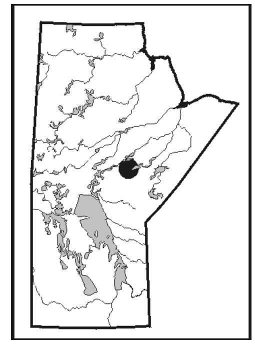
GS-25 GEOCHEMICAL CHARACTERISTICS AND PRELIMINARY U-PB ZIRCON AGE OF PROTEROZOIC MAFIC DYKES FROM THE EASTERN PART OF THE CARROT RIVER GREENSTONE BELT (PART OF NTS 63I/16)

by D.C. Peck and L.M. Heaman[1]



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SUMMARY

The eastern part of the Carrot River greenstone belt (CRGB) is intruded by <1 m to 200 m wide Proterozoic mafic or mafic-ultramafic dykes that are petrologically similar to intrusions that belong to the "Molson dyke swarm". However, recent chronological and paleomagnetic observations indicate that the "Molson dyke swarm" comprises at least 2 distinct magmatic episodes, viz. an older northeast-trending suite of dykes emplaced at ca. 2.09-2.07 Ga (Cauchon swarm) and a younger, ca. 1.88 Ga suite of dykes and the coeval 1.883 Ga Fox River Sill (Cuthbert swarm). In the CRGB, Proterozoic mafic-ultramafic dykes have compositions of diorite, leucogabbro, gabbro, pyroxenite and olivine pyroxenite and preserve primary igneous fabrics and low grade metamorphic mineral assemblages. The largest of the intrusions, the Wakehao Lake dyke, displays centimetre-scale to decametre-scale igneous layering and delicate, sedimentary-type structures. The geochemistry of the CRGB dykes suggests that they evolved from MORB- or continental-rift tholeiitic basalt parental magmas and in this way are analogous to other 2.1-1.8 Ga "Molson dykes".

A small amount of zircon and baddeleyite was recovered from a sample of pegmatitic gabbro collected from a layered gabbroic intrusion exposed on the southern shoreline of the Carrot River (Wakehao Lake dyke). A single U-Pb analysis of zircon shards indicates an emplacement age for this intrusion of ca. 1861 Ma. This age is slightly younger than any of the reported ages for the "Molson dyke swarm", but is similar to the 1864 +6/-4 Ma age (Hulbert et al., 1994) obtained for a coarse-grained mafic flow (sill ?) from the Winnipegosis Komatiite Belt that adjoins the southeastern margin of the Thompson Nickel Belt (TNB). The tectonomagmatic and metallogenic significance of these 1.86 Ga ages remains unclear at this early stage of our investigation.

INTRODUCTION

The eastern part of the Carrot River greenstone belt (CRGB) contains an <2.5 km thick, apparently homoclinal section of well-preserved Archean oceanic crust and is believed to be part of the Hayes River Group (e.g., Gilbert, 1985; Hubregtse, 1985) - the general name given to many of the volcanic terranes within the greenstone belts of the northwestern Superior Province in Manitoba (Fig. GS-25-1). Peck et al. (1997) reported on the geology, geochemistry and mineral potential of a composite komatiite-basalt + andesite-dacite succession, and associated mafic and ultramafic intrusions, in the eastern CRGB (Fig. GS-25-2).

This report focuses on the geology, petrology and geochemistry of Proterozoic mafic-ultramafic dykes from the CRGB. The dykes intrude both the Archean supracrustal units and the Archean (?) granitic plutons in the eastern CRGB. They contain lower grade metamorphic mineral assemblages (greenschist facies) than the Archean country rocks (amphibolite facies) and lack the penetrative S_1 foliation that is developed in the older rocks. Field and petrographic observations (Peck et al., 1997) indicate a general petrologic similarity between the CRGB dykes and the "Molson dyke swarm" (Scoates and Macek, 1978). The latter, as indicated by Scoates and Macek (1978), comprises predominantly north-northeast-striking, dioritic, gabbroic and peridotitic dykes that postdate all of the Archean deformation in the Superior Craton and are characterized by the excellent preservation of their igneous textures, mineral assemblages and tholeiitic to komatiitic geochemical compositions. However, recent geochronological (Heaman et al., 1986, Heaman and Corkery, 1996; Halls and Heaman, 1997) and paleomagnetic (Zhai et al., 1994) investigations of the "Molson dyke swarm" have demonstrated that the Proterozoic "Molson dykes" may differ in age by as much as 300 Ma. Zhai et al. (1994) discuss the problems associated with the "Molson dyke swarm" terminology. They recognize three stable magnetization components and two (Cuthbert and Cauchon dyke suites) distinctive "Molson dyke" ages (2170-2120 Ma = Cauchon swarm; 1883 Ma = Cuthbert swarm). As pointed out by Zhai et al. (1994), major element lithogeochemical data (Ermanovics and Fahrig, 1975; Scoates and Macek, 1978) have not been able to distinguish between the temporally distinct suites of "Molson dykes".

In this paper, we report new lithogeochemical data for selected dykes from the CRGB and the Cauchon Lake area, and examine a wider range of elements than has previously been utilized in studies of the "Molson dyke swarm". We also present a preliminary U-Pb zircon age obtained for the largest known Proterozoic mafic dyke in the eastern CRGB.

GENERAL GEOLOGY

The CRGB is a <2.5 km wide, 50 km long, east-northeast-trending volcanic belt in the Gods Lake Domain of the northwestern Superior Province (Fig. GS-25-1). Hubregtse (1985) mapped the CRGB and correlated the rocks with the Hayes River Group - a composite, predominantly basaltic volcanic sequence accounting for the older, volcanic portions of the exposed greenstone belts in the Knee-Gods-Oxford-Island lakes region (Hubregtse, 1985). Within the study area, the CRGB is <2.5 km wide and comprises abundant mafic to ultramafic volcanic and intrusive rocks and subordinate intermediate volcanic flows and pyroclastic rocks (Fig. GS-25-2). Minor fine-grained metasedimentary rocks, including oxide-facies banded iron formation, mafic mudstone and intermediate siltsone are locally developed. The CRGB is intruded by granite and granodiorite plutons to the south, and by tonalite, granodiorite and diorite to the north, all of which are correlated with the Bayly Lake Complex (Gilbert, 1985; Hubregtse, 1985).

The age of the CRGB and adjacent granitic rocks is unknown. An U-Pb zircon age of 2830 Ma was obtained for a felsic volcanic unit within the Hayes River Group at Knee Lake (Syme et al., 1993). During the current study, five samples were collected for U-Pb geochronology, including two samples of pegmatitic gabbro from a large, layered mafic dyke - the Wakehao Lake dyke, from the southern shoreline of Wakehao Lake (Fig. GS-25-2).

MAFIC DYKES IN THE EASTERN PART OF THE CARROT RIVER GREENSTONE BELT

Mafic dykes recognized in the Carrot River area include: (1) small, planar to irregular diabase dykes (<1 m) that display highly variable orientations and typically lack chilled margins; (2) medium-sized gabbroic dykes (>1 to <10 m) that strike north-northeast and east-northeast and have well-developed chilled margins but lack significant internal petrologic variation; and (3) large dykes (>10 to 200 m), that display abrupt planar contacts with Archean host rocks, have well-developed chilled margins, and are strongly differentiated and, commonly, display igneous modal layering. The two largest dykes observed in the study area have variable strikes of ca. 040° to 070° and have broadly tabular surface expressions. The largest of the two dykes (Wakehao Lake dyke, Fig. GS-25-2, 3) crops out on the south shore of Wakehao Lake and displays well-developed modal layering and sedimentary-type structures, including scour channels, size and modally-graded layering and truncated layers (akin to cross-bedding in clastic sedimentary rocks; see Fig. GS-25-3).

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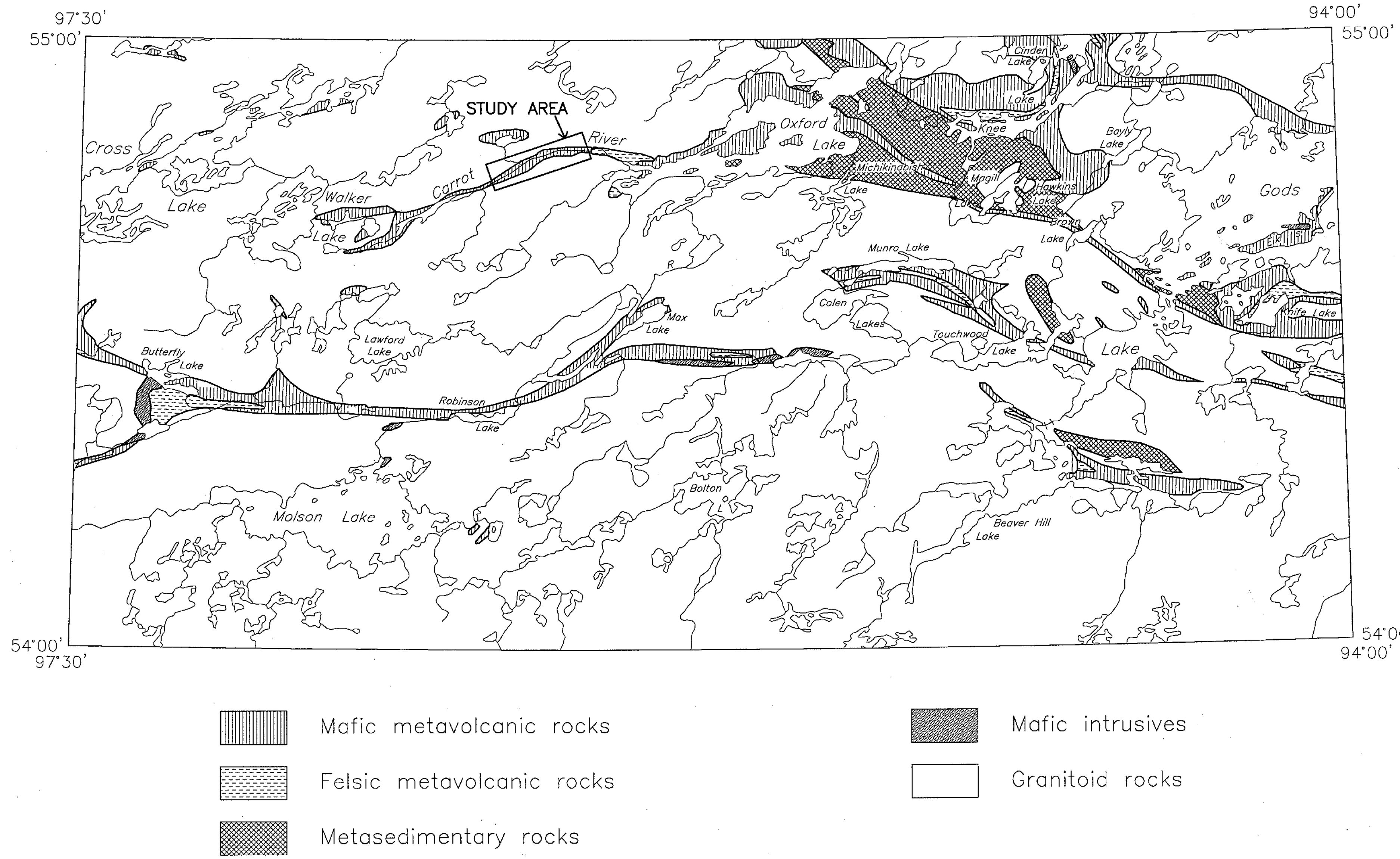

Figure GS-25-1: Location of the eastern part of the Carrot River greenstone belt in northeastern Manitoba.

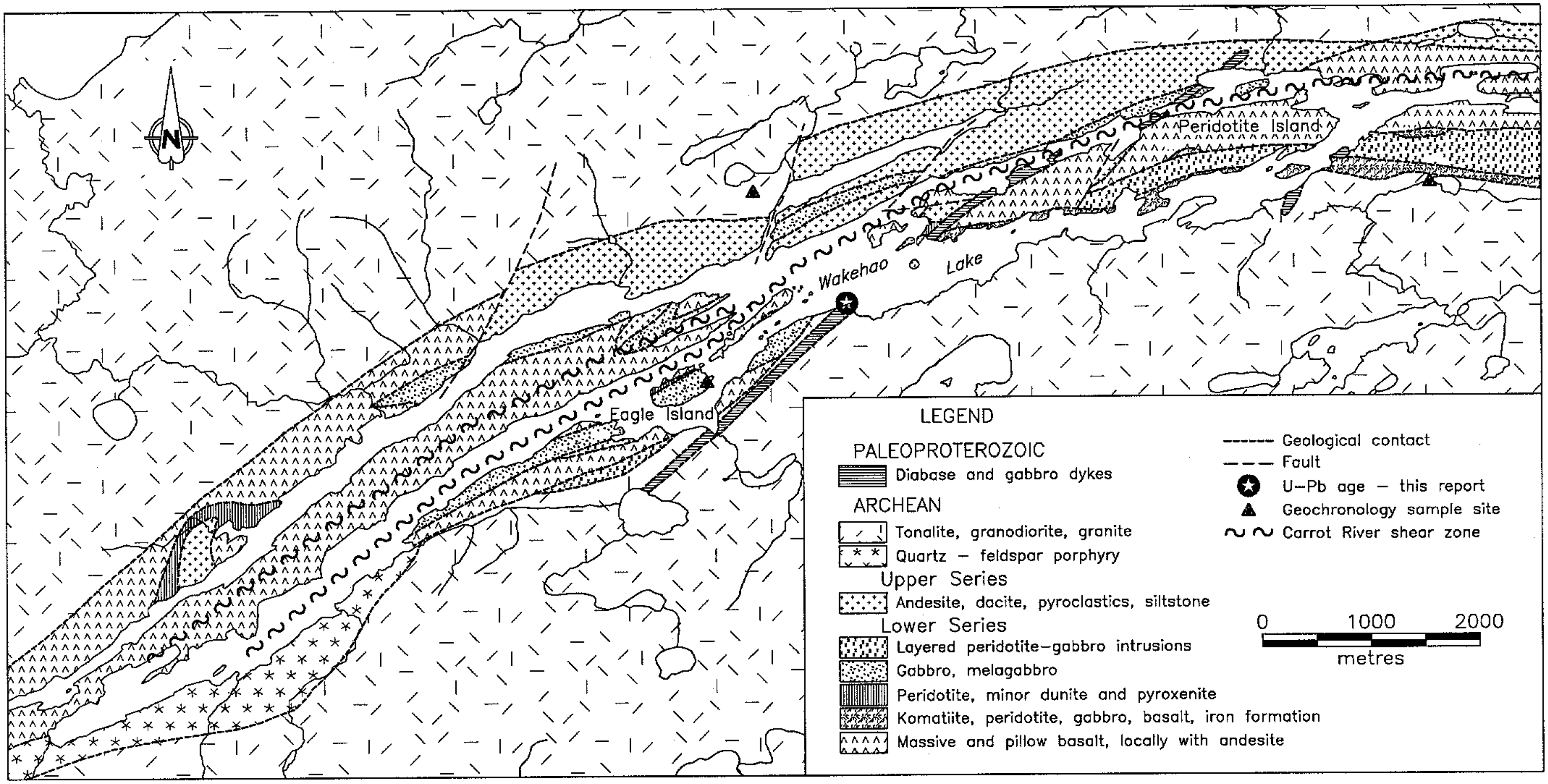

Figure GS-25-2: Geology of the eastern part of the Carrot River greenstone belt (Peck et al., 1997; Hubregtse, 1985) showing the location of some of the Proterozoic mafic dykes and the geochronology sample site within the Wakehao Lake dyke.

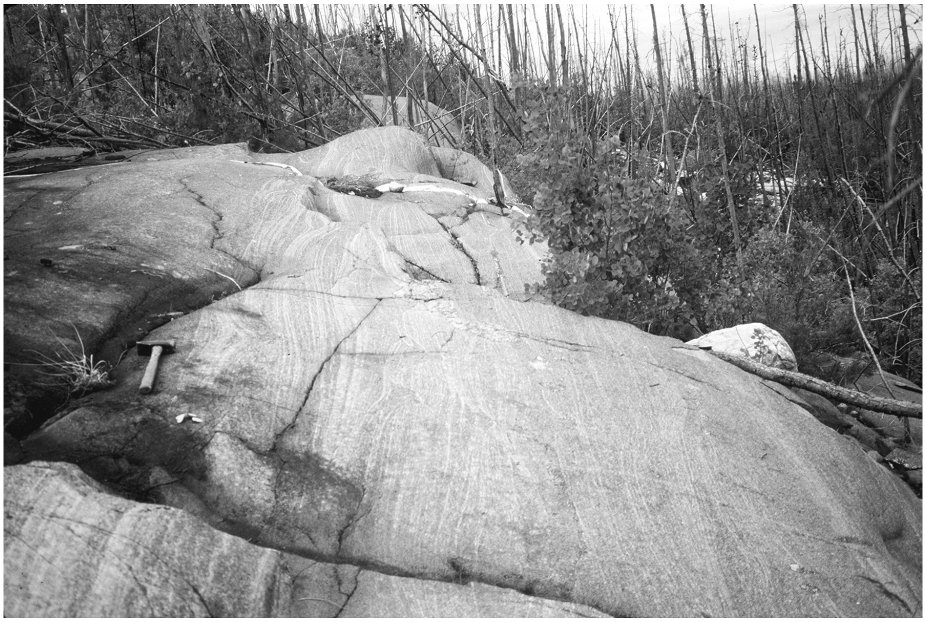

Figure GS-25-3: Fine-scale modal layering in the Wakehao Lake dyke. The modal layers are typically <5 cm thick and are gabbroic in composition.

PETROLOGY AND GEOCHEMISTRY OF MAFIC DYKES IN THE CARROT RIVER GREENSTONE BELT

A summary of the geology, petrology and geochemistry of the mafic dykes in the eastern part of the Carrot River greenstone belt is given in Table GS-25-1. The Wakehao Lake dyke comprises olivine gabbronorite, melagabbronorite, gabbronorite, leucogabbronorite, quartz gabbronorite and vari-textured gabbronorite and leucodiorite. The dyke intrudes granitic rocks that have been correlated with the Bayly Lake Complex (Gilbert, 1985; Hubregtse, 1985) and layering and sedimentary-type structures are best developed along its northern margin.

The Wakehao Lake dyke records the following paragenesis: olivine > opx > cpx > plag > magnetite > granophyre and/or quartz. Low grade metamorphism at greenschist facies resulted in variable replacement of primary pyroxenes by actinolitic amphibole, of plagioclase by saussurite and of olivine by serpentine. Another large mafic dyke seen within the eastern CRGB crops out on the southern shoreline of the the Carrot River directly opposite the east end of Peridotite Island (Fig. GS-25-2). This dyke is composed of olivine pyroxenite and olivine gabbronorite in which orthocumulate textures involving olivine, orthopyroxene, clinopyroxene and plagioclase, are preserved. Most of the small- and medium-size (e.g., <10 m wide) mafic dykes are massive, aphyric, fine grained to medium grained, sub-ophitic and have well-defined chilled margins. The small- and medium-sized dykes are typically northeast trending, although the medium-sized dykes commonly develop complex, vein-like apophyses with random orientations within the Archean host rocks. The large dykes have strikes of 030°-070° (on average, these are northeast striking).

Whole-rock geochemical analyses have been completed for 7 dykes from the Carrot River area (samples 98-97-212-2, 216-3, 219-2, 220-1, 228-1, 249-1, 323-12; Table GS-25-1). Major and minor element abundances were determined at Activation Laboratories (Ancaster, Ontario) using an ICP-OES procedure. Trace element analyses, including rare-earth elements (REE) and many of the high field strength elements (HFSE), were completed by the Geoscience Laboratories (Sudbury, Ontario) using a fusion - ICP-MS procedure. Details of the analytical methods and quality control data are available on request from the authors.

The geochemical data were derived from an ongoing study (Manitoba Energy and Mines) of the petrology and geochemistry of Proterozoic dykes ("Molson dyke swarm") from the Churchill-Superior Boundary Zone and the northwestern Superior Province. Here, preliminary geochemical results for dykes from the CRGB and the Cauchon Lake area (Pikwitonei Domain; see Peck et al., 1996) are compared. Relevant studies of mafic dyke geochemistry from the TNB and/or Superior Province include those of Ermanovics and Fahrig (1975), Scoates and Macek (1978), Peredery (1979) and Paktunc (1984).

The CRGB dyke samples, based on their calculated normative mineralogy (CIPW norms; D. Peck, unpublished data), are gabbronorites with either quartz or olivine present in the norm. Plots (Figs. GS-25-4, 5) based on whole-rock abundances are used to demonstrate the general geochemical characteristics of the CRGB dykes in comparison to dyke samples obtained from Cauchon Lake, Butterfly Lake (Cross Lake greenstone belt) and Cuthbert Lake. Referring to Figure GS-25-5, the CRGB dykes are relatively fractionated in comparison to many of the Cauchon Lake samples, in that they have higher incompatible element abundances and, with one exception (sample 98-249-1), lower Mg# and MgO contents. The bivariate plots suggest, in a qualitative manner, that the chemical variation observed in the CRGB dykes, if they are part of a cogenetic suite, are related to pyroxene + plagioclase + chromite fractionation. Preliminary analyses of the geochemical data for the CRGB dykes using molecular ratio diagrams also suggest pyroxene-plagioclase control. The CRGB data are consistent with an early period of orthopyroxene +/- clinopyroxene crystallization followed by plagioclase + orthopyroxene crystallization (D. Peck, unpublished data). The least magnesian CRGB dykes record relatively high S tenors (up to ca. 2000 ppm), likely in excess of the saturation level for these rock types and indicative of the presence of small amounts of sulphide. The low Cu and Ni tenor of these S-rich samples suggests that the sulphide component could be late- or post-magmatic. The CRGB dykes also record the strong Fe-Ti enrichment that is observed in the more evolved "Molson dykes" (e.g., Scoates and Macek, 1978) and is consistent with a protracted stage of plagioclase fractional crystallization in the case of the CRGB dykes (Figs. GS-25-4, 5).

Six of the seven mafic dykes sampled from the CRGB display relatively flat mantle-normalized rare-earth element (REE) and high field strength element (HFSE) abundances. Their REE abundances are very similar to those of mid-ocean ridge basalts (MORB). One of the dykes has pronounced negative Nb, Ta, Zr, Hf and Ti anomalies (Fig. GS-25-6) and a strongly fractionated Th to Yb profile that suggests an arc association. This sample may be from an older, Archean dyke related to the calc-alkaline volcanic sequence in the CRGB. The remaining CRGB dykes display variable enrichment in the light REE and incompatible trace elements (Th) relative to the heavy REE (Fig. GS-25-6). Coupled with the observed small, but distinct, negative Nb and Ta anomalies and absence of significant Zr, Ti and Hf anomalies, these trends suggest variable amounts of crustal contamination during emplacement of the CRGB dykes. Similar geochemical patterns are recognized from ancient and modern continental margin and ensialic rift regimes.

In review, preliminary lithogeochemical data for the CRGB Proterozoic mafic to ultramafic dykes suggests a continental rift tholeiitic basalt affinity. The most evolved dykes show strong Fe-enrichment, characteristic of tholeiitic magmas in which plagioclase fractional crystallization promotes enrichment of Fe and Ti in the liquids and a low

Table GS-25-1
Geochemistry of mafic dykes from the eastern part of the Carrot River greenstone belt, Manitoba

Part A. Major element oxide abundances (weight %). Fe2O3* = total iron expressed as ferric iron.

Sample #	Rock Type	Width (m)	Strike	Host Rock	SiO2	TiO_2	Al_2O_3	Fe_2O_3*	MnO	MgO	CaO	Na2O	K2O	P_2O_5	LOI	TOTAL	Mg#
98-97-212-1	Diabase	1	NNE	Gabbro	48.62	1.29	13.69	14.82	0.21	5.78	9.59	2.29	0.05	0.12	2.47	98.93	43.6
98-97-216-3	Gabbro	2	ENE	Gabbro	54.32	0.82	13.90	7.90	0.12	8.43	6.32	3.72	0.38	0.58	2.22	98.71	67.9
98-97-219-2	Diabase	10	NE	Gabbro	48.58	1.02	14.76	13.86	0.19	7.09	9.74	2.34	0.09	0.09	2.66	100.42	50.3
98-97-220-1	Gabbro	12	ENE	Gabbro	49.80	1.02	14.28	14.38	0.21	5.84	10.09	2.39	0.09	0.11	2.35	100.56	44.6
98-97-228-1	Pegmatitic Gabbro	200	NE	Granite	49.43	2.05	12.76	17.83	0.30	4.31	8.86	2.29	0.19	0.23	1.39	99.64	32.4
98-97-249-1	Olivine Gabbro	100	NE	Basalt	49.44	0.29	8.61	11.50	0.19	21.61	6.11	0.92	0.21	0.04	0.88	99.80	78.8
98-97-323-12	Plag-Phyric Gabbro	2	N	Basalt	49.54	0.66	12.33	13.19	0.20	10.61	10.88	1.87	0.22	0.09	1.21	100.80	61.4

Part B. Trace element abundances (ppm)

Sample #	Rock Type	S	Sc	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	Th	U
98-97-212-1	Diabase	1520	35.9	324	61	41.2	74.1	87.0	78.6	0.35	111	26.1	83	2.63	25.6	1.10	0.28
98-97-216-3	Gabbro	360	16.8	129	439	33.5	245	24.2	61.6	3.76	301	21.0	160	6.06	164	6.06	1.63
98-97-219-2	Diabase	1920	43.4	300	181	51.8	125	120	83.4	1.28	93.5	22.9	61	2.35	28.5	0.36	0.09
98-97-220-1	Gabbro	900	46.4	335	51	50.2	89.4	102	90.3	1.24	117	23.7	66	2.37	33.7	0.91	0.23
98-97-228-1	Pegmatitic Gabbro	nd	41.6	364	14	51.0	49.1	136	142.1	5.17	126	36.0	120	6.21	51.1	0.72	0.19
98-97-249-1	Olivine Gabbro	420	29.8	132	2500	82.0	600	61.9	56.3	4.69	59.8	7.2	32	0.93	65.4	0.59	0.15
98-97-323-12	Plag-Phyric Gabbro	nd	33.6	229	590	56.6	177	28.6	72.4	7.00	105	16.0	55	1.61	46.1	0.38	0.10

Part C. Rare-earth element abundances (ppm)

Sample #	Rock Type	La	Ce	Pr	Nd	Sm	Eu	Tb	Gd	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta
98-97-212-1	Diabase	6.57	14.7	2.00	9.17	2.70	0.89	0.56	3.14	4.38	0.97	2.79	0.43	2.51	0.41	2.16	0.19
98-97-216-3	Gabbro	31.50	70.9	8.98	37.59	8.37	1.91	0.85	6.74	4.11	0.73	1.79	0.25	1.57	0.24	3.91	0.38
98-97-219-2	Diabase	3.15	8.50	1.36	6.87	2.32	0.75	0.49	2.76	3.74	0.84	2.43	0.39	2.48	0.38	1.77	0.18
98-97-220-1	Gabbro	5.39	12.4	1.71	7.91	2.39	0.81	0.50	2.80	3.91	0.89	2.53	0.40	2.46	0.39	1.82	0.18
98-97-228-1	Pegmatitic Gabbro	6.83	18.1	2.83	14.37	4.44	1.46	0.89	5.13	6.56	1.40	3.83	0.57	3.65	0.55	3.35	0.46
98-97-249-1	Olivine Gabbro	3.11	6.55	0.81	3.42	0.84	0.29	0.18	0.93	1.18	0.27	0.76	0.13	0.82	0.12	0.71	0.09
98-97-323-12	Plag-Phyric Gabbro	2.68	6.61	0.97	4.70	1.57	0.50	0.34	1.87	2.60	0.57	1.59	0.25	1.51	0.23	1.30	0.11

nd = not determined

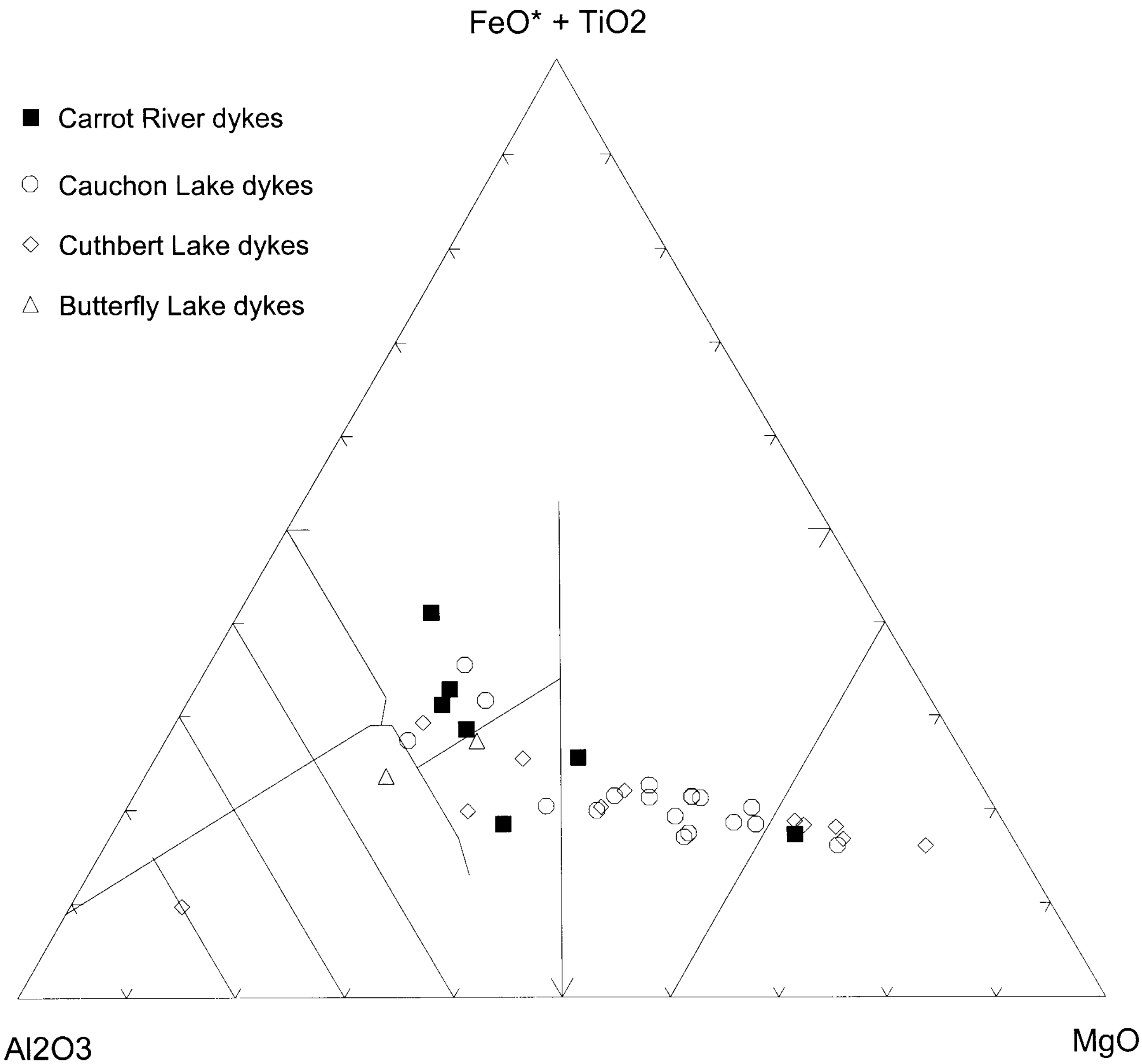

Figure GS-25-4: Jensen Cation Plot (Jensen, 1976) for mafic and ultramafic dykes from the eastern CRGB and "Molson" dykes from the Churchill-Superior Boundary Zone, the Pikwitonei Domain and the Cross Lake greenstone belt (unpublished data, D. Peck).

oxygen fugacity delays the onset of Fe-Ti oxide crystallization. Other "Molson dykes" from Cauchon and Cuthbert lakes display major and minor element compositions that are similar to the CRGB dykes. The Cauchon and Cuthbert dyke suites, recognized from paleomagnetic data (Zhai et al., 1994), are not distinguishable from major and minor element data. Additional REE and HFSE data are currently being gathered for these two suites and should provide a more robust means of comparing the geochemical evolution of these dykes.

PRELIMINARY U-PB ZIRCON AGE FOR THE WAKEHAO LAKE DYKE

A small amount of zircon and baddeleyite was recovered from a pegmatitic gabbro sample collected from northern side of the Wakehao Lake dyke, along the southern shoreline of Wakehao Lake (Fig. GS-25-2). The baddeleyite grains are minuscule (20 microns) and show incipient development of polycrystalline metamorphic zircon. The zircon fraction analysed in this study consists of irregular shards that are typical of primary magmatic zircon found in some mafic rocks (e.g., Bossart et al., 1986; Heaman and LeCheminant, 1993). Additional support for the primary nature of these zircon grains is the relatively high Th/U ratio (>1). The analysed fraction is slightly discordant (1.8%) and has a $^{207}Pb/^{206}Pb$ age of 1861±4 Ma that is interpreted as a minimum estimate for the time of dyke emplacement. Although the emplacement age could be slightly older than this 1861 Ma age, it is unlikely to be as old as the 1883 Ma mafic-ultramafic dykes at Cuthbert and Cross Lakes (Heaman et al., 1986) and indicates the "Molson dyke swarm" contains a suite of younger dykes.

DISCUSSION

The preliminary minimum age for emplacement of the Wakehao Lake dyke is similar to that obtained for a coarse-grained gabbroic unit (thick flow or sill) from the Winnipegosis Komatiite Belt in the Cedar Lake area, along the southeastern margin of the Thompson Nickel Belt (1864 +6/-4 Ma; Hulbert et al., 1994). Field observations (Scoates and Macek, 1978, Peck et al., GS-25, this volume) suggest that the larger mafic-ultramafic dykes in the TNB, like most of their counterparts in the Superior Province, occupy north-northeast-striking lineaments and preserve similar petrological characteristics. However, large differences exist in the degree of preservation of primary features in the Proterozoic dykes of the TNB and the "Molson" dykes of the northwestern Superior Province. A pervasive Proterozoic metamorphic overprint that caused

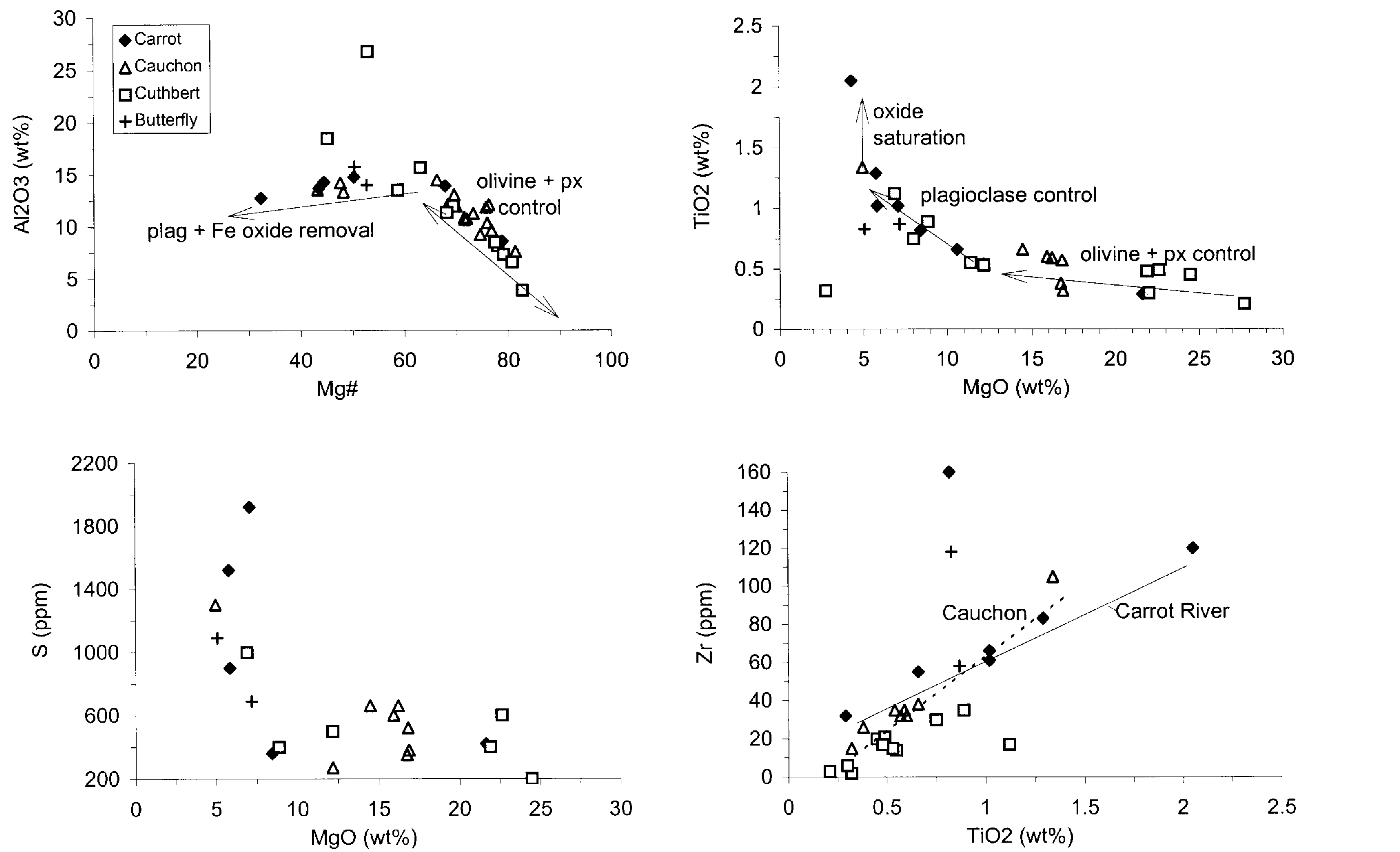

Figure GS-25-5: Bivariate plots based on whole-rock geochemical analyses of mafic and ultramafic dykes from the "Molson dyke swarm" in the northwestern Superior Province, Manitoba. See text for discussion.

retrograde metamorphism in much of the western Pikwitonei granulite domain during the ca. 1.8 Ga collisional orogeny (reflecting the amalgamation of the Trans-Hudson Orogen and the Superior Craton; e.g., Weber, 1990), also affected the north-northeast-striking "Molson dykes" within the Churchill-Superior Boundary Zone. This overprinting is best developed in the highly deformed and complexly recrystallized mafic-ultramafic dykes of the TNB. Some of the TNB dykes record granulite facies mineral assemblages and most of the dykes appear to predate the regionally important F_3 folding event (see Bleeker, 1990, Kraus et al., GS-14 and Peck et al., GS-12, this volume).

This line of investigation may be of importance to future exploration for Ni sulphide deposits in the TNB, the Churchill-Superior Boundary Zone and within the larger Proterozoic mafic-ultramafic dykes of the northwestern Superior Province. Based on existing data, it is probable that several episodes of continental rifting and consanguineous mafic-ultramafic magmatism occurred along the western marin of the Superior Province during the Paleoproterozoic. Petrological and preliminary geochemical data suggest that ultramafic rocks in the TNB, some of the "Molson dykes" in the Superior Province, and the Fox River sill, are coveal and crystallized at ca. 1.88 Ga (Cuthbert dyke swarm ?). This 1.88 Ga magmatism preceeded terminal collision along the Trans Hudson Orogen-Superior Province boundary. The Wakehao Lake dyke may belong to a younger rift-facies magmatic event, at ca. 1.86 Ga, that may have included the Winnipegosis Komatiite Belt. An older period of rift-facies mafic-ultramafic magmatism (Cauchon dyke swarm ?) of unknown duration and aerial extent occurred at ca. 2.07-2.09 Ga (Heaman and Corkery, 1996) and may extend to 2.2 Ga (Zhai et al., 1994). Additional geochronological and petrochemical studies of the "Molson dyke swarm" will be required to clarify the temporal and petrogenetic significance of Early to Mid Proterozoic rifting, magmatism and metallogeny within the northwestern Superior Province and the Churchill-Superior Boundary Zone.

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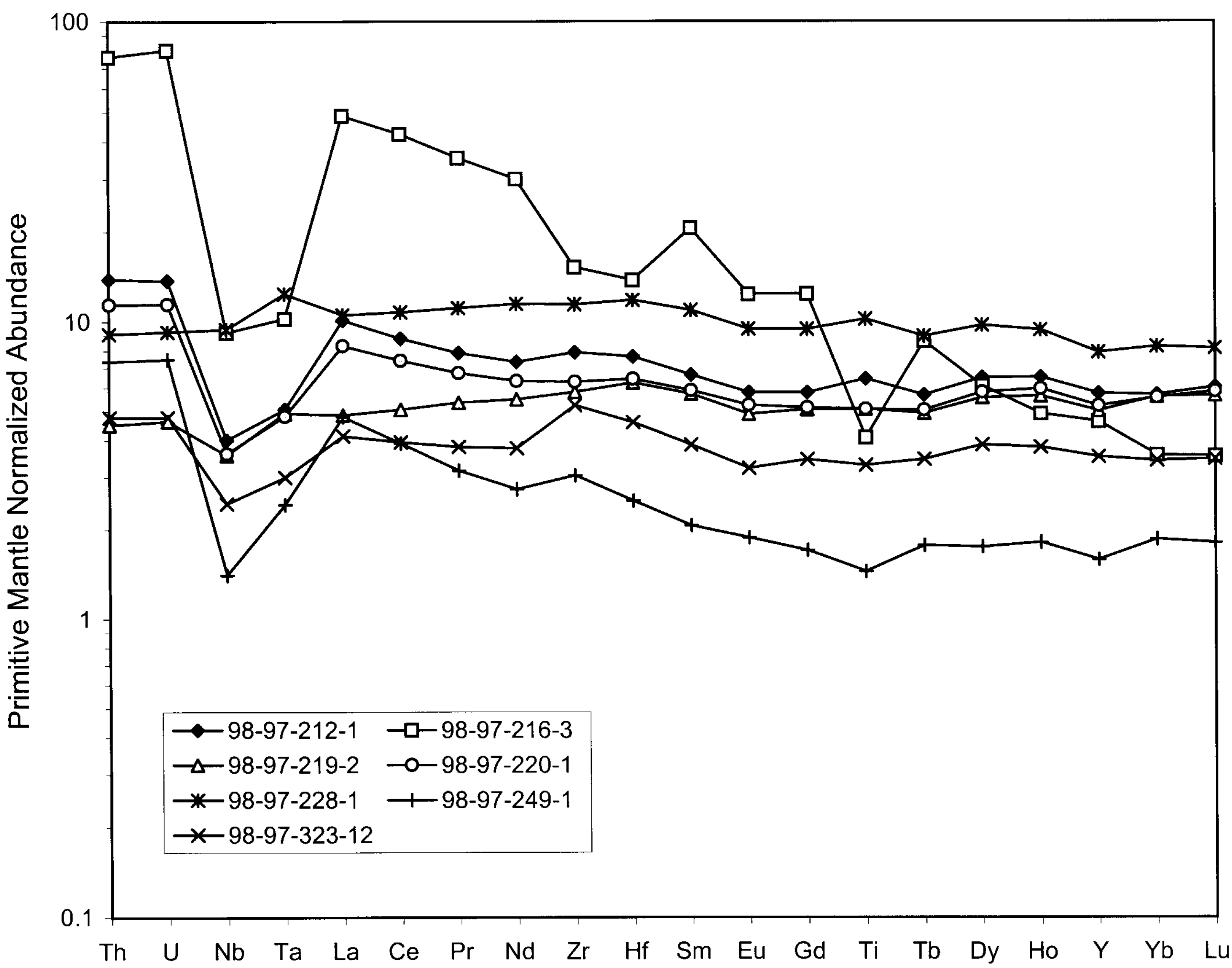

Fig.ure GS-25-6: Primitive mantle normalized spider diagram showing similarity in REE-HFSE relative abundances in the Carrot River dykes. Data are from Table GS-25-1. Mantle normalizing values are from McDonough and Sun (1995).

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