Kimberlites of Central Saskatchewan: Compilation and Significance of Indicator Mineral Geochemistry with Respect to Diamond Potential

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Abstract

Geochemical indicator mineral data from non-confidential mineral assessment files have been compiled for 33 kimberlites from central Saskatchewan (Figure 1). These include 22 kimberlites from the Fort à la Corne cluster, three each from the Snowden cluster and the Candle Lake kimberlites, two from the Foxford group, and one each from the Weirdale, Smeaton, and Sturgeon Lake kimberlites. The diamond potential for the kimberlites investigated was assessed via indicator mineral geochemistry data. The assessment was based on the principle that diamonds, and co-genetic indicator minerals, are disaggregated from peridotitic and eclogitic mantle xenoliths entrained by ascending kimberlitic magma.

Assessment of diamond potential was based on garnet, chromite, and ilmenite geochemistry. Garnet compositions, suggesting favourable diamond potential, were found in most of the kimberlites. Eight have significant concentrations of G10 harzburgitic garnets which indicate the kimberlitic magma might have sampled diamondiferous harzburgitic upper mantle. Abundant chromites, with compositions favourable for associated diamond, were in 11 of the kimberlites. These are interpreted to have formed in diamondiferous chromite harzburgite/dunite assemblages. Although in no way genetically linked to diamond-bearing mantle, megacrystic ilmenite compositions have been used to assess the oxygen fugacity of an ascending kimberlitic magma, which affects diamond preservation. The majority of the kimberlites studied have good to very good diamond preservation potential, while four have a poor rating and might have been subjected to diamond resorption.

Based on indicator mineral compositions, not all the central Saskatchewan kimberlites appear equally prospective. It is apparent that some have potential for diamonds based on favourable indicator mineral chemistries, including G10 garnets, diamond-inclusion composition chromites, and ilmenites that indicate high diamond-preservation potential.

This study is a good framework for more detailed examination of kimberlites in central Saskatchewan. Further work will include defining stratigraphic and geographic trends based on indicator mineral data, and relating them to kimberlite architecture and diamond grade.

1. Introduction

One of the world's largest kimberlite fields is located 60 km east-northeast of Prince Albert and north of the Saskatchewan River (Figure 1). Diamonds were first reported in Saskatchewan in 1948, but the current level of exploration did not begin until 1988, initiated by the discovery of a glacially rafted kimberlite block near Sturgeon Lake, 30 km northwest of Prince Albert (Gent, 1992). Shortly thereafter, Uranerz Mining and Exploration examined several regional government aeromagnetic surveys and delineated numerous circular magnetic anomalies in the Fort à la Corne forest. Ground magnetic surveys were followed by drill testing in July 1989, verifying the first (in place) kimberlite body. Since then, approximately 71 kimberlite bodies have been identified, however, recent work has revealed that some are actually composite in character. The main kimberlite trend, the Fort à la Corne cluster, is in a north-northwest-trending linear zone approximately 50 km long and 15 km wide (Figure 1). Several satellite clusters, also elongate north-northwest, surround the main cluster. These include the large Snowden cluster to the northeast, the Foxford kimberlites to the northwest, the Weirdale kimberlites to the west, and the Candle Lake kimberlites to the north.

In central Saskatchewan, the Phanerozoic succession, which is in excess of 700 m thick, unconformably overlies Archean and Paleoproterozoic basement. The Archean rocks of the Sask Craton were overthrust by the Paleoproterozoic Glennie–Flin Flon micro-continent during Trans-Hudsonian orogenesis

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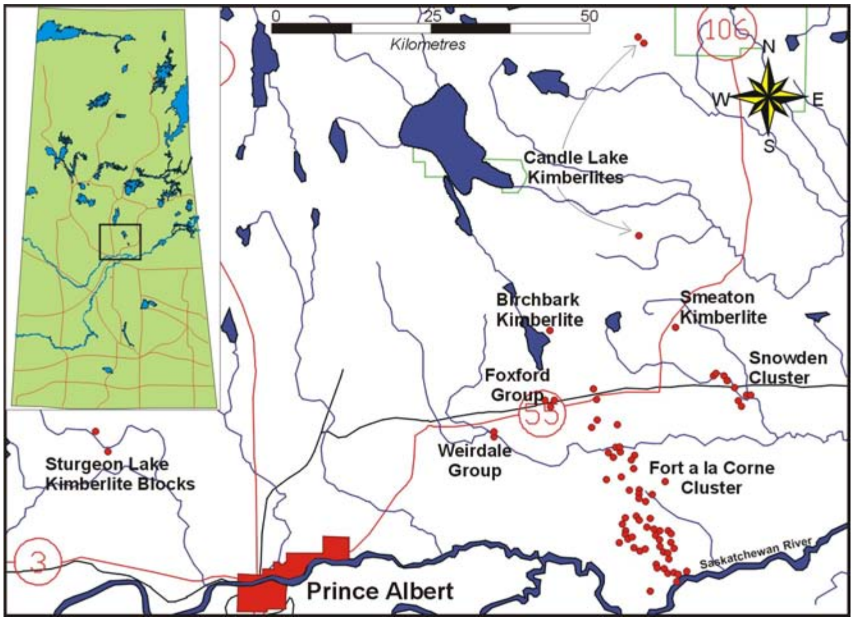


Figure 1 - Location map of central Saskatchewan kimberlites.

(Chiarenzelli, 1989; Lewry and Collerson, 1990). The basal part of the Phanerozoic comprises 400 m of Paleozoic mixed clastic and carbonate rocks (Leckie *et al.*, 1997). These are overlain by about 200 m of Lower Cretaceous Mannville and Colorado Group sedimentary rocks that host the kimberlites (Figure 2). Age dating and stratigraphic relationships indicate that the kimberlites range in age from approximately 105 to 93 Ma (Leckie *et al.*, 1997; Kjarsgaard, pers. comm., 2001). The kimberlites are reworked by a Middle to Upper Albian marine transgression associated with deposition of Colorado Group shales. The Cretaceous sedimentary rocks and/or the kimberlites were partially eroded during glaciation which deposited 70 to 120 m of glacial and glaciolacustrine sediments.

Based on mineralogy, the kimberlites are classified as group I bodies, characterized by two generations of olivine in a groundmass of monticellite, spinel, perovskite, serpentine, and carbonate (Lehnert-Thiel *et al.*, 1992; Scott-Smith *et al.*, 1994; Jellicoe *et al.*, 1998). Most of the kimberlites contain mantle derived (peridotitic and eclogitic) xenoliths and xenocrysts (e.g. garnet, chromite), along with xenoliths of Precambrian basement and Phanerozoic rocks. They are different from most kimberlites worldwide in that they are dominantly comprised of ‘crater facies’ volcaniclastic rocks (Lehnert-Thiel *et al.*, 1992; Scott-Smith *et al.*, 1994), which consist of pyroclastic lapilli- and olivine-dominated rocks, local debris flows, and reworked volcaniclastic kimberlite (Kjarsgaard *et al.*, 1995, this volume; Leckie *et al.*, 1997; Jellicoe *et al.*, 1998). Hypabyssal facies rocks, which dominate most kimberlite fields, have recently been identified on the Star Kimberlite in the Fort à la Corne cluster (Figure 3; Shore Gold Inc. press release, Jan. 2001). Modeling of the Saskatchewan kimberlite bodies has resulted in variable geometric descriptions including pancake or sheet-like (Lehnert-Thiel *et al*., 1992), saucer or champagne-shaped (Scott-Smith *et al.*, 1994), truncated cones (Leckie *et al.*, 1997), and stacked disks (Jellicoe *et al.*, 1998). Despite the modeling terms used to describe these bodies they can be immense in size ranging up to 2 km in diameter and 700 million tonnes in mass. The total mass of the central Saskatchewan kimberlites exceeds nine billion tonnes (Jellicoe *et al*., 1998).

Analytical geochemical data for indicator minerals (garnet, chrome spinel, and ilmenite) from 33 kimberlites have been compiled and interpreted (Figure 3; Table 1). The bulk (22 of 33) of the mineral chemistry data are from kimberlites in the main Fort à la Corne field; the others are from the outlying clusters (see Figures 1 and 3). The quality of the compiled data is highly variable and caution must be exercised when interpreting it: sampling procedure, mineral selection and analytical methodology varied between companies; sample weights and the number of drill holes utilized per kimberlite differed, resulting in a highly variable number of indicator grains analysed per kimberlite; and many of the kimberlite bodies are very large and composite, thus data from one drill hole may not be representative.

Previous published studies on indicator mineral data from Saskatchewan kimberlites are limited to brief descriptions (e.g. Lehnert-Thiel *et al.*, 1992; Kjarsgaard, 1995; Jellicoe *et al.*, 1998) and limited plots in Schulze (1993), Fipke *et al.* (1995), and Leahy (1996). Based on this previous work, the kimberlites in central Saskatchewan contain both peridotite-type (P-type) and eclogite-type (E-type) garnets, with some of the pipes containing sub-populations of garnets, and other indicator minerals, that are commonly associated with diamonds. Within the Saskatchewan Energy and Mines assessment files there is a vast quantity of indicator mineral geochemistry and this report presents a compilation of these public-domain data.

2. Diamond Paragenesis

Extensive research studies have revealed that 99 percent of diamond inclusions, which are deemed to be co-genetic with diamond, consist of sulphides, olivine, orthopyroxene, garnet, chromite, clinopyroxene or kyanite (Gurney, 1984). Most importantly, some of these xenocrysts have identifiable geochemical signatures that allow interpretation of diamond genesis (Gurney and Zweistra, 1995). Overall the assessment of geochemical information relies on the recognition of those minerals that are co-genetic with diamond and

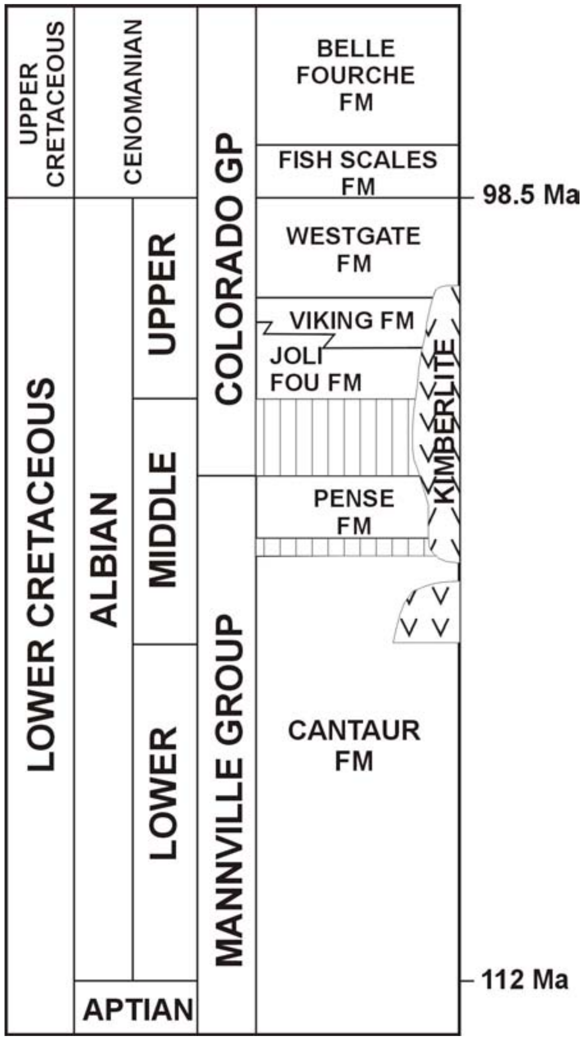


Figure 2 - Stratigraphic position of the central Saskatchewan kimberlites. Vertical hatched pattern represents no time-rock record (modified from Kjarsgaard, 1995).

comparing their mineral geochemistry with those of diamond inclusions (ibid.).

One of the fundamental discoveries of diamond genesis research is that diamond is unrelated to its kimberlitic host rock (e.g. Dawson, 1980). Diamond inclusion studies reveal that there are two major diamond types: peridotitic (P-type) and eclogitic (E-type). As a kimberlitic magma ascends through the mantle, diamondiferous eclogite and peridotite may be sampled and incorporated as xenoliths. As the magma continues to rise, the mantle xenoliths become disaggregated to form discrete mineral crystals (xenocrysts), including diamond itself (Gurney, 1984). Worldwide, both eclogitic and peridotitic diamonds occur in every known diamond deposit (Fipke *et al.*, 1995), although peridotitic diamonds appear to be more abundant than eclogitic ones.

Peridotitic diamonds are found in three major sub-groups: garnet harzburgite, chromite harzburgite, and rarely garnet lherzolite (Meyer, 1987). Compositionally, the upper mantle is predominantly lherzolitic (~60% olivine, 20% orthopyroxene, and 20% clinopyroxene) and Ca-bearing; harzburgites, which are generally void of clinopyroxene and low in calcium, are less abundant (Gurney, 1984). However, the relative potential for a peridotite to host diamonds is deemed to be garnet harzburgite>chromite harzburgite>>garnet lherzolite, although the latter has yet to be established as a major diamond inclusion suite (ibid.). On the other hand, eclogitic diamonds are derived from eclogitic assemblages consisting of garnet and clinopyroxene (Fipke *et al.*, 1995).

According to Gurney (1984), minerals from both eclogitic and peridotitic suites have never been found together in one diamond crystal, indicating they represent separate processes. This is supported by carbon isotope analyses on diamond itself (Kirkley *et al.*, 1991). Eclogitic diamond $\delta^{13}C$ values range from -34 to +5 per mil, while peridotitic diamond $\delta^{13}C$ values are restricted to values between -2 and -9 per mil. The theory behind this difference is that peridotitic diamonds formed in a homogenized convecting asthenosphere, while eclogitic diamonds have carbon sources possibly derived from recycled (subducted) crustal sources causing the wide spread in $\delta^{13}C$ values (Helmstaedt and Gurney, 1984; Kirkley *et al.*, 1991). Dating of inclusions, deemed to be co-genetic with diamond, has revealed that diamonds themselves are typically much older than the kimberlitic host rocks. Further evidence of distinct diamond sources is the fact that peridotitic diamonds are older than 3 Ga (Kirkley, 1998), while eclogitic diamonds formed between 0.99 and 2.7 Ga (Fipke *et al.*, 1995).

3. Indicator Mineral Chemistry

Indicator mineral analysis is widely utilized in exploration for, and the evaluation of, diamondiferous kimberlite (Gurney, 1984; Sobolev, 1984; Gurney and Moore, 1991; Gurney *et al.*, 1993; Fipke *et al.*, 1995). The essential premise is that during kimberlite ascent, along with diamond, other minerals are disaggregated from upper mantle peridotitic and eclogitic sources, and most importantly indicator minerals are much more common (thousands of times) and therefore easier to find than diamond.

Based on inclusion studies, the most useful indicator minerals for assessing diamond-potential are garnet and chromite (Gurney, 1984). Diamond indicator minerals allow the distinction between peridotitic and eclogitic suites (ibid.), with chromite usually only found in the peridotitic suite, while garnet is found in both suites. Compositionally, peridotitic (P-type) garnets have distinctive CaO, Cr_2O_3, and MgO compositions, while eclogitic (E-type) garnets are further sub-divided on the basis of distinct Na_2O and TiO_2 content (Sobolev and Lavrent'yev, 1971; McCandless and Gurney, 1989).

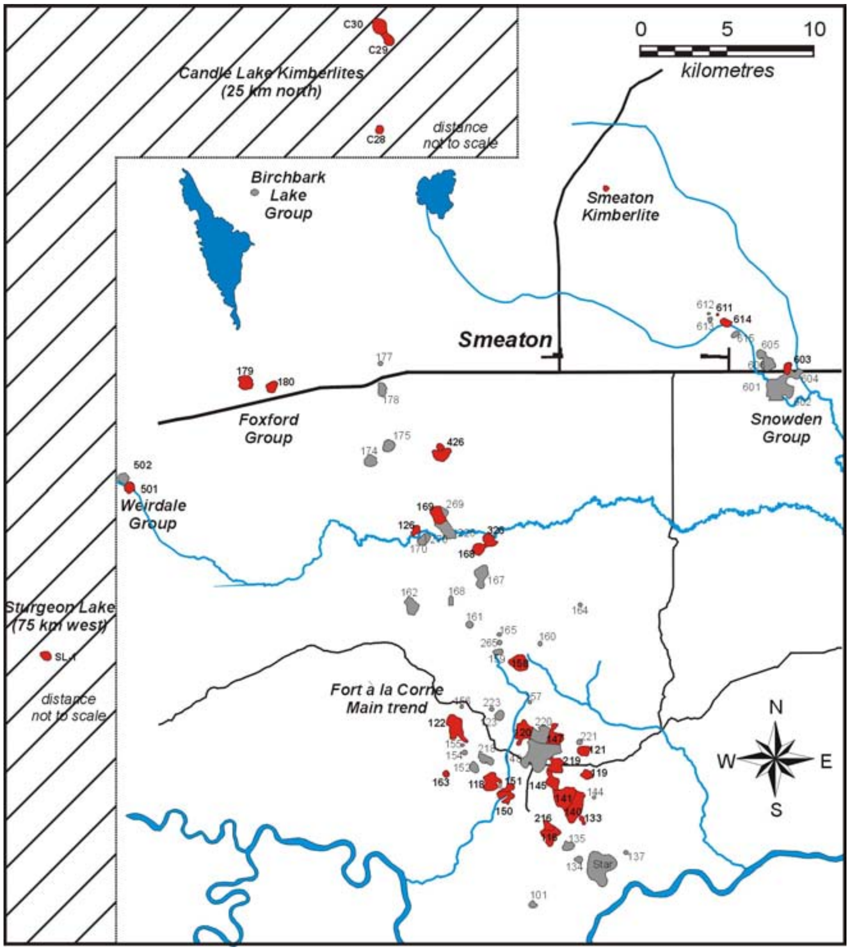


Figure 3 - Map of central Saskatchewan kimberlites investigated in this study (red) (modified from *Jellicoe et al.*, ***1998). (Note: Sturgeon Lake and Candle Lake areas are projected into the location map and distances are not to scale).***

a) Garnet

Peridotitic garnets contain more than 2 wt% Cr_2O_3; in contrast eclogitic garnets contain less than 2 wt% Cr_2O_3 (Figure 4) (Gurney, 1984; Gurney and Moore, 1993). As kimberlites commonly contain large numbers of crustal garnet xenocrysts and kimberlite-derived garnet megacrysts (Gurney, 1984; Schulze and McCandless, 2000), which although not genetically related to diamond, must be identified. On a CaO-Cr_2O_3 plot, megacryst garnets overlap with P-type, E-type and crustal garnets (Figure 4) in the range 0 to 4 wt% Cr_2O_3 and 3.75 to 6.0 wt% CaO (Schulze and McCandless, 2000). Crustal garnets are distinguished by low CaO and low Cr_2O_3 content, which overlaps with that of megacrystic and eclogitic garnets.

P-type Garnets

On the basis of calcium content, three subgroups of P-type garnets are recognized (Figure 4): low Ca-garnets from harzburgite/dunite assemblages (olivine+garnet± opx±chromite); intermediate Ca-content garnets from lherzolitic assemblages (olivine+opx+cpx+garnet± chromite); and Ca-rich garnets from wehrlite assemblages (olivine+cpx+garnet±chromite). On Figure 4, a narrow central band (lherzolite field), separates the wehrlite field at higher CaO, from the harzburgite/dunite field at lower CaO. The harzburgite field is bounded by a minimum Cr_2O_3 concentration of 5 wt%. This boundary was defined by Sobolev (1974) to distinguish sub-calcic garnets formed in the diamond stability field (high Cr) from sub-calcic garnets formed in the graphite stability field (low Cr).

The presence of garnets as diamond inclusions reveals that the vast majority of diamond-hosted garnets are too low in calcium content to be in equilibrium with clinopyroxene and therefore belong to the harzburgite or dunite assemblage (Gurney, 1984; Schulze and McCandless, 2000). Based on this observation and the statistical analysis of thousands of samples, Gurney (1984) plotted a line, sub-parallel to the lherzolite trend that separated 85 percent of the diamondiferous harzburgitic garnets from the lherzolite field. Those that fall into the calcium-depleted, diamondiferous harzburgite field are termed G10 garnets, while the calcium-enriched lherzolitic garnets, are termed G9. These designations are similar, although not strictly identical, to Dawson and Stephens (1975) statistical classification of garnets.

E-type Garnets

Most diamond mines worldwide produce predominantly P-type (i.e. peridotitic) diamonds. However, diamonds in the Orapa kimberlite (Botswana) and the Sloan kimberlite (Colorado) are dominated by eclogite paragenesis stones (Otter and Gurney, 1989; Schulze, 1993). Garnet inclusions in eclogitic diamonds have characteristic Na-enrichment compositions and elevated titanium (Figure 5) (>0.07 wt% Na_2O) (Danchin and Wyatt, 1979; Gurney, 1984). These garnets from diamondiferous eclogites are known as group I garnet eclogites, while group II eclogites are barren in diamond and low in sodium. Greater proportions of group I eclogitic garnet xenocrysts and sodium enrichment are taken as indicators of the likelihood that a kimberlite sampled diamondiferous eclogitic mantle.

Table 1 - Summary of heavy mineral sample compositions and counts from the central Saskatchewan kimberlites investigated.

Kimberlite	Total Garnet	Cr-Garnet (>2 wt%)	% Cr-Garnet (>2 wt%)	"G10" Garnets	% "G10" Garnets**	Sub-Cr Garnet (<2 wt%)	% Sub-Cr garnet (<2 wt%)	Total Chromite	DI	% DI	Total Ilmenite	DPP	Assessment File
	n=	n=		n=		n=		n=			n=		
116	34	31	91	2	5.9	3	9	105	0	Nil	23	poor	73H07-SW-0023
118	53	22	42	0	Nil	31	58	9	0	Nil	14	v good	73H-0003
119	400	338	85	0	Nil	62	16	200	1	0.5	187	good	73H07-SW-0023
120	392	191	49	12	3.1	201	51	46	2	4.3	118	v good	73H-0002; 73H-0003
121	46	18	39	3	6.5	28	61	13	3	23.1	12	poor	73H-0003
122	500	433	87	11	2.2	67	13	270	1	0.4	299	good	73H07-SW-0019; 73H07-SW-0023
126	399	355	89	8	2.0	44	11	200	15	7.5	198	good	73H07-SW-0023
133	598	547	91	12	2.0	51	9	300	2	0.7	300	good	73H07-SW-0023
140	700	676	97	40	5.7	24	3	395	4	1.0	399	good	73H07-SW-0021; 73H07-SW-0023
141	100	89	89	5	5.0	11	11	103	3	2.9	100	good	73H07-SW-0021
145	100	77	77	2	2.0	23	23	105	0	Nil	99	good	73H07-SW-0021
147	200	157	79	3	1.5	43	22	100	3	3.0	100	good	73H07-SW-0023
150	247	217	88	4	1.6	30	12	215	1	0.5	212	good	73H-0003; 73H07-SW-0019; -0021
151	48	17	35	0	Nil	31	65	9	0	Nil	13	good	73H-0003
158	42	14	33	1	2.4	28	67	14	0	Nil	15	good	73H-0003
163	203	186	92	8	3.9	17	8	187	0	Nil	126	good	73H07-SW-0023
168	99	86	87	0	Nil	13	13	91	1	1.1	103	good	73H07-SW-0021
169	294	134	46	25	8.5	160	54	78	0	Nil	97	good	73H-0002; 73H-0003
216	99	71	72	1	1.0	28	28	66	2	3.0	27	v good	73H-0002; 73H-0003
219	66	38	58	4	6.1	28	42	5	0	Nil	21	v good	73H-0003
326	19	13	68	0	Nil	6	32	115	0	Nil	97	poor	73H07-SW-0021
426	192	115	60	1	0.5	77	40	110	0	Nil	72	v good	73H-0002; 73H-0003
Candle Lk C28	652	588	90	65	10.0	64	10	123	6	4.9	323	good	73H10-NW-0001
Candle Lk C29	176	156	89	22	12.5	20	11	59	2	3.4	10	good	73H10-NW-0001
Candle Lk C30	518	438	85	27	5.2	80	15	201	9	4.5	55	good	73H10-NW-0001
Foxford 179	101	67	66	2	2.0	34	34	106	0	Nil	122	good	73H06-NE-0008
Foxford 180	180	159	88	0	Nil	21	12	30	1	3.3	15	good	73H-0002
Smeaton RS-1	29	19	66	0	Nil	10	34	44	0	Nil	ND		73H10-SW-0001
Snowden 603	47	44	94	0	Nil	3	6	117	0	Nil	101	poor	73H07-NE-0020
Snowden 614	28	28	100	0	Nil	0	0	130	0	Nil	96	v good	73H07-NE-0020
Snowden 611	63	32	51	2	3.2	31	49	17	0	Nil	20	v good	73H-0003
Sturgeon SL-1	89	53	60	0	Nil	36	40	3	0	Nil	45	good	73G08-NE-0005
Wierdale 501	4	3	75	0	Nil	1	25	123	0	Nil	85	v good	73H06-NE-0009
**	% G10 = # G10/Total Garnets												
DI	chromites that plot in the diamond inclusion field												
DPP	Diamond Preservation Potential: based on comparison with Fipke *et al.* (1995) analyses												

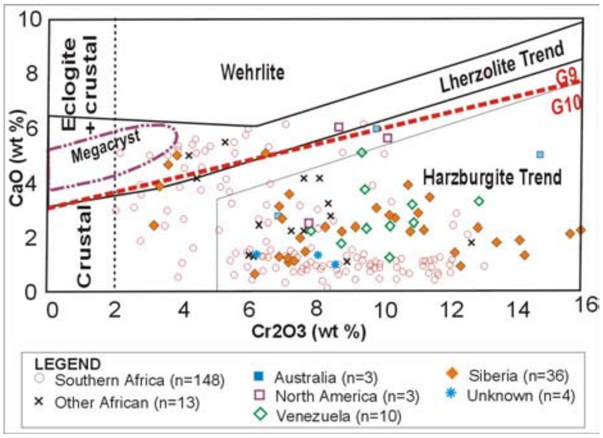


Figure 4 - CaO-Cr_2O_3 plot of peridotitic garnets found as diamond inclusions from worldwide kimberlite localities (P-type garnets >2 wt% Cr_2O_3) (Peridotite fields from Sobolev** et al.**, 1973; G10/G9 line from Gurney, 1984; Megacryst field from Schulze, 1993).

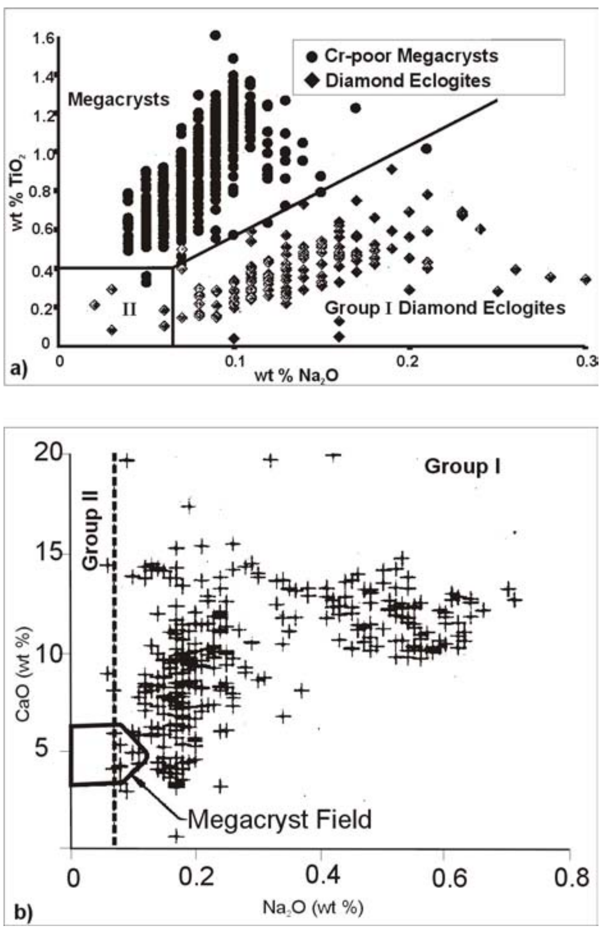


Figure 5 - a) TiO_2-Na_2O plots for Cr-poor garnets (<2 wt% Cr_2O_3) found as inclusions in eclogitic diamonds (from Schulze, 1997). b) CaO-Na_2O plot for Cr-poor garnets (<2 wt% Cr_2O_3) from diamond inclusions (from Fipke** et al.**, 1995).

Low-Cr garnets (defined as <2 wt% Cr_2O_3) are not always of eclogitic parentage. They can also be megacrystic or crustal in origin (Gurney, 1984). Eclogitic and crustal garnets typically have a wide range in calcium contents with very low levels of chromium (usually <0.05 wt% Cr_2O_3) (Schulze, 1993). Eclogitic garnets generally contain between 3.5 and 20 wt% CaO, while crustal garnets contain less than 3.5 wt% CaO, making their differentiation on a CaO-Cr_2O_3 diagram relatively straightforward (Figure 4). As a plot of CaO-Cr_2O_3 does not discriminate between garnets of megacrystic origin from those of eclogitic origin, different oxides must be used to differentiate the true group I (i.e. diamond bearing) and group II eclogites. Megacrystic garnets have higher TiO_2 than group II, and lower Na_2O relative to group I eclogites (Figure 5a) (Gurney, 1984). They are characterized by a calcium content (Figure 5b) between approximately 3 and 6 wt% CaO (Fipke et al., 1995).

b) Chromite

Chromite xenocrysts, like garnet xenocrysts, are deemed to have formed co-genetically with diamond as evidenced by chromite inclusions in diamond (Gurney, 1984). Unlike garnet, chromite is believed to be solely peridotitic in paragenesis and chromite harzburgite/dunite assemblages are also considered to be an important mantle diamond source. High-Cr chromites with moderate to high MgO contents, similar to that of chromite compositions found as diamond inclusions and diamond intergrowths, are considered to be indicators of potential for diamond derived from chromite harzburgite (Fipke *et al.*, 1995; Schulze and McCandless, 2000). Ninety-eight percent of known harzburgitic chromite inclusions in diamond fall within a rather restricted field on Cr_2O_3-MgO plots (Figure 6), with the chromites having an average chrome content between 60 and 70 wt% Cr_2O_3 and an average MgO

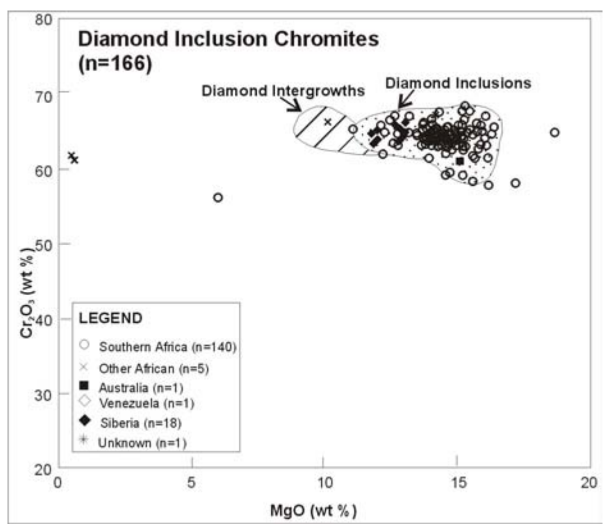


Figure 6 - Cr_2O_3-MgO plot of worldwide chromite diamond inclusions. More than 98% of the data fall into the diamond inclusion and diamond intergrowth field (from Fipke** et al.**, 1995).

concentration between 8 and 16 wt% (Fipke *et al.*, 1995). This is accompanied by low TiO_2 contents (<0.7 wt%) (Schulze and McCandless, 2000).

c) Ilmenite

Kimberlites that sample potentially diamond-bearing mantle may not always be high in diamond content. Kimberlite is simply a conveyor of diamond and diamond grade depends upon the amount of diamond-bearing material sampled and the degree of diamond resorption during ascent and emplacement (Gurney, 1984). The preservation of the diamonds during kimberlite ascent to the surface is a critical factor in diamond grade (Gurney *et al.*, 1993), and the rate at which the diamonds are resorbed is highly dependant on oxygen fugacity: if the kimberlitic magma is too oxidizing, diamond may be converted to graphite or CO_2 (Eggler, 1989).

Ilmenite is an extremely rare constituent in peridotitic xenoliths and as diamond inclusions (Gurney, 1984), and as such it is deemed unlikely to have a genetic relationship to diamond (Schulze *et al.*, 1995). This means that most, if not all, ilmenite macrocrysts and megacrysts are kimberlitic in origin and have no genetic relationship to diamond. However, ilmenite is very useful in that its composition can gauge the redox conditions of a kimberlitic magma (Haggerty, 1986; Gurney and Moore, 1991), although some workers feel this may not the case (Schulze *et al.,* 1995).

Like the megacrystic garnets described earlier, high-Mg ilmenites are believed to be fragments of the very coarse-grained, Cr-poor megacryst suite (includes opx, cpx, and olivine) deemed to have crystallized from high-temperature and high-pressure magmas (Schulze and McCandless, 2000). Kimberlitic ilmenites are typically dominated by Mg-rich varieties (approximately 4 to 15 wt% MgO), while crustal ilmenites have restricted MgO values, generally less than 4 wt% MgO (Fipke *et al.*, 1995; Schulze and McCandless, 2000).

In terms of diamond preservation, ilmenites with a low Fe_2O_3 (Fe^{+3}) component are deemed to have formed in a relatively reducing kimberlite, increasing the diamond preservation potential (DPP). Corresponding to a low Fe_2O_3 component is a high MgO-component in ilmenite, giving rise to the simple concept that the higher the MgO content the higher the DPP. In this way, ilmenite is believed to gauge the DPP of a kimberlite. A very important aspect to note is that the diamond preservation potential is only useful if diamonds were sampled in the first place.

4. Indicator Mineral Chemistry of Central Saskatchewan Kimberlites

a) Garnet

Most of the kimberlite bodies studied are dominated by garnets of peridotitic composition (>2 wt% Cr_2O_3) (Figure 7; Table 1). Megacryst garnets are also common in many of the kimberlites including bodies FalC 120, 121, 168, 169, and Candle 28. In some bodies however, there are few garnets from this suite (e.g. FalC 151). Inferred crustal populations were found in a few bodies such as Sturgeon SL-1 that contained nine percent crustal-derived garnet compositions (Figure 7).

P-type Garnets

Cr_2O_3 contents of the P-type garnets reach 15.2 wt% and CaO contents vary from 0.6 to 9.7 wt%. Lherzolitic garnets predominate, which supports previous observations (Jellicoe *et al.,* 1998). This lherzolitic trend is clearly defined in many of the kimberlite bodies (e.g. FalC 140, 133, 119, Candle C28, and C30). Some of the garnets with >12 wt% Cr_2O_3 (e.g. FalC 140, Candle C28 and C30) may be derived from garnet dunites.

Twenty-two of the 33 kimberlite bodies contained G10 garnets and show a large range in abundance, degree of calcium depletion, and chrome enrichment (Figure 7; Table 1). G10 populations range from 2.6 to 15.2 wt% Cr_2O_3, and 0.9 to 6.2 wt% CaO. Relative abundance of G10 garnets might be an indication for the potential of garnet harzburgite diamonds (Figure 8). At Candle Lake, the kimberlites contain 5.2 to 12.5 percent G10 garnets. Other kimberlites with significant G10 populations include FalC 169 (8.5 percent), 140 (5.7 percent), 141 (5.0 percent), 120 (3.1 percent), and 163 (3.9 percent). A few others possibly contain G10 populations (e.g. FalC 116, 121, 158, 219, Snowden 611), however there are too few data for a meaningful assessment.

Gurney (1984) pointed to calcium depletion in the G10 population as another significant indication of prospectivity. Those kimberlites with significant G10 populations, described above, along with very sub-calcic garnets (<3 wt% CaO) include FalC 120, 140, 141, and 169. FalC bodies 140 and 169 are particularly interesting in that they both have significant G10 populations, with very low calcium and high chromium contents (Figures 7 and 8). Those kimberlites with garnet compositions that spread across and well into the sub-calcic G10 field may have the strongest potential for higher diamond contents.

E-type Garnets

Several of the kimberlites contain a significant population of sub-chromium (<2 wt% Cr_2O_3) eclogite-, megacryst- or crust-derived garnet xenocrysts. Figure 7 shows that some of the cub-chromium garnets examined have intermediate Ca compositions and consequently plot in the megacryst composition field, as seen in FalC 120 and 169. In terms of eclogitic differentiation, sodium concentrations in garnets are generally less than 1 wt%, however the accuracy and precision of the Na_2O analyses are not sufficiently

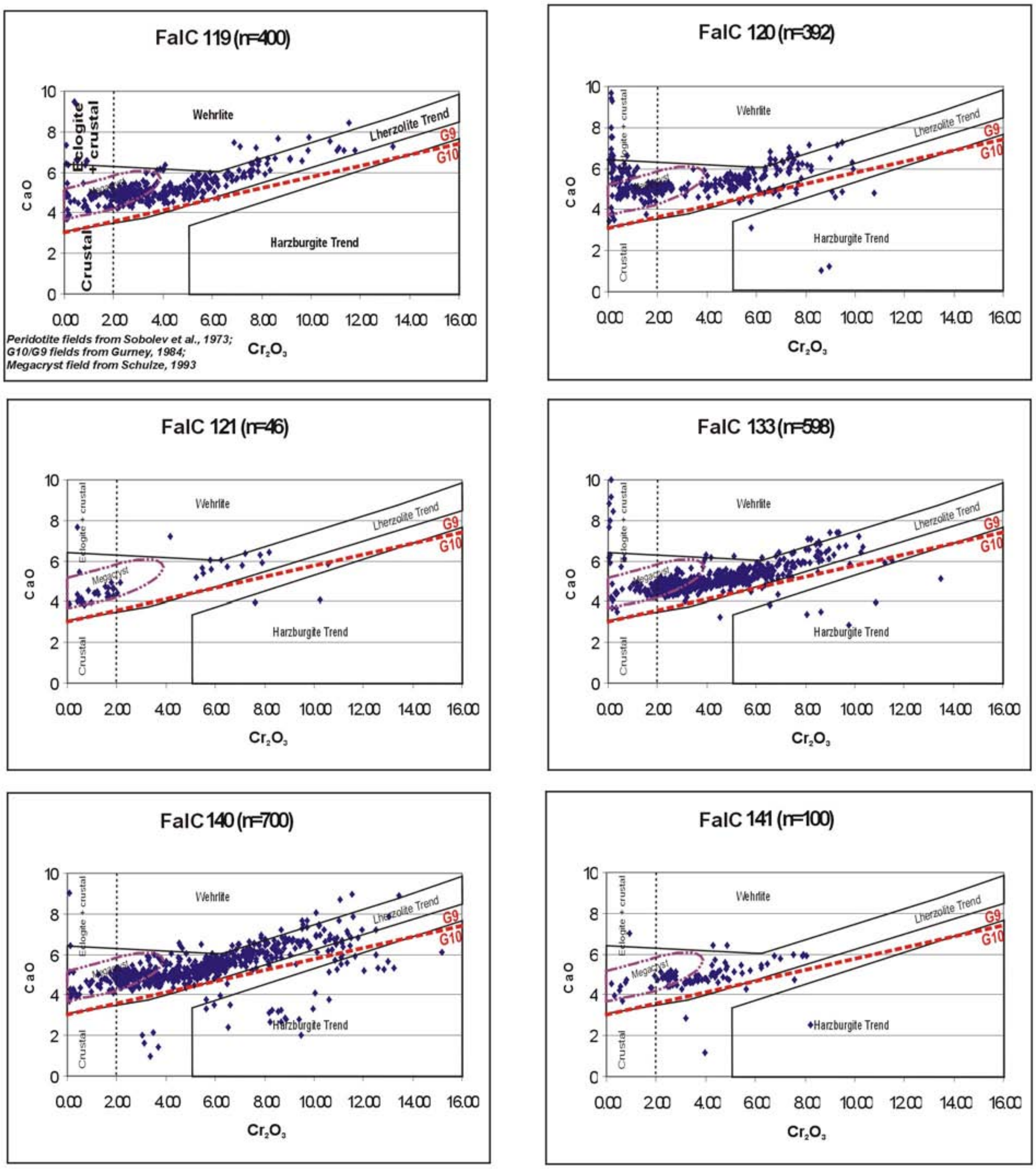
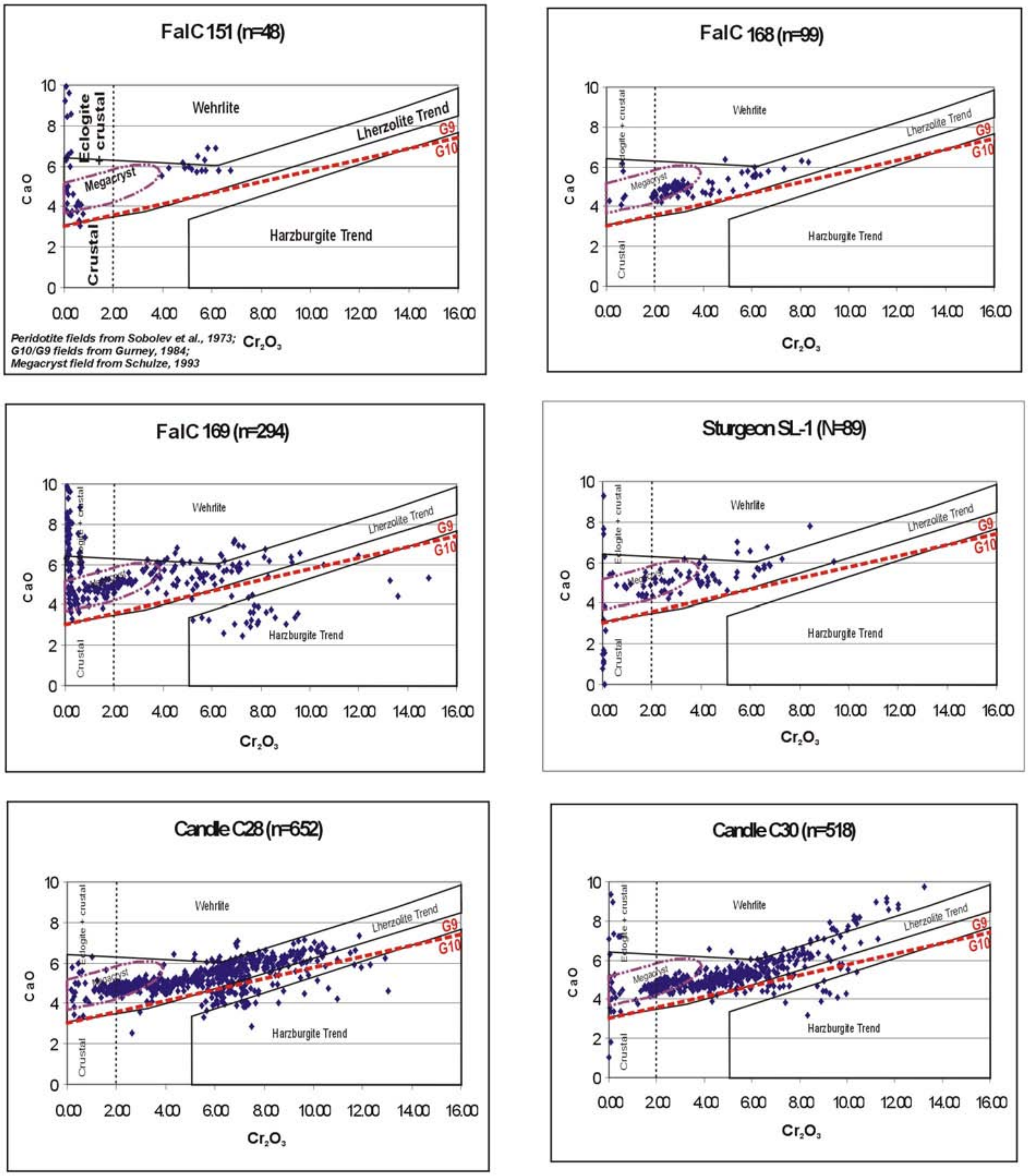


Figure 7 - CaO vs. Cr_2O_3 plot of garnets from some of the kimberlites examined in this study (all compositions in wt%)



(Peridotite fields from Sobolev* et al.*, 1973; G10/G9 fields from Gurney, 1984; Megacryst field from Schulze, 1993).

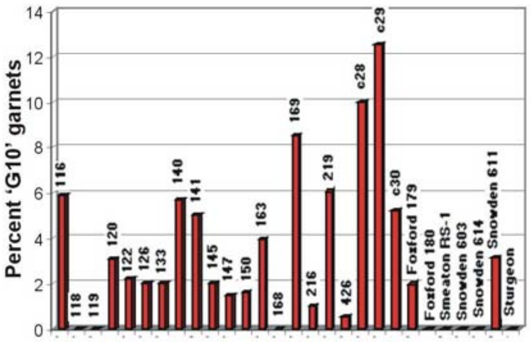


Figure 8 - Percent G10 garnets in kimberlites investigated (% G10=number of G10 garnets ÷ number of total garnets).

known to confidently discriminate between group I and group II garnets.

b) Chromite

Chromite macrocrysts have highly variable compositions (Figure 9), with MgO values ranging from 1.84 to 19 wt% and Cr_2O_3 values from 16 to 69 wt%. Chromite compositions plotted on a MgO-Cr_2O_3 graph often display an inverted "U" shape (e.g. FalC 122, 150, and Candle C30), as previously noted by Jellicoe *et al.* (1998). Between approximately 5 and 9 wt% MgO there is a positive correlation between Cr_2O_3 and MgO. Between 9 and 11 wt% MgO, Cr_2O_3 remains constant, and at MgO contents greater than about 11 wt%, there is a negative correlation with Cr_2O_3.

Of the studied kimberlites, seven had too few chromite analyses to permit confident interpretation. Of those with larger data sets, 15 contained chromites with compositions similar to chromites from diamond inclusions (i.e. plot in the diamond inclusion (DI) field) (Figures 9 and 10; Table 1). Six of those had greater than 0 and less than 1.5 percent of their sample set plot in the DI field, while the remaining nine had greater than 2.5 percent of their sampled chromite compositions plot in the diamond inclusion field. Higher DI percentages suggest potential for diamonds from the diamond harzburgite suite. From Figures 9 and 10 it can be seen that the highest proportion of chromites with DI-compositions occurs in FalC 126 (7.5 percent DI-composition), 120 (4.3 percent), Candle Lake C28 (4.9 percent), and 30 (4.5 percent), while FalC, 141, 147, Candle Lake C29 and Foxford 180 contain approximately 3 percent DI compositions. FalC 121 also contained 23 percent DI-composition chromites in a very small data set.

c) Ilmenite

Ilmenite analyses were available for 32 of the kimberlites, although six of those had sample populations of fewer than 20 (Table 1). Most of the remaining analyses indicate moderate to high MgO contents (average 12.02 wt% MgO), with highly variable Cr_2O_3 contents (Figure 11). Crustal ilmenites (<4 wt% MgO) are observed in a few bodies, with some having anomalously high concentrations (e.g. Snowden 614 and FalC 163). Snowden 614 has a clear and significant population (approximately 23 percent) of ilmenites of interpreted crustal origin and forms a sub-population distinct from the kimberlitic ilmenites. Magnesium in some exceeds 16 wt% MgO, and only one body, Snowden 603, has a relatively low MgO content (average 9.85 wt% MgO). Chromium contents are highly variable with some being very low (average <0.5 wt% Cr_2O_3) and others very high (average >2.5 wt% Cr_2O_3).

Three compositional groups of ilmenite are distinguished (Figure 11). The first group defines backwards "L" shaped plots with most grains in the lower part of the graph (e.g. FalC 169 and Candle C28) (Figure 11). For ilmenites containing 10 to 15 wt% MgO, Cr_2O_3 is constant at about 0.75 wt%. In contrast, ilmenites with more than 15 wt% MgO exhibit a sharp to steep increase in Cr_2O_3 (up to 5 wt%). This group represents 60 percent of the kimberlite bodies and probably corresponds to the MgO-rich limb of the "Haggerty parabola" (Haggerty, 1975). Most of these bodies have high MgO and Cr_2O_3 contents conducive to diamond preservation. However, four have low MgO or Cr_2O_3 contents that might indicate diamond resorption. FalC 116, 121, and 326 (not shown) all have very low Cr_2O_3 contents (<0.5 wt%), while Snowden 603 has both low MgO (avg. 9.85 wt%) and low Cr_2O_3 (avg. 0.49 wt%).

FalC 120, 147 (Figure 11), 145 and 426 (not shown) yielded two distinct sub-populations of ilmenite which define the second compositional group. The main sub-population contains high MgO and low to moderate Cr_2O_3 versus the other that is composed of high (2.5 to 6 wt%) Cr_2O_3 and variable MgO (7.5 to 12 wt%). The first three of the four (FalC 120, 145, and 147) have a second sub-population that plots within a very consistent range, and may indicate a relationship between them. The three kimberlites are found in a cluster surrounding kimberlite 148 (Figure 3), for which no geochemical data was available. These sub-populations were also identified in FalC 120 by Schulze *et al.* (1995), and the Sturgeon Lake body by Fipke *et al.* (1995). The fourth kimberlite body with a major sub-population is FalC 426, which unlike the previous three has slightly increased MgO content relative to the main population. This group has good diamond preservation potential based on the high magnesium contents (avg. 11.87 wt% MgO) and high Cr_2O_3 contents (avg. 2.35 wt%).

The third grouping of chromites is defined by Cr_2O_3 contents that are independent of MgO, resulting in a large degree of scatter (Figure 11) (e.g. FalC 133 and Snowden 614). For example, Snowden 614 ilmenite compositions show that the main kimberlitic population (separate from the crustal population) has a wide range in MgO contents (8 to 16 wt%) and Cr_2O_3 contents (0.25 to 4.6 wt%). These bodies also have a good preservation potential as they also have high average MgO content (11.95 wt%) and moderate to high Cr_2O_3 (avg. 1.26 wt%).

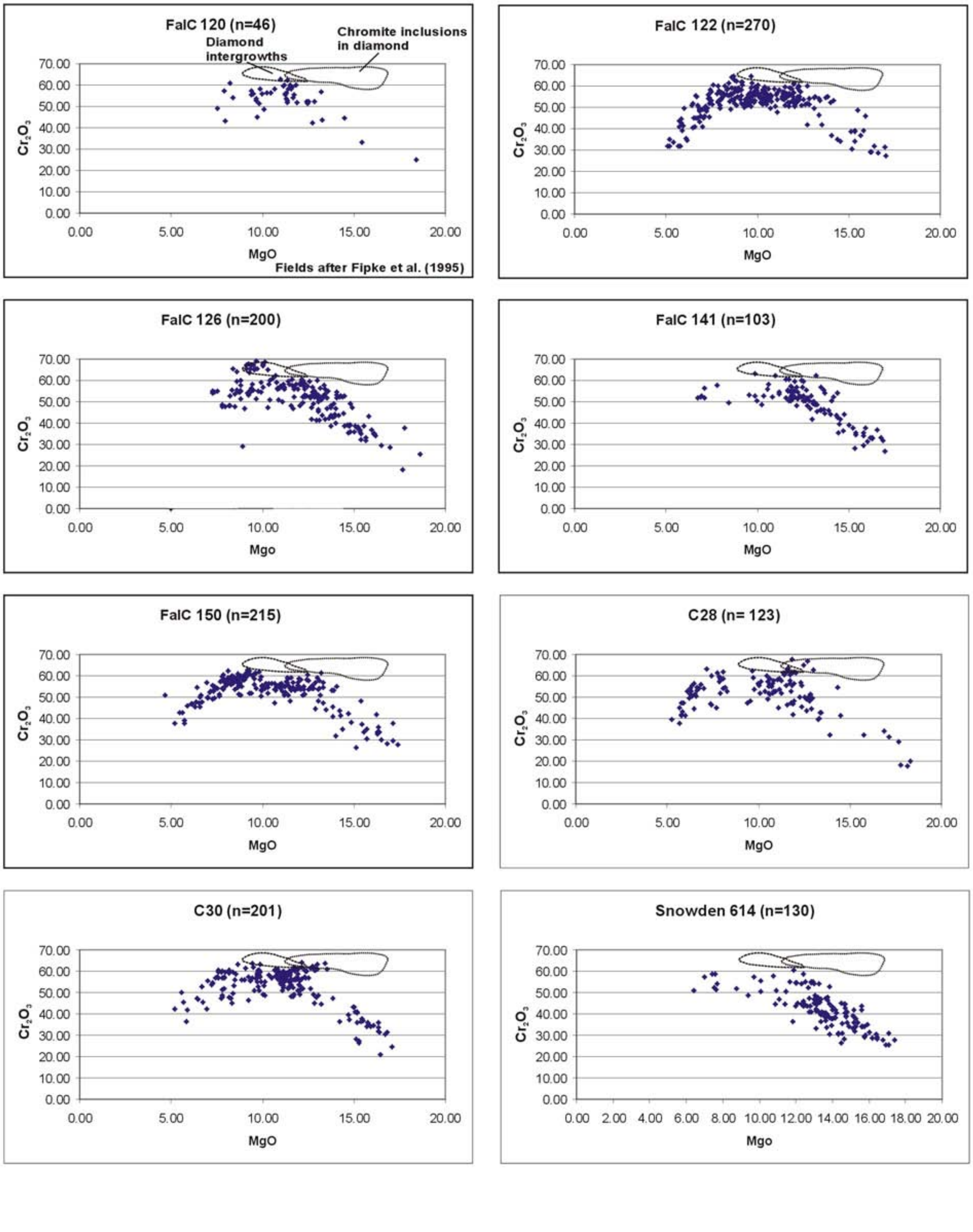


Figure 9 - Chromite compositions from some of localities investigated (all compositions in wt%).

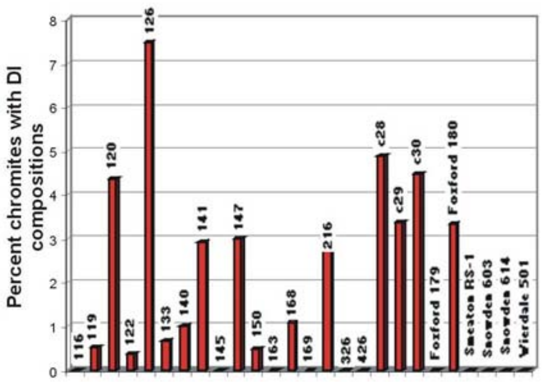


Figure 10 - Percent chromites that have compositions plotting in the diamond inclusion and diamond intergrowth (DI) fields (% DI chromites = number of chromite compositions in the DI field ÷ number of total chromites).

In order to gauge the relative diamond preservation potential based on ilmenite compositions the MgO-Cr_2O_3 plots were compared with those of Fipke *et al.* (1995), who distinguished categories of diamond preservation potential (DPP). Overall the DPP of central Saskatchewan kimberlites appears encouraging with many showing good to very good preservation potential (Table 1). Four kimberlites, FalC 116, 121, 326, and Snowden 603, apparently have a poor preservation rating based on their very low MgO and/or Cr_2O_3 contents.

5. Discussion

The compiled indicator mineral data are interpreted to suggest great variation in potential of individual Saskatchewan kimberlites to contain diamonds. As described above, diamond can be derived from three potential sources: garnet harzburgites, chromite harzburgites, and garnet eclogites. The overall diamond potential is based on the sum of all possible sources as all known kimberlite deposits contain both peridotitic and eclogitic diamonds (Fipke *et al.*, 1995). The possible eclogitic diamond contribution to central Saskatchewan kimberlites remain unresolved as the Na_2O analyses are of varying and questionable quality. The interpretations below are based on relationships between indicator mineral geochemistry and diamond prospectivity recognized by various workers including Gurney (1984), Gurney and Moore (1991), and Fipke *et al.* (1995) predominantly on South African kimberlites, and Sobolev *et al.* (1973) on Russian kimberlites. The applicability of such relationships in assessing the prospectivity of Saskatchewan kimberlites will only be known with time.

FalC 169 has a high content of sub-chromium garnets (approximately 50 percent of the garnet population), with G10 garnets being well represented, comprising 8.5 percent of the total garnet population, making it a promising target. It also exhibits moderate to high calcium-depletion in garnet, which is considered a good indication of potentially higher diamond contents (Gurney and Zweistra, 1995).

Data for FalC 120 indicates that it may have derived diamonds from at least two mantle sources. It has a moderate G10 population (3.1 percent of all garnets) with some compositions being highly calcium-depleted and 4.3 percent of the chromite compositions plot in the diamond inclusion field. Therefore, FalC 120 may have sampled potential diamond sources of garnet harzburgite and chromite harzburgite.

The Candle Lake kimberlites also appear to contain diamond potential from both garnet harzburgite and chromite harzburgite. G10 percentages are 10, 12.5, and 5.2 percent of all garnets for Candle Lake C28, C29, and C30. The degree of calcium depletion varies, with C29 having moderate calcium depletion, while C28 and C30 have G10 garnet compositions that plot near the G10/G9 boundary. In addition, several percent of their chromites (4.9, 3.4, and 4.5) plot in the diamond-inclusion field.

FalC 141 has a very low proportion of sub-chromium garnets (11 percent) and indicates potential diamond input from at least two sources. The G10 content of this kimberlite is about five percent of the total garnet population. Some of those garnets exhibit strong calcium-depletion, although the corresponding Cr_2O_3 values are somewhat low, which may indicate that some of the sub-calcic garnets formed in the graphite stability field (Sobolev, 1974). None the less, in addition to garnet harzburgite diamonds, chromites with diamond-inclusion compositions comprise 2.9 percent of the total chromite population.

One of the most interesting kimberlites is FalC 121, which has potential from at least two diamond sources. Unfortunately, the garnet sample set is quite small (n=46) for a confident analysis. About 6.5 percent of the garnets are G10s. This kimberlite has an extremely high proportion (23 percent) of chromite compositions that plot in the diamond inclusion field, although there are only 13 chromite analyses. These numbers are very encouraging, but this kimberlite body may have decreased potential due to possible diamond resorption (i.e. low Cr_2O_3 content in ilmenite). More work is needed to verify the potential diamond source contents and the Cr_2O_3 content of ilmenite.

An example of a low potential kimberlite, based on indicator mineral geochemistry, is FalC 119. This body has a very good sample set with 400 garnet analyses, 200 chromite analyses, and 187 ilmenite analyses. It is dominated by peridotitic garnets (85 percent of total garnets), all of which are lherzolitic in paragenesis (Figure 6). There are no sub-calcium G10 garnets suggesting this kimberlite did not sample diamondiferous harzburgitic mantle material. Likewise, only 1 out of 200 chromite compositions plot in the diamond inclusion field. Thus there is very little chance that this kimberlite contains any appreciable diamond contents. The ilmenite compositions are favourable, indicating good diamond preservation potential, however, as mentioned, if there are no diamonds present, preservation potential is meaningless.

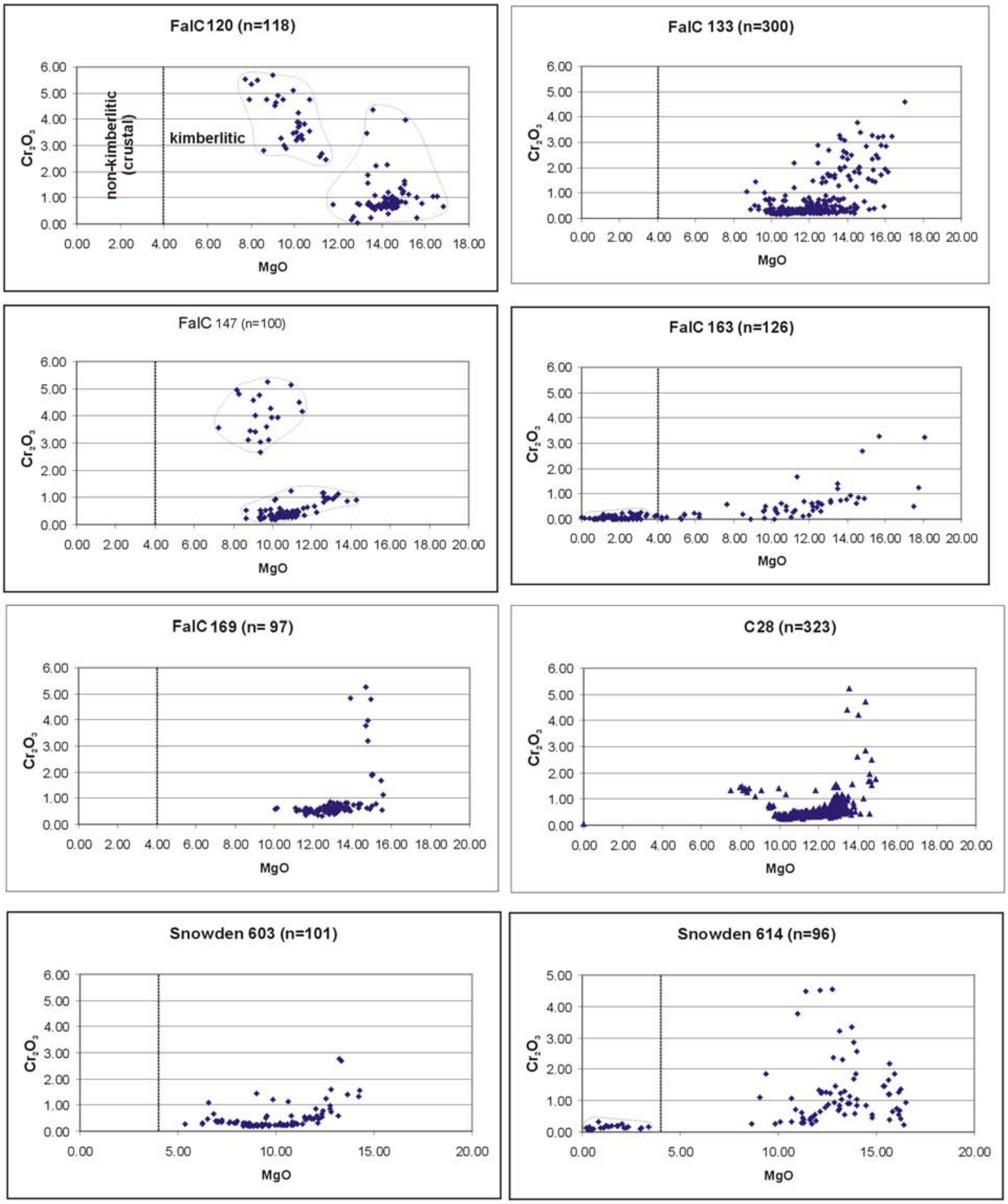


Figure 11 - Cr_2O_3-MgO plot for ilmenite compositions from some kimberlites investigated (all compositions in wt%).

Overall, a few kimberlites appear to have potential to be significantly diamondiferous based on indicator mineral geochemistry. Caution must be exercised, however, as the data set may not be completely representative as one or even a few drill holes can be concentrated in zones that are atypical of a particular kimberlite. Additionally, many of the bodies are very large and may be comprised of several eruptive phases emplaced over millions of years. Thus one drill hole may only represent a small fraction of these complexly diverse bodies. Further work, utilizing indicator mineral geochemistry, will include the characterization of distinct kimberlitic horizons and possible geographic trends.

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