex are commonly mildly foliated, consisting of quartz, plagioclase, and potassium-feldspar-rich layers separated by wispy biotite-chlorite-magnetite septa. Feldspar and quartz grains are typically anhedral and interlocking.

Results

The volcanic rock samples collected are variably altered by greenschist facies metamorphism. Given the observation that the rare earth elements (REE) and the high-field-strength elements (HFSE: Th, Nb, Ta, Zr, Hf, Ti) remain relatively immobile in rocks metamorphosed to greenschist facies (Humphris and Thompson 1978; Ludden et al. 1982; Brewer and Menuge 1998), the discussion of the data will focus on these elements. All data plotted in the following figures are recalculated to 100% on an anhydrous basis.

Anton Complex and Bell Lake Group. Five samples were collected from the plutonic complex that underlies the YVB, sampled at Dwyer, Bell, and Nelson Lakes (figs. 2, 3). The granitoids can be divided into two groups. The first includes gneissic granitoids (RL-1, DL-1, DL-3), which include mostly discordant zircons with $^{207}Pb/^{206}Pb$ ages >2900 Ma (Isachsen 1992; Isachsen and Bowring 1997). A sample of Anton mylonite gneiss from Bell Lake yielded concordant zircons with an age of 2947 ± 1.3 Ma. The second group includes biotite granites (NL-4, RL-13) that are assumed to be part of the ~2640-Ma Western Granodiorite Complex

Table 2. Representative Nd Isotopic Data, Kam Group, and Basement Rocks

Sample	Nd (ppm)	Sm (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ [a]	ε^{T}_{Nd} [b]
RL-1	37.03	5.46	.0892	.510283	−8.6
K92-94	25.00	5.31	.1284	.511279	−2.6
40869	7.45	2.40	.1948	.512808	+4.0
YK-28	20.80	6.24	.1815	.512372	+.1
YK-17	17.40	3.72	.1293	.511323	−2.2
YK-13	4.63	1.55	.2024	.512832	+1.8
YK-6	38.02	7.65	.1216	.511292	−.2
YK-7	6.58	2.26	.2072	.512861	+.7
GS-18	9.98	2.23	.1353	.511273	−5.3
GS-4	12.40	3.48	.1697	.512008	−2.9

[a] $^{143}Nd/^{144}Nd$ at present.
[b] ε_{Nd} at time of crystallization based on U-Pb ages (Isachsen 1992), with the exception of granitoids RL-1 and dacite K92-94, where T is set at 2700 Ma.

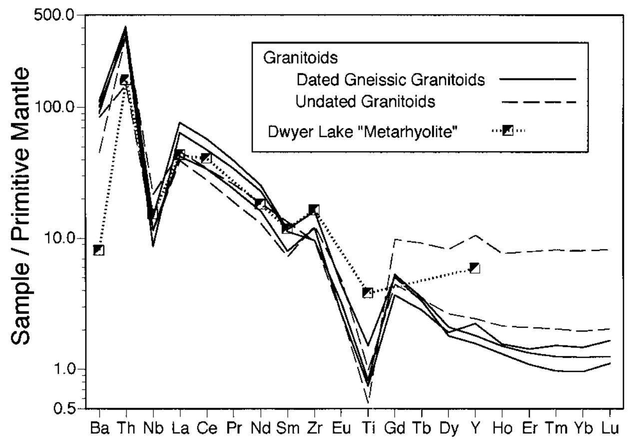

Figure 4. Primitive mantle-normalized (Sun and McDonough 1989) incompatible element abundances in Anton Complex gneissic granitoids and a Bell Lake Group "metarhyolite" from Dwyer Lake. Solid lines are granitoid samples from geochronology sampling localities that include zircons with ages >2.9 Ga (Isachsen 1992), whereas dashed lines are undated granitoids that may be younger than the Yellowknife Volcanic Belt.

that postdates Kam Group volcanism (Henderson et al. 1987; van Breeman et al. 1992).

With the exception of RL-1, the granitoids have $Na_2O/K_2O > 1$. The three gneissic granitoids from Bell and Dwyer Lakes have very similar primitive-mantle normalized incompatible element patterns and are characterized by enrichments in Th and the LREEs with strong depletions in the HREE relative to primitive mantle (fig. 4). The biotite granitoids have lower La/Yb_{pmn} (normalized to primitive mantle; Sun and McDonough 1989) than the gneissic granitoids, NL-4 in particular, and NL-4 has a large negative Eu anomaly. All of the granitoids have pronounced negative Nb, Sr, P, and Ti anomalies (Sr and P not shown for clarity).

The granitoids vary considerably in initial isotopic composition (table 2). The gneissic granitoids have ε_{Nd}^{2700} (i.e., at the time of Kam Group volcanism) ranging from −6.2 to −8.6 and have depleted mantle model (T_{DM}) ages of 3.4–3.5 Ga. The biotite granitoids have ε_{Nd}^{2640} values of −1.8 and 1.0, with T_{DM} ages of 3.3 and 2.9 Ga, respectively. The gneissic granitoids have the highly negative ε_{Nd} values at 2700 Ma, typical of continental crust formed during the early Archean (e.g., Theriault and Tella 1997).

The "Dwyer metarhyolite" from the Bell Lake Group at Dwyer Lake is actually transitional between a low-K andesite and a dacite (fig. 4). This metavolcanic rock is quite similar in trace element composition to felsic flows and tuffs of the Crestaurum and Townsite Formations. The sample has an ε_{Nd}^{2700} value of −2.6 and a T_{DM} of 3.3 Ga, most likely a reflection of inheritance of older crustal material (consistent with U-Pb zircon systematics, Isachsen 1992).

Chan Formation. Pillow basalts and synvolcanic gabbro sills from the Chan Formation from the Dwyer Lake, Oro Lake, and Likely Lake areas are virtually all tholeiitic basalts (fig. 5*A*). The mafic

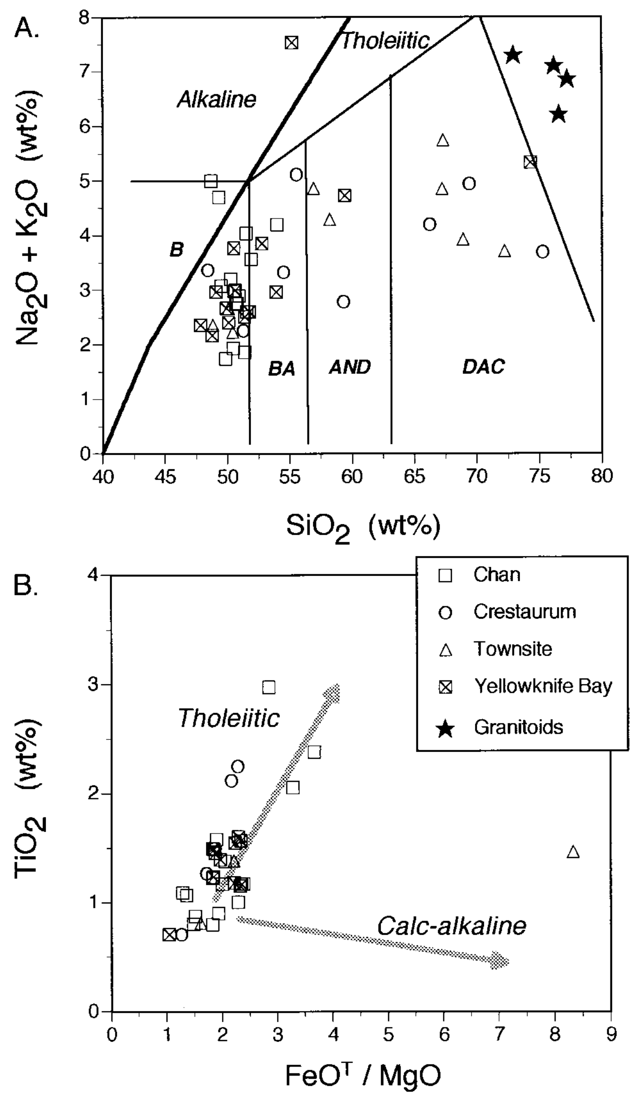

Figure 5. *A*, Alkalis-silica diagram showing classification of Yellowknife Volcanic Belt volcanic rocks (Le Bas et al. 1986). *B* = basalt, *BA* = basaltic andesite, *AND* = andesite, *DAC* = dacite. Tholeiitic/alkaline boundary indicated by bold curve (Irvine and Baragar 1971). *B*, TiO_2-FeO^T/MgO plot showing tholeiitic and calc-alkaline differentiation trends. Only mafic to intermediate volcanic rocks are plotted.

rocks define a tholeiitic fractionation trend of TiO_2 and FeO enrichment (fig. 5*B*). Abundances of the compatible trace elements Ni and Cr decrease rapidly as the basalts become more evolved, whereas Sc abundances remain roughly constant, and V concentrations increase. Thus, magmas parental to Chan basaltic rocks have followed a fractional crystallization history involving olivine, chrome-spinel, and minor clinopyroxene but not Fe-Ti oxides.

Previously analyzed pillow basalts, diabase dikes, and synvolcanic sills from the Chan Formation at Dwyer and Oro Lakes all have similar, flat primitive mantle-normalized patterns that lack negative Nb anomalies, thus strongly resembling modern mid-ocean ridge basalt (MORB) (fig. 6*A*) (MacLachlan and Helmstaedt 1995). Of the basaltic rocks from the Likely Lake area, only one is similar to the Dwyer/Oro Lake suite, and two have elevated incompatible element abundances with small negative Nb anomalies compared with the Dwyer/Oro basalts. However, most of the Likely Lake samples have higher La/Sm_{pmn} and negative Nb anomalies and are enriched in Th. Whereas LREE enrichment is observed in some modern MORB, depletions in Nb relative to La are extremely uncommon.

Chan basalts and gabbros have ε^{T}_{Nd} ranging from +4.0 to +0.4, indicating that they have a depleted mantle source(s). Chan Formation lavas from Oro and Dwyer Lakes cover the same range in isotopic compositions as Chan basalts from Likely Lake. Many of the basaltic rocks have ε^{T}_{Nd} that are lower than the estimate of +2.5 to +3.0 for depleted mantle at 2.7 Ga, however, and another component may be contributing to their isotopic compositions.

Crestaurum Formation. The Crestaurum Formation marks the first appearance of conformable

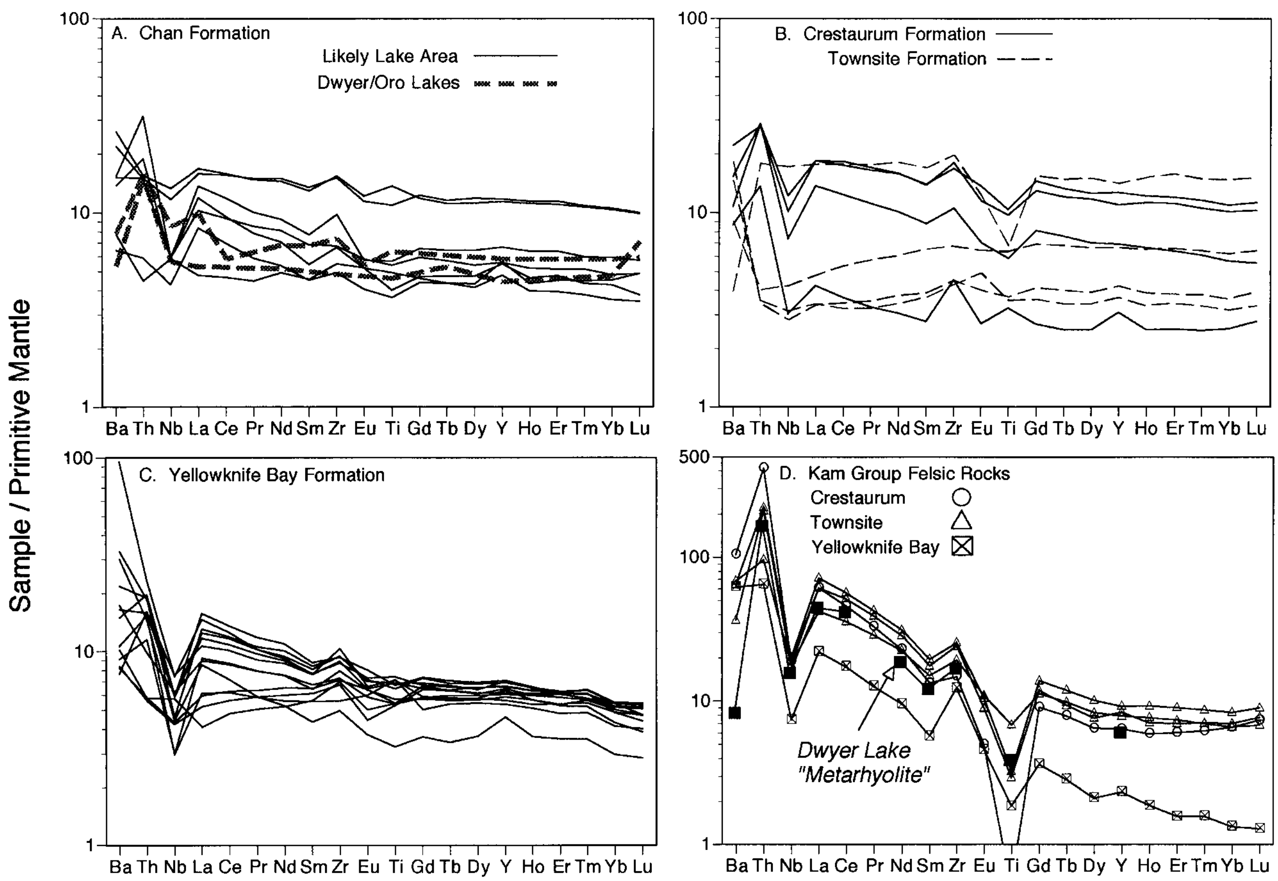

Figure 6. Primitive mantle-normalized (Sun and McDonough 1989) incompatible element patterns for mafic volcanic rocks from the Chan (*A*), Crestaurum and Townsite (*B*), and Yellowknife Bay (*C*) formations. Chan Formation rocks include samples from Dwyer and Oro Lakes (*dashed line*, from MacLachlan and Helmstaedt 1995) and a suite from Likely Lake (*solid line*). *D*, Patterns for felsic volcanic rocks from the Kam Group and Bell Lake Group.

felsic tuffaceous units within the dominantly mafic stratigraphy of the Kam Group. Samples from the Crestaurum Formation include basalts, basaltic andesites, andesites, and dacites (fig. 5*A*). Crestaurum mafic rocks follow a tholeiitic fractionation trend with strong Ti enrichment in the more evolved rocks (fig. 5*B*). Compatible trace elements Ni, Sc, V, and Cr follow the same trend with magma evolution as Chan basaltic rocks.

Primitive mantle-normalized incompatible element patterns for Crestaurum volcanic rocks are shown in figure 6*B* and 6*D*. The mafic volcanic rocks are generally more evolved than Chan basalts and have higher overall incompatible element abundances. Crestaurum mafic rocks all have La/Sm_{pmn} between 1.2 and 1.5, have small negative Nb anomalies, and are enriched in Th. The almost fivefold difference in incompatible element abundances between Crestaurum mafic rocks is unlikely to be explicable by fractional crystallization alone and requires that the degree of partial melting was quite variable or that the mantle sources of the primary magmas had variable incompatible element abundances. Felsic tuffaceous units in the Crestaurum Formation are strongly enriched in the LREE and Th and have prominent negative Nb anomalies compared with mafic rocks. The observed depletion in Ti is largely caused by fractionation of Fe-Ti oxides, and the tuffs are also depleted in Sr and P (not shown) because of crystallization of feldspar and apatite.

ε^T_{Nd} values range from +1.2 to +0.1 in mafic to intermediate rocks of the Crestaurum Formation, whereas felsic tuffs have ε^T_{Nd} between −2.2 and −3.0. Thus the felsic rocks could not have evolved from mafic parents of the Crestaurum Formation by fractional crystallization alone. The mafic to intermediate rocks of the Crestaurum Formation fall within the lower part of the range of Chan Formation mafic rocks.

Townsite Formation. Mafic and felsic rocks from all three members of the Townsite Formation were collected for analysis. The mafic units from the Niven member are very fresh, whereas the Brock and Vee Lake mafic rocks have higher loss-on-ignitions. Note that the Brock member is close to the hydrothermally altered, gold-bearing shear zones of the Giant Mine. The mafic rocks from the Niven and Brock members are basalt to basaltic andesite in composition, whereas the Vee Lake sample is an andesite (fig. 5). Similar to the Chan and Crestaurum Formations, Townsite mafic to intermediate rocks follow a tholeiitic fractionation trend. Ni, Cr, and V contents also decrease with increasing FeO^T/MgO.

The incompatible element patterns of the Townsite mafic rocks are typical of modern MORB, showing depletion in the LREE compared with the middle and HREE and no depletion in Nb relative to La (fig. 6*B*). The andesite from the Vee Lake member is significantly REE enriched, but the pattern is parallel to other Townsite mafic rocks. The incompatible element patterns of felsic units in the Townsite Formation are all very similar to one another and resemble the patterns of the Crestaurum felsic tuffs (fig. 6*D*).

The mafic rocks from the three Townsite members have near-identical ε^T_{Nd}, ranging from +1.8 to +2.7, corresponding closely to the estimate of the depleted mantle at 2.7 Ga. (DePaolo 1988). These ε^T_{Nd} values fall in the upper part of the range for the Chan Formation. The felsic units in the Townsite Formation are isotopically homogeneous, with an ε^T_{Nd} of −0.2 to −0.9 (i.e., within analytical error). As is the case for the Crestaurum Formation, the mafic and felsic units are distinct isotopically and require either different magma sources or the addition of an enriched component during the evolution from intermediate to felsic composition.

Yellowknife Bay Formation. The uppermost part of Kam Group, including pillow lavas and synvolcanic sills, has been sampled within the town of Yellowknife, at the Giant Mine property, and at the "Giant Section" adjacent to the Giant Mine. One rhyodacite boulder from the Bode Tuff paraconglomerate was also analyzed. Similar to other Kam mafic rocks, the bulk of the samples collected are tholeiitic basalts, but the mafic units are as evolved as andesite (fig. 5*A*). The basalts, basaltic andesites, and andesites follow a tholeiitic fractionation trend (fig. 5*B*).

Ni, Cr, Sc, and V abundances in Yellowknife Bay mafic rocks generally follow the trends demonstrated by samples from the Chan, Crestaurum, and Townsite Formations, except that the most evolved Yellowknife Bay Formation lavas and diabases have slightly higher Ni and Cr but lower Sc and V abundances than Chan Formation basalts and basaltic andesites.

Three pillow lava units sampled from the Yellowknife Bay Formation near downtown Yellowknife have incompatible element patterns typical of modern normal (N-)MORB, with chondrite-normalized $La/Sm_{pmn} < 1$ and no Nb or Ta depletion relative to La (fig. 6*C*). These pillow lavas resemble the gabbros of the Townsite Formation and some of the basalts from the Chan Formation. The basaltic rocks at the Giant Section have $La/Sm_{pmn} > 1$ and have negative Nb anomalies but overlap with the MORB-like Yellowknife Bay basalts in the middle and HREE (fig. 6*C*). As a group, the Yellowknife Bay Formation patterns form a fan shape between Gd and Th, punctuated by negative Nb anomalies in rocks with high La/Sm_{pmn}.

The rhyodacite boulder from the Bode Tuff at the Giant Section is distinguished from other felsic units in the Kam Group by its lower incompatible element abundances and its strong depletion in the middle to HREE's (fig. 6*D*). Thus the magmatic history of the rhyodacite was quite different from that of the source of the felsic units in the Townsite and Crestaurum Formations. A rhyodacite boulder from the Giant Section yields a concordant U-Pb zircon age of 2704 ± 1, an age indistinguishable from those of cherty tuffaceous units also from the upper Yellowknife Bay Formation (2701 ± 3, 2702 ± 1, 2701 ± 1 Ma), demonstrating that the rhyodacite was contemporaneous with Upper Kam Group volcanic rocks (Isachsen 1992). Whereas an obvious source of these boulders is the underlying Townsite Formation (Falck 1990), the geochemistry of felsic units of the Townsite Formation analyzed in this study does not match that of the Bode Tuff boulders.

ε_{Nd}^{T} in the Yellowknife Bay mafic rocks range from +3.4 to −2.9, an extremely large range compared with the lower three formations in the Kam Group. Most samples fall between 2.0 and 0. The boulder from the Bode Tuff has the lowest ε_{Nd}^{T} of all Kam Group rocks, −5.3, which falls below the range of the mafic to intermediate rocks of the Yellowknife Bay Formation.

Discussion

Groupwide Geochemical Relationships. The volcanic rocks of the four formations in the Kam Group have many geochemical similarities. First, all mafic to intermediate rocks follow a tholeiitic fractionation trend. Second, all four formations within the Kam Group include basaltic rocks with flat to slightly LREE-depleted incompatible element patterns, similar to modern N-MORB. Third, three of the four formations includes some lavas that are enriched in the LREE, similar to enriched (E-) MORB that are less commonly found along modern mid-ocean ridges (Sun and McDonough 1989). However, the Kam REE-enriched lavas also have negative Nb anomalies, which are virtually unknown in E-MORB. Note that this also applies to the Chan Formation, which was previously thought to include only N-MORB-like basaltic rocks (MacLachlan and Helmstaedt 1995). Fourth, the volcanic rocks of the Kam Group have variable ε_{Nd}^{T}, the mafic lavas generally having positive values and the felsic rocks having negative values.

The major, trace element, and isotopic characteristics of Kam Group volcanic rocks are inconsistent with an origin from a single, homogeneous source. Figure 7 demonstrates the negative correlation of ε_{Nd}^{T} with SiO_2 (fig. 7*A*) and La/Sm_{pmn} (fig. 7*B*) for volcanic rocks of the Kam Group. There is a significant gap in SiO_2 content between mafic and felsic rocks from the Townsite and Crestaurum Formations but not in the Yellowknife Bay Formation. At least for the mafic to intermediate rocks, this correlation could be interpreted to result from melting of a heterogeneous mantle, with locally variable histories of light to middle REE enrichment. However, the correlation of isotopic composition with SiO_2 suggests that the isotopic and trace element compositions of the volcanic rocks are more strongly controlled by crustal contamination (e.g., Harris 1989). For mafic to felsic volcanic rocks of the Crestaurum and Yellowknife Bay Formations, the contaminant has an $\varepsilon_{Nd}^{2700} < -4$. The gneissic granitoids, with ages of >2900 Ma and ε_{Nd}^{2700} of −6 to −9, are possible candidates for the contaminant. The felsic rocks of the Townsite Formation imply a contaminant with a less negative ε_{Nd}^{2700}, although given the gap in SiO_2 between the mafic and felsic rocks, it is also possible that the felsic rocks are unrelated petrogenetically to the mafic rocks.

The decrease in ε_{Nd}^{T} and increase in La/Sm_{pmn} coincide with a decrease in Nb/La, reflecting the progressive increase in the size of the negative Nb anomaly in Kam Group volcanic rocks. Assimilation of LREE-rich but Nb-poor granitoid material (fig. 4) would impart this signature on more evolved mafic to intermediate rocks and would also produce the fanning of incompatible element patterns (fig. 6*C*) in mafic to intermediate rocks of the Yellowknife Bay Formation.

Plotted in figure 7*B* are two examples of assimilation-fractional crystallization (AFC) model curves (DePaolo 1981) and a bulk mixing curve for a basaltic parent magma and gneissic granitoid assimilant. The bulk mixing curve is calculated by incrementally adding assimilant to the parental liquid. The AFC model is more realistic, as it describes the chemical evolution of a magma as it crystallizes in a magma chamber and concurrently assimilates crustal material along chamber walls. The change in concentration of a trace element in the evolving magma depends on fractionation of that element between crystallizing minerals and magma (distribution coefficient, D), the ratio of the rate (mass/unit time) of assimilation to crystallization (r), the

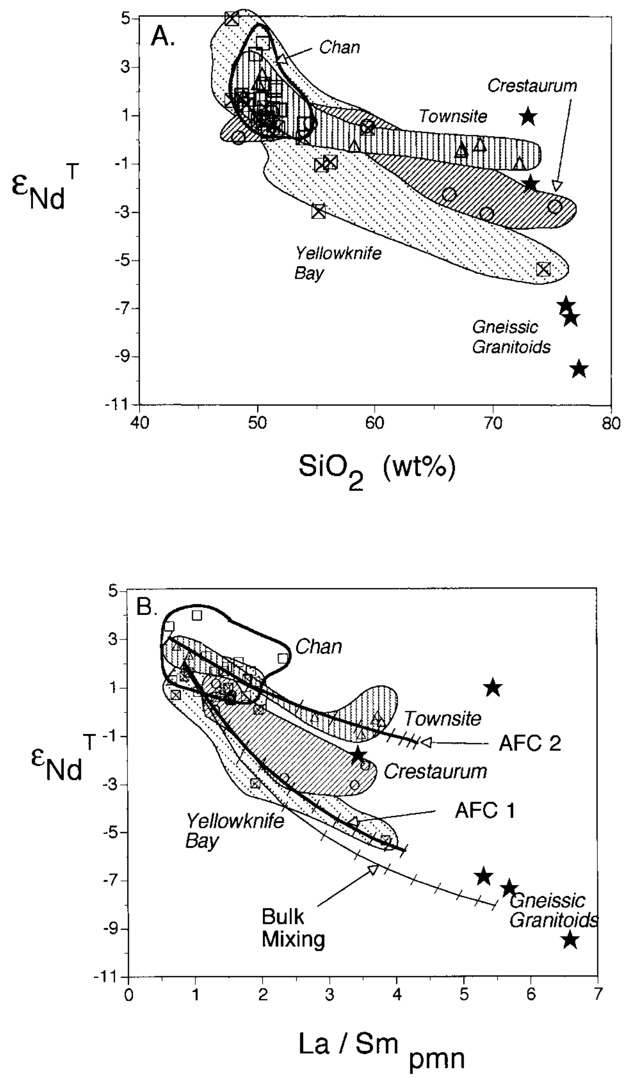

Figure 7. *A*, ε_{Nd}^{T} versus SiO_2 in mafic to felsic volcanic rocks of the four formations in the Kam Group. Symbols as in figure 5. *B*, ε_{Nd}^{T} versus La/Sm$_{pmn}$ (normalized to primitive mantle). Curve labeled "Bulk Mixing" demonstrates incorporation of average gneissic granitoid (tick marks in 10% increments) into an average Townsite Formation basalt magma. The *AFC 1* and *AFC 2* curves are two assimilation-fractional crystallization models for the Yellowknife Bay and Townsite Formations, respectively, where parental basaltic magmas are simultaneously fractionating and assimilating granitoids with $\varepsilon_{Nd}^{2700} = -8$ and -2, respectively. Tick marks on the AFC curves indicate *F* (mass magma remaining/mass initial magma) from 1 to 0.1, in increments of 0.1. See text for details.

initial concentration of the element in the parent magma and in the assimilant, and the mass fraction of magma remaining after a certain period of time (mass magma/mass initial magma, *F*). $^{143}Nd/^{144}Nd$ in the magma is not changed during fractional crystallization since minerals do not fractionate the heavy isotopes from the magma, but assimilation of crustal material may dramatically change isotope ratios in the evolving magma if there is a difference in isotopic composition between magma and wallrocks. The "AFC 1" model in figure 7*B* assumes a fractionating assemblage of olivine, clinopyroxene, Fe-Ti oxides, and plagioclase in the proportions 20% : 30% : 5% : 45%; bulk *D* values of 0.06 and 0.12 for La and Sm, respectively (Green 1994); an initial composition of a Yellowknife Bay Formation depleted tholeiite Yk-7 ($\varepsilon_{Nd} = +1.5$); an average Anton gneissic granitoid contaminant ($\varepsilon_{Nd}^{2700} = -8$); and an *r* value of 0.6. The "AFC 1" curve follows the data array for the Yellowknife Bay Formation, whereas the bulk-mixing curve generally passes below the Kam data array. The Townsite and Crestaurum data arrays require an assimilant with a less negative ε_{Nd}^{2700}, approximately -2 and -4, respectively. The "AFC 2" curve in figure 7*B* demonstrates how evolved rocks from the Townsite Formation could be derived from a Niven Member basaltic parent ($\varepsilon_{Nd} = +3$) with a granitoid assimilant having an ε_{Nd}^{2700} of -2, assuming the same fractionating assemblage, *D* values and value of *r* as the "AFC 1" model. The AFC modeling generally supports the hypothesis that the intermediate to felsic Kam Group volcanic rocks were derived from mafic parent magmas with depleted mantle incompatible-element patterns and isotopic compositions but were modified by interaction with older basement rocks before their eruption. This interaction produces the fanlike set of incompatible element patterns in the Yellowknife Bay Formation (fig. 6*C*).

The geochemical evidence for interaction between mafic magmas and continental basement rocks supports the field interpretation that the décollement between the basement rocks and the greenstones in the central Slave Province involves only limited transport of the upper-plate greenstones (Bleeker and Ketchum 1998). The basement granitoids are clearly excellent candidates for the contaminant in the intermediate to felsic volcanic rocks at Yellowknife, suggesting that they underlay the greenstones at their time of eruption.

Tectonic Setting of the Kam Group. Proposed origins for greenstone belts of the southern Slave Province include (1) an island arc (Folinsbee et al. 1968), (2) slivers of oceanic crust trapped in a suture zone during the accretion of two terranes (e.g., Kusky 1989, 1990), (3) a back-arc basin intruded and overlain by later arc volcanism of the Banting Group (Helmstaedt and Padgham 1986; Helmstaedt et al. 1986), and (4) a continental rift (summarized in Henderson 1985). The geochemistry of the volcanic rocks in the four formations of the Kam Group has important implications for the tectonic setting in which these rocks were erupted. In their analysis of the geochemistry of the Yellowknife Volcanic Belt, Cunningham and Lambert (1989) concluded that geochemical diagrams used to classify the tectonic setting of Cenozoic volcanic rocks (e.g., Pearce and Cann 1973) produce inconsistent results for the Archean Yellowknife rocks. To some extent this is because of element mobility during greenschist facies metamorphism. Even so, Kam Group volcanic rocks generally plot in the ocean floor basalt field, and Banting Group rocks fall in the convergent margin field (Cunningham and Lambert 1989).

It is proposed that greenstone belts in the southern Slave Province are slivers of oceanic crust trapped between two colliding cratons, the Anton Terrane to the west and the Contwoyto/Hackett River Terrane to the east (Kusky 1989, 1990). The "oceanic crust" could actually consist of any volcanic pile trapped between the colliding terranes, and such rocks could include mid-ocean ridge basalts, oceanic plateau basalts, intraplate seamount lavas, island arc lavas, or a back-arc complex. A mid-ocean ridge, oceanic seamount, or oceanic plateau (see Mahoney 1987; Sun and McDonough 1989) setting for the Kam Group appears unlikely based on the large variations in La/Sm_{pmn} and ε^{T}_{Nd} with SiO_2 and the abundant evidence for a nearby craton (>2800 Ma detrital zircons in felsic cherty tuffs). There is only one documented case of modern mid-ocean ridge basalts that include a "continental" component, namely, the easternmost segments of the southern Chile Ridge, where it is being subducted beneath South America (Klein and Karsten 1995; Sturm et al. 1999). Basalts from the spreading segments closest to the trench show a similar fanning of incompatible element patterns, development of a negative Nb anomaly and LILE enrichment, and variation in isotopic composition as is seen in the Crestaurum and Yellowknife Bay Formations. However, there is no apparent correlation between La/Sm, isotopic composition, and SiO_2 in South Chile Ridge basalts.

Mantle plumes are implicated in the origin of Mesozoic and Cenozoic intraplate seamounts and oceanic plateaus. Archean mantle plumes are proposed to produce komatiites rather than alkaline rocks (e.g., Herzberg 1995), but komatiites are rare in the YVB and in other Slave greenstone belts (Helmstaedt et al. 1986).

Modern oceanic island arcs, such as the Mariana and Tonga-Kermadec arcs, generally erupt submarine and subareal lavas that follow a tholeiitic fractionation trend (e.g., Ewart and Hawkesworth 1987; Lee et al. 1995). However, rocks with $SiO_2 > 62\%$ are rare, and the basalts and basaltic andesites have ubiquitous negative Nb (and other HFSE) anomalies coupled with LILE enrichment. As in the other purely oceanic settings, the source of the >2.8-Ga zircons in the Ranney tuff and Niven member felsic rocks of the Kam Group remains problematic: older basement rocks must be present to provide the mixed zircon populations found in these units. No such older basement exists beneath modern island arcs. Continental volcanic arcs, such as the Cascade Range or the Andes, are built on older crust, and magmas could potentially inherit zircons from their basement rocks. However, continental arc lavas are usually subareal, whereas Kam Group rocks are dominantly submarine, and continental arc lavas usually follow calc-alkaline rather than the tholeiitic fractionation trend of Kam volcanic rocks (Irvine and Baragar 1971; McBirney 1978).

One modern tectonic environment where lavas are dominantly submarine but can form in proximity to a continent with older basement rocks is a back-arc basin. Excellent modern examples include the Japan Sea (Tamaki 1988) and the Woodlark Basin (Taylor et al. 1995). Miocene lavas from the Japan Sea back-arc are tholeiitic, submarine basalts that range in composition from normal MORB-like basalts to LREE and LILE-enriched basalts with small negative Nb anomalies (Cousens et al. 1994; Pouclet et al. 1995). Radiogenic isotope ratios covary strongly with LREE enrichment, in the same manner as volcanic rocks from the Kam Group. The source of the "enriched" component in Japan Sea back-arc tholeiites has been proposed to be either crustal or lithospheric contamination of MORB-like parental magmas (Nohda et al. 1988) or incorporation of subducted sediments into the mantle beneath the back-arc (Cousens et al. 1994). One question that remains is, If the Kam Group is the result of back-arc extension, then where is the remnant of the associated volcanic arc? No arc-related volcanic or plutonic rocks of early or middle Kam age are found in the southern Slave Province (van Breeman et al. 1992), with the exception of minor calc-alkaline volcanic rocks in parts of the Cameron and Beaulieu River volcanic belts (Dostal and Corcoran 1998). It is possible that the arc sequence has been removed by postorogenic processes, but it is remarkable that there are no plutons preserved in the Western Granodiorite Complex that can be related to a putative Kam-age arc complex.

Finally, it is proposed that Kam Group volcanism represents volcanic activity at the margin of an intracratonic basin (Henderson 1985). The submarine nature and entirely tholeiitic composition of the volcanism in the Yellowknife area is not consistent with the predominantly subareal, alkaline volcanism of Proterozoic and Phanerozoic intracontinental rifts such as the Midcontinent Rift of North America, the East African Rift, the Basin and Range Province of the southwestern United States, and the Oslo Rift (Williams 1982; Hutchinson et al. 1990). However, many Mesozoic flood basalt suites associated with the opening of the modern Atlantic Ocean are submarine to subareal tholeiitic basalt sequences that are as thick as 5 km (e.g., Harris 1989; Robillard et al. 1992; Saunders et al. 1997). These volcanic suites overlie continental basement, commonly include minor felsic rocks, and customarily exhibit geochemical evidence for assimilation of older basement rocks, producing correlations between LREE enrichment, isotope ratios, and SiO_2. The mantle sources of young flood basalt suites include depleted mantle, mantle plumes, and enriched subcontinental lithosphere, all with different trace element and isotopic characteristics. It could be argued that the LREE-enriched, Nb-depleted lavas of the Kam Group were derived from juvenile enriched lithospheric mantle (modified by addition of subduction-related fluids) with an ε^T_{Nd} only slightly lower than that of depleted mantle at 2.7 Ga. However, the observed correlation between ε^T_{Nd} and SiO_2 is more difficult to explain in this way (e.g., Harris 1989; Saunders et al. 1997).

Conclusions

The volcanic rocks of the Kam Group are tholeiitic basalts, basaltic andesites, and subordinate andesites and dacites. The mafic to intermediate rocks range from N-MORB-like basalts with flat incompatible element patterns and positive ε^T_{Nd} to lavas with LREE-enrichment, depletion in Nb relative to La, and $\varepsilon^T_{Nd} \sim 0$. Felsic volcanic rocks are strongly LREE-enriched, are highly depleted in Nb, and have $\varepsilon^T_{Nd} < 0$. The contrasts in trace element and isotopic characteristics between mafic and felsic rocks negate magmatic evolution by fractional crystallization alone. Incompatible element ratios such as La/Sm, Nb/La, and ε^T_{Nd} correlate with SiO_2, indicating that the more evolved lavas have been contaminated by continental crust. Gneissic granitoids that underlie the Kam Group have incompatible element and isotopic compositions that make them appropriate contaminants.

The geology, geochronology, and geochemistry of the Kam Group are consistent with a marginal continental rift setting. The presence of older gneissic granitoids of the Anton Complex and the observation that the metasedimentary and metavolcanic rocks of the Bell Lake Group at Dwyer Lake are crosscut by dikes that feed the mafic volcanic rocks of the Chan Formation constitute good evidence for a preexisting continental basement on which the Kam Group was erupted. The ages of inherited zircons in the lowermost cherty tuffs of the Crestaurum Formation are similar to ages of Anton Complex rocks, consistent with the hypothesis that the lower Kam Group was deposited on or close to these older basement rocks (Isachsen 1992; Bleeker and Ketchum 1998). The predominantly submarine eruptive setting, the tholeiitic nature of the lavas, and the evidence for interaction with granitic continental basement in the intermediate volcanic rocks are also consistent with a continental margin rift or, perhaps, a back-arc setting. Without evidence of a coexisting volcanic arc, however, the latter model is overly specific.

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