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Remnants of (Possibly Diamondiferous) Ultramafic Igneous Rocks in Bedrock of the Kakwa/Wapiti Area, West Central Alberta

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Alberta Energy and Utilities Board

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REMNANTS OF (POSSIBLY DIAMONDIFEROUS) ULTRAMAFIC IGNEOUS ROCKS IN BEDROCK OF THE KAKWA/WAPITI AREA, WEST CENTRAL ALBERTA

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Abstract

Bedrock sampling at 23 sites, heavy mineral separation and microprobing confirmed that indicator minerals of ultramafic igneous rocks are present in Cretaceous bedrock of the Wapiti area (NTS 83L). Indicator minerals among 74 heavy mineral grains obtained from these samples include: eclogitic garnet, picro chromite (chromite geochemically similar to diamond inslusion chromite), chrome diopside and picro ilmenite. In addition, some of the non-diamond inclusion chromites are similar in composition to chromites found in diamondiferous lamproites from Argyle in Australia. Para-magnetic heavy minerals (>3.3 SG) from several of these samples were mounted on polished thin sections and microprobed, resulting in an additional 140 chromite and 50 garnet analyses. These analyses confirmed the presence of diamond inclusion chromites and eclogitic garnet (Group 5). In three of these thin sections kyanite was found. Indicator minerals are more easily identified petrographically in thin section than as rough grains under the binocular microscope.

A supplementary study of thin sections from fist size samples at the same sample sites show that tiny chromite and garnet grains (generally smaller than 0.2 mm) can be recognized in thin section. A total of 90 chromite and garnet grains from 7 sample sites were microprobed and can be compared to the analyses from grains separated after crushing a 25 kg sample. The mineralogy of the heavies is similar to the ones separated from the rock and include one diamond inclusion chromite, chromites similar in composition to those found in the lamproites of Argyle (Australia) and Group 5 eclogitic garnets.

The indicator minerals are generally from the Upper Cretaceous Brazeau Formation, but they also include one diamond inclusion chromite from the Lower Cretaceous Gates Formation, and indicate possible local ultramafic diatremes (which could include diamondiferous ones). The exact source of the indicator minerals is uncertain, but because the general provenance of the clastics in these sediments is from the west and the Buffalo Head Hills area are to the northeast, this area can not have been a source. Finding the source ultramafic diatremes of the indicator grains in Cretaceous sediments is a continuing challenge for explorationists in west-central Alberta. Indications are that there were two periods of ultramafic (kimberlite/lamproite?) intrusion: one in the Maastrichtian around 70 Ma ago and an older one, possibly in the Aptian around 110 Ma ago.

1 Introduction

This report forms part of the Integrated Kakwa/Wapiti Study by the Alberta Geological Survey (AGS), which was conducted from 1996 to 1999. Micro diamonds were found in stream samples north of the Hinton area (Dufresne *et al.*, 1996) and diamond indicator minerals have been found in Cretaceous and Tertiary clastic sediments south of Hinton (Langenberg, 1996). The purpose of this study was to determine if diamond indicator minerals, which are present in till (Pawlowicz *et al.*, 1998) and stream samples (Eccles *et al.*, 1998), are also present in the bedrock. The results of this study are reported here. The area covered by this report is situated between latitudes 54 and 55 degrees North and between longitudes 118 and 120 degrees West (NTS 83L, Figure 1).

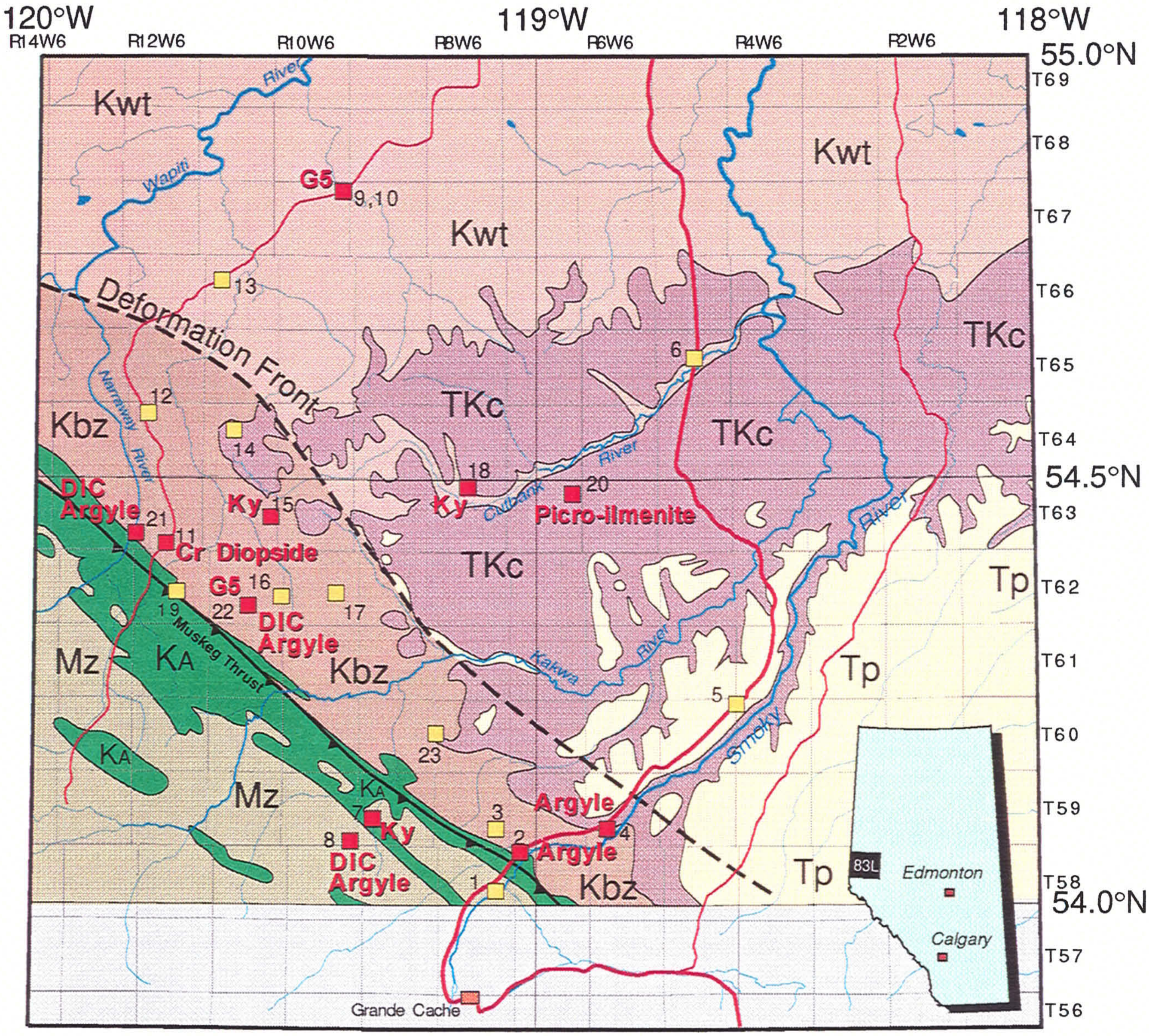
2 General Geology

The area can be divided into three main belts, from NE to SW: Plains, Outer Foothills and Inner Foothills (McMechan, 1999 and Friis *et al.*, 1998). The boundary between Plains and Outer Foothills is defined by the eastern edge of the Cordilleran deformation front and the boundary between Inner and Outer Foothills is the Muskeg Thrust (Figure 1).

The bedrock exposed at the surface can be divided into many different stratigraphic units (McMechan and Dawson, 1995). For the purpose of this report these units can be grouped in five intervals: Triassic-Jurassic-Lower Cretaceous, Alberta Group, Brazeau/Wapiti Formation, Coalspur/Scollard Formation and Paskapoo Formation. These are the same intervals as used on the Geological Map of Alberta (Hamilton *et al.*, 1999). These units are briefly described in the following sections. For a more extensive description the reader is referred to the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetson, 1994), McMechan (1994 and 1996), Stott (1963, 1982 and 1998) and Langenberg *et al.* (1987).

2.1 Triassic, Jurassic and Lower Cretaceous

The Mesozoic consists of Triassic, Jurassic and Lower Cretaceous rocks. The Triassic is represented by the Spray River Group, consisting of siltstone (Sulphur Mountain Formation) and some dolostone (Whitehorse Formation). The Jurassic Fernie Formation consists largely of marine shales. The overlying, mainly Jurassic Minnes Group consists of marine and non-marine sandstones and shales (Stott, 1998). The upper Minnes Group is probably lower Cretaceous in age. It is unconformably overlain by the Cadomin Formation of the Luscar Group. The Lower Cretaceous rocks comprise the Luscar Group, Hullcross Formation and Boulder Creek Formation. The Luscar Group consists of the Cadomin, Gladstone, Moosebar and Gates formations (Langenberg and McMechan, 1985) and is equivalent to the Mannville Group of central Alberta. The Luscar Group comprises both marine and non-marine clastics and include economically significant coal seams, which are mined in the southern part of the study area by Smoky River Coal Ltd. The Hullcross Formation is largely marine shale, while the overlying Boulder Creek Formation is characterized by sandstone and pebble conglomerates (Stott, 1982).



Wapiti Map Area
NTS 83L

Tp	Paskapoo Formation
TKc	Coalspur Formation
Kwt	Wapiti Formation
Kbz	Brazeau Formation
KA	Alberta Group
Mz	Triassic, Jurassic and Lower Cretaceous

21 DIC - Sample site (and sample number) with indicator mineral type

DIC - Diamond Inclusion Chromite

Argyle - Chromite with Argyle-type composition

G5 - Mg-Almandine (Eclogitic garnet)

Ky - Kyanite

- Sample site without indicator grains

Figure 1. Simplified geological map of the study area with location of samples and indicator minerals. The grouping of stratigraphic units is from Hamilton *et al.* (1999).

2.2 Alberta Group

The Alberta Group, which is Upper Cretaceous, consists of rocks of the Shaftesbury, Dunvegan, Kaskapau, Cardium, Muskiki, Badheart and Puskwaskau formations (Stott, 1963 & 1982). The Shaftesbury, Kaskapau and Puskwaskau formations are mainly marine shales, while the Dunvegan, Cardium and Badheart (also called Marshybank) formations are generally marine near-shore sandstones. The Puskwaskau Formation includes a marine sandstone member (called Chungo Member).

2.3 Brazeau Formation

The Brazeau Formation is equivalent to the Belly River-Edmonton Sequence (Jerzykiewicz, 1997). The Wapiti Formation is equivalent to the Brazeau Formation, but this terminology is only valid east of the deformation front (Hamilton *et al.*, 1999). The Brazeau (and Wapiti) Formation consists of sandstones, conglomerates, shales and some coal seams deposited by fluvial systems, above the marine shales of the Puskwaskau Formation and below the basal Entrance Conglomerate of the Coalspur/Scollard Formation. The Cutbank and Red Willow coal zones are in the upper part of the formation (Dawson *et al.*, 1994).

2.4 Coalspur Formation

The Coalspur Formation contains a continental succession of interbedded sandstones, mudstones and thick economic coal seams. The base of the Coalspur Formation is the Entrance Conglomerate or equivalents. Thick coal seams interbedded with coaly shales and numerous bentonites occur in the upper part of the formation. This interval is known as the Kakwa Coal zone. The Cretaceous-Tertiary boundary (66.5 Ma ago) is at or near the base of this coal zone. The Coalspur Formation represents a nonmarine, fluvially dominated environment of deposition. East of the deformation front this formation is known as the Scollard Formation (Jerzykiewicz, 1997).

2.5 Paskapoo Formation

The Paleocene Paskapoo Formation consists of a thick succession of alluvial sandstones and mudstones above the uppermost coal seam of the Coalspur/Scollard Formation. Jerzykiewicz (1997) has informally divided the Paskapoo into two members: the lower and upper Paskapoo members.

3 Overview of Diamond-bearing Igneous Rocks in Alberta

Traditionally, the search for diamonds has been directed to the ultrabasic rock kimberlite, because in South Africa (and later elsewhere) diamonds have been found in these rocks. However, more recently many diamonds have also been found in lamproites, rocks that are probably related to kimberlites. It is useful to briefly review these diamond-bearing rocks, in addition to some related rocks (lamprophyres, peridotites, eclogites, komatiites, gabbros and picrobasalts), which are generally non-diamond bearing. All these types of rock are present on the North American continent and most have also been found in Alberta (except lamproites and komatiites). These rocks contribute heavy clastic minerals to younger sedimentary rocks (including Quaternary sediments). The occurrence of these rocks in Alberta will be briefly described in this section of the report. The challenge in the Western Canada Sedimentary Basin (and other sedimentary basins) is to distinguish different sources of heavy minerals (Fipke *et al.*, 1995; Langenberg and Skupinski, 1996) and to establish the source of kimberlite/lamproite and diamond indicator minerals in bedrock, till and stream samples.

3.1 Kimberlites

Early definitions of kimberlite took into consideration that kimberlites contain up to 50% xenoliths and xenocrysts derived from the mantle and crust. Consequently, they were defined as hybrid rocks. This definition may still be useful as a field term (where kimberlite can be thought of as a type of peridotite), but Mitchell (1986) proposed a definition that excludes any referral to xenoliths and xenocrysts. Somewhat shortened, his definition is:

> Kimberlites are a clan of volatile-rich (dominantly CO_2) potassic ultrabasic igneous rocks, commonly exhibiting an inequigranular texture with macrocrysts (and megacrysts) set in a fine-grained matrix. The megacryst/macrocryst assemblage consists of rounded anhedral crystals of Mg ilmenite, Cr-poor Ti pyrope, olivine, Cr-poor clinopyroxene, phlogopite, enstatite and Ti-poor chromite. Olivine is the dominant member of the macrocryst assemblage. The matrix minerals include olivine, phlogopite, perovskite, spinel, diopside, monticellite, apatite, calcite and serpentine.

Clement *et al.* (1984) defined kimberlites with a note that they commonly contain inclusions of mantle- and crust-derived xenoliths and xenocrysts, in addition to rare diamonds. It is now generally accepted that diamonds are either xenocrysts or form part of xenoliths, that are generally much older than the kimberlite host, which sampled the diamonds from the diamond stability field in the earth's mantle.

Kimberlites have been confirmed to be present in Alberta in the Buffalo Head Hills area (Carlson, *et al.*, 1998; Skelton and Bursey, 1998; Hamilton *et al.*, 1999).

3.2 Lamproites

The term lamproite was introduced in the 1920's for potassium-rich mafic to ultramafic alkaline igneous rocks. The discovery of diamond-bearing lamproites in NW Australia and the reclassification of some mineralogically anomalous kimberlites as lamproites (e.g. Prairie Creek, Arkansas) has now given the group a status as a source of diamonds.

It is not possible to devise a simple definition of lamproites based on mineralogy. The reason is that lamproites are a clan of ultrapotassic mafic hypabyssal or extrusive rocks, characterized by the presence of widely varying amounts of Ti phlogopite, K-Ti richterite, olivine, diopside, sanidine and leucite (Mitchell and Bergman, 1991). Thus, lamproites refer to a clan of rocks and not to a specific rock variety. Many different historical names exist (e.g. Wyomingite, Verite, Jumillite, Fortunite, etc.) and these rocks might not posess all the diagnostic features of the clan, but are named lamproites on the basis of their containing one or more typomorphic minerals, having the requisite geochemical character, and occurring with other bona fide members of the suite.

In contrast to kimberlites, lamproites contain only a limited suite of xenoliths (Mitchell and Bergman, 1991). This might be related to a difference in the associated lithospheric mantle, below the intrusions.

The presence of lamproites in Alberta has not yet been confirmed.

3.3 Lamprophyres

Lamprophyre is a field term for a group of mafic, porphyritic, hypabyssal (dyke) rock, containing phenocrysts of biotite or amphibole, and possibly clinopyroxene and olivine in a fine-grained groundmass. Many different types of lamprophyre exist (e.g. Minette, Vogesite, Camptonite, Alnoite, etc), but only minette bears a resemblance to some lamproites.

Minettes consisting of biotite, augite, potassium feldspar and olivine and containing abundant xenoliths, are found in southern Alberta, where they form part of the Sweetgrass intrusives. They appear to be non-diamond bearing (Kjarsgaard, 1994 and 1997).

3.4 Peridotites

A peridotite is a coarse grained ultramafic plutonic rock, composed chiefly of olivine with or without other mafic minerals such as pyroxenes, amphiboles or micas and containing little or no feldspar and quartz. They have generally ascended to the surface of the earth too slowly to retain any diamonds (for example in ophiolite complexes). However, peridotite xenoliths in kimberlite and lamproite may have retained diamonds, if they were originally present in the mantle. Varieties of peridotite, that may be included in kimberlites are: wehrlite, dunite, harzburgite and lherzolite. Of these xenoliths, harzburgite and lherzolite are especially important as diamond hosts. The Alberta kimberlites may contain harzburgite xenoliths (Skelton and Bursey, 1998).

3.5 Eclogites

Eclogites are rocks formed by regional (dynamo-metamorphic) metamorphism under which conditions diamonds may have formed. Eclogites are characterized by omphacite (a pyroxene) and pyrope (a garnet). Generally these rocks have cooled too slowly to retain these diamonds, but eclogite inclusions in kimberlite may have retained diamonds.

3.6 Komatiites

Komatiites are ultramafic volcanic rocks that contain at least 18% MgO and are the volcanic equivalents of peridotite. They are characterized by the so-called spinifex structure (criss-crossing sheafs of olivine crystals, named after spinifex grass in Australia) and are unique to Archean greenstone belts (for example in Ontario). They are inferred to originate from depleted mantle material (Philpotts, 1990) and are non-diamond bearing. No komatiites have been found yet in Alberta.

3.7 Gabbros

Gabbros are a group of basic plutonic rocks composed principally of plagioclase and clinopyroxene, with or without olivine and orthopyroxene. Abundant gabbros are present in the Canadian Precambrian Shield (including Alberta). They are non-diamond bearing.

3.8 Picrobasalts

Picrobasalts are ultrabasic alkaline volcanic rocks that may contain olivine, pyroxene and amphibole. Picrobasalts form part of most basaltic lava flows. They are non-diamond bearing. According to Kjarsgaard (in Leckie *et al.*, 1997), the Mountain Lake diatreme near Grande Prairie is mainly composed of picrobasaltic pyroclastic tuff, although it can not be excluded that kimberlite phases could be present (Kjarsgaard, 1997). Wood and Williams (1994) consider the Mountain Lake Diatreme a real kimberlite.

4 Methodology

For the purpose of this study, 23 large bedrock samples were collected from Cretaceous and Tertiary horizons. Buckets were filled until the weight was about 25 kg. The different horizons sampled are shown in Table 1, together with the sample locations. The rock was described at each outcrop locality. Small representative samples were selected from the buckets as a source for thin sections. Diamond indicator minerals, which were identified in thin sections, were analyzed by microprobe at the University of Calgary.

4.1 Sample Crushing and Mineral Separation

The 25 kg samples were shipped to Loring Laboratories Ltd. in Calgary, where the samples were crushed to particles smaller in size than 2mm. Using the shaker table, the heavy minerals (>2.9 SG) were obtained. The fraction finer than 0.2 mm (using an 80 mesh screen) was separated and not used. The heavy mineral fraction of 0.2 to 2 mm was separated by heavy liquid separation (tetrabromoethane) into a 'heavy' (>3.3 SG) and a 'middlings' (2.9-3.3 SG) fraction. Only cursory inspection of the non-magnetic middlings fraction (2.9-3.3 SG) was made, because generally it will only contain pyroxenes, besides non-indicative silicates. The magnetic fractions were removed and the remaining heavy grains were separated into a 'fine' fraction (0.2-0.5 mm) and a 'coarse' fraction (>0.5 mm). The coarser fraction (0.2-0.5 mm) is too coarse to be used in the Franz magnetic separator. The fine fraction of the heavies (0.2-0.5 mm) was separated with the Franz separator into 6 fractions: one non-magnetic fraction, three paramagnetic fractions (at current settings 0.5, 0.6 and 0.7 on the Franz separator) and two weak paramagnetic fractions (at current settings 1.2 and 2.0 on the Franz separator).

This resulted in 7 fractions of heavy minerals (>3.3 SG), that are used for manually picking potential indicator minerals. The coarser fraction of the heavies (0.5-2 mm) was not looked at extensively; but obvious purple garnets and green chrome diopsides were picked from this fraction. The majority of garnets were picked from the non-magnetic fraction and the weakly paramagnetic fractions. Chromites were mainly picked from the 3 paramagnetic fractions. Chrome diopsides are in the nonmagnetic fraction; olivine and ilmenite can be expected in the 0.6 paramagnetic fraction.

These selected grains were mounted in plugs and microprobed. Half of the grains were analyzed using the University of Alberta (U. of A.) microprobe. The other half was processed at the University of Saskatchewan's probe, due to down-time of the U. of A. machine. The analyses are listed in Appendix 1. The garnets were classified according to Dawson and Stephens (1975) and plotted on a ternary diagram suggested by Dufresne *et al.* (1996). Pyroxenes were classified according to Stephens and Dawson (1977). The compositions of the chromites were plotted to see if they fall in the diamond inclusions field (Fipke *et al.*, 1995).

Table 1. Sample identification, stratigraphic horizons and locations in UTM zone 11.

ID	Formation	Easting(in m)	Northing (in m)
KW-1	Gates	363670	5986885
KW-2	Brazeau	367040	5991030
KW-3	Brazeau	364050	5995130
KW-4	Coalspur	378400	5994750
KW-5	Paskapoo	395640	6010640
KW-6	Coalspur	391600	6056200
KW-7	Gates	347670	5996340
KW-8	Gates	345300	5994050
KW-9	Wapiti	346610	6079500
KW-10	Wapiti	346610	6079500
KW-11	Brazeau	322190	6033910
KW-12	Brazeau	320400	6051170
KW-13	Brazeau	330650	6068200
KW-14	Coalspur?	331620	6048560
KW-15	Brazeau	336150	6036930
KW-16	Brazeau	337160	6026490
KW-17	Brazeau	344210	6026770
KW-18	Brazeau?	361620	6040170
KW-19	Brazeau	322330	6026650
KW-20	Coalspur	375090	6038800
KW-21	Brazeau	317000	6033450
KW-22	Brazeau	332740	6025560
KW-23	Coalspur	356660	6007880

4.2 Extra Mineral Separation

Ten chromite and 14 garnet grains were originally selected by Loring from various fractions of samples KW21 and KW22. An additional 140 chromite grains and 50 garnet grains were found by mounting the paramagnetic 0.5 and 0.6 fractions of these 2 samples (which consisted largely of chromite and garnet) in polished thin sections. These 190 grains were further investigated by microprobing at the University of Alberta. These analyses are listed in Appendix 2. In addition, the heavy mineral grains of samples KW-7, KW-15 and KW-18 were examined in thin section, revealing the presence of kyanite. The fact that so many heavy indicator minerals were found in these fractions indicates that the 25 kg samples, used in this study, will procure many heavies. Not all of these grains could be microprobed, for budgetary reasons.

4.3 Thin Sections

As part of a supplementary study, polished thin sections were prepared from seven of the bedrock samples. Five to six polished thin sections were prepared from each sample (37 thin sections in total). Due to extensive porosity and the cement weakness, the samples were cut into slabs and impregnated under vacuum with a low viscosity Epo-Tec 301 resin. After a final grinding, the samples were polished on 9 and 3 micron diamond disks.

In-situ heavy minerals grains (mainly garnet, chromite and ilmenite) were marked on the thin sections and microprobed at the University of Calgary using standard procedures. On average, three analyses per grain were done, of which one analysis was selected for evaluation. The criteria for selection were totals closest to 100% (this will exclude impurities) and high Mg and Cr contents. The resulting analyses are listed in Appendix 3.

5 Diamond Indicator Minerals

A summary of the results is given in Table 2; a complete listing of these results is given in Appendices 1, 2 and 3. The most significant indicator mineral is chromite. In addition, several G5 eclogitic garnets, one chrome-diopside and one picro-ilmenite are present.

5.1 Chromite

Several chromites with high Cr_2O_3 and MgO contents (picro-chromites) plot inside the diamond inclusions field as outlined from data by Fipke *et al.* (1995). Hereafter, these grains will be referred to as diamond inclusion chromites (DIC's). It is interesting to note that these DIC's were found in all three data sets (Figure 2). A significant number of the grains (about 15) plot in the Argyle Chromite field, indicating that their composition is similar to chromites found in lamproites. The Cr_2O_3 versus TiO_2 plots (Figure 3) also indicate potential diamond inclusion compositions for the chromites.

Table 2. Number of indicator minerals in bedrock samples of the Wapiti area

ID	DI Chromite	Argyle Chromite	G5	Cr-Diopside	Picro-ilmenite	Kyanite
KW-2		2				
KW-4		3				
KW-7						8
KW-8	1	2				
KW-10			1			
KW-11				1		
KW-15						2
KW-18						6
KW-20					1	
KW-21	1	5	1			
KW-22	1	2	6			

DI: Diamond Inclusion G5: Mg-Almandine garnet

Griffin *et al.* (1997) have developed statistical techniques in classifying chromites in diamond exploration samples based on chemical composition. This technique distinguishes chromites derived from kimberlite/lamproite from those more likely to be derived from greenstone/gabbro sources. A confidential report by Griffin to Cameco Corporation indicates that 50% of the high chromium chromites in the Hinton area were probably derived from kimberlite/lamproite sources (G. Drever, pers. comm., 1994). The ratios of elements used in this statistical classification have not been published because they are considered proprietary (Griffin et al, 1997, p.238). However, from other papers (e.g. Griffin *et al.*, 1994) it can be deduced that Ni and Zn contents are important (besides Cr and Mg), with Ni contents typically higher than 0.06% and Zn contents lower than 0.07% indicating kimberlite/lamproite. These criteria can only be used for xenocryst chromites of kimberlites/lamproites and are not valid for phenocrysts. Trace amounts of Zr and Nb can also be used, where contents over 6 ppm indicate that a chromite has

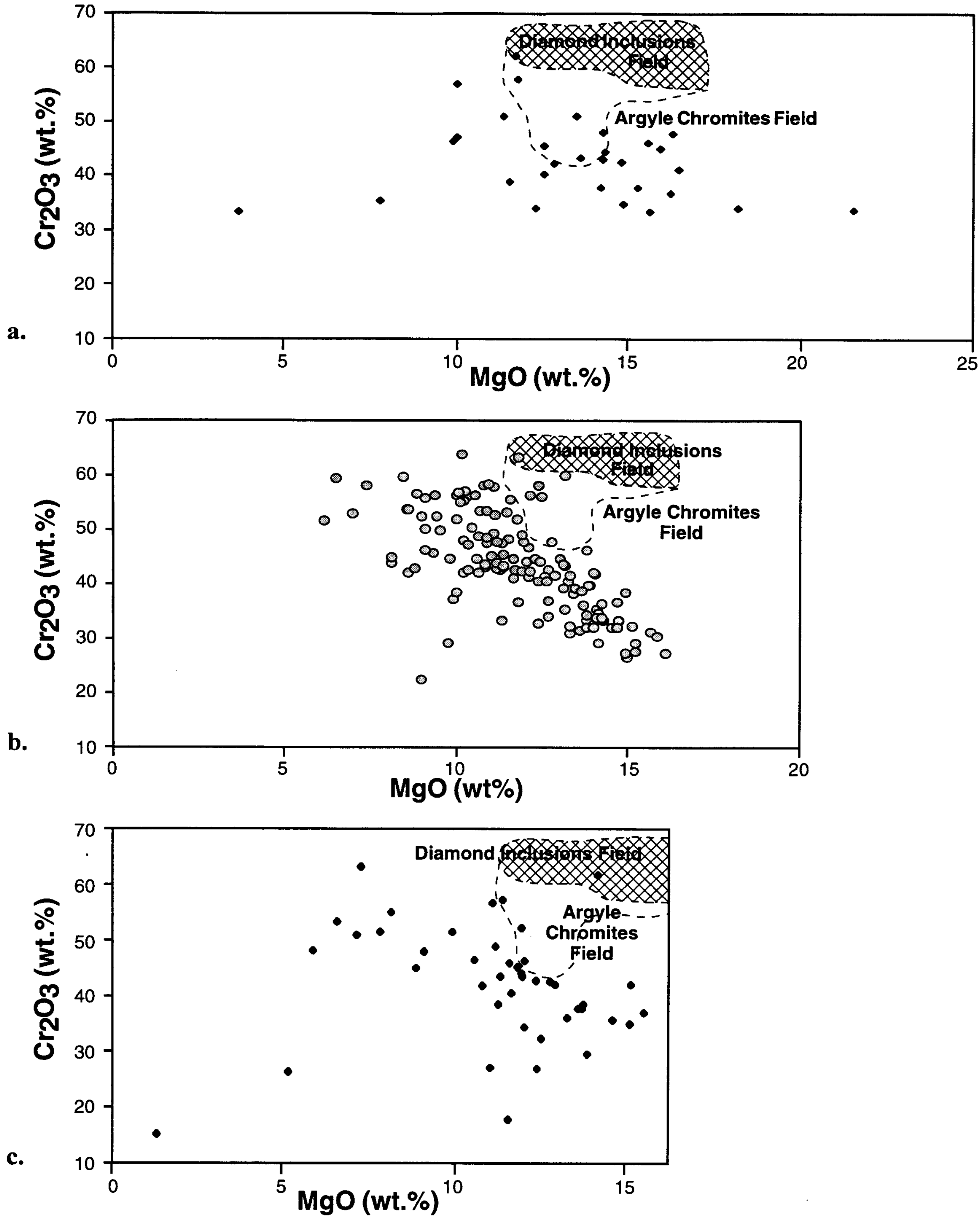


Figure 2. Cr_2O_3 versus MgO cross plot of chromites
a. In crushed bedrock samples
b. For additional grains from crushed bedrock samples KW-21 and KW-22
c. In bedrock thin sections

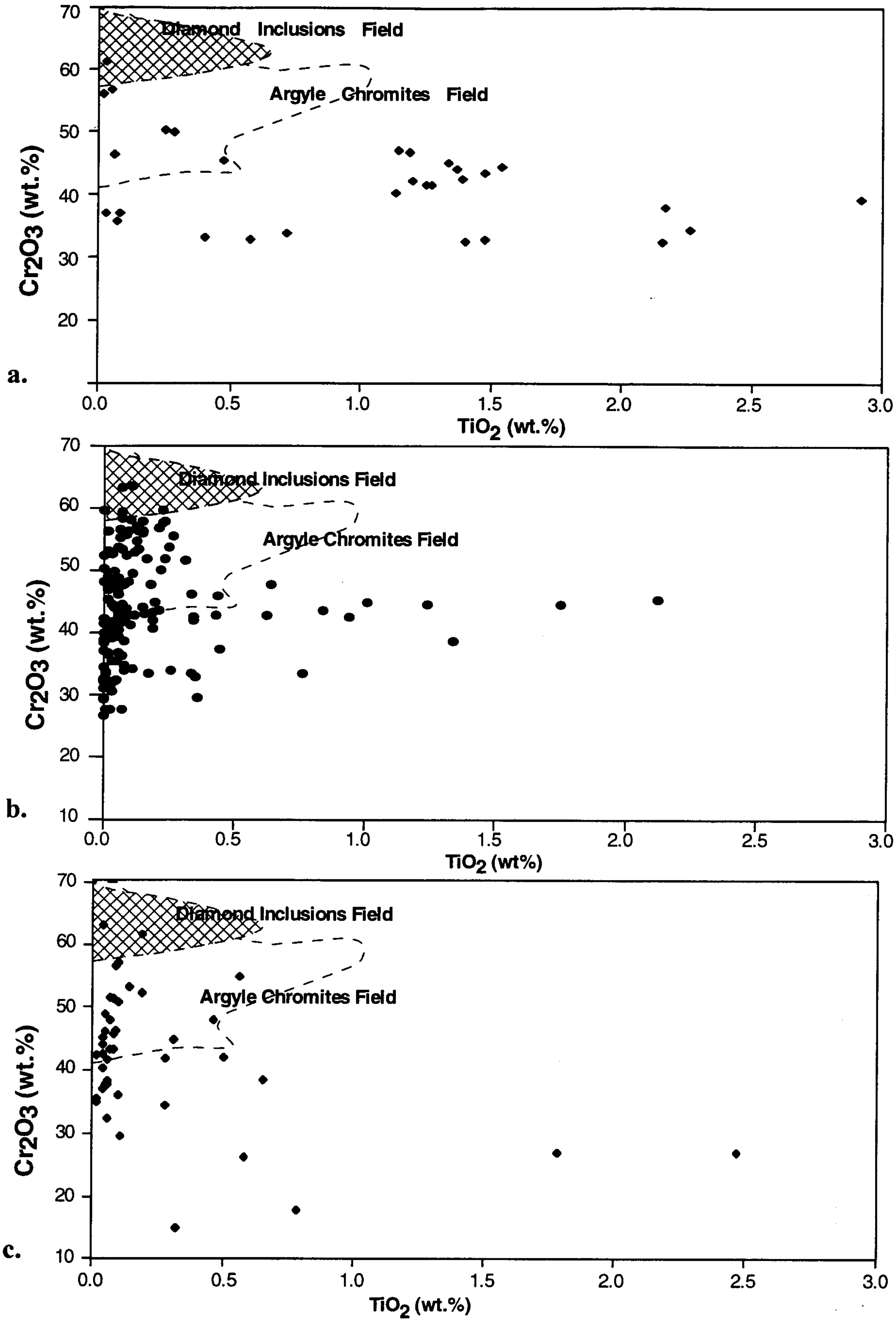


Figure 3. Cr_2O_3 versus TiO_2 cross plot of chromites

a. In crushed bedrock samples

b. For additional grains from crushed bedrock samples KW-21 and KW-22

c. In bedrock thin sections

resided in a highly alkaline magma such as kimberlite, lamproite or ultramafic lamprophyre, which may be desirable exploration targets (Griffin and Ryan, 1995).

It should be noted that contents of these elements have to be determined by a proton microprobe in order to be comparable to the discrimination developed by Griffin and co-workers in Australia. Our analyses (Appendices 1 and 3) indicate that several of the Ni and Zn contents have the potential for these chromites to be derived from kimberlites/lamproites. However, it is impossible to determine if these chromites were indeed xenocrysts. Griffin *et al.* (1994) suggests that Ga contents might discriminate between xenocrysts and phenocrysts, but no reliable Ga contents have been determined in the Wapiti area.

Most of the indicator chromites (DIC's and Argyle chromites) are from the Foothills belt (Figure 1), but this result might be somewhat biased because there is more bedrock exposed in the Foothills than in the Plains and most of the samples are from the Foothills.

5.2 Garnet

Garnets are classified according to Dawson and Stephens (1975), and this classification indicates that no G9 or G10 garnets are present (low Cr contents). Nevertheless, there are several Group 5 (G5) eclogitic garnets (Table 2 and Appendices). G5 garnets are believed to indicate the presence of kimberlitic or eclogitic source rocks. The garnet compositions are plotted in a ternary CaO-MgO-FeO diagram, proposed by Dufresne *et al.* (1996). Figure 4 indicates that some of these G5's fall in the diamond inclusions field. Most G5's were collected in the Foothills belt (Figure 1), but one G5 grain was found in a bentonite sample from the Plains area (KW-10) along Pinto Creek. This sample was collected at the same site as the bentonite sample described by Eccles *et al.* (1998, p.42).

However, it should be noted that many of these G5 garnets have relatively high Fe contents (over 22%) and are more likely regional almandines of crustal origin, and not true deep eclogitic garnets (Schulze, 1997).

5.3 Pyroxene

Pyroxenes are classified according to Stephens and Dawson (1977). Sample KW-11 (in the Outer Foothills) contains a low Cr-diopside (clinoproxene Group 4), which might indicate a kimberlite/lamproite source. Other pyroxenes were found in the thin sections (see chapter on Petrography of Selected Samples), but these grains were not microprobed.

5.4 Picro-Ilmenite

Ilmenite from kimberlite is Mg-rich picro-ilmenite, which is distinguished from crustal ilmenite by its higher concentrations of MgO (>3%) and Cr_2O_3 (>0.3%). A picro-ilmenite (consequently indicating a kimberlite source) was found in sample KW-20, which is located along the Cutbank River in the Plains area.

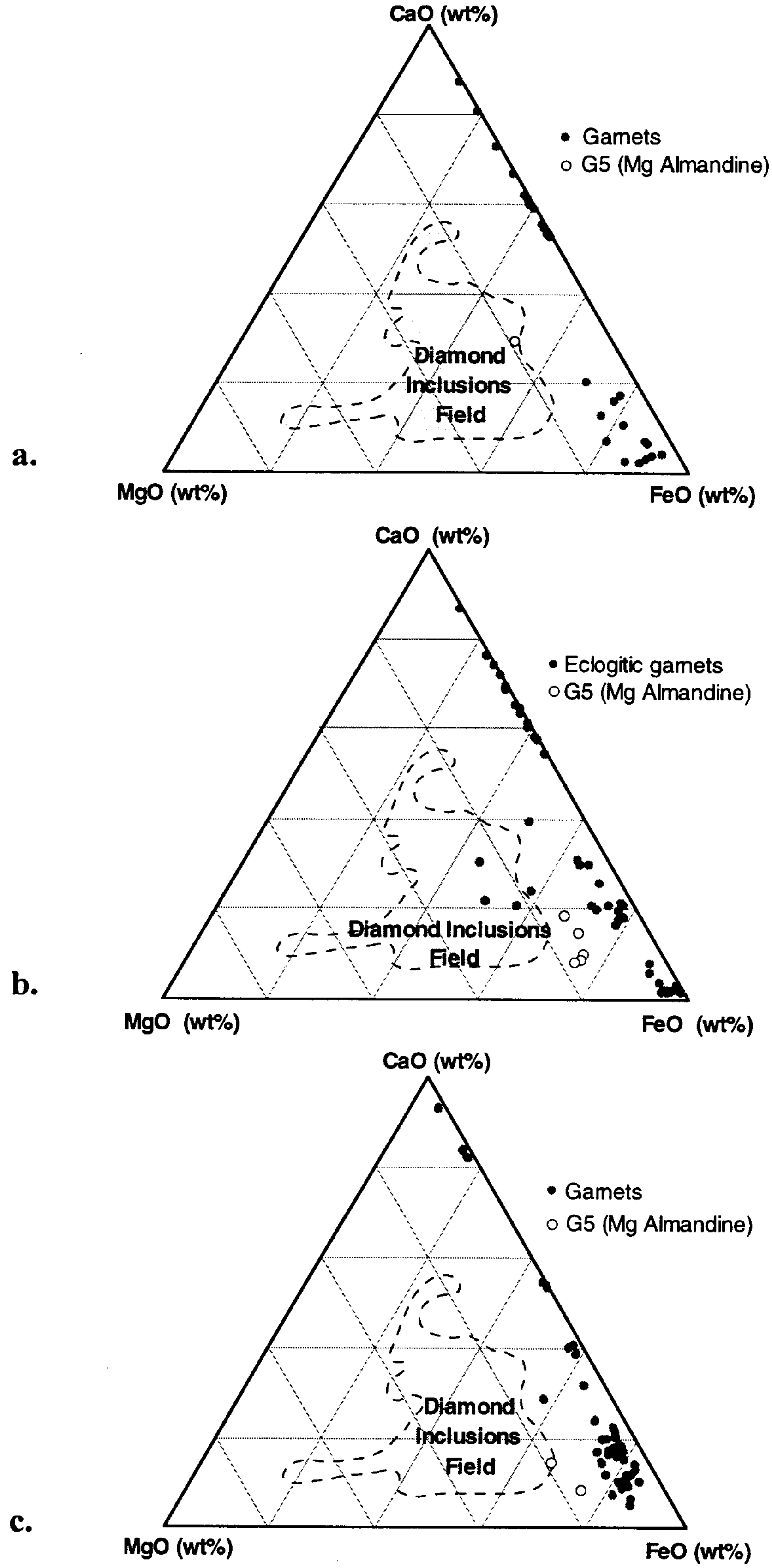


Figure 4. Ternary diagram of eclogitic garnets
a. From crushed bedrock samples
b. For additional grains from crushed bedrock samples KW-21 and KW-22
c. In bedrock thin sections

5.5 Serpentine

Serpentine clusters were found in several of the thin sections (see chapter on Petrography of Selected Samples). Serpentine may indicate altered ultrabasic rocks, such as peridotites and kimberlites. Serpentine forms by the action of water on olivine or pyroxene. Thus, the presence of serpentine supports the prior existance of ultrabasic rocks that were also indicated by the other minerals.

5.6 Kyanite

Kyanite was found in samples KW-7, KW-15 and KW-18. Kyanite is fairly typical for eclogites and indicates this type of rock existed in the area. Kyanite is also common in some (non-diamondiferous) amphibolite facies metamorphic rocks. Nevertheless, the co-existance of kyanite with the other indicator minerals helps to confirm the presence of ultramafic igneous rocks in the Kakwa/Wapiti area.

5.7 Thin sections versus Mineral Plugs

Indicator mineral grains are generally more easily identified in thin section than under the binocular microscope, although it requires an experienced petrographer to do the thin section work.

6 Petrography of Selected Samples

Seven samples from the Brazeau Formation were analyzed in reflected and transmitted light by means of a Zeiss polarizing microscope, using several polished thin sections per sample. Special attention was paid to identifying potential diamond indicating minerals. In the Kakwa/Wapiti samples, only garnet, chromite, ilmenite and possibly serpentine might be considered as potential diamond indicators. The chromite group is not differentiated because it comprises petrographically similar minerals such as beresovskite, picro-chromite and picotite. Subsequent microprobing revealed the presence of picro-chromites (DIC's) that may indicate (diamondiferous) ultramafic rocks (Appendix 3).

6.1 Sample KW2 (Thin Sections: A, B, C, D and E)

6.1.1 Stratigraphic Unit: Brazeau Formation

6.1.2 Rock Name: Subfeldspathic lithic wacke

6.1.3 Macroscopic Description

The rock is medium-grained and equigranular, consisting of dark and light mineral grains. Particles of mudstone, up to 5 mm in size, are randomly included in a medium-grained groundmass. On a fresh surface, the sample is grey in colour. Some intergranular pores occur in the groundmass.

6.1.4 Microscopic Description

The rock consists of very tightly packed lithic grains and mineral particles. They are subangular to angular in shape and 0.2 - 0.6 mm in size. Several grain types are evenly distributed in the rock space and among the size grades. The most common mineral particles are quartz and feldspar, with feldspar being mostly plagioclase. Potassium feldspar, microcline and perthite are less common. The anorthite content of the plagioclase (10 grains determined by the universal stage) varies from 6% (albite) to 22% (oligoclase). Other minerals occur in accessory or trace amounts.

Irregularly shaped intraclasts of mudstones are randomly included in the sediment. The grains are cemented by very fine-grained mica. Due to the tight packing, the intergranular cement is sparse. Structural porosity is ubiquitous and occupies about 15% of the volume. The voids, up to 0.4 mm in size, are randomly distributed between grains.

Modal Content:

Lithic particles	~60%
Quartz	~30%
Feldspar	~4%
Other minerals	~5%
Clay cement	~1%

Lithic Fragments:
- Chert (common)
- Carbonaceous pieces (common)
- Quartzite (minor)
- Mudstone (rare)
- Crystalline schist (rare)
- Granitic fragments (minor)
- Volcanic fragments (rare)

Other Minerals:
- Chalcedony (minor)
- Muscovite (minor)
- Biotite (minor)
- Chlorite (minor)
- Clay mineral (minor)
- Glauconite (rare)

Heavy Minerals:
- Epidote (common)
- Rutile (minor)
- Anatase (minor)
- Sphene (5 grains)
- Kyanite (1 grain)
- Xenotime (2 grains)
- Zircon
- Corundum (2 grains)
- Tourmaline (1 grain)

Potential Diamond Indicator Minerals:
- **Chromite** (4 grains)
- **Serpentine** (Several clusters)
- **Garnet** (1 grain)

6.1.5 Comments

The detrital particles came from the following sources: plutonic, metamorphic, volcanic and sedimentary rocks. The chert particles and chalcedony are possibly products of epithermal silicification of volcanic material. Some of them show porphyritic textures. Some volcanic particles with trachytic texture are included in the sample. Crystalline schist, granite fragments, quartz and the majority of feldspar result from erosion of a plutonic-metamorphic massif.

Diamond indicating minerals occur as very small grains. The garnet grain is 0.06 mm in size. Chromites vary in size from 0.08 mm to 0.15 mm. Two of them are totally opaque, while another two grains are translucent, brown-red in colour. One of these grains plots in the Argyle chromites field (Appendix 3). Serpentine clusters, up to 0.5 mm in size, occur randomly in the sample. Serpentine and chromite might be derived from the same ultrabasic source. The origin of the garnet is uncertain.

6.2 Sample KW4 (Thin Sections: A, B, C, D and E)

6.2.1 Stratigraphic Unit: Coalspur Formation (Entrance equivalent)

6.2.2 Rock Name: Carbonate cemented lithic wacke

6.2.3 Macroscopic Description

The rock is fine- to medium-grained. On a freshly broken surface, it is light-grey in colour. An intensive reaction with HCl indicates abundant carbonate content. A bedding fissility of the sample is distinctive.

6.2.4 Microscopic Description

The detrital grains are up to 0.5 mm in size, subangular to angular in shape and generally equigranular. However, elongated grains display some preferred orientation parallel to bedding. The grains are well sorted, very loosely packed and cemented with carbonate, which most likely is calcite or aragonite or both. The cement is microcrystalline, frequently fibrous and has radial texture. It occupies about 50% of the rock volume. Some grains show a distinctive, although not very high, optical biaxiality typical for aragonite.

The detrital feldspar is mostly plagioclase. It is usually very clear with only minor alteration to sericite. Anorthite content, determined on 10 grains on the universal stage, varies from 36% to 40% (andesine). Microcline is much less frequent. Both feldspars are well preserved.

Modal Content:

Lithic particles	~25%
Quartz	~15%
Feldspar	~5%
Other minerals	~5%
Carbonate cement	~50%

Lithic Particles:

- Chert (common)
- Carbonaceous pieces (less common)
- Crystalline schist (minor)
- Granitic (minor)
- Volcanic pieces (rare)

Other Minerals:

- Chalcedony (minor)
- Muscovite (minor)
- Biotite (minor)
- Chlorite (minor)
- Celadonite (rare)

Heavy Minerals:

Epidote (common)	Magnetite (2 grains)	Zircon (4 grains)
Rutile (>5 grains)	Tourmaline (1 grain)	Anatase (>5 grains)
Sphene (3 grains)		

Potential Diamond Indicator Minerals:

Chromite (5 grains)	**Ilmenite** (>10 grains)
Garnet (2 grains)	**Serpentine** (7 clusters)

6.2.5 Comments

The origin of the lithic particles and grains is similar to those in sample KW2. However, feldspar-plagioclase included in the rock is more calcic (around 40% compared to around 20% for sample KW2) than feldspar in the KW2 sample.

Serpentine clusters occur more frequently than in sample KW2, and may indicate a precursor ultramafic rock, such as kimberlite. In addition, three more potential diamond indicator minerals occur in the sample: chromite, garnet and ilmenite. Chromite occurs as totally opaque grains and as translucent red brown grains. The grains are frequently broken and are up to 0.2 mm in size. Two of the grains were microprobed (Appendix 3 and Figure 2C), but no DIC or Argyle field compositions were determined. Garnet occurs as angular fragments of larger grains, up to 0.2 mm in size, but they were not microprobed. Grains of ilmenite are numerous. In each thin section, there are over 10 grains of ilmenite of different size and shape. They have not been microprobed to ascertain if picro-ilmenite is present.

6.3 Sample KW14 (Thin Sections: A, B, C, D, E and F)

6.3.1 Stratigraphic Unit: Brazeau Formation

6.3.2 Rock Name: Lithic wacke.

6.3.4 Macroscopic Description

The sample consists mainly of subangular lithic particles of variable size and shape. The principal groundmass is coarse-grained. The mudstone intraclasts included in the groundmass are of pebble size (0.5 cm to 5 cm). An extensive structural porosity is ubiquitous. The rock is brownish grey and very brittle.

6.3.5 Microscopic Description

Lithic particles, subangular and angular in shape, are predominant in the rock. Their size is variable up to 2 mm. Subangular quartz grains, up to 0.5 mm in size, are less common. Large intraclasts of mudstone and siltstone, subrounded in shape and up to 8 mm in size, are also present. The quartz grains and lithic particles are clast supported. Intergranular pores, up to 1 mm in size, are ubiquitous. The voids occupy about 15% of the rock volume. Scarce cementing matter is a fine-grained clay, yellow-brown in colour. Two tiny grains of native gold, up to 5 microns in size, have been found within lithic fragments. The origin of this gold is uncertain.

Modal Content:

Lithic particles	~70%
Quartz	~15%
Cement and other	~1%
Porosity	~15%

Lithic Particles:

Chert (most common)
Carbonaceous shale (common)
Mudstone (common)
Siltstone (common)
Chalcedonite (minor)
Fine-grained wacke (minor)
Quartzite (minor)
Crystalline schist (minor)

Other:

Chalcedony (minor)
Muscovite (rare)
Carbonaceous particles (rare)

Heavy Minerals:

Sphene (1 grain)	Zircon (7 grains)
Tourmaline (1 grain)	Rutile (4 grains)

Potential Diamond Indicator Minerals:
Garnet (10 grains)

6.3.5 Comments

Chert particles are dominant in the sample, and particles of granitic origin were not observed. Garnet grains, up to 0.3 mm in size, frequently are cracked. Some of them contain inclusions of highly birefringent grains (pyroxene?). None of these grains were microprobed.

6.4 Sample KW17 (Thin Sections: A, B, C, D and E)

6.4.1 Stratigraphic Unit: Brazeau Formation

6.4.2 Rock Name: Calcareous lithic wacke

6.4.3 Macroscopic Description

Psammitic equigranular rock consisting of very fine-grained particles of quartz and light grey carbonate cement. The rock is grey-yellowish in colour. The effervescence with HCl is strong.

6.4.4 Microscopic Description

The subangular grains of quartz and lithic cherts, up to 0.25 mm in size, are the dominant detrital components. Subhedral detrital grains of dolomite, up to 0.1 mm in size, are common. Chalcedony grains, heavy minerals and carbonaceous particles are less common, and siltstone grains are rare. One particle of glauconite, 0.1 mm in size, exists. In general, the clastic particles are well sorted, loosely packed and cemented by fine-grained micrite calcite. Some very fine-grained clay is included in the cementing calcite. Locally, the interstitial cement is enriched in vermiculite.

Zircon, tourmaline and rutile are most common among the heavy mineral grains, whereas sphene, xenotime and cassiterite are less common. One very small particle of native gold, about 1 micron in size, was found. Some round garnet grains occur, which are up to 0.13 mm in size. Fine-grained and highly birefringent minerals are included in some garnets.

Modal Content:

Quartz	~25%
Lithic particles	10-15%
Dolomite	~5%
Other minerals	>5%
Calcite-clay cement	~50%

Lithic particles:

Chert (most common)
Carbonaceous particles (common)
Siltstones (rare)

Other minerals:

Chalcedony (minor)
Biotite (rare)
Glauconite (rare)

Heavy Minerals:

Zircon
Tourmaline
Rutile
Sphene
Cassiterite

Potential Diamond Indicator Mineral:

Garnet (19 grains)

6.4.5 Comments

None of the heavy minerals were microprobed.

6.5 Sample KW20 (Thin Sections: A, B, C, D, E and F)

6.5.1 Stratigraphic Unit: Coalspur Formation

6.5.2 **Rock Name:** Calcareous lithic wacke.

6.5.3 Macroscopic Description

The rock is macroscopically identical to sample KW17. However, bedding fissility is more pronounced in sample KW20.

6.5.4 Microscopic Description

The clastic particles are mostly angular and subangular in shape, and are about 0.2 mm in size. Rounded grains are uncommon. The grains are loosely packed and display a weak preferred orientation parallel to the bedding plane.

Feldspar is mostly plagioclase with anorthite content ranging from oligoclase to andesine. Ten plagioclase crystals were analysed on the universal stage in the cross section perpendicular to X. The anorthite contents are: 20%, 25-31%, 30%, 32%, 33%, 28-33%, 36%, 36%, 40%, 47%. The crystals are usually broken. Some of them are zonally-textured. They are commonly twinned accordingly to the albite law. Plagioclase is well preserved with only insignificant sericite alteration. In a few places, microcline grains randomly occur. Broken fragments of myrmekite feldspar are rare.

Lithic particles are mostly chert and carbonaceous fragments. Minor broken fragments of altered volcanic glass (hyaloclasites) occur in a few places, but definite volcanic grains are rare. Some of the volcanic pieces have trachytic textures. Their feldspar (anorthoclase?) is lathy-textured and polysynthetically twinned. However, due to the very fine-grained crystals, other optical characteristics were impossible to obtain.

The rock contains a lot of potential diamond indicator minerals. The most interesting are chromites, up to 1.5 mm in size, showing colours from light brown to opaque. Other frequent potential diamond indicator minerals are garnet and ilmenite. One pyroxene and 8 clusters of serpentine were also found.

Modal Content:

Lithic particles	~15%
Quartz	~10%
Feldspar (plagioclase + microcline)	>10%
Other minerals	5-10%
Calcite cement	45-55%

Lithic Particles:

Carbonaceous (common)	Chert (common)
Volcanic (rare)	Siltstone (rare)
Crystalline schist (rare)	

Other Minerals:

Dolomite (common)	Rutile (rare)
Biotite (minor)	Xenotime (rare)

Epidote (minor)	Sphene (rare)
Chlorite (rare)	Sphalerite (rare)
Zircon (rare)	

Potential Diamond Indicator Minerals (in 6 thin sections):

Ilmenite (103 grains)
Garnet (100 grains)
Chromite (10 grains)
Pyroxene (1 grain)
Serpentine (8 clusters)

6.5.5 Comments

The thin sections from this sample contain abundant garnet (100 grains) and ilmenite (103 grains). The garnets are relatively low in Mg (as shown by the analyses in Appendix 3) and are almandines of probable regional metamorphic origin. The ilmenites were not analyzed, but a grain separated by heavy liquids is a picro-ilmenite with 16% MgO (Appendix 1). Eight chromite grains were microprobed (Appendix 3 and Figure 2C), but none plot in the Diamond Inclusion (DIC) or Argyle fields. The serpentine clusters are probably altered olivine grains.

6.6 Sample KW21 (Thin Sections A, B, C, D and E)

6.6.1 Stratigraphic Unit: Brazeau Formation

6.6.2 Rock Name: Lithic arenite.

6.6.3 Macroscopic Description

The rock is fine-grained and grey in colour. A bedding fissility is well pronounced. The rounded particles of mudstone, up to 1 cm in size, and small coal pieces are randomly present in the rock.

6.6.4 Microscopic Description

The grains, which are rather poorly sorted, range in size from 0.1 to 0.4 mm, are mostly subangular to angular in shape and tightly packed. The cement matrix consists of fine-grained clay minerals that are greenish-brown. Insignificant structural porosity exists in the cement. With the exception of the micaceous particles, the other detrital grains do not show a preferred orientation in the bedding plane.

The most common grains are lithic particles of chert, cherty siltstone and volcanic pieces. The volcanic particles show a fine-grained trachytic matrix with random phenocryst feldspar. A larger feldspar was determined as sanidine.

Among the mineral particles, quartz and plagioclase are most frequent. Feldspar grains are mostly very clean with no alteration. A dozen of randomly choosen plagioclase crystals were analysed on the universal stage and their anorthite contents are: 0%, 10%, 20%, 21%, 23%, 29%, 33%, 35%, 37%, 39%, 42% and 50-58%. Potassium-feldspar grains (microcline) are rare.

The potential diamond indicator minerals are chromites and garnets. The chromite grains are up to 0.25 mm in size and are variable in colour ranging from brown translucent to reddish semi-opaque. Some spinels are euhedral in shape. Garnet grains are less common and are up to 0.08 mm in size.

Modal Content:

Lithic particles	~45%
Quartz	~20%
Feldspar	~20%
Other minerals	>5%
Cement clay	5-10%

Lithic Particles:

Chert (most common)	Mudstone (minor)
Volcanic particles (common)	Shale (minor)
Carbonaceous pieces (less common)	Quartzite (minor)
Siltstone (less common)	Mica schist (minor)

Other Minerals:

Dolomite (minor)	Muscovite (minor)
Biotite (minor)	Serpentine (minor)
Chlorite (minor)	Epidote (rare)
Chalcedony (minor)	Tourmaline (rare)
Microcline (minor)	Rutile and Zircon (rare)

Potential Diamond Indicator Minerals (in 5 thin sections):

Chromite (26 grains)
Garnet (11 grains)
Serpentine (several clusters)

6.6.5 Comments

Over 35 indicator grains were found in these thin sections. Nineteen chromite grains were probed, of which one falls in the diamond inclusions (DIC) field and two in the Argyle chromite field (Appendix 3 and Figure 2C). This supports the diamond inclusion chromites (DIC) found in samples KW8 and KW22, which are southeast of sample site KW21 (Figure 1 and Appendices 1 and 2). The one garnet grain probed (Appendix 3 and Figure 4C) is an almandine of probable regional metamorphic origin.

6.7 Sample KW22 (Thin Sections A, B, C, D and E)

6.7.1 Stratigraphic Unit: Brazeau Formation

6.7.2 Rock Name: Lithic wacke.

6.7.3 Macroscopic Description

The rock is fine-grained and light grey in colour. The bedding is weak. Some fractures occur in the bedding plane.

6.7.4 Microscopic Description

The clastic particles are up to 0.2 mm in size, subangular to angular in shape, moderately packed, and cemented by chlorite and fine-grained clay minerals. The flat clasts are oriented in the bedding plane.

The lithology of the clasts is mostly chert and cherty siltstone, and less commonly, carbonaceous pieces, quartzite, or schistose, micaceous and volcanic fragments. The volcanic grains generally have a trachytic texture, but some display a cherty matrix with included euhedral plagioclase phenocrysts. However, due to fine-grained crystals, the composition of most volcanic feldspars is not determinable.

The common mineral grains are quartz, plagioclase, microcline and detrital calcite. Plagioclase grains are frequently not altered, and twinning lamellae are common. A dozen randomly chosen grains were analysed by means of the universal stage, and their anorthite content are as follows: 0%, 2%, 9%, 16%, 23-56%, 26%, 26%, 33%, 33%, 35%, 37%, and 46%. They are mostly crushed pieces of larger crystals. Zonal texture is noticeable. The sericitized plagioclase crystals were not analysed on the universal stage.

Less common mineral particles are chlorite, biotite and muscovite. Tourmaline, zircon, epidote, serpentine, magnetite also occur in small amounts. Traces of glauconite have been noticed as well.

Potential diamond indicator minerals are mostly garnets, up to 0.14 mm in size. Chromite grains, up to 0.1 mm in size, are less common.

Modal Content:

Lithic particles	~45%
Feldspar	~20%
Quartz	~15%
Other minerals	~5%
Cement clay	~15%

Lithic Particles:

- Chert (common)
- Siltstone (less common)
- Volcanic particles (minor)
- Carbonaceous pieces (minor)
- Shale (minor)
- Quartzite (minor)
- Mica schist (minor)

Other Minerals:

- Muscovite (minor)
- Biotite (minor)
- Chlorite (minor)
- Microcline(minor)
- Serpentine (minor)
- Epidote (are)
- Tourmaline (rare)
- Zircon (rare)
- Rutile (rare)
- Magnetite (rare)

Potential Diamond Indicator Minerals (in 5 thin sections):

- **Garnet (44 grains)**
- **Chromite (21 grains)**
- **Ilmenite (one grain)**
- **Pyroxene(?) (9 grains)**
- **Serpentine (several clusters)**

6.7.5 Comments

Garnet and chromite occur frequently in this sample. Amongst the garnets, two are relatively high in MgO and classify as G5 (Mg Almandine, see Appendix 3). No diamond indicator chromites were found among the grains analyzed (Appendix 3 and Figure 2C), but a diamond inclusion chromite was found at this sample site (Appendix 2 and Figure 2B). None of the pyroxene grains were analyzed.

7 Source Areas of Clastic Material

Clastic material in the sediments of the Wapiti area give information about possible source areas (see also Langenberg and Skupinski, 1996). Potential source areas are discussed below for volcanic and ultrabasic rock clasts.

7.1 Volcanic Rocks

Volcanic fragments are a common component of the clastic sediments in the Wapiti area. It is often assumed that plagioclase with oscillatory zoning is of volcanic origin. This explains the large percentages of volcanic detritus reported by Mack and Jerzykiewicz (1989) for post-Wapiabi sandstones. The Cadomin and Gladstone formations of the Luscar Group contain little feldspar and no plagioclase (Langenberg *et al.*, 1987). This indicates that volcanic sources were not available until late early Albian when extensive mountain ranges were emerging from the accretion to the North-American continent of various terranes to the west in British Columbia.

Volcanic rocks are uncommon in the Rocky Mountains and Omenica Belt, but the Slide Mountain Terrane of the Omenica Belt does contain felsic to intermediate volcanics and thus is a potential source for the Hinton sediments. However, another possibility is that more Cretaceous and Tertiary volcanics are present in the Foothills and Plains than is generally assumed and thus may represent more local sources of the volcanic material in the Kakwa/Wapiti area.

7.2 Ultrabasic Rocks

Ultrabasic intrusives (kimberlites) occur in the Buffalo Head Hills of northern Alberta (Skelton and Bursey, 1998; Hamilton *et al.*, 1999). These rocks could have contributed Diamond Inclusion Chromites and G5 garnets to the Cretaceous sediments of the Wapiti area, but this is unlikely because the general paleocurrent directions (which indicate the sediment source was to the west) contradict this possibility (Langenberg and Skupinski, 1996). Another possible source for ultrabasic detritus (including diamond indicator minerals) are the alkaline ultrabasic rocks in the Rocky Mountains of British Columbia described by Pell (1987), which include several ultramafic diatremes in the Golden-Columbia Icefields area. A diamond was recovered from the Jack Pipe in this kimberlite cluster (Pell, 1987). Consequently, these diatremes could have contributed ultrabasic detritus to the Wapiti sediments.

8 Conclusions

Bedrock sampling confirmed that minerals indicative of potentially diamondiferous ultramafic rocks are present in Cretaceous rocks of the Kakwa/Wapiti area, Alberta. Because the general provenance of the clastics in these sediments is from the west, the Buffalo Head Hills area, which is to the east, can not have been a source. The possibility remains that the indicator grains were derived from local sources, and that the composition of some of the heavy minerals indicates a diamondiferous kimberlite/lamproite source.

These conclusions are confirmed by similar indicator minerals in stream sediment (Eccles *et al.*, 1998) and till samples (Pawlowics *et al.*, 1998) of this area. However, finding ultramafic diatremes probably will be a continuing challenge for explorationists in the Alberta Foothills, because the topographic relief and the presence of magnetic sediments mask the magnetic signature of the rock. The indicator minerals are generally from the Upper Cretaceous Brazeau Formation, but they also include one diamond inclusion chromite from the lower Cretaceous Gates Formation. This might indicate that there were two periods of ultramafic (kimberlite/lamproite?) intrusion: one in the Maastrichtian around 70 Ma ago and an older one, possibly in the Aptian around 110 Ma ago.

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APPENDIX 1. MICROPROBE ANALYSES OF GRAINS FROM CRUSHED BEDROCK, SELECTED BY LORING LABORATORIES

SILICATES (43 grains)

Sample	Lab	SiO2	TiO2	Al2O3	Cr2O3	FeO	MnO	MgO	CaO	Na2O	K2O	Total	Mineral
KW-2	U. of A.	36.14	0.18	9.90	0.02	20.28	2.57	0.05	29.06	0.00	0.00	98.20	garnet
KW-2	U. of A.	35.24	1.60	6.44	0.00	20.37	0.12	0.22	33.83	0.01	0.01	97.84	garnet
KW-2	U. of A.	34.63	0.00	0.58	0.00	27.50	0.26	0.07	33.36	0.07	0.03	96.50	garnet
KW-2	U. of A.	36.72	0.40	19.76	0.04	16.86	21.90	1.42	2.23	0.01	0.00	99.32	garnet
KW-2	U. of A.	34.87	0.00	0.01	0.00	28.38	0.59	0.04	33.02	0.00	0.01	96.92	garnet
KW-2	U. of A.	36.33	0.48	7.44	15.49	4.50	1.30	0.12	32.03	0.00	0.00	97.67	garnet
KW-2	U. of A.	36.83	0.14	9.76	0.01	16.46	1.60	0.07	33.45	0.00	0.01	98.33	garnet
KW-2	U. of A.	37.46	1.17	13.61	0.00	12.22	0.44	0.20	33.66	0.00	0.03	98.79	garnet
KW-2	U. of A.	35.80	1.02	6.44	0.01	20.66	0.52	0.18	32.79	0.00	0.03	97.44	garnet
KW-2	U. of A.	35.38	1.60	8.04	0.00	19.98	1.52	0.26	30.31	0.05	0.01	97.15	garnet
KW-2	U. of A.	38.16	0.27	18.73	0.00	7.85	0.73	0.05	33.20	0.00	0.01	98.99	garnet
KW-2	U. of A.	37.51	0.00	22.41	0.03	31.44	2.98	4.59	2.85	0.01	0.00	101.82	garnet
KW-2	U. of A.	35.06	0.00	1.87	0.00	26.19	0.12	0.07	33.11	0.01	0.01	96.44	garnet
KW-2	U. of A.	36.38	0.10	21.06	0.00	21.99	17.35	1.14	1.72	0.03	0.03	99.78	garnet
KW-3	U. of A.	36.82	0.10	21.10	0.01	16.61	24.03	1.18	0.58	0.00	0.00	100.42	garnet
KW-3	U. of A.	36.29	0.16	20.65	0.00	22.49	18.68	0.68	1.03	0.04	0.00	100.01	garnet
KW-4	U. of A.	39.31	0.08	22.35	0.03	20.44	0.48	7.38	10.62	0.00	0.02	100.70	garnet
KW-4	U. of A.	34.23	0.04	0.15	0.02	28.19	0.31	0.11	32.67	0.00	0.00	95.72	garnet
KW-4	U. of A.	34.75	0.00	0.08	0.00	28.48	0.46	0.08	32.31	0.04	0.01	96.20	garnet
KW-4	U. of A.	34.05	0.01	0.15	0.00	28.43	0.35	0.03	32.79	0.02	0.01	95.81	garnet
KW-6	U. of A.	37.57	0.60	20.74	0.03	28.21	2.06	3.68	8.17	0.05	0.02	101.11	garnet
KW-6	U. of A.	33.67	0.00	0.31	0.02	27.72	0.60	0.23	32.24	0.00	0.02	94.80	garnet
KW-9	U. of A.	37.42	0.00	22.10	0.00	33.47	5.07	3.04	0.92	0.04	0.01	102.06	garnet
KW-9	U. of A.	37.49	0.29	21.56	0.00	30.21	1.75	3.98	5.22	0.01	0.00	100.51	garnet
KW-10	U. of A.	37.27	0.08	21.04	0.01	32.73	0.78	2.55	6.71	0.00	0.00	101.17	garnet
KW-10	U. of A.	37.66	0.00	22.01	0.03	35.11	0.89	4.34	1.09	0.02	0.01	101.16	garnet
KW-10	U. of A.	37.22	0.23	21.39	0.00	33.17	0.73	1.77	7.41	0.00	0.04	101.95	garnet
KW-10	U. of A.	40.57	1.81	13.09	0.00	20.17	0.11	7.08	11.27	1.19	0.01	95.31	**Mg Almandine (G5)**
KW-11	U. of A.	51.62	0.51	5.32	1.38	5.13	0.10	17.13	18.82	0.65	0.01	100.65	**low Cr Diopside**
KW-12	U. of A.	35.90	0.15	20.21	0.00	20.36	19.31	0.98	1.54	0.01	0.03	98.48	garnet
KW-14	U. of A.	34.77	0.26	20.84	0.00	16.44	23.41	0.91	0.71	0.03	0.02	97.37	garnet
KW-17	U. of S.	38.1	0.03	22.15	0	13.48	0.07	0	22.87	0.02	0	96.72	garnet
KW-17	U. of S.	38.14	0.03	23.08	0.01	12.66	0.4	0.02	22.82	0.01	0	97.16	garnet
KW-17	U. of S.	37.98	0.1	23.33	0.03	12.11	0.18	0	23.09	0.08	0	96.9	garnet
KW-16	U. of S.	38.36	0.1	23.56	0.01	11.92	0.54	0.04	22.73	0	0	97.27	garnet
KW-22	U. of S.	36.6	0.1	24.37	0.03	10.44	0.47	0.04	22.27	0.01	0	94.33	garnet
KW-21	U. of S.	38.57	0.1	24.31	0	11.45	0.4	0.07	23.07	0	0	97.97	garnet
KW-20	U. of S.	36.81	0.07	23.29	0.03	11.97	0.48	0.04	22.5	0	0	95.19	garnet
KW-15	U. of S.	38.01	0.06	23.69	0.02	11.79	0.12	0.05	22.45	0.01	0	96.21	garnet
KW-19	U. of S.	38.38	0.05	23.44	0.05	11.49	0.25	0.04	22.91	0	0	96.6	garnet
KW-22	U. of S.	37.29	0.22	20.42	0.05	31.2	3.5	0.99	6.25	0.04	0	99.95	garnet
KW-22	U. of S.	36.43	0.04	20.56	0	34.91	7.66	0.24	0.29	0.02	0	100.14	garnet
KW-17	U. of S.	36.26	0.02	20.17	0	30.96	9.41	0.11	1.41	0.1	0	98.44	garnet

APPENDIX 1 (Continued)

OXIDES (31 grains)

Sample	Lab	ZrO2	TiO2	Al2O3	Cr2O3	Nb2O5	FeO	MnO	MgO	NiO	ZnO	V2O3	Total	Mineral
KW-1	U. of A.	nd	0.04	29.95	37.46	nd	13.49	0.21	15.30	0.13	0.12	0.18	96.88	chromite
KW-2	U. of A.	nd	0.59	7.33	33.38	nd	42.20	0.28	12.35	0.31	0.00	0.05	96.48	**A chromite**
KW-2	U. of A.	nd	0.50	15.86	45.84	nd	25.16	0.38	9.91	0.06	0.04	0.17	97.92	chromite
KW-4	U. of A.	nd	1.56	14.08	44.92	nd	24.60	0.27	12.56	0.20	0.00	0.20	98.38	**A chromite**
KW-4	U. of A.	nd	1.16	15.22	47.48	nd	19.41	0.22	14.28	0.23	0.00	0.14	98.13	**A chromite**
KW-4	U. of A.	nd	1.41	17.20	42.83	nd	21.28	0.27	13.63	0.21	0.00	0.15	96.98	**A chromite**
KW-4	U. of A.	nd	1.27	17.29	41.83	nd	23.79	0.20	12.87	0.20	0.00	0.19	97.62	chromite
KW-4	U. of A.	nd	0.03	11.67	56.60	nd	19.60	0.34	10.01	0.05	0.00	0.27	98.57	chromite
KW-4	U. of A.	nd	0.08	13.05	46.76	nd	27.82	0.40	10.02	0.11	0.01	0.14	98.39	chromite
KW-4	U. of A.	nd	0.09	28.12	37.38	nd	16.78	0.23	14.22	0.11	0.14	0.21	97.30	chromite
KW-8	U. of S.	0	0.73	24.29	34.25	0.01	25.72	0.22	14.87	0.18	0.11	nd	100.40	chromite
KW-8	U. of S.	0.01	0.27	12.11	50.64	0	22.47	0.31	13.51	0.16	0.05	nd	99.54	**A chromite**
KW-8	U. of S.	0.05	0.06	10.34	57.25	0	18.96	0.29	11.76	0.02	0.13	nd	98.86	**A chromite**
KW-8	U. of S.	0	0.04	7.09	61.68	0	17.14	0.36	11.74	0	0.12	nd	98.20	**DI Chromite**
KW-12	U. of A.	nd	2.17	6.79	32.97	nd	33.11	0.25	3.69	0.11	0.13	0.26	79.48	chromite
KW-14	U. of A.	nd	0.42	31.12	33.56	nd	12.42	0.15	18.18	0.25	0.00	0.12	96.20	chromite
KW-14	U. of A.	nd	1.41	25.13	33.01	nd	21.00	0.24	15.64	0.21	0.00	0.17	96.81	chromite
KW-16	U. of S.	0.01	1.39	16.58	44.37	0.04	21.24	0.27	15.94	0.13	0.06	nd	100.03	chromite
KW-17	U. of S.	0.08	2.18	15.93	38.42	0.05	30.51	0.22	11.58	0.21	0.06	nd	99.23	chromite
KW-19	U. of S.	0.03	2.28	12.76	34.89	0	36.39	0.31	7.76	0.19	0.19	nd	94.81	chromite
KW-20	U. of S.	0.07	55.6	0.53	1.2	0.21	26.67	0.27	16.28	0.18	0.02	nd	101.02	**Picro-ilmenite**
KW-20	U. of S.	0.01	2.94	12	39.82	0	30.91	0.23	12.53	0.22	0.06	nd	98.75	chromite
KW-21	U. of S.	0.05	1.49	31.06	33.26	0	13.21	0.19	21.54	0.3	0.06	nd	101.18	chromite
KW-21	U. of S.	0	0.09	29.02	36.21	0.01	17.35	0.22	16.24	0.09	0.16	nd	99.41	chromite
KW-21	U. of S.	0	1.15	21.9	40.56	0.06	20.16	0.18	16.48	0.21	0.09	nd	100.80	chromite
KW-22	U. of S.	0	1.29	18.23	42.06	0.05	22.39	0.26	14.8	0.2	0.05	nd	99.32	chromite
KW-22	U. of S.	0.05	1.2	15.1	47.2	0	20.07	0.26	16.29	0.23	0.06	nd	100.50	chromite
KW-22	U. of S.	0.02	1.35	15.07	45.53	0.1	21.25	0.2	15.59	0.22	0.06	nd	99.39	chromite
KW-22	U. of S.	0	1.21	16.59	42.45	0.05	23.33	0.25	14.27	0.18	0.05	nd	98.40	chromite
KW-22	U. of S.	0	0.3	12.82	50.47	0	22.59	0.36	11.38	0.08	0.12	nd	98.12	chromite
KW-21	U. of S.	0	1.49	14.37	43.8	0	24.68	0.23	14.31	0.2	0.07	nd	99.17	chromite

A Chromite: Argyle type chromite
DI Chromite: Diamond Inclusion Chromite

APPENDIX 2. MICROPROBE ANALYSES (U. OF A.) OF ADDITIONAL GRAINS OF CRUSHED SAMPLES 21 AND 22

GARNET (50 GRAINS)

Sample	#	Na2O	MgO	Al2O3	SiO2	CaO	TiO2	Cr2O3	MnO	FeO	Total	Indicator
KW21	05-E8	0.00	0.81	20.48	36.57	0.21	0.09	0.00	24.94	17.84	100.94	
KW21	05-E9	0.06	0.16	19.96	36.26	0.68	0.08	0.00	19.67	22.98	99.85	
KW21	05-E10	0.00	0.68	20.75	36.25	0.35	0.13	0.00	18.02	24.62	100.80	
KW21	05-E11	0.00	2.49	21.56	37.75	6.33	0.06	0.00	11.22	22.08	101.49	
KW21	05-E16	0.04	1.21	21.02	37.26	7.09	0.12	0.03	2.70	31.45	100.90	
KW21	05-F2	0.03	0.63	20.93	37.04	0.83	0.06	0.00	27.83	13.58	100.94	
KW21	05-F5	0.02	0.90	21.10	37.51	8.57	0.13	0.00	0.91	32.00	101.15	
KW21	05-F10	0.02	1.42	21.45	37.49	7.72	0.07	0.00	1.78	31.07	101.02	
KW22	05-E1	0.00	0.97	20.00	36.03	0.90	0.28	0.00	16.92	25.79	100.89	
KW22	05-E5	0.01	0.64	20.07	36.54	1.42	0.29	0.00	23.74	16.97	99.69	
KW22	05-E6	0.00	0.98	20.76	36.68	0.58	0.07	0.02	8.04	33.93	101.06	
KW22	05-E7	0.00	0.15	20.75	36.00	0.44	0.11	0.02	11.73	31.91	101.10	
KW22	05-E11	0.00	0.97	18.84	36.43	0.46	0.00	0.00	10.11	32.11	98.92	
KW22	05-E14	0.03	0.69	19.66	36.43	3.33	0.37	0.01	25.28	14.58	100.38	
KW22	05-E15	0.00	1.11	20.82	35.87	0.54	0.21	0.02	9.30	32.67	100.54	
KW22	05-F17	0.05	0.73	18.59	36.44	4.78	0.61	0.00	25.85	13.26	100.31	
KW21	06-A11	0.03	5.41	20.33	38.36	5.78	0.05	0.00	0.60	28.84	99.40	G5
KW21	06-A12	0.02	0.08	6.81	36.25	30.88	0.37	0.00	1.12	22.76	98.30	
KW21	06-B2	0.00	0.12	9.17	36.87	31.50	0.42	0.02	1.06	19.87	99.01	
KW21	06-B6	0.01	1.58	20.95	37.16	11.70	0.10	0.00	2.61	26.22	100.32	
KW21	06-B8	0.00	0.56	20.55	36.07	0.60	0.27	0.00	4.21	38.53	100.79	
KW21	06-C8	0.00	2.70	20.86	37.89	7.27	0.15	0.00	4.85	27.15	100.87	
KW21	06-C9	0.02	4.24	20.00	38.40	15.43	0.32	0.00	1.63	19.97	100.02	
KW22	06-A1	0.00	1.72	20.93	37.32	6.71	0.32	0.00	3.40	30.59	100.99	
KW22	06-A2	0.04	2.25	20.45	37.21	11.69	0.97	0.01	1.93	25.65	100.19	
KW22	06-A5	0.00	0.66	21.29	37.11	8.42	0.05	0.01	1.65	31.89	101.08	
KW22	06-B3	0.01	6.72	20.19	38.34	3.12	0.00	0.00	0.65	29.65	98.69	G5
KW22	06-B10	0.02	8.44	21.53	39.11	7.85	0.40	0.03	0.97	21.88	100.22	
KW21	07-A5	0.03	0.37	4.44	34.45	32.66	3.79	0.00	0.42	21.27	97.43	
KW21	07-A6	0.00	0.15	9.73	36.91	32.48	0.68	0.01	0.74	18.75	99.43	
KW21	07-B1	0.01	1.83	21.44	37.55	5.66	0.08	0.02	7.35	27.54	101.49	
KW21	07-B5	0.00	0.02	20.95	37.42	22.92	0.00	0.00	0.20	12.84	94.34	
KW21	07-B7	0.00	0.17	13.49	37.85	35.27	0.42	0.00	0.42	11.09	98.71	
KW21	07-C4	0.00	0.05	25.09	37.87	23.05	0.10	0.00	0.22	10.19	96.58	
KW21	07-D3	0.00	0.13	9.49	37.01	34.30	0.56	0.00	0.38	15.21	97.07	
KW21	07-D8	0.02	0.10	17.91	38.18	36.87	0.74	0.01	0.17	5.71	99.70	
KW21	07-F3	0.05	0.21	14.75	33.71	29.41	1.08	0.05	0.16	15.60	95.00	
KW22	07-A3	0.00	1.96	21.42	37.96	8.48	0.15	0.01	0.31	31.00	101.30	
KW22	07-B3	0.03	9.27	22.05	39.73	11.28	0.21	0.01	0.39	17.07	100.05	
KW22	07-B4	0.00	0.21	16.71	37.91	29.61	0.37	0.01	1.30	13.27	99.39	
KW22	07-B6	0.00	0.11	0.00	35.23	33.07	0.01	0.01	0.31	28.07	96.80	
KW22	07-C1	0.00	2.17	21.66	37.90	11.28	0.12	0.02	3.57	23.72	100.42	
KW22	07-C4	0.01	0.15	13.52	37.69	33.73	0.40	0.00	0.92	11.80	98.22	
KW22	07-C5	0.02	5.95	21.70	38.19	3.78	0.18	0.16	0.92	29.68	100.58	G5
KW22	07-C6	0.03	10.20	22.65	39.91	7.76	0.13	0.05	0.46	18.55	99.74	
KW22	07-C7	0.00	0.04	8.70	36.35	30.05	0.08	0.00	1.24	21.77	98.24	
KW22	07-C9	0.04	5.59	22.15	38.05	7.04	0.14	0.04	0.98	25.94	99.96	G5

Sample	#	Na2O	MgO	Al2O:	SiO2	CaO	TiO2	Cr2O	MnO	FeO	Total	**Indicator**
KW22	07-C10	0.03	6.09	21.86	38.37	3.49	0.21	0.07	1.14	29.77	101.03	**G5**
KW22	07-C11	0.00	0.06	12.14	37.15	34.24	0.52	0.02	1.07	13.53	98.71	
KW22	07-D3	0.00	7.01	21.98	39.02	8.99	0.12	0.02	1.00	22.50	100.64	

CHROMITE (140 grains total)

Sample	#	Na2O	SiO2	CaO	NiO	MgO	Al2O3	TiO2	FeO	ZnO	V2O3	MnO	Cr2O3	Total	Indicator
KW21	05-E1	0.00	0.02	0.00	0.06	8.98	12.52	0.09	24.38	0.08	0.18	0.37	52.51	99.18	
KW21	05-E3	0.00	0.00	0.00	0.05	14.13	35.00	0.00	18.03	0.17	0.09	0.22	29.34	97.02	
KW21	05-E4	0.00	0.03	0.01	0.18	10.80	7.36	0.84	35.23	0.09	0.19	0.36	43.72	98.80	
KW21	05-E6	0.00	0.00	0.00	0.15	14.08	30.32	0.26	17.83	0.12	0.22	0.26	33.97	97.20	
KW21	05-E7	0.00	0.02	0.01	0.12	13.68	29.00	0.07	17.49	0.18	0.15	0.25	36.27	97.22	
KW21	05-E12	0.00	0.04	0.02	0.17	9.06	14.89	0.33	28.01	0.18	0.31	0.41	46.25	99.67	
KW21	05-E13	0.00	0.00	0.00	0.17	14.09	31.06	0.08	16.95	0.10	0.13	0.25	34.79	97.61	
KW21	05-E14	0.00	0.02	0.01	0.24	9.75	26.18	0.35	31.36	0.21	0.23	0.34	29.44	98.13	
KW21	05-E15	0.00	0.04	0.00	0.29	8.93	20.13	2.15	42.66	0.17	0.54	0.27	22.60	97.77	
KW21	05-F1	0.00	0.01	0.00	0.06	12.08	24.79	0.05	18.82	0.13	0.10	0.29	41.38	97.71	
KW21	05-F3	0.02	0.00	0.00	0.13	11.14	20.60	0.11	22.78	0.20	0.18	0.31	42.86	98.34	
KW21	05-F4	0.00	0.03	0.00	0.11	10.00	14.73	0.16	21.76	0.19	0.20	0.39	51.97	99.53	
KW21	05-F6	0.01	0.09	0.00	0.17	11.95	14.76	0.63	22.70	0.07	0.22	0.31	47.75	98.65	
KW21	05-F7	0.01	0.00	0.00	0.15	14.91	36.80	0.01	16.05	0.26	0.18	0.21	27.56	96.12	
KW21	05-F8	0.00	0.00	0.00	0.16	15.62	34.77	0.02	14.44	0.14	0.13	0.20	31.28	96.76	
KW21	05-F9	0.00	0.08	0.03	0.29	11.00	12.14	2.12	27.48	0.06	0.47	0.34	45.32	99.32	
KW21	05-F11	0.01	0.01	0.03	0.14	10.62	22.85	0.08	21.72	0.35	0.28	0.35	42.14	98.58	
KW21	05-F12	0.00	0.01	0.05	0.17	8.77	15.92	0.43	29.46	0.10	0.30	0.43	42.88	98.51	
KW21	05-F13	0.02	0.01	0.01	0.10	13.16	29.66	0.04	17.90	0.26	0.17	0.21	35.56	97.08	
KW22	05-E2	0.00	0.08	0.00	0.23	11.23	16.66	0.94	25.68	0.16	0.32	0.34	42.60	98.23	
KW22	05-E3	0.00	0.10	0.02	0.17	11.53	9.05	0.27	20.78	0.09	0.16	0.39	55.65	98.20	
KW22	05-E4	0.00	0.01	0.00	0.09	12.67	23.57	0.10	17.65	0.16	0.27	0.29	42.76	97.58	
KW22	05-E8	0.00	0.10	0.03	0.34	13.79	7.53	0.76	39.80	0.01	0.14	0.30	33.38	96.17	
KW22	05-E12	0.00	0.00	0.00	0.09	13.76	21.50	0.06	14.94	0.06	0.04	0.30	46.28	97.03	
KW22	05-E13	0.00	0.00	0.00	0.17	9.86	22.20	0.44	26.01	0.18	0.14	0.38	37.44	96.81	
KW22	05-E16	0.00	0.00	0.00	0.14	11.20	19.60	0.16	22.79	0.09	0.12	0.38	43.17	97.65	
KW22	05-E17	0.00	0.02	0.00	0.04	8.40	8.64	0.00	21.27	0.11	0.00	0.42	59.80	98.69	
KW22	05-E18	0.00	0.01	0.00	0.08	8.54	10.33	0.25	24.93	0.15	0.00	0.50	53.89	98.67	
KW22	05-F1	0.00	0.05	0.02	0.15	11.69	7.61	0.62	33.38	0.00	0.03	0.31	42.84	96.70	
KW22	05-F2	0.00	0.00	0.00	0.12	13.99	32.08	0.00	17.62	0.16	0.00	0.18	32.64	96.78	
KW22	05-F3	0.00	0.00	0.00	0.08	14.92	37.05	0.00	15.99	0.13	0.00	0.16	26.66	94.97	
KW22	05-F4	0.02	0.01	0.00	0.18	15.18	37.45	0.03	16.03	0.08	0.00	0.20	27.69	96.85	
KW22	05-F5	0.00	0.01	0.00	0.13	11.79	26.75	0.05	21.91	0.30	0.05	0.30	36.93	98.23	
KW22	05-F6	0.02	0.01	0.02	0.22	13.77	32.04	0.03	18.62	0.20	0.05	0.24	32.24	97.43	
KW22	05-F7	0.00	0.01	0.00	0.12	11.46	19.61	0.10	18.47	0.16	0.07	0.33	48.41	98.74	
KW22	05-F8	0.01	0.02	0.02	0.13	8.06	21.35	0.15	24.23	0.57	0.12	0.59	44.04	99.30	
KW22	05-F9	0.00	0.01	0.00	0.04	8.10	15.77	0.19	28.25	0.06	0.04	0.40	45.05	97.91	
KW22	05-F10	0.00	0.00	0.00	0.01	10.26	11.85	0.08	19.69	0.01	0.00	0.37	56.12	98.39	
KW22	05-F12	0.01	0.00	0.00	0.09	15.20	36.31	0.00	14.75	0.09	0.00	0.16	29.40	96.01	
KW22	05-F13	0.01	0.01	0.00	0.02	10.16	17.24	0.00	21.71	0.13	0.00	0.35	48.21	97.85	
KW22	05-F14	0.00	0.00	0.00	0.05	11.64	21.33	0.03	18.84	0.10	0.00	0.32	44.75	97.06	
KW22	05-F15	0.00	0.00	0.00	0.07	12.85	24.19	0.03	17.42	0.09	0.00	0.28	41.69	96.61	
KW22	05-F18	0.00	0.04	0.00	0.09	6.45	7.06	0.07	24.54	0.32	0.01	0.58	59.51	98.67	
KW22	05-F19	0.00	0.00	0.00	0.13	13.58	31.51	0.01	19.11	0.11	0.00	0.28	31.65	96.39	
KW22	05-F22	0.01	0.00	0.00	0.00	8.59	17.30	0.19	28.31	0.32	0.00	0.37	42.11	97.19	
KW22	05-F24	0.03	0.00	0.00	0.00	10.39	15.98	0.00	20.53	0.26	0.00	0.36	50.37	97.91	
KW21	06-A1	0.01	0.02	0.00	0.07	12.13	11.55	0.10	18.09	0.12	0.00	0.34	56.40	98.80	Argyle

Sample	#	Na2O	SiO2	CaO	NiO	MgO	Al2O3	TiO2	FeO	ZnO	V2O3	MnO	Cr2O3	Total	Indicator
KW21	06-A2	0.01	0.02	0.00	0.02	10.77	12.32	0.15	17.39	0.04	0.00	0.36	58.07	99.13	
KW21	06-A3	0.01	0.00	0.00	0.07	13.77	30.57	0.00	17.88	0.12	0.00	0.22	34.57	97.22	
KW21	06-A4	0.01	0.00	0.00	0.07	13.83	26.56	0.00	16.46	0.11	0.00	0.24	39.96	97.24	
KW21	06-A5	0.02	0.00	0.00	0.05	12.55	24.81	0.00	18.20	0.15	0.00	0.28	41.52	97.58	
KW21	06-A6	0.01	0.02	0.02	0.04	10.60	19.44	0.02	19.33	0.12	0.05	0.31	48.83	98.77	
KW21	06-A7	0.00	0.02	0.01	0.08	9.03	12.20	0.09	20.49	0.13	0.09	0.39	55.91	98.44	
KW21	06-A8	0.00	0.02	0.03	0.06	11.89	18.45	0.01	17.85	0.12	0.06	0.30	49.03	97.82	
KW21	06-A9	0.00	0.02	0.01	0.04	11.32	21.06	0.02	19.45	0.12	0.00	0.31	45.46	97.79	
KW21	06-A10	0.00	0.01	0.00	0.08	8.82	11.40	0.06	21.71	0.02	0.02	0.39	56.59	99.10	
KW21	06-A13	0.00	0.05	0.03	0.18	10.05	14.14	0.12	17.48	0.19	0.15	0.42	54.95	97.78	
KW21	06-B1	0.00	0.04	0.01	0.15	11.17	22.96	0.08	18.39	0.26	0.08	0.34	43.90	97.38	
KW21	06-B3	0.00	0.02	0.00	0.17	12.67	31.01	0.11	17.37	0.13	0.08	0.29	34.16	96.01	
KW21	06-B4	0.01	0.00	0.00	0.17	12.35	26.62	0.05	16.47	0.14	0.14	0.32	40.57	96.83	
KW21	06-B9	0.00	0.03	0.00	0.17	15.81	35.46	0.03	14.47	0.13	0.04	0.16	30.66	96.96	
KW21	06-B10	0.00	0.04	0.01	0.15	14.20	31.27	0.08	16.97	0.17	0.05	0.23	33.96	97.13	
KW21	06-B11	0.00	0.03	0.03	0.04	11.07	18.57	0.11	18.80	0.26	0.10	0.36	49.50	98.86	
KW21	06-C1	0.00	0.03	0.03	0.11	11.15	19.00	0.08	19.67	0.15	0.13	0.37	47.89	98.61	
KW21	06-C2	0.00	0.06	0.02	0.09	10.21	11.42	0.12	19.58	0.21	0.10	0.41	57.21	99.44	
KW21	06-C3	0.02	0.00	0.01	0.05	11.33	21.05	0.19	21.44	0.17	0.00	0.34	43.24	97.82	
KW21	06-C4	0.00	0.00	0.00	0.06	12.10	24.28	0.05	18.02	0.14	0.00	0.31	42.52	97.48	
KW21	06-C5	0.00	0.00	0.01	0.06	12.03	22.91	0.05	17.68	0.09	0.00	0.29	44.23	97.34	
KW21	06-C6	0.01	0.00	0.00	0.07	12.61	24.79	0.19	18.44	0.18	0.00	0.30	40.77	97.37	
KW21	06-C7	0.00	0.00	0.00	0.10	13.30	31.68	0.05	18.71	0.23	0.00	0.27	32.34	96.68	
KW21	06-C10	0.00	0.00	0.01	0.11	14.66	30.01	0.01	15.80	0.18	0.00	0.26	36.81	97.85	
KW22	06-A3	0.00	0.03	0.02	0.12	12.75	20.21	0.18	16.85	0.16	0.05	0.32	47.81	98.48	Argyle
KW22	06-A4	0.00	0.00	0.01	0.12	13.15	23.53	0.06	17.09	0.08	0.05	0.33	43.62	98.02	
KW22	06-A6	0.00	0.24	0.14	0.13	9.30	15.02	0.43	26.89	0.11	0.13	0.47	45.88	98.73	
KW22	06-A7	0.00	0.00	0.00	0.11	13.27	34.20	0.00	17.93	0.44	0.00	0.28	31.09	97.31	
KW22	06-A8	0.01	0.02	0.00	0.02	9.99	11.81	0.15	19.71	0.15	0.00	0.38	56.35	98.58	
KW22	06-A9	0.01	0.00	0.00	0.04	12.07	21.22	0.01	17.11	0.27	0.00	0.30	46.97	98.00	
KW22	06-B1	0.00	0.00	0.00	0.04	13.26	26.29	0.01	16.56	0.21	0.00	0.29	40.70	97.35	
KW22	06-B2	0.00	0.05	0.02	0.06	6.94	10.41	0.12	27.32	0.37	0.05	0.53	53.10	98.97	
KW22	06-B4	0.00	0.00	0.03	0.07	13.27	25.66	0.01	15.98	0.07	0.05	0.30	41.72	97.16	
KW22	06-B5	0.00	0.00	0.00	0.10	14.72	31.37	0.01	16.07	0.02	0.00	0.25	33.47	96.00	
KW22	06-B6	0.00	0.00	0.00	0.15	16.05	36.41	0.07	15.28	0.11	0.00	0.19	27.65	95.91	
KW22	06-B7	0.00	0.05	0.03	0.07	11.78	8.78	0.07	14.68	0.06	0.02	0.38	63.44	99.35	DIC
KW22	06-B8	0.00	0.00	0.00	0.09	13.40	27.34	0.00	17.58	0.06	0.00	0.26	38.38	97.11	
KW22	06-B9	0.00	0.02	0.01	0.07	11.87	22.93	0.07	18.70	0.19	0.04	0.32	42.44	96.65	
KW22	06-B11	0.00	0.00	0.00	0.06	10.31	18.60	0.06	20.63	0.11	0.06	0.36	47.29	97.48	
KW22	06-B12	0.00	0.01	0.00	0.11	14.04	23.44	0.07	16.37	0.11	0.04	0.26	41.82	96.29	
KW22	06-B13	0.00	0.04	0.02	0.11	10.79	21.69	0.06	20.80	0.19	0.03	0.36	43.25	97.33	
KW22	06-B14	0.00	0.00	0.00	0.12	14.07	30.08	0.03	15.70	0.12	0.00	0.23	35.56	95.91	
KW22	06-B15	0.00	0.02	0.00	0.00	9.35	11.87	0.02	20.75	0.13	0.03	0.39	56.38	98.92	
KW22	06-C1	0.00	0.01	0.00	0.07	11.31	27.79	0.17	24.06	0.23	0.00	0.28	33.48	97.40	
KW22	06-C2	0.00	0.15	0.01	0.19	7.35	7.44	0.10	25.10	0.06	0.00	1.00	58.16	99.56	
KW22	06-C3	0.00	0.07	0.00	0.02	6.15	11.02	0.31	29.39	0.19	0.04	0.65	51.81	99.64	
KW22	06-C4	0.00	0.08	0.00	0.15	13.13	7.03	0.23	18.27	0.02	0.03	0.33	59.92	99.19	Argyle
KW22	06-C5	0.00	0.02	0.01	0.03	10.83	19.53	0.01	19.66	0.20	0.00	0.34	47.64	98.28	
KW22	06-C6	0.00	0.02	0.01	0.03	11.42	16.13	0.02	17.51	0.12	0.00	0.36	53.19	98.79	
KW22	06-C7	0.00	0.00	0.00	0.07	13.98	25.65	0.00	15.41	0.10	0.00	0.24	42.25	97.70	

Sample	#	Na2O	SiO2	CaO	NiO	MgO	Al2O3	TiO2	FeO	ZnO	V2O3	MnO	Cr2O3	Total	Indicator
KW21	07-A1	0.00	0.00	0.00	0.08	15.08	33.60	0.00	15.23	0.11	0.00	0.22	32.50	96.81	
KW21	07-A2	0.00	0.02	0.00	0.03	13.09	23.12	0.09	17.85	0.17	0.00	0.27	43.77	98.40	
KW21	07-A3	0.00	0.00	0.00	0.15	14.20	30.28	0.02	15.97	0.12	0.00	0.22	36.56	97.52	
KW21	07-A4	0.00	0.02	0.01	0.11	10.03	9.47	0.21	22.61	0.12	0.05	0.45	57.00	100.10	
KW21	07-A7	0.00	0.04	0.00	0.12	10.65	13.05	0.07	20.87	0.05	0.06	0.38	53.65	98.94	
KW21	07-B2	0.00	0.03	0.03	0.15	12.44	13.44	0.14	16.24	0.01	0.06	0.33	56.04	98.91	**Argyle**
KW21	07-B3	0.00	0.00	0.00	0.10	10.90	10.11	0.07	18.60	0.08	0.00	0.34	58.45	98.66	
KW21	07-B4	0.01	0.00	0.00	0.15	14.63	32.89	0.00	16.70	0.11	0.00	0.17	32.06	96.71	
KW21	07-B6	0.00	0.05	0.00	0.20	14.89	22.06	1.34	20.12	0.00	0.18	0.20	38.62	97.67	
KW21	07-C2	0.00	0.00	0.00	0.01	8.58	12.75	0.06	23.09	0.04	0.08	0.43	53.68	98.71	
KW21	07-C3	0.00	0.00	0.00	0.02	13.63	28.02	0.00	16.30	0.06	0.00	0.24	38.92	97.19	
KW21	07-D1	0.01	0.00	0.00	0.04	12.66	27.10	0.00	19.37	0.15	0.00	0.24	37.00	96.57	
KW21	07-D2	0.00	0.03	0.01	0.09	9.06	12.71	0.22	25.94	0.00	0.07	0.37	50.23	98.72	
KW21	07-D4	0.00	0.00	0.00	0.14	13.97	33.15	0.04	17.77	0.17	0.00	0.27	32.15	97.65	
KW21	07-D5	0.00	0.03	0.02	0.15	11.61	23.96	0.10	20.55	0.17	0.01	0.33	41.18	98.12	
KW21	07-D6	0.00	0.04	0.03	0.11	10.10	5.80	0.11	19.20	0.07	0.07	0.41	63.83	99.78	
KW21	07-D7	0.00	0.07	0.03	0.15	10.85	17.09	0.05	20.91	0.12	0.04	0.37	48.72	98.38	
KW21	07-E1	0.00	0.01	0.01	0.10	11.33	22.07	0.21	20.78	0.19	0.05	0.34	43.57	98.65	
KW21	07-E2	0.01	0.00	0.00	0.18	12.38	28.60	0.35	23.07	0.13	0.04	0.30	32.99	98.05	
KW21	07-E3	0.00	0.01	0.01	0.10	10.87	13.82	0.13	20.03	0.14	0.07	0.39	53.64	99.22	
KW21	07-E4	0.00	0.09	0.01	0.25	9.78	14.91	1.24	27.24	0.16	0.19	0.36	44.77	98.99	
KW21	07-E5	0.01	0.00	0.00	0.10	13.08	27.01	0.05	17.62	0.12	0.00	0.28	39.47	97.74	
KW21	07-E6	0.00	0.01	0.01	0.14	12.27	19.52	0.07	21.14	0.09	0.02	0.32	44.71	98.30	
KW21	07-E7	0.00	0.02	0.00	0.09	12.42	22.14	0.04	17.88	0.12	0.03	0.25	44.19	97.17	
KW21	07-F1	0.00	0.32	0.01	0.12	10.19	17.38	0.34	26.84	0.09	0.11	0.35	42.10	97.85	
KW21	07-F2	0.00	0.03	0.00	0.06	10.53	11.39	0.13	19.05	0.09	0.07	0.36	56.43	98.14	
KW21	07-F4	0.00	0.06	0.01	0.10	12.37	7.63	0.24	19.79	0.03	0.10	0.34	58.10	98.76	**Argyle**
KW21	07-F5	0.02	0.21	0.06	0.15	10.34	16.65	0.34	26.92	0.12	0.09	0.35	42.61	97.86	
KW21	07-F6	0.02	0.01	0.00	0.14	9.99	22.46	0.08	26.23	0.17	0.03	0.34	38.65	98.11	
KW21	07-F7	0.02	0.02	0.00	0.08	9.47	15.16	0.04	23.23	0.16	0.07	0.35	49.82	98.42	
KW21	07-F8	0.03	0.02	0.00	0.09	9.38	13.38	0.00	22.91	0.19	0.07	0.37	52.41	98.86	
KW22	07-A1	0.01	0.06	0.01	0.20	12.99	14.31	1.75	23.67	0.08	0.28	0.28	44.75	98.39	
KW22	07-A2	0.04	0.00	0.00	0.05	11.09	15.42	0.03	18.62	0.10	0.00	0.32	52.82	98.49	
KW22	07-A4	0.00	0.00	0.00	0.15	14.28	29.29	0.33	18.67	0.11	0.08	0.25	33.40	96.55	
KW22	07-A6	0.01	0.04	0.00	0.16	11.05	8.78	0.23	20.21	0.19	0.12	0.40	57.80	98.98	
KW22	07-B2	0.02	0.02	0.00	0.13	11.74	13.63	0.23	20.16	0.05	0.08	0.31	51.98	98.34	
KW22	07-B5	0.00	0.00	0.00	0.14	13.43	26.53	0.03	16.76	0.08	0.01	0.25	39.25	96.49	
KW22	07-C2	0.01	0.02	0.00	0.09	11.28	19.62	0.04	18.83	0.06	0.07	0.29	47.73	98.04	
KW22	07-C3	0.00	0.09	0.01	0.17	10.54	16.46	1.01	23.91	0.00	0.17	0.30	44.86	97.51	
KW22	07-C8	0.00	0.00	0.00	0.12	13.88	27.36	0.04	15.35	0.15	0.01	0.22	39.91	97.05	
KW22	07-C12	0.00	0.00	0.00	0.11	14.48	33.88	0.01	15.32	0.05	0.00	0.18	32.16	96.18	
KW22	07-D1	0.00	0.00	0.00	0.04	10.16	13.02	0.06	19.95	0.08	0.00	0.37	55.34	99.02	
KW22	07-D2	0.00	0.00	0.00	0.10	14.20	31.50	0.01	16.76	0.01	0.00	0.21	33.74	96.53	

APPENDIX 3. MICROPROBE ANALYSES OF GARNET AND CHROMITE GRAINS IN BEDROCK THIN SECTIONS

University of Calgary microprobe

GARNETS (46 grains)

ID	SiO2	TiO2	Al2O3	FeO	MgO	CaO	Na2O	F	Cr2O3	Total	**Eclogite indicator**
KW2	37.80	0.07	19.85	32.03	1.12	6.28	0.00	0.07	0.00	97.22	
KW20	38.03	1.03	20.06	28.11	2.10	8.72	0.09	0.06	0.04	98.24	
•	38.84	0.09	21.19	29.87	2.22	7.29	0.01	0.00	0.00	99.51	
•	37.23	0.12	20.36	29.86	2.44	6.01	0.02	0.00	0.00	96.04	
•	37.03	0.08	20.36	36.55	1.44	3.68	0.01	0.05	0.00	99.20	
•	37.82	0.08	20.67	32.08	1.31	8.07	0.00	0.02	0.00	100.05	
•	38.72	0.08	20.71	32.07	1.82	4.05	0.03	0.13	0.00	97.61	
•	38.02	0.08	20.28	31.40	1.22	6.88	0.03	0.14	0.00	98.05	
•	34.07	0.01	0.09	27.86	0.04	30.45	0.00	0.13	0.01	92.62	
•	35.78	0.08	21.59	34.03	2.91	3.67	0.00	0.05	0.00	98.09	
•	35.04	0.04	21.19	36.53	3.06	1.53	0.01	0.03	0.00	97.42	
•	35.45	0.05	20.52	33.18	1.63	5.77	0.00	0.00	0.02	96.58	
•	36.12	0.32	19.70	32.50	1.24	6.89	0.00	0.08	0.01	96.86	
•	34.79	0.43	15.84	11.00	0.23	7.35	0.00	0.15	0.05	69.83	
•	35.25	0.10	20.50	30.82	2.53	6.01	0.01	0.08	0.02	95.31	
•	34.03	0.00	1.36	26.35	0.11	30.20	0.00	0.00	0.00	92.04	
•	35.75	0.05	21.22	34.45	2.42	3.77	0.00	0.00	0.00	97.66	
•	34.84	0.06	21.00	34.74	1.78	4.32	0.03	0.07	0.02	96.87	
•	35.12	0.07	21.24	28.47	3.09	5.99	0.00	0.07	0.02	94.07	
•	36.14	0.03	21.26	33.91	2.69	3.78	0.02	0.09	0.01	97.93	
•	35.93	0.11	20.61	30.81	1.14	8.53	0.00	0.05	0.00	97.17	
•	37.90	0.37	20.22	3.71	0.10	33.44	0.00	0.12	0.01	95.87	
•	35.64	0.10	20.49	33.11	1.33	6.73	0.00	0.02	0.02	97.42	
•	37.30	0.22	18.57	11.38	2.40	5.25	0.02	0.15	0.03	75.32	
•	38.18	0.36	20.65	29.67	2.03	7.15	0.03	0.06	0.00	98.13	
•	37.69	0.10	20.88	30.72	3.46	5.14	0.06	0.16	0.00	98.21	
•	36.71	0.20	20.84	31.09	3.49	4.05	0.02	0.04	0.01	96.45	
•	35.98	0.16	20.63	29.39	1.15	7.66	0.01	0.02	0.00	95.00	
•	36.74	0.23	20.39	19.88	0.65	12.18	0.00	0.02	0.00	90.05	
•	36.69	0.74	17.20	7.07	0.16	31.96	0.00	0.05	0.00	93.84	
•	37.71	0.03	21.09	33.21	3.94	2.62	0.00	0.06	0.00	98.66	
•	35.02	0.49	21.14	19.31	0.68	12.90	0.00	0.06	0.01	89.60	
•	35.34	0.14	20.55	34.33	1.21	4.82	0.00	0.10	0.00	96.46	
•	35.99	0.04	20.82	34.78	2.46	3.36	0.00	0.01	0.02	97.48	
•	36.28	0.04	21.47	36.49	2.94	2.22	0.00	0.02	0.01	99.44	
•	38.19	0.52	17.14	6.66	0.30	33.53	0.00	0.05	0.00	96.36	
KW21	37.72	0.10	20.82	34.44	1.10	5.10	0.04	0.07	0.00	99.39	
KW22	38.37	0.08	20.30	34.79	1.81	4.27	0.01	0.02	0.02	99.67	
•	37.56	0.40	19.59	18.41	0.89	8.63	0.00	0.05	0.00	85.53	
•	38.13	0.12	20.73	31.59	1.95	5.83	0.02	0.10	0.03	98.50	
•	39.18	0.12	21.88	25.68	7.21	5.37	0.04	0.00	0.00	99.48	**Mg Almandine (G5)**
•	38.11	0.07	18.77	21.03	1.26	4.16	0.03	0.14	0.00	83.57	
•	39.64	0.19	21.42	29.68	6.43	3.20	0.01	0.09	0.00	100.66	**Mg Almandine (G5)**
•	37.95	0.08	21.21	28.89	1.54	6.09	0.03	0.13	0.00	95.92	
•	38.29	0.15	20.62	31.71	1.97	6.37	0.01	0.07	0.00	99.19	
•	37.56	0.02	20.84	34.32	2.82	3.10	0.00	0.10	0.00	98.76	

APPENDIX 3 (Continued)
CHROMITES (44 grains)

SAMPLE	SiO2	TiO2	Al2O3	FeO	MgO	CaO	Na2O	F	Cr2O3	Total	**Indicator type**
KW2	0.05	0.10	11.51	19.01	11.22	0.01	0.02	0.00	57.24	99.16	**Argyle field**
•	6.45	0.58	4.80	41.51	5.07	0.28	0.17	0.03	26.31	85.20	
•	0.09	0.09	12.23	18.68	10.94	0.03	0.00	0.39	56.54	98.99	
•	0.14	0.78	9.27	53.63	11.40	0.02	0.02	0.01	17.79	93.06	
•	0.19	1.78	21.47	31.36	10.88	0.04	0.04	0.07	27.03	92.86	
KW4	0.01	0.04	21.17	17.94	11.64	0.09	0.04	0.00	45.21	96.14	
•	0.06	0.28	30.80	22.08	11.86	0.03	0.00	0.01	34.35	99.33	
KW20	0.00	0.05	28.93	18.74	13.54	0.10	0.00	0.02	37.70	99.08	
•	0.05	0.31	16.70	27.84	8.73	0.06	0.00	0.00	44.87	98.56	
•	0.06	0.02	31.50	17.74	14.42	0.11	0.03	0.00	35.60	99.48	
•	0.10	2.47	25.23	29.78	12.22	0.26	0.01	0.08	27.00	97.15	
•	0.24	0.07	15.55	22.60	8.96	0.12	0.04	0.00	47.99	95.57	
•	0.05	0.06	28.59	17.35	13.57	0.04	0.01	0.00	38.39	98.06	
•	0.07	0.07	23.55	19.23	11.15	0.11	0.02	0.00	43.37	97.57	
•	0.06	0.09	21.14	21.58	10.40	0.27	0.04	0.00	46.44	99.95	
KW21	0.00	0.04	27.23	19.70	11.47	0.02	0.01	0.00	40.40	98.87	
•	0.00	0.28	25.46	17.29	14.93	0.01	0.01	0.09	41.95	100.02	
•	0.11	0.32	10.60	64.95	1.28	0.02	0.00	0.16	15.15	92.59	
•	0.04	0.05	21.25	18.31	11.86	0.03	0.04	0.16	46.19	97.93	**Argyle field**
•	0.00	0.11	35.24	20.11	13.68	0.01	0.04	0.04	29.51	98.74	
•	0.06	0.04	3.95	24.35	7.13	0.01	0.03	0.01	63.09	98.67	
•	0.04	0.02	23.44	19.87	12.61	0.02	0.01	0.00	42.49	98.50	
•	0.04	0.65	10.16	35.64	11.09	0.04	0.01	0.00	38.45	96.08	
•	0.05	0.10	10.05	29.19	7.00	0.04	0.07	0.00	50.91	97.41	
•	0.00	0.19	16.97	18.04	11.78	0.02	0.03	0.00	52.26	99.29	**Argyle field**
•	0.13	0.19	5.88	17.55	13.98	0.01	0.01	0.05	61.63	99.43	**Diamond Inclusion**
•	0.03	0.50	7.63	33.28	12.76	0.03	0.03	0.00	42.04	96.30	
•	0.00	0.02	33.60	16.24	14.89	0.00	0.00	0.03	35.00	99.78	
•	0.00	0.07	14.87	22.13	9.78	0.00	0.03	0.03	51.48	98.39	
•	0.02	0.05	19.00	20.41	11.11	0.00	0.03	0.04	48.69	99.35	
•	0.08	0.06	23.74	22.84	10.63	0.02	0.02	0.00	41.75	99.14	
•	0.00	0.10	29.06	20.62	13.09	0.01	0.01	0.09	36.03	99.01	
•	0.17	0.04	25.51	18.87	12.21	0.01	0.01	0.09	42.65	99.56	
•	0.30	0.08	26.77	17.24	11.80	0.02	0.03	0.05	43.45	99.74	
KW22	0.02	0.08	20.47	20.22	11.43	0.03	0.01	0.00	45.88	98.14	
•	0.03	0.06	31.37	20.10	12.36	0.04	0.04	0.05	32.35	96.40	
•	0.03	0.14	10.23	26.81	6.45	0.02	0.04	0.04	53.20	96.96	
•	0.00	0.08	13.88	25.40	7.69	0.02	0.05	0.09	51.38	98.59	
•	0.10	0.56	6.09	27.40	8.01	0.04	0.01	0.00	55.00	97.21	
•	0.00	0.04	31.98	15.45	15.29	0.01	0.00	0.10	37.04	99.91	
•	0.08	0.04	24.38	19.51	11.76	0.01	0.03	0.01	44.03	99.85	
•	0.00	0.06	30.11	16.43	13.43	0.02	0.01	0.12	37.76	97.94	
•	0.03	0.46	8.38	33.80	5.76	0.05	0.04	0.00	48.01	96.53	