Geology and alteration signature of a Middle Proterozoic Bear River dyke in the Slats Creek map area, Wernecke Mountains, Yukon (106D/16)

***Danette L. Schwab*[1] *and Derek J. Thorkelson*[2]**
Simon Fraser University

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ABSTRACT

The Middle Proterozoic Bear River dykes (ca. 1.27 Ga) are mafic intrusions that crosscut the Gillespie Lake Group of the Wernecke Supergroup in the Slats Creek and Fairchild Lake map areas (106D/16, 106C/13). The dykes are fine- to medium-grained gabbros and basalts with tholeiitic affinities. The most northwesterly dyke was examined in detail. It was emplaced into mainly dolostone, and crosscuts an older fault. A white-weathering aureole along the margins of the dyke consists of calcite-magnetite-serpentine skarn. Within the dyke, hydrothermal effects are dominated by Fe (hematite and magnetite), with local enrichments of Cu (chalcopyrite) and U, a signature characteristic of earlier-formed zones of Wernecke Breccia (1.6 Ga). Alteration of the dyke indicates that a later pulse of hydrothermal fluids was channelled along the dyke or the fault. The Bear River dykes may belong to the coeval, giant radiating Mackenzie dyke swarm of the northern Canadian Shield.

RÉSUMÉ

Les dykes du Protérozoïque moyen de Bear River (1,27 Ga) sont des intrusions mafiques qui recoupent le Groupe de Gillespie Lake du Supergroupe de Wernecke dans les zones cartographiques de Slats Creek et de Fairchild Lake (106D/16 et 106C/13). Ces dykes sont formés de gabbros et de basaltes de granulométrie fine à moyenne d'affinité tholéiitique. Le dyke situé à l'extrême nord-ouest a été l'objet d'une étude approfondie. Ce dyke, qui s'est mis en place principalement dans des dolomies, recoupe une faille plus ancienne. Une auréole de métamorphisme superficielle de couleur blanche observée le long de la bordure du dyke est composée de skarns à calcite-magnétite-serpentine. Au sein de ce dyke, l'altération hydrothermale est dominée par le fer (hématite et magnétite), accompagné, par endroits, d'enrichissements en cuivre (chalcopyrite) et en uranium, ce qui correspond à une signature caractéristique des zones plus anciennes de la brèche de Wernecke (1,6 Ga). L'altération du dyke indique qu'une arrivée tardive de solutions hydrothermales a eu lieu le long du dyke ou de la faille. Les dykes de Bear River font sans doute partie du gigantesque groupe de dykes de Mackenzie, d'âge équivalent, situé dans la partie septentrionale du Bouclier canadien.

[1]*Department of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6*
[2]*dthorkel@sfu.ca*

INTRODUCTION

The Bear River dykes are gabbroic intrusions of Middle Proterozoic age that intrude dolostone and minor mudrock of the Early Proterozoic Wernecke Supergroup (Thorkelson, 2000). The dykes were identified during a regional mapping program from 1992 to 1995 (Thorkelson and Wallace, 1993, 1994). They occur in five localities in the Slats Creek and Fairchild Lake map areas of northeastern Yukon (106D/16, 106C/13), where they crop out as single dykes or swarms of up to eight dykes (Figs. 1, 2). Individual dykes are up to 5 km long, and typically 5-15 m wide. Dyke orientations vary but typically strike northwest. They are commonly flanked by a white-weathering metasomatic contact aureole.

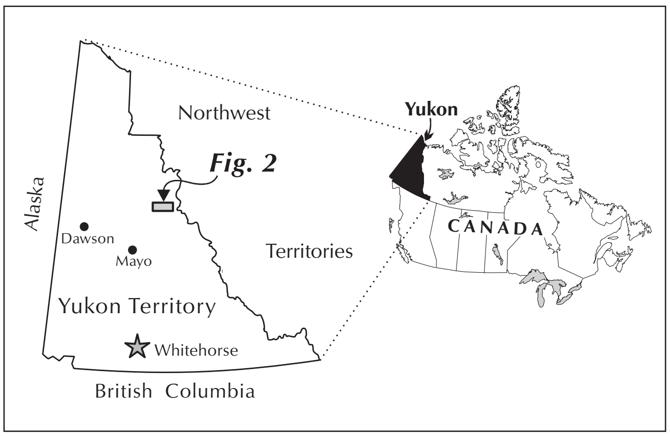

Figure 1. *Location map showing region of Bear River dyke exposures in northeastern Yukon (area of Fig. 2).*

The most northwestern occurrence of the Bear River dykes consists of a single intrusion approximately 5 km west of the headwaters of Slats Creek (herein termed the *study area*; Figs. 2, 3). This dyke was dated by U-Pb (baddeleyite) at ca. 1.27 Ga by J.K. Mortensen (pers. comm., 1995; Thorkelson, 2000), and was examined in detail in the summer of 2000. Another Bear River dyke, approximately 16 km east-southeast of the study area, has also been dated at ca. 1.27 Ga by Mortensen (Fig. 2; Thorkelson, 2000). The dyke in the study area is hydrothermally altered and mineralized in a manner similar to the earlier-formed Wernecke Breccias, whose emplacement and main pulse of alteration has been dated at ca. 1.6 Ga (R.A. Creaser, pers. comm., 1994; Thorkelson, 2000). The metasomatic effects in and around the Bear River dyke in the study area represent a younger pulse (≤1.27 Ga) of hydrothermal activity.

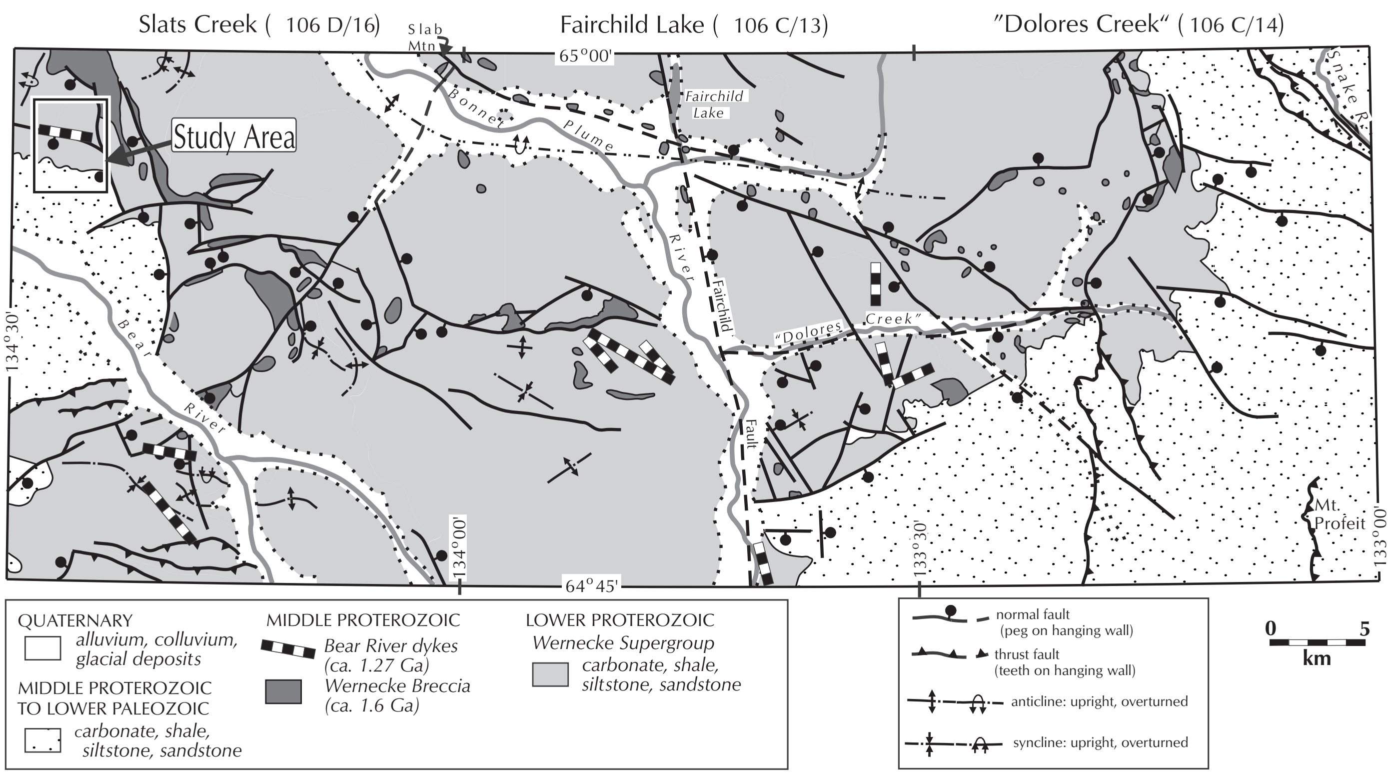

Figure 2. *Simplified geological map of Slats Creek, Fairchild Lake and "Dolores Creek" map areas (106C/13, 106C/14, 106D/16) showing schematic location of Bear River dykes and Wernecke Breccia zones (after Thorkelson, 2000). Study area indicated in northwestern part of map area.*

This report provides an overview of the Bear River dykes, and focuses on the field relations and metasomatic alteration in the study area. Metal enrichments, notably of Cu and U, are characterized using a new method of quantifying geochemical systems including those involving hydrothermal alteration. The dykes are placed in context with the time-equivalent Mackenzie dyke swarm of north-central Canada.

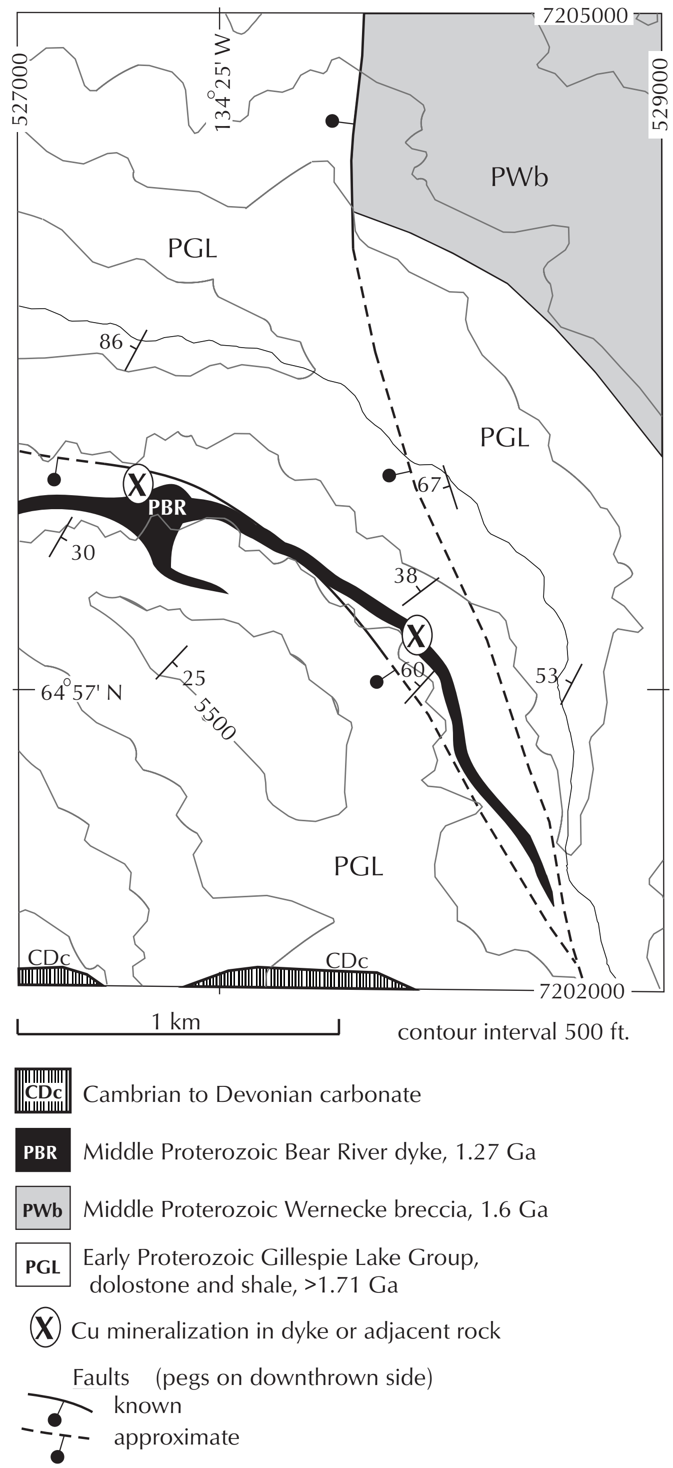

Figure 3. *Simplified geology of the study area, showing Bear River dyke and related Cu-mineralization. Location of study area shown in Figure 2.*

GEOLOGY OF THE STUDY AREA

FIELD RELATIONS AND IGNEOUS MINERALOGY

The Bear River dyke in the study area is approximately 2 km long and pinches and swells in thickness from 0-150 m (Fig. 3). Two or more offshoots extend from the thickest part of the dyke, which is irregularly shaped. The dyke crosscuts orange-weathering dolostone and minor black shale of the Gillespie Lake Group, the highest of the three groups that constitute the Early Proterozoic Wernecke Supergroup (Fig. 4). The dyke strikes east-

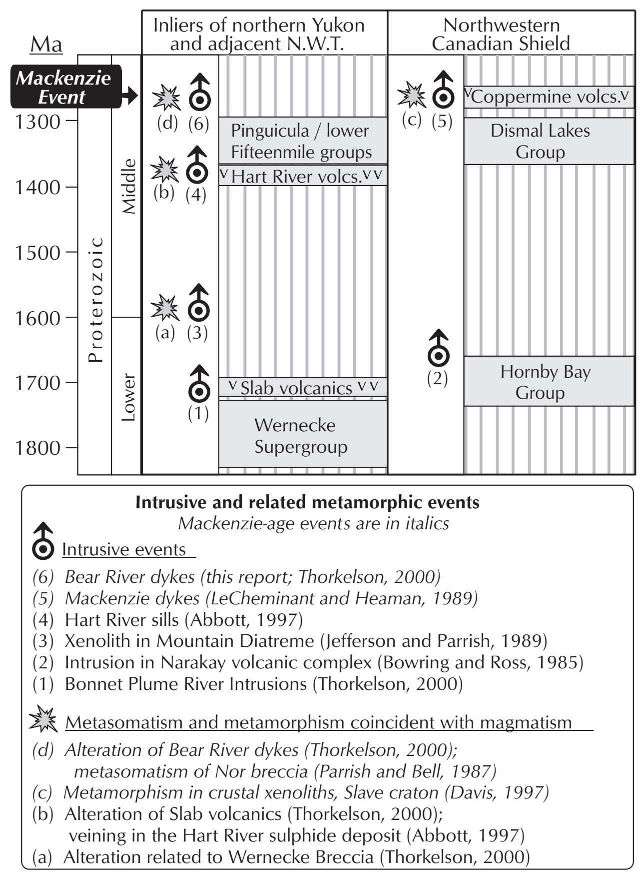

Figure 4. *Time-stratigraphic columns of the Yukon and the western Canadian Shield, showing timing of intrusive and metasomatic events (modified from Thorkelson, 2000). Bear River dyking and related metasomatic activity indicated as items (6) and (d), respectively, and correlate with the Mackenzie igneous event.*

southeast, dips steeply to the southwest, and is locally flanked by a 5- to 10-m thick white-weathering contact aureole. Thorkelson and Wallace (1993) indicated that the dyke parallels a fault within the Gillespie Lake Group. Our re-examination indicates that the dyke cuts across the fault at a low angle. The fault is evident from an abrupt change in bedding attitude in the vicinity of the dyke, and is locally marked by zones of coarse red-weathering dolomite spar up to 30 m wide. The spar was apparently deposited in dilatant zones adjacent to the fault surface. The intrusion is medium grained in the centre and fines towards the margins, where it is chilled against the host sedimentary strata.

Inside the chilled margins, the dyke consists of dark greenish-grey weathering, greenish-grey fine- to medium-grained gabbro. The essential igneous mineralogy of the dyke in the study area locality is similar to that of the other Bear River dykes and consists mainly of subequal amounts of plagioclase and clinopyroxene, with accessory magnetite ranging from 1-7%. Interstitial granophyre is commonly present in proportions up to 10% and consists of quartz and alkali feldspar and associated apatite. The igneous mineralogy has been largely supplanted by secondary minerals under conditions of low-grade metamorphism. Plagioclase has altered to clay, mica, calcite, chlorite and epidote, and clinopyroxene has altered to chlorite. Hydrothermal activity has also affected the mineralogy and geochemistry, as described below.

METASOMATIC ALTERATION

Three events of metasomatic activity are recorded in the study area. Subsequent regional metamorphism at sub- to lower-greenschist grades (Thorkelson, 2000) has further affected the rocks. The first metasomatic event occurred during emplacement of a zone of Wernecke Breccia approximately 1 km north of the dyke (Figs. 2, 3, 4, event (a)). The breccia zone and adjacent wall rocks are characterized by disseminations and veins of specular hematite, and other minerals such as quartz, carbonate, feldspar, and minor chalcopyrite. Earlier-formed (1.6 Ga) Wernecke Breccia zones typically host localized enrichments of Cu, Co, U and Au (e.g., Laznicka and Edwards, 1979; Bell, 1986; Hitzman et al., 1992; Thorkelson, 2000), but the Wernecke Breccia zone in the study area was not examined in detail in this investigation, and the degree to which enrichments may exist has not been evaluated.

In the second metasomatic event, dolostone wall rock of the Gillespie Lake Group was thermally and metasomatically altered to skarn by magma of the Bear River dyke. The age of skarnification is, therefore, the same as the age of dyke emplacement, 1.27 Ga (Fig. 4, event (6)). The skarn ranges in thickness from 5 to 10 m and is mainly restricted to the margins of the thickest part of the intrusion (in other localities of the Bear River dykes, skarnification is more continuous). The skarn presently consists of an assemblage of calcite, serpentine, magnetite, and minor chalcopyrite and pyrite. Olivine was probably a primary constituent of the skarn that has since been retrograded to serpentine. The calcite, which comprises 90 to 95% of the skarn, is white-weathering, pale green and fine-grained. Original sedimentary laminations are typically well preserved on weathered surfaces, and are commonly accentuated by thin (1 to 5 mm) layers of serpentine. The serpentine also occurs as veins, pods, and along fractures, some of which are sheared and have slickensides. Magnetite occurs as clots, drusy fracture fillings, disseminations, and intergrowths with serpentine. Chalcopyrite and pyrite occur locally as coarse- to fine-grained clusters and fine disseminations. Malachite grain coatings and fracture fillings occur adjacent to chalcopyrite. In a few localities, irregular veins of specular hematite occur in the skarn, but their origin is ascribed to the third phase of metasomatism.

The third metasomatic event (Fig. 4, event (d)) produced veins, metasomatic bands, and large patches of pervasive alteration in the Bear River dyke. Mineralogical changes of the dyke include alteration of plagioclase feldspar to potassium feldspar (giving the rock a pinkish colour), and growth of chlorite, carbonate, hematite and quartz in veins, and magnetite, hematite, pyrite and chalcopyrite as fine disseminations. These features are very similar to those which occurred during Wernecke Breccia development. The third event also produced sinuous, discontinuous hematite veins from 1 to 7 cm thick, within in the skarn. Beyond the skarn, the country rock shows hematitic and sparry carbonate alteration, but it is unclear what proportion of these features developed during the third event of metasomatism, and how much was produced during the first phase of hydrothermal activity, when the Wernecke Breccias were emplaced and voluminous metasomatic cells permeated the crust.

The age of the third phase of metasomatism occurred, at least in part, after dyke emplacement ($\leq$1.27 Ga). This event may have occurred in response to fluid migration induced by general heating of the country rock during dyke emplacement. In this scenario, the third event would be a localized, late-stage hydrothermal product of Bear River magmatism (Fig. 4). No other cause of the fluid activity has been identified. The localized nature of this hydrothermal event is clear from field relations which reveal that, in other parts of the Wernecke Mountains, metasomatism related to Wernecke Breccia ceased prior to deposition of the Pinguicula Group at ca. 1.38 Ga (Fig. 4; Thorkelson, 2000). No hydrothermal activity that could correlate with the third event in the study area has been found to penetrate the Pinguicula Group. However, limited evidence corroborates the presence of minor hydrothermal activity elsewhere at ca. 1.27 Ga (Fig. 4). In the Richardson Mountains of northern Yukon, hydrothermal monazite in the Nor breccia occurrence was dated at ca. 1.27 Ga by Parrish and Bell (1987). In the Northwest Territories, heating of the middle crust is evident from ages of reset rutile and metamorphic zircon growth in xenoliths, and ascribed to crustal heating during 1.27 Ga Mackenzie magmatism (Davis, 1997). Earlier, at 1.38 Ga, hydrothermal activity at Slab Mountain, approximately 30 km east-northeast of the study area, led to rutile precipitation in a megaclast of volcanic rocks in a zone of Wernecke Breccia dated at 1.6 Ga (Fig. 4; Thorkelson, 2000). This hydrothermal event may have been related to 1.38 Ga magmatism of the Hart River mafic intrusions in the Ogilvie and Wernecke Mountains (Thorkelson, 2000; Abbott, 1997). Taken together, these data suggest that weaknesses in the upper crust occupied by intrusions and breccia zones acted as paths for later hydrothermal activity during subsequent igneous events at 1.38 and 1.27 Ga.

GEOCHEMISTRY

Research-grade geochemical analyses were obtained by X-ray fluorescence and inductively coupled mass spectrometry for 11 samples of the Bear River dykes from all 5 of the dyke localities. In addition, assays for a broad range of metals, including gold, were determined for six samples. All of the data is provided in Tables 1, 2 and 3. Geochemical analyses for five of the samples were originally reported by Thorkelson (2000).

IGNEOUS GEOCHEMISTRY

Major and trace element geochemistry is given in Table 1. Magnesium numbers (Mg#) calculated using $[100Mg^{2+}/(Mg^{2+}+Fe^{2+})]_{atomic}$ based on $(Fe^{3+}/Fe^{2+})_{atomic} = 0.117$, range from 42 to 59. These quotients are far below the minimum value of 72 for primary mantle melts, and indicate that the Bear River magmas are geochemically evolved. Most of the samples are quartz normative with the exception of three samples, which are olivine normative. Preliminary analysis indicates that the dykes have a tholeiitic affinity, are compositionally categorized as basalts to basaltic andesites, and have major and trace element abundances similar to those of continental flood basalts. Details of igneous petrology and geochemistry will be published elsewhere.

Table 1. *Major oxides – analyses obtained by X-ray fluorescence and reported on a volatile-free basis.*

Sample no.			Lab	Location			SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Mg #
Geol	Yr	Number	Sample#	NTS	UTM E	UTM N	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	
TOA	96	6-7-2B	6-7-2B	106D/16	527600	7203300	54.3	1.05	14.2	10.7	0.20	7.20	7.83	2.17	2.16	0.11	58
DT	96	1-1-1B	1-1-1B	106C/13	563700	7181700	51.8	2.29	12.0	14.9	0.31	6.93	6.73	3.86	0.99	0.21	49
DT	92	11-1B	G-2	106D/16	532000	7186800	53.5	1.09	13.4	11.4	0.15	8.05	6.74	2.21	3.24	0.12	59
CW	93	19-1B	G-125	106C/13	556900	7192900	48.8	1.30	12.7	17.0	0.16	6.19	9.48	1.61	2.65	0.14	42
DT	93	72-1B	G-112	106C/13	569600	7196900	51.9	2.28	13.1	14.0	0.23	5.89	8.34	2.91	1.11	0.23	46
DS	00	2-2-8B	2-2-8B	106D/16	528500	720300	55.6	1.18	14.0	12.12	0.21	6.67	6.50	2.23	1.36	0.13	53
DS	00	2-2-9B	2-2-9B	106D/16	528500	720300	63.6	1.54	12.9	6.98	0.13	6.28	1.58	0.06	6.63	0.28	65
DS	00	3-1-1B	3-1-1B	106D/16	527500	720350	65.1	0.48	10.7	12.13	0.13	7.10	1.45	-0.01	2.65	0.28	54
DS	00	3-1-2B	3-1-2B	106D/16	527500	720350	58.6	0.44	10.2	6.86	0.11	6.45	12.18	0.79	4.25	0.12	66
DS	00	3-2-1B	3-2-1B	106D/16	527500	720350	55.5	1.38	17.5	8.76	0.18	6.25	3.39	0.14	6.66	0.15	59
DS	00	3-2-5B	3-2-5B	106D/16	527500	720350	55.7	1.15	14.5	10.54	0.20	5.83	7.85	2.55	1.52	0.12	53

Table 2. *Trace elements from inductively coupled mass spectrometry and X-ray fluorescence on pressed powders.*

Sample No.	Ba ppm	Rb ppm	Cs ppm	Th ppm	Ta ppm	U ppm	Nb ppm	La ppm	Ce ppm	Pb ppm	Sr ppm	Pr ppm	Nd ppm	Zr ppm	Sm ppm	Hf ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Ho ppm
6-7-2B	387	76.0	1.89	4.08	0.47	0.87	7.70	15.8	32.7	5	145.5	3.33	15.3	100	3.47	2.94	1.09	3.80	0.66	3.69	0.72
1-1-1B	238	24.2	0.86	1.75	0.54	0.49	9.53	11.8	29.8	-5	122.6	3.40	17.4	122	4.85	3.77	1.85	5.10	0.80	4.84	0.89
11-1B	268	164.7	5.72	2.81	0.52	0.68	6.44	13.0	27.3	21.69	102.8	3.25	13.8	73	3.15	2.22	0.96	3.50	0.50	3.36	0.62
19-1B	431	35.3	0.90	4.36	1.09	1.93	15.01	21.9	49.3	15.73	294.5	5.95	22.3	113	4.77	3.55	1.43	4.78	0.71	4.26	0.84
72-1B	332	25.2	2.57	1.81	0.59	1.04	10.30	12.5	31.6	22.94	256.0	4.42	20.2	137	5.28	3.82	1.84	6.18	0.86	5.23	0.97
2-2-8B	240	32.7	na	4.26	na	2.81	8.00	na	53.4	7.36	93.7	na	na	105	na	na	na	na	na	na	na
2-2-9B	615	106.7	na	13.01	na	3.53	16.13	na	47.5	6.71	22.2	na	na	218	na	na	na	na	na	na	na
3-1-1B	218	35.6	na	9.69	na	14.81	12.67	na	216.2	-3.68	8.5	na	na	138	na	na	na	na	na	na	na
3-1-2B	730	111.5	na	6.87	na	6.93	10.98	na	44.7	-7.35	36.4	na	na	120	na	na	na	na	na	na	na
3-2-1B	3561	102.9	na	2.29	na	5.81	8.75	na	-40.1	-2.56	81.1	na	na	123	na	na	na	na	na	na	na
3-2-5B	323	41.4	na	6.26	na	3.07	9.13	na	24.2	-3.59	157.5	na	na	118	na	na	na	na	na	na	na

Sample No.	Er ppm	Tm ppm	Y ppm	Yb ppm	Lu ppm	V ppm	Sc ppm	Cr ppm	Co ppm	Ni ppm	Ga ppm	Cu ppm	Zn ppm	Be ppm	Li ppm	Tl ppm	Bi ppm	Ag ppm	Sn ppm	Sb ppm
6-7-2B	2.20	0.29	21	2.15	0.32	263	na	357	69.8	162	na	122	50	na	na	0.35	0.81	-0.50	0.80	2.09
1-1-1B	2.53	0.35	25	2.26	0.32	369	na	129	69.9	678	na	354	267	na	na	1.05	0.17	-0.50	1.10	2.58
11-1B	1.86	0.25	15.5	1.63	0.24	284	31.3	479	41.5	151	na	142	102.0	0.54	32.06	0.62	0.26	0.66	35.58	7.39
19-1B	2.20	0.31	19.2	2.04	0.29	238	25.8	208	33.8	82	na	70	120.6	0.54	27.33	0.30	0.05	1.44	1.95	2.40
72-1B	2.58	0.37	23.4	2.05	0.29	419	28.2	109	45.6	78	na	371	156.4	1.50	17.36	0.19	0.05	0.95	1.66	1.19
2-2-8B	na	na	17.7	na	na	292	29.0	331	na	84	16.2	167	30.4	na	na	na	na	na	na	na
2-2-9B	na	na	26.7	na	na	262	28.9	5	na	23	16.7	338	104.3	na	na	na	na	na	na	na
3-1-1B	na	na	17.6	na	na	126	2.0	48	na	19	13.8	5135	78.6	na	na	na	na	na	na	na
3-1-2B	na	na	22.5	na	na	203	8.7	46	na	112	9.8	501	0.3	na	na	na	na	na	na	na
3-2-1B	na	na	12.0	na	na	369	44.7	471	na	134	14.1	305	67.5	na	na	na	na	na	na	na
3-2-5B	na	na	21.0	na	na	285	25.6	289	na	87	18.8	101	15.7	na	na	na	na	na	na	na

na = not analyzed

Table 3. *Assays by inductively coupled mass spectrometry except for gold, obtained by fire assay and atomic absorption.*

Sample No.	Au ppb	Ag ppm	Al %	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	Hg ppm	K %	Mg %	Mn ppm	Mo ppm
2-2-8B	5	<1	3.49	10	<20	<5	<10	2.71	<5	45	210	200	7.37	<10	0.12	3.03	1190	<5
2-2-9B	<5	<1	2.46	<10	120	<5	<10	1.1	<5	40	<10	360	5.33	<10	0.09	4.08	870	<5
3-1-1B	<5	2	3.76	<10	<20	<5	<10	1	<5	25	40	5950	9.28	<10	0.06	4.31	870	<5
3-1-2B	<5	1	1.59	30	320	<5	<10	8.33	<5	120	30	640	4.32	<10	0.56	2.44	650	15
3-2-1B	10	1	2.97	<10	3320	<5	<10	2.35	<5	55	340	365	6.17	<10	0.47	3.93	1250	<5
3-2-5B	<5	1	2.38	<10	40	<5	<10	1.79	<5	35	160	110	4.61	<10	0.17	1.82	700	<5
4-3-1B	<5	1	2.14	<10	20	<5	<10	1.32	<5	20	60	165	2.76	<10	0.08	0.95	250	<5

Sample No.	Na %	Ni ppm	P ppm	Pb ppm	Sb ppm	Sc ppm	Sr ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Zn ppm
2-2-8B	0.1	105	400	15	<10	5	45	0.31	<20	20	180	<20	60
2-2-9B	0.09	50	1100	15	<10	15	10	0.03	<20	<20	200	<20	165
3-1-1B	0.09	50	1000	<5	<10	<5	15	0.01	20	<20	100	<20	130
3-1-2B	0.11	140	400	<5	<10	5	25	0.11	<20	20	140	<20	30
3-2-1B	0.1	185	500	25	<10	25	85	0.03	<20	20	240	<20	120
3-2-5B	0.12	85	500	5	<10	<5	25	0.34	<20	<20	140	<20	30
4-3-1B	0.38	45	300	5	10	<5	25	0.13	<20	<20	120	<20	20

METASOMATISM EVALUATED WITH STONERGRAMS

The geochemical signature of metasomatism of the Bear River dykes has been evaluated by comparing major oxide and selected element abundances of metasomatized samples to that of the least-altered dyke sample (sample TOA-96-6-7-2B). The comparison has been made using a new type of graphical display, herein called *Stonergrams* (Fig. 5). The numerical method for Stonergrams is based on the same logic used in the construction of Pearce Element Ratio diagrams (Pearce, 1968), and the Isocon diagram (Grant, 1986), but the results are shown in a familiar Spider Diagram-like display. For each sample, the abundances of oxides and elements are divided by the concentration of a suspected immobile component (in this case, Al_2O_3 was used). The quotients obtained for metasomatized samples are then divided by the quotient for the non-metasomatized sample. The

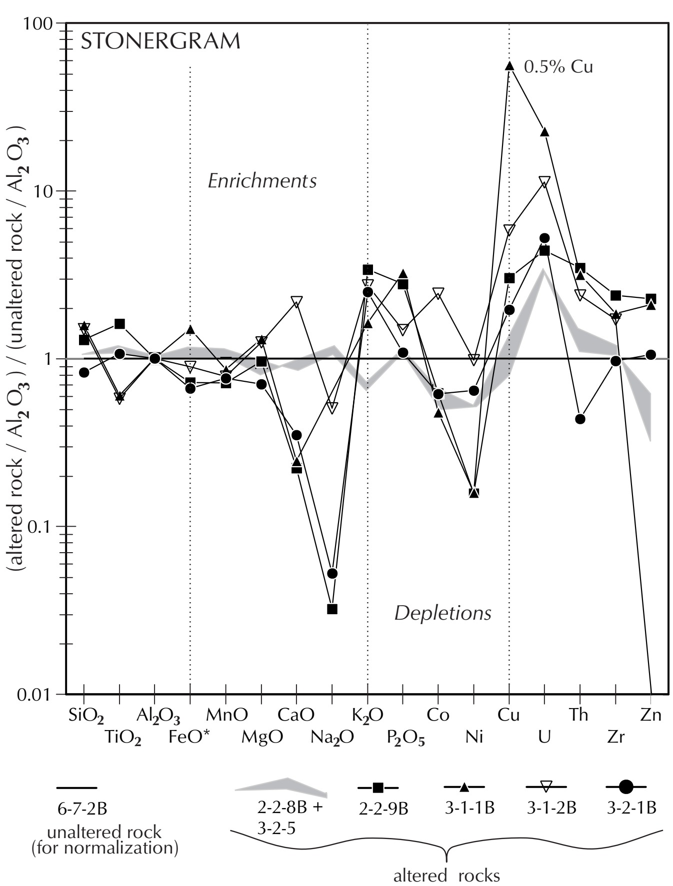

***Figure 5.** Stonergram indicating metasomatic alteration in six samples of the Bear River dyke, compared to a relatively unaltered sample, and normalized to alumina. See text for interpretation and methodology.*

resultant Stonergram displays the enrichment or depletion of each component on a logarithmic scale. If, for example, Na_2O for a metasomatized sample plots with a value of 10, then metasomatism has (at face value) enriched Na_2O in that sample to ten times its original composition. If the value of Na_2O for an altered rock lies at 0.25, then only one-quarter of the Na_2O remains, meaning that metasomatism has removed 75% of the original Na_2O. If Na_2O plots with a value of 1, then it has been neither enriched nor depleted. A major assumption in this analysis is that the composition of all samples was nearly identical prior to metasomatic alteration. Details and pitfalls of the method will be published elsewhere.

In the Stonergram (Fig. 5), the major oxides SiO_2, TiO_2, FeO*, MnO and MgO in all metasomatized samples show modest enrichments or depletions relative to 'unaltered' sample 6-7-2B (FeO* = total Fe as FeO). In most samples, SiO_2 is elevated, demonstrating a general trend toward silica metasomatism. The remaining oxides, CaO, Na_2O, K_2O and P_2O_5, and trace elements Co to Zn, display greater variability and indicate pronounced mobility. Overall, the least-altered compositions are those of samples 2-2-8 and 3-2-5, whose combined range of variability is represented by a shaded pattern. This pattern shows little enrichment or depletion in the major oxides and trace elements, except for U, which is elevated approximately four times above normal, and Zn, which is depleted. The remaining four metasomatized samples show greater chemical variability and have experienced significant losses or gains in CaO, losses of Na_2O, and gains of K_2O and P_2O_5. In addition, some of the samples show pronounced enrichments or depletions of trace elements, particularly in Ni, Cu, U, Th, and Zn. In two of the samples, significant depletions in Ni are paired with enrichments in Cu. The most Cu-enriched sample contains approximately 5000 ppm (0.5%) Cu as chalcopyrite and malachite (Table 3).

Altogether, the metasomatism may be broadly described as one of silica-potassium alteration, with concomitant losses in sodium and calcium, gains in uranium, thorium and phosphorous, and striking, localized enrichments of copper. Gold, silver, and a variety of other elements were not significantly enriched (Tables 1-3). The trend toward potassium enrichment is consistent with K-feldspar replacement of plagioclase, which is evident petrographically. The absence of consistently elevated FeO* concentrations is surprising, given the abundance of hematite mineralization in much of the study area. Nevertheless, the sample with the greatest Fe-enrichment also displays the greatest gains in Cu and U. The metasomatic effects on the Bear River dyke in the study area are similar to those in some zones of Wernecke Breccia, particularly the local enrichments of Cu and U. However, enrichments of Co, Au, Ag and Mo, which also occur locally in Wernecke Breccia, were not identified in the dyke.

REGIONAL SIGNIFICANCE

The preliminary U-Pb dates of ca. 1.27 Ga for the Bear River dykes indicates that the dykes are coeval and perhaps comagmatic with the 1.27 Ga Mackenzie igneous event (Francis, 1994; Baragar et al., 1996). This event includes the 1270+4 Ma Muskox layered intrusion, the 1267+2 Ma Mackenzie dyke swarm, and their extrusive equivalent, the Coppermine River continental tholeiitic basalts (LeCheminant and Heaman, 1989), located more than 1500 km to the east in the Canadian Shield. The Mackenzie dykes make up the world's largest continental dyke swarm (Ernst et al., 1995), radiating from western Victoria Island to the Arctic Coast through the Northwest Territories, southeastward into Nunavut, and southward for more than 2000 km into Ontario (Fig. 6). The western extent of the swarm is obscured beneath sedimentary cover, and may be evident only in localities such as the study area where the age of exposed strata exceeds 1.27 Ga.

Figure 6. *Principal features of the Mackenzie igneous event. Mackenzie dykes are shown as thick lines (after Fahrig, 1987; Hoffman, 1989). CR = Coppermine River basalts; M = Muskox intrusion; B = location of Bear River dykes. Shaded area indicates possible westward continuation of dyke swarm.*

The large volume of magma emplaced over a relatively short time period (a few million years), and the radiating nature of the Mackenzie dykes, lead LeCheminant and Heaman (1989) to propose a mantle plume origin for the magmas with a focus on Victoria Island. The predicted trend of Mackenzie dykes in the study area, based on radiation of dykes from this focus, would be approximately northeast. The lack of concordance between this expected trend and the orientation of the Bear River dykes (which strike mainly northwestward), may be explained by the location of the Bear River dykes in the Cordilleran orogen which developed after the Mackenzie event, mainly in Mesozoic and early Tertiary times. In and near the study area, post-Mackenzie tectonic events include contractional, extensional and strike-slip deformation (Green, 1972; Norris and Dyke, 1997; Thorkelson, 2000). These events may have caused crustal block rotations and reorientation of the Bear River dykes from trends originally concordant with the radiating Mackenzie pattern. Alternatively, crustal features and a local stress field may have controlled the orientation of the dykes during emplacement. Pehrsson et al. (1993) identified a Mackenzie dyke 1000 km from the proposed focal point that trends perpendicular to the main trend of the Mackenzie dyke swarm. They speculated that the similar-trending Great Slave Lake shear zone in the Slave craton may have controlled the orientation of the dyke, or that changes in the local stress regime at the time of emplacement affected the orientation of the intrusions.

If the Bear River dykes are indeed part of the Mackenzie dyke swarm, then the demonstrated radius of the dyke swarm would be increased by over 50 degrees, expanding the recognized arc of the swarm by 50% (Fig. 6). Correlation between the Bear River dykes and the Mackenzie dyke swarm will be further explored using geochemistry and additional geochronology.

CONCLUSIONS

The Bear River dyke in the study area has undergone extensive hydrothermal alteration at, or after, 1.27 Ga. The alteration may be generally characterized by enrichments in silica, potassium, phosphorous, copper, uranium, and thorium, and depletions of sodium, calcium, and nickel. Although iron enrichments are not ubiquitous, growth of hematite in veins and as disseminations is common. These characteristics are similar to those developed in the Wernecke Breccias at ca. 1.6 Ga, and appear to represent a secondary pulse of fluids with similar compositions. Skarn is well developed in parts of the dolostone host-rock flanking the dyke. The dolostone was altered to an assemblage of calcite-olivine-magnetite, and the olivine has since been retrograded to serpentine. The Bear River dykes may belong to the giant radiating Mackenzie dyke swarm. If so, they represent Mackenzie magmatism far to the west (>1500 km) from its currently identified western limit in the western Canadian Shield. Thus, the arc of the swarm may have been at least 50 degrees larger, and 50% greater, than previously thought.

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