Geological Survey of Canada Open File 5807

Energy Resources Conservation Board/Alberta Geological Survey Special Report 97

Geochemical, Mineralogical and Kimberlite Indicator Mineral Electron Microprobe Data from Silts, Heavy Mineral Concentrates and Waters from National Geochemical Reconnaissance Stream Sediment and Water Surveys in the Northeastern and Southern Clear Hills, Alberta (NTS 84E/01 and 84E/02 and Parts of 84D/10 and 84D/11)

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McCurdy, M.W.[1], Prior, G.J.[2], Day, S.J.A. [1], Weiss, J.A. [2], Friske, P.W.B.[1], Pawlowicz, J.G. [2], McNeil, R.J. [1], Hathway, B. [2], Wilson, R.S.[3] and Goulet, D.E. [2]

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INTRODUCTION

The Alberta Geological Survey (AGS) of the Energy Resources Conservation Board (formerly the Alberta Energy and Utilities Board) and the Geological Survey of Canada (GSC) have, since 2001, conducted cooperative reconnaissance-scale sampling of tills, stream sediments and waters in northern Alberta to assess potential for kimberlite (diamonds), base metals and other economic minerals. Significant results from heavy mineral and geochemical surveys indicate the possibility of base metal deposits hosted within Cretaceous shale (Paulen, et al., 2007; Plouffe et al., 2007; 2008) and have expanded the area with potential for kimberlite in north-central Alberta (Prior et al., 2006).

This report includes data from two separate geochemical surveys in the Clear Hills, Alberta (Fig. 1). A geochemical orientation survey was carried out in 2004 north of Worsley in an area underlain, in part, by oolitic ironstone of the Clear Hills iron deposit (Worsley Block). The water and silt-sized fraction from 31 stream sediment sites and the sand-sized sediment fraction from 12 of these sites were collected and analyzed. Using the same field methods, a geochemical reconnaissance survey within the watersheds of the Hotchkiss and upper Notikewin rivers in the northeastern Clear Hills was completed in 2005, during which silt and water samples were collected from 142 sites and bulk sand-sized fraction samples were taken from 72 of these sites (Fig. 1). This work was funded by the GSC, under the Northern Resources Development Program, and the AGS.

The location of the orientation survey north of Worsley was selected based on proximity to the Clear Hills iron deposit (Hamilton, 1982). The Hotchkiss River survey was carried out to evaluate the potential for base and precious metal mineralization and kimberlite in a previously unexplored area of northwestern Alberta.

Geochemical data from a total of 173 sites sampled in 2004 and 2005 are included in this report. Mineralogical data from 84 of these sites are also included.

Location and Physiography

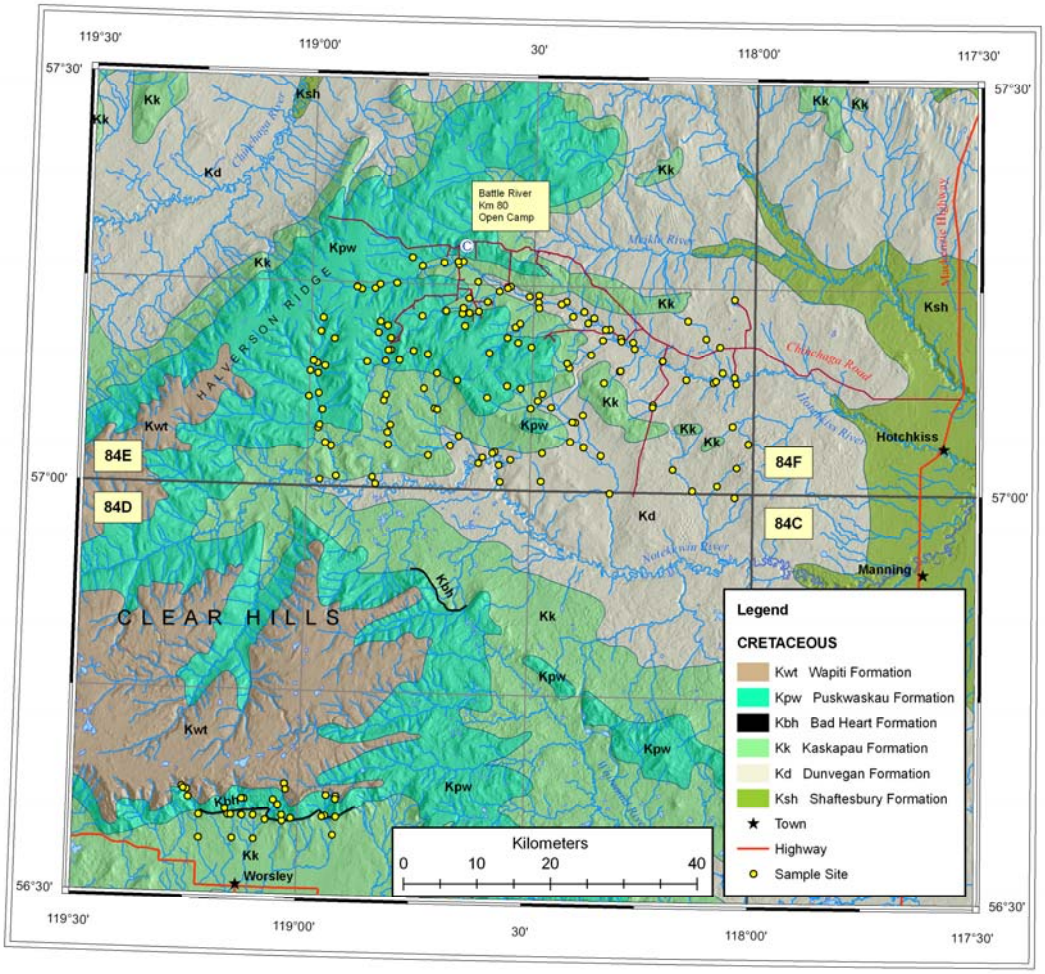

Figure 1. Physiography and bedrock geology (Hamilton et al, 1999) of areas surveyed in the Clear Hills of northwest Alberta are shown with sample locations from the 2004 survey (84D north of Worsely) and the 2005 survey (84E south of the Chinchaga Road).

The Clear Hills occur within the southern part of the Clear Hills Uplands, one of several upland areas in northwestern Alberta that include the Caribou Mountains, Cameron Hills and Buffalo Head Hills (Pettapiece, 1986). Upland areas are separated by the lowland drainage basins of the Peace, Wabasca and Hay rivers.

The Clear Hills Upland ecoregion spans the Alberta-British Columbia boundary north and west of the Peace River. Mean annual precipitation ranges between 400-600 mm. The ecoregion represents a transition between boreal and cordilleran vegetation, with forested areas comprising a mixture of lodgepole pine, white spruce and fir in the uplands, and black spruce in valleys. Elevations range from 550 to1050 m asl. There are steep slopes, some rolling plateau remnants and broad, gently undulating valleys. Most of the area is covered with moderately fine-textured till with clayey lacustrine deposits in valleys, often overlain by organic soils. (http://www.ec.gc.ca/soer-ree/english/ecozones.cfm). Oil and gas exploration has resulted in extensive networks of seismic lines. Forestry operations in the Hotchkiss River area and mixed farming around Worsley have left significant gaps in the forest cover.

The Hamlet of Worsley is located 90 km north of Fairview, Alberta (Fig. 1). This community of approximately 130 people provides services to the surrounding grain and mixed farming operations. Oil and gas are also important to the local economy (http://www.discoverthepeacecountry.com/htmlpages/worsley.html). Travel to sample sites north of Worsely was by truck, all-terrain vehicle (quad) and foot.

Although there are no communities within the upper Hotchkiss River watershed, accommodation is available at an open construction camp 80 km west of the Mackenzie Highway on the Chinchaga Forestry Road (Fig. 1). The Town of Manning is the closest community providing food, fuel, accommodation and shipping facilities. Travel to sample sites in the upper Hotchkiss River watershed was by helicopter, truck, all-terrain vehicle (Argo) and foot.

Bedrock and Surficial Geology

The bedrock underlying the survey areas consists of a horizontal to gently dipping succession of Upper Cretaceous sandstone and shale (Fig. 1). The Shaftsbury Formation represents the oldest bedrock unit in the region and occurs only in the eastern sector (Fig. 1). Fine-grained feldspathic deltaic to marine sandstones of the Dunvegan Formation are overlain by Kaskapau Formation dark-grey marine shale interspersed with thin beds of concretionary ironstone, fine-grained quartzose sandstone and ferruginous oolitic mudstone. Fine-grained quartzose marine sandstone with ferruginous oolitic sandstone and mudstone of the Bad Heart Formation underlies dark grey fossiliferous shale of the Puskwaskau Formation. The non-marine Wapiti Formation consists of grey, feldspathic, clayey sandstone and grey bentonitic mudstone and bentonite beds with scattered coal beds (Green et al., 1970; Hamilton et al., 1999).

Oolitic ironstone beds within the Bad Heart Formation, which form outcrops along the southern and eastern flanks of the Clear Hills, have been examined as a source of iron. The potential resource of the Clear Hills iron deposit was estimated by Hamilton (1982) to be at least 1 billion tonnes with an average grade of about 34% iron. The Worsley Block of the Clear Hills iron deposit is estimated to contain 23 million tonnes of oolitic ironstone (Hamilton, 1982). The main iron-bearing minerals are goethite and nontronite with lesser amounts of ferruginous opal and siderite (Hamilton, 1982).

The Buffalo Head Hills kimberlite field, where 38 kimberlites have been discovered since 1997 (Eccles et al., 2004), lies about 200 km east of the Clear Hills. The Mountain Lake kimberlitic cluster, originally targeted as the result of a positive stream sediment heavy mineral sample, is located south of the survey areas, northeast of Grande Prairie (Eccles et al., 2004).

Cretaceous bedrock, modified by at least one Quaternary glaciation, is the dominant control on the physiography of the Clear Hills. Unconsolidated glacial and minor non-glacial sediments (drift) overlying the bedrock generally thin towards the uplands and thicken in the valleys. Bedrock outcrops occur locally in the upper Clear Hills and limited subsurface data suggests drift is generally less than 15 m thick within the survey areas (Pawlowicz and Fenton, 1995). Surficial sediments consist primarily of till, glaciolacustrine silt and clay (at lower elevations) and preglacial quartzite-rich gravels, which occur near the top of the Clear Hills (R. Paulen, personal communication, 2008). The glacial sediments were deposited during the southwesterly advance, and subsequent retreat, of the Late Wisconsinan Laurentide Ice Sheet (Dyke et al., 2002).

Sample Collection

Stream Sediments (Silts)

At each site, a pre-labelled Kraft paper bag (12.5 cm x 28 cm with side gusset) was two-thirds filled with silt or fine sand collected from the active stream channel (Fig. 2). The silt sample was collected after the water sample(s) and before the bulk sediment sample. Commonly, the sampler collected silt by hand from various points in the active channel while moving upstream, over a distance of 5 to 15 m. If the stream channel was found to consist mainly of clay, coarse material or organic sediment from which suitable sample material is scarce or absent, moss mat from the stream channel, which commonly contains trapped silt, may have been added to the sample. A field duplicate pair of silt samples, assigned sequential sample numbers, was collected within each block of 20 samples. The first sample of the pair was assigned a replicate status value of 10 and the second was assigned a replicate status value of 20. Routine (non-duplicate) field samples were assigned replicate status values of 0.

Figure 2: Pre-labelled Kraft paper bags and plastic bottles are used to collect samples of stream silts and stream waters. A bulk sample, for heavy mineral processing, is collected by wet-sieving coarse-grained stream sediment using a US Sieve Series 12-mesh (1.68 mm) sieve and collecting <12 mesh grains in a plastic pail lined with a polyethylene sample bag. The gold pan is used for adding water for wet sieving, not for heavy mineral concentrate panning. A sample composed of granules and pebbles, for archive, is collected at bulk sample sites by sieving >12 mesh material through a US Sieve Series 2-mesh (10 mm) sieve and collecting the <10 mm material in a labelled Kraft paper bag. Flagging tape with a sample site number is used to mark sample sites. Field observations are noted on pre-printed water-resistant paper (see Appendix).

Stream Waters

Waters were sampled in mid-channel, from flowing water where possible. During the 2004 survey two water samples were collected at each site whereas during the 2005 survey, the GSC

laboratory carrying out ion chromatography analyses was unavailable, and only one water sample was collected per site. The samples were collected in 125-ml Nalgene HDPE bottles (Fig. 2). Samples were collected after rinsing each bottle two times in flowing water before a final fill. Field duplicate pairs of water samples, assigned sequential sample numbers, were collected within each block of 20 samples. The first sample of each pair was assigned a replicate status value of 10 and the second was assigned a replicate status value of 20. Routine (non-duplicate) field samples are assigned replicate status values of 0.

Heavy Mineral Concentrates

Ideal sites for the collection of sediments for the heavy mineral concentrate fraction are located at the upstream ends of mid-channel boulder bars and behind mid-stream boulders (Prior et al., 2007). Material was collected by shovel from one (preferred) or more holes dug in the stream bed (commonly to depths of a few 10's of centimetres. A 22.7 litre (5-gallon) plastic pail was lined with a heavy-duty polyethylene bag measuring 46x61 cm (18x24 inches, 4 Mil). Material was wet-sieved into the pail through a 12-mesh (1.68 mm) stainless steel sieve until a sample weight of 10-15 kg was attained. The bag lining the pail, labelled with the sample number, was taped shut with black plastic (electrical) tape and placed into a second bag, also labelled with the sample number, and taped. Samples were shipped directly to a commercial lab for preparation and analysis.

SAMPLE PREPARATION

Stream Sediments (Silts)

The Kraft paper bags containing the silt samples were placed into plastic bags, taped with electrical tape and shipped directly to a commercial lab, where they were air-dried at temperatures below 40ºC and sieved through a minus 80-mesh (177 µm) screen. Control reference and duplicate samples were inserted into each block of twenty samples by a GSC representative at the commercial laboratory.

Waters

One set of water samples remained unaltered and was packed and shipped to a laboratory for analysis (2004 survey only). Water samples for acidification (2004 and 2005 surveys) were filtered within 24 hours of collection through single-use Millipore Sterivex-HV 0.45-µm filter units attached to 50-ml sterile plastic syringes. After 50-ml of water from the second set of samples was filtered into new 60-ml bottles, the remainder was used for the determination of pH and conductivity before being discarded. Eppendorf pipettors with disposable plastic tips were used to add 0.5 ml 8M HNO_3 to filtered water samples. Syringes were re-used after rinsing with distilled, de-ionized water (syringes were replaced daily). Control reference samples (filter, acid and travel blanks[*]) were added to each batch of samples. Filtered and acidified waters were

[*] Filter (sample) blanks are 60-ml bottles filled with deionized water used in the field that has been filtered and acidified at the same time as routine samples; acid blanks are samples of the deionized water used in the field and

kept in a cool dark place until shipment to the lab. Control reference samples were inserted into each block of 20 water samples. No duplicate water samples were introduced.

Heavy Mineral Concentrates

Before processing, a 500-g character sample was collected from each sample and archived. The bulk sediment samples were then progressively reduced by a range of laboratory procedures to concentrate heavy minerals. Initially a low-grade table concentrate was prepared from each of the samples. Gold grains were observed at this stage and were counted, measured and classified as to degree of wear (reflecting distance of transport). The table reject was re-tabled to scavenge possible unrecovered kimberlite indicator minerals and magmatic massive sulphide indicator minerals. The concentrate from both tabling runs was separated in methylene iodide diluted with acetone to S.G. 3.20 to recover heavy minerals including Cr-diopside and olivine. Magnetite was removed after the heavy liquid separation and the remaining concentrate cleaned with oxalic acid to remove limonite stains. The dried concentrate was sieved into several size fractions, (<0.25 mm, 0.25 to <0.5 mm, 0.5 mm to <1.0 mm, ≥ 1.0 mm to 2.0 mm). The <0.25 mm fraction was kept for chemical analysis and the 0.25 to 0.50 mm fraction was sorted with a Carpco® drum magnetic separator into strongly, moderately, weakly and non-paramagnetic fractions.

Analytical Procedures

Analytical results are presented in a single file in a spreadsheet format included with this report: ERCB_AGS SPE 097_GSC OF 5807 Data.xls.

Stream Sediment (Silt) and Heavy Mineral Concentrate (<0.25 mm Fraction) Geochemical Analyses

Instrumental Neutron Activation Analysis (INAA)

Weighed and encapsulated samples, normally 30 g, were packaged for irradiation along with internal standards and international reference materials. Samples and standards were irradiated together with neutron flux monitors in a two-megawatt pool type reactor. After a seven-day decay period, samples were measured with a high-resolution germanium detector. Typical counting times were 500 seconds. Elements determined by INAA are listed in Table 1.

Table 1: Elements in stream sediments and the <0.25 mm fraction of heavy mineral concentrates determined by Instrumental Neutron Activation analysis.

ELEMENT		DETECTION LEVEL	
As	Arsenic	0.5	ppm
Au	Gold	2	ppb
Ba	Barium	50	ppm
Br	Bromine	0.5	ppm
Ce	Cerium	5	ppm
Co	Cobalt	5	ppm
Cr	Chromium	20	ppm
Cs	Cesium	0.5	ppm

acidified (but not filtered) at the same time as routine samples; travel blanks are bottles of deionized water pre-filled at the GSC lab in advance of field sampling and acidified in the field with the survey samples.

Eu	Europium	1	ppm
Fe	Iron	0.2	pct
Hf	Hafnium	1	ppm
La	Lanthanum	2	ppm
Lu	Lutetium	0.2	ppm
Mo	Molybdenum	1	ppm
Na	Sodium	0.02	pct
Ni	Nickel*	10	ppm
Rb	Rubidium	5	ppm
Sb	Antimony	0.1	ppm
Sc	Scandium	0.2	ppm
Sm	Samarium	0.1	ppm
Ta	Tantalum	0.5	ppm
Tb	Terbium	0.5	ppm
Th	Thorium	0.2	ppm
Ti	Titanium*	500	ppm
U	Uranium	0.2	ppm
W	Tungsten	1	ppm
Yb	Ytterbium	2	ppm
* HMC samples only			

INAA data for silver, cadmium, iridium, selenium, tin, tellurium, zinc, and zirconium are not published because of inadequate detection limits and/or precision.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Other Analyses

For determination of the 38 elements listed in Table 2, a one-gram sample was leached with a 6-ml mixture of HCl, HNO_3, and distilled, deionized water (2:2:2 v/v) at 95° C for one hour. The sample solution was diluted with de-ionized water to 20 ml and analysed by inductively coupled plasma emission spectroscopy on a Jarell-Ash instrument and inductively coupled plasma mass spectroscopy on a Perkin-Elmer Elan instrument.

Loss-on-ignition was determined using a one-gram sample. Each sample, in a Leco® crucible, was placed into a 100ºC muffle furnace and brought up to 500° C for one hour. The oven was then cooled to 100ºC and the crucibles transferred to a desiccator followed by cooling to room temperature. The crucibles were re-weighed to determine the loss-on-ignition.

Tin in heavy mineral concentrates was prepared for analysis by heating a 0.2 g sample mixed with 1.5 g of $LiBO_2$ flux in a muffle furnace for 15 minutes at 1050°C in a graphite crucible. The molten mixture was removed and immediately poured into 100 mL of 5% HNO_3. The solution was shaken for two hours before an aliquot was poured into a test tube for analysis. Analytical values were determined using a Perkin-Elmer Elan 6000 ICP-MS (Gravel, 2003).

Table 2 Variables in stream silts and the <0.25 mm fraction of heavy mineral concentrates determined by Inductively Coupled Plasma - Mass Spectrometry and other analytical methods

VARIABLE		DETECTION LEVEL	
Ag	Silver	2	ppb
Al	Aluminum	0.01	pct
As	Arsenic	0.1	ppm
B†	Boron	1	ppm
Ba	Barium	0.5	ppm
Bi	Bismuth	0.02	ppm
Ca	Calcium	0.01	pct
Cd	Cadmium	0.01	ppm
Co	Cobalt	0.1	ppm
Cr	Chromium	0.5	ppm

Cu	Copper	0.01	ppm
F	Fluorine	10	ppm
Fe	Iron	0.01	pct
Ga	Gallium	0.2	ppm
Hg	Mercury	5	ppb
K	Potassium	0.01	pct
La	Lanthanum	0.5	ppm
LOI*	Loss-on-ignition	1	pct
Mg	Magnesium	0.01	pct
Mn	Manganese	1	ppm
Mo	Molybdenum	0.01	ppm
Na	Sodium	0.001	pct
Ni	Nickel	ppm	
P	Phosphorus	0.001	pct
Pb	Lead	0.01	ppm
S	Sulphur	0.01	pct
Sb	Antimony	0.02	ppm
Sc	Scandium	0.1	ppm
Se	Selenium	0.1	ppm
Sn	Tin ($LiBO_2$ Fusion)	1	ppm
Sr	Strontium	0.5	ppm
Te	Tellurium	0.02	ppm
Th	Thorium	0.1	ppm
Ti	Titanium	0.001	pct
Tl	Thallium	0.02	ppm
U	Uranium	0.1	ppm
V	Vanadium	2	ppm
W	Tungsten	0.1	ppm
Zn	Zinc	0.1	ppm
*Silt samples only			

Fluorine was determined using 0.25-gram sample splits weighed into Ni crucibles. One gram of sodium hydroxide was added and the mixture was fused at 600ºC in a muffle furnace. The fusion product was dissolved into a mixture of 7 ml of de-ionized water and 5 ml of 30% sulphuric acid. The solutions were transferred to plastic beakers and 5 ml of 30% ammonium acetate added. The volume was made up to 90 ml with de-ionized water. The pH was tested and adjusted to 7.8 with either sodium hydroxide or sulphuric acid. Fluorine content was determined using a fluorine selective ion electrode.

Water Analyses

The pH of stream waters in 2005 was determined at the field base using a Hanna Instruments Combo® waterproof tester with automatic temperature compensation, a range of 0.00 to +14.00 pH, resolution of 0.01 pH and an accuracy of ±0.05 pH. The pH of stream waters in 2004 was determined at the field base using a Fisher Scientific Accumet AP62 tester with automatic temperature compensation, a range of -1.99 to +19.99 pH, resolution of 0.01 pH and a relative accuracy of ±0.01 pH. Meters were calibrated using commercial buffer solutions with pH values of 4.0, 7.0 and 10.0.

The conductivity of stream waters in 2005 was determined at the field base using a Hanna Instruments Combo® waterproof tester with a range of 0 to 3999 µS/cm, a resolution of 1 µS/cm and an accuracy of ±2%. The conductivity of stream waters in 2004 was determined at the field base using a waterproof Oakton Instruments ECTestr (low) tester with automatic temperature compensation, a range of 0 to 1999 µS/cm, a resolution of 1 µS/cm and a full-scale accuracy of ±1%. Meters were calibrated using commercial conductivity standards with values of 1413 µS/cm and 84µS/cm.

In 2004, chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-) and sulphate (SO_4^{2-}) in untreated waters (water samples not filtered or acidified in the field) were determined by ion chromatography (IC) at GSC laboratories in Ottawa. Untreated water is identified as UU-Water (unfiltered, unacidified) in the data table. There are no ion chromatography data for the 2005 survey.

Uranium in untreated waters was determined by inductively coupled plasma-mass spectrometry (ICP-MS) at GSC laboratories in Ottawa (not available for the 2005 survey).

Trace and Major Elements

Acidified and filtered stream water samples were analyzed for trace metal and major elements at GSC laboratories in Ottawa. A complete list of elements and stated detection limits are given in Table 3.

Trace metal analysis was performed using a VG PQII ICP-MS with a Meinhard concentric glass nebulizer, Type K (solution uptake rate 1 ml min^{-1}), a quartz Scott-type double-pass chilled spray chamber (2ºC) and a 27 MHz standard quartz torch. The argon flow-rates are: Cool 12.5 l min^{-1}, Auxiliary 0.85 l min^{-1}, and Nebulizer 0.9 l min^{-1}. The RF power is 1350 watts. Isotopes measured and corrections for spectral interferences are detailed in Hall et al. (1995, 1996). Data for hafnium and zirconium are not published because these elements are not sufficiently stabilized in waters by the addition of nitric acid. Data for indium, selenium, silver, tantalum and thulium are not published because of inadequate detection limits and/or precision.

Table 3: Major and trace elements determined in stream waters.

ELEMENT		DETECTION LEVEL		LABORATORY METHOD
Waters –Filtered, Acidified (FA-Water)				
Al	Aluminum	2	ppb	ICP-MS
As	Arsenic	0.1	ppb	ICP-MS
B	Boron	0.5	ppb	ICP-MS
Ba	Barium	0.2	ppb	ICP-MS
Be	Beryllium	0.005	ppb	ICP-MS
Cd	Cadmium	0.02	ppb	ICP-MS
Ce	Cerium	0.01	ppb	ICP-MS
Cs	Cesium	0.01	ppb	ICP-MS
Co	Cobalt	0.05	ppb	ICP-MS
Cr	Chromium	0.1	ppb	ICP-MS
Cu	Copper	0.1	ppb	ICP-MS
Dy	Dysprosium	0.005	ppb	ICP-MS
Er	Erbium	0.005	ppb	ICP-MS
Eu	Europium	0.005	ppb	ICP-MS
Ga	Gallium	0.01	ppb	ICP-MS
Gd	Gadolinium	0.005	ppb	ICP-MS
Ge	Germanium	0.02	ppb	ICP-MS
Ho	Holmium	0.005	ppb	ICP-MS
La	Lanthanum	0.01	ppb	ICP-MS
Li	Lithium	0.02	ppb	ICP-MS
Lu	Lutetium	0.005	ppb	ICP-MS
Mn	Manganese	0.1	ppb	ICP-MS
Mo	Molybdenum	0.05	ppb	ICP-MS
Nb	Niobium	0.01	ppb	ICP-MS
Nd	Neodymium	0.005	ppb	ICP-MS
Ni	Nickel	ppb		ICP-MS
Pb	Lead	0.01	ppb	ICP-MS
Pr	Praseodymium	0.005	ppb	ICP-MS
Rb	Rubidium	0.05	ppb	ICP-MS
Re	Rhenium	0.005	ppb	ICP-MS
Sb	Antimony	0.01	ppb	ICP-MS
Sm	Samarium	0.005	ppb	ICP-MS

Sn	Tin	0.01	ppb	ICP-MS
Sr	Strontium	0.5	ppb	ICP-MS
Tb	Terbium	0.005	ppb	ICP-MS
Te	Tellurium	0.02	ppb	ICP-MS
Ti	Titanium	0.5	ppb	ICP-MS
Tl	Thallium	0.005	ppb	ICP-MS
U	Uranium	0.005	ppb	ICP-MS
V	Vanadium	0.1	ppb	ICP-MS
W	Tungsten	0.02	ppb	ICP-MS
Y	Yttrium	0.01	ppb	ICP-MS
Yb	Ytterbium	0.005	ppb	ICP-MS
Zn	Zinc	ppb		ICP-MS
Ca	Calcium	0.02	ppm	ICP-ES
Fe	Iron	0.005	ppm	ICP-ES
K	Potassium	0.05	ppm	ICP-ES
Mg	Magnesium	0.005	ppm	ICP-ES
Na	Sodium	0.05	ppm	ICP-ES
P	Phosphorus	0.05	ppm	ICP-ES
S	Sulphur	0.05	ppm	ICP-ES
Si	Silicon	0.02	ppm	ICP-ES
Waters –Unfiltered, not Acidified (UU-Water)				
Cl^-	Chloride	100	ppb	IC
F^-	Fluoride	50	ppb	IC
NO_3^-	Nitrate	50	ppb	IC
SO_4^-	Sulphate	50	ppb	IC
Cond.	Conductivity	1	µS/cm	EC (electrolytic conductivity)
pH	-	0.1	-	GCE (glass-calomel electrode)
U	Uranium	0.05	ppb	ICP-MS

Major element analysis was performed using a Perkin-Elmer 3000DV Inductively Coupled Plasma – Emission Spectrometer (ICP-ES) with a cross-flow nebulizer (solution uptake rate 1 ml min^{-1}), a Ryton Scott-type double-pass spray chamber and a custom demountable quartz ICP-ES torch. The argon flow-rates are: Plasma 15.0 l min^{-1}, Auxiliary 0.5 l min^{-1}, and Nebulizer 0.7 l min^{-1}. The RF power is 1350 watts. All elements were analyzed in axial mode except for sodium and potassium, which were run in radial mode. Inter-element correction factors were applied as required to correct for various spectral interferences. Data for scandium are not published because of inadequate detection limits and/or precision.

Heavy Mineral Concentrate Analyses

Kimberlite indicator minerals (KIMs) were visually identified and hand-picked from each of three size fractions (0.25-0.5 mm, 0.5 mm-1.0 mm, 1.0-2.0 mm). Fractions exceeding a 100 g threshold were characterized by a 100 g split and normalized to represent the total sample weight. Following removal of the kimberlite indicator minerals, 100 grains were randomly selected from each 0.25-0.5 mm fraction and identified. After 100 grains were identified they were recombined with the source sample fraction. The 0.25-0.5 mm, 0.5-1.0 mm and 1.0-2.0 mm fractions (minus KIMs) were archived. The <0.25 mm fraction of the heavy mineral concentrate was sent to a commercial lab where it was ground in a ceramic mill and analyzed by a combination of ICP-MS, INAA and specific methods.

Electron Microprobe Data

Selected kimberlite indicator mineral grains underwent electron microprobe analysis for chemical characterization. Visually-identified and hand-picked kimberlite indicator mineral grains undergoing microprobe analysis were shipped to a commercial lab and set into epoxy to create polished blocks fitting specialized holders developed at the GSC (Stirling & Pringle,

1996). Polished blocks were analyzed at the GSC and Canadian Museum of Nature electron microprobe labs. Table 4 shows the analytical variables determined in visually identified grains undergoing major element analysis. The count time settings selected for these grains resulted in data accurate to one decimal place. In the microprobe data file a value of '0.0' indicates a value below detection limit: blanks indicate that the grain was not analyzed for the listed variable. Electron microprobe data were evaluated by a mineralogical consultant.

	GP	GO	DC	FO	CR	IM	LDC
Al_2O_3	x	x	x	x	x	x	x
As_2O_3					x	x	
CaO	x	x	x	x	x	x	x
CoO					x	x	
Cr_2O_3	x	x	x	x	x	x	x
FeO	x	x	x	x	x	x	x
K_2O	x	x	x	x			x
MgO	x	x	x	x	x	x	x
MnO	x	x	x	x	x	x	x
Na_2O	x	x	x	x			x
Nb_2O_5					x	x	
NiO	x	x	x	x	x	x	x
SiO_2	x	x	x	x	x	x	x
SO_3					x	x	
TiO_2	x	x	x	x	x	x	x
V_2O_3	x	x	x	x	x	x	x
ZnO					x	x	

Table 4. Visually identified kimberlite indicator mineral grains underwent microprobe analysis for variables listed above (GP-peridotitic garnet, GO-eclogitic garnet, DC-chrome diopside, FO-olivine, IM-ilmenite, LDC-low-chrome diopside).

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Richmond, British Columbia

Preparation: Acme Analytical Laboratories
Vancouver, British Columbia

Overburden Drilling Management
Ottawa, Ontario

Analysis: Acme Analytical Laboratories
Vancouver, British Columbia

Becquerel Laboratories Inc.
Mississauga, Ontario

Canadian Museum of Nature
Ottawa, Ontario

GSC Analytical Chemistry Laboratory
Ottawa, Ontario

GSC Analytical Method Development Laboratory
Ottawa, Ontario

GSC Mineralogical Laboratory (electron microprobe)
Ottawa, Ontario

SGS Lakefield Research Limited
Lakefield, Ontario

Overburden Drilling Management
Ottawa, Ontario

Ingrid Kjarsgaard (Mineral Consultant)
Ottawa, Ontario

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Appendix 1. Field Observations and Explanatory Notes

NATIONAL GEOCHEMICAL RECONNAISSANCE
(Silt Sediment, Bulk Sediment and Water Field Card - 2005)

NTS SHEET | YEAR | SAMPLE NUMBER | REP STAT | WIDTH | DEPTH | DATE (DAY MO) | TIME | COLLECTORS

GENERAL PHYSIOGRAPHY
- ☐ Mountainous
- ☐ Hilly
- ☐ Plateau
- ☐ Plain
- ☐ Swamp

SURFACE EXPRESSION
- ☐ Hummocky
- ☐ Inclined
- ☐ Level

DRAINAGE PATTERN
- ☐ Dendritic
- ☐ Herringbone
- ☐ Rectilinear
- ☐ Trellis
- ☐ Poor
- ☐ Discontinuous
- ☐ Closed

SITE DRAINAGE
- ☐ Well
- ☐ Moderate
- ☐ Poor

STREAM SOURCE(S)
- ☐ Ground
- ☐ SpringMelt
- ☐ Glacier
- ☐ Recent Rain
- ☐ Unknown

STREAM CLASS
- ☐ Primary
- ☐ Secondary
- ☐ Tertiary
- ☐ Quaternary
- ☐ Undefined

STREAM TYPE
- ☐ Permanent
- ☐ Intermittent
- ☐ Re-emergent
- ☐ Undefined

STREAM FLOW
- ☐ Stagnant
- ☐ Slow
- ☐ Moderate
- ☐ Fast
- ☐ Torrential

WATER COLOUR

WATER CLARITY
- ☐ Transparent
- ☐ Partially Cloudy
- ☐ Cloudy

VEGETATION
- ☐ Coniferous
- ☐ Deciduous
- ☐ Mixed
- ☐ Grass
- ☐ Bog
- ☐ Other

BANK TYPE(S)
- ☐ Alluvium
- ☐ Colluvium
- ☐ Till
- ☐ Outwash
- ☐ Bare Rock
- ☐ Talus/Scree
- ☐ Organic
- ☐ Other

CONTAMINATION(S)
- ☐ None
- ☐ Possible
- ☐ Probable
- ☐ Definite
  - ☐ Mining
  - ☐ Industry
  - ☐ Agriculture
  - ☐ Domestic
  - ☐ Forestry
  - ☐ Burn
  - ☐ Other

BANK PRECIPITATE
☐ No Yes ☐

Colour(s)

BOTTOM PRECIPITATE
☐ No Yes ☐

Colour(s)

STREAM SEDIMENT SAMPLE COLOUR(S)

STREAM SEDIMENT COMPOSITION
- Sand ____ %
- Silt & Clay ____ %
- Organics ____ %

SAMPLE TYPE(S)
- ☐ Silt Sediment (SS)
- ☐ Bulk Sediment (BS)
- ☐ Pebble (PB)
- ☐ Water (SW)
- ☐ Other

IN-SITU WATER
PH | COND

BULK SITE
- ☐ Longitudinal Bar
- ☐ Transverse Bar
- ☐ Point Bar
- ☐ Diagonal Bar
- ☐ Boulder Trap
- ☐ Log Trap
- ☐ Vegetation Trap
- ☐ Bedrock Step
- ☐ Pool
- ☐ Gravel Veneer
- ☐ Stream Bed
- ☐ Beaver Dam

BULK SITE COMPOSITION
- Cobbles ____ %
- Pebbles ____ %
- Sand ____ %
- Silt ____ %
- Clay ____ %
- Organics ____ %

PEBBLE LITHOLOGY(IES)
____ %
____ %
____ %
____ %

SITE RATING
- ☐ Good
- ☐ Good to Moderate
- ☐ Moderate
- ☐ Moderate to Poor
- ☐ Poor

BEDROCK EXPOSED
☐ No Yes ☐

Type(s)

CLAST SHAPE
- Rounded ____ %
- Sub-Angular/ Sub-Rounded ____ %
- Angular ____ %
- Platy/Flat ____ %

BOULDERS PRESENT
☐ No Yes ☐

Type(s)

Longitude (DD) | **Latitude (DD)**
NAD | Decimal Degrees | Decimal Degrees

COMMENTS:

NTS SHEET | YEAR | SAMPLE NUMBER | REP STAT | WIDTH | DEPTH | DATE (DAY MO) | TIME | COLLECTORS

GENERAL PHYSIOGRAPHY
- ☐ Mountainous
- ☐ Hilly
- ☐ Plateau
- ☐ Plain
- ☐ Swamp

SURFACE EXPRESSION
- ☐ Hummocky
- ☐ Inclined
- ☐ Level

DRAINAGE PATTERN
- ☐ Dendritic
- ☐ Herringbone
- ☐ Rectilinear
- ☐ Trellis
- ☐ Poor
- ☐ Discontinuous
- ☐ Closed

SITE DRAINAGE
- ☐ Well
- ☐ Moderate
- ☐ Poor

STREAM SOURCE(S)
- ☐ Ground
- ☐ SpringMelt
- ☐ Glacier
- ☐ Recent Rain
- ☐ Unknown

STREAM CLASS
- ☐ Primary
- ☐ Secondary
- ☐ Tertiary
- ☐ Quaternary
- ☐ Undefined

STREAM TYPE
- ☐ Permanent
- ☐ Intermittent
- ☐ Re-emergent
- ☐ Undefined

STREAM FLOW
- ☐ Stagnant
- ☐ Slow
- ☐ Moderate
- ☐ Fast
- ☐ Torrential

WATER COLOUR

WATER CLARITY
- ☐ Transparent
- ☐ Partially Cloudy
- ☐ Cloudy

VEGETATION
- ☐ Coniferous
- ☐ Deciduous
- ☐ Mixed
- ☐ Grass
- ☐ Bog
- ☐ Other

BANK TYPE(S)
- ☐ Alluvium
- ☐ Colluvium
- ☐ Till
- ☐ Outwash
- ☐ Bare Rock
- ☐ Talus/Scree
- ☐ Organic
- ☐ Other

CONTAMINATION(S)
- ☐ None
- ☐ Possible
- ☐ Probable
- ☐ Definite
  - ☐ Mining
  - ☐ Industry
  - ☐ Agriculture
  - ☐ Domestic
  - ☐ Forestry
  - ☐ Burn
  - ☐ Other

BANK PRECIPITATE
☐ No Yes ☐

Colour(s)

BOTTOM PRECIPITATE
☐ No Yes ☐

Colour(s)

STREAM SEDIMENT SAMPLE COLOUR(S)

STREAM SEDIMENT COMPOSITION
- Sand ____ %
- Silt & Clay ____ %
- Organics ____ %

SAMPLE TYPE(S)
- ☐ Silt Sediment (SS)
- ☐ Bulk Sediment (BS)
- ☐ Pebble (PB)
- ☐ Water (SW)
- ☐ Other

IN-SITU WATER
PH | COND

BULK SITE
- ☐ Longitudinal Bar
- ☐ Transverse Bar
- ☐ Point Bar
- ☐ Diagonal Bar
- ☐ Boulder Trap
- ☐ Log Trap
- ☐ Vegetation Trap
- ☐ Bedrock Step
- ☐ Pool
- ☐ Gravel Veneer
- ☐ Stream Bed
- ☐ Beaver Dam

BULK SITE COMPOSITION
- Cobbles ____ %
- Pebbles ____ %
- Sand ____ %
- Silt ____ %
- Clay ____ %
- Organics ____ %

PEBBLE LITHOLOGY(IES)
____ %
____ %
____ %
____ %

SITE RATING
- ☐ Good
- ☐ Good to Moderate
- ☐ Moderate
- ☐ Moderate to Poor
- ☐ Poor

BEDROCK EXPOSED
☐ No Yes ☐

Type(s)

CLAST SHAPE
- Rounded ____ %
- Sub-Angular/ Sub-Rounded ____ %
- Angular ____ %
- Platy/Flat ____ %

BOULDERS PRESENT
☐ No Yes ☐

Type(s)

Longitude (DD) | **Latitude (DD)**
NAD | Decimal Degrees | Decimal Degrees

COMMENTS:

NTS SHEET → e.g. 0 8 5 E 1 3

NTS Sheet: National Topographic System 1:250,000 index reference, consisting of three numbers and one letter e.g. 085E and occupy the first four boxes. The final two boxes are used for the 1:50,000 sheet identification e.g. 13, if applicable.

YEAR e.g. 2 0 0 5

Year: The four-digit year, e.g. 2005.

SAMPLE NUMBER e.g. 1 0 0 2

Sample Number: A four-digit sample number e.g. 1002. The first digit refers to the collection party crew number, while the other three digits are a sequential series from 001 to 999, for example:

Crew 1 samples range from 1002 to 1999,
Crew 2 samples range from 2002 to 2999,
Crew 3 samples range from 3002 to 3999, …

REP STAT e.g. 0 0

Rep Stat (Replicate Status): A two digit number e.g. 00, defining the relationship of the current sample to others in the survey

00 routine sample
10 first sample of a field duplicate pair
20 second sample of a field duplicate pair
80 blind duplicate number (empty bag) for a blind duplicate cut of one of previous 18 field samples
90 control reference number (empty bag) for cut of a control reference sample

WIDTH e.g. 1 1

Stream Width: width of the stream estimated in metres to the closest 1/10th of a metre e.g. 1.1metres wide.

DEPTH e.g. 0 1

Stream Depth: depth of the stream estimated in metres to the closest 1/10th of a metre e.g. 0.1 metres deep.

DATE (DAY MO) e.g. 1 1 0 7

Date: date of collection, DD MM format, e.g. July 11 = 11 07

TIME e.g. 1 4 2 6

Time: time of day (24 hour clock), e.g. 2:26pm = 14:26

COLLECTORS e.g. A B C D E F

Collectors: initials of the collection crew, first three boxes for the navigator (A.B.C.), and the last three for the second sampler (D.E.F.), e.g. ABC DEF

GENERAL PHYSIOGRAPHY

- ☐ Mountainous - rugged area of uplift having at least 300m gain from base to peak
- ☐ Hilly - natural elevation change, of less than 300m, while having a well defined outline
- ☐ Plateau - an elevated area of fairly level ground
- ☐ Plain - any area of level or near-level open land
- ☐ Swamp - low waterlogged area having shrubs and/or trees

SURFACE EXPRESSION

- ☐ Hummocky - series of rounded knobs and kettles
- ☐ Inclined - constant sloping surface
- ☐ Level - flat or gently sloping

DRAINAGE PATTERN

- ☐ Dendritic - "tree-like" network of streams
- ☐ Herringbone - V-shaped pattern of streams
- ☐ Rectilinear/Trellis - series of parallel streams with near right-angle turns and perpendicular intersections
- ☐ Parallel - streams flowing parallel before joining at small angles
- ☐ Poor/Deranged - no clear geometry in the drainage and no true stream valley pattern
- ☐ Discontinuous - stream disappears for a short distance then re-appears down slope
- ☐ Closed

SITE DRAINAGE

- ☐ Well - stream channel well developed and well drained
- ☐ Moderate
- ☐ Poor - stream channel poorly developed and poorly drained

STREAM SOURCE

- ☐ Ground - stream flow originates from natural springs or seeps
- ☐ SpringMelt - stream flow greater due to melting of winter's snow
- ☐ Glacier - stream originates from melting glacier
- ☐ Recent Rain - stream flow greater due to recent rain
- ☐ Unknown

STREAM CLASS *(determined from 1:250,000 NTS)*

- ☐ Primary - smallest stream, originates from springs and seeps
- ☐ Secondary - stream below confluence of two primary streams
- ☐ Tertiary - stream below confluence of two secondary streams
- ☐ Quaternary - stream below confluence of two tertiary streams
- ☐ Undefined

STREAM TYPE

- ☐ Permanent - year-round flow
- ☐ Intermittent - seasonal flow during wet season or spring runoff
- ☐ Re-emergent - discontinuous stream course
- ☐ Undefined -

STREAM FLOW

- ☐ Stagnant - little or no flow
- ☐ Slow - speed of a slow walker
- ☐ Moderate - speed of someone briskly walking
- ☐ Fast - speed of a jogger
- ☐ Torrential - speed of a quick jogger

WATER COLOUR

_____ ⇩ dominant colour (if any) of the stream **water**

WATER CLARITY

- ☐ Transparent - clear (any colour)
- ☐ Partially Cloudy - semi opaque (any colour)
- ☐ Cloudy - opaque or nearly opaque (any colour)

VEGETATION

- ☐ Coniferous - having needle-like leaves, e.g. spruce, pine, incl. tamarack.
- ☐ Deciduous - trees that shed their leaves annually, e.g. maple, poplar ...
- ☐ Mixed - roughly equal mixture of coniferous and deciduous trees
- ☐ Grass - grasslands surrounding site
- ☐ Bog - waterlogged spongy ground, sphagnum moss dominate
- ☐ Other _____

BANK TYPE

- ☐ Alluvium - clay, silt, sand or gravel recently deposited by stream action
- ☐ Colluvium - accumulation of material through the action of gravity
- ☐ Till - glacial till (unsorted)
- ☐ Outwash - stratified sand or gravel deposited by glaciofluvial melt water
- ☐ Bare Rock - bedrock
- ☐ Talus/Scree - loose rock fragments derived from an adjacent steep rocky slope
- ☐ Organic - peaty organic soil or sediment
- ☐ Other _____

CONTAMINATION

- ☐ None - no sign of any human activity
- ☐ Possible - some human activity in area, no obvious sign of contamination
- ☐ Probable - site, area disturbed by human activity
- ☐ Definite - obvious contamination due to human activity

(Specify)

- ☐ Mining
- ☐ Industry
- ☐ Agriculture
- ☐ Domestic
- ☐ Forestry
- ☐ Burn
- ☐ Other

SAMPLE TYPE(S)

Check ***ALL*** applicable boxes

- ☐ Silt Sediment (SS)
- ☐ Bulk Sediment (BS)
- ☐ Pebble (PB)
- ☐ Water (SW)
- ☐ _____

BANK PRECIPITATE

☐ No Yes ☐

_____

Colour(s)

Syntax

single colour
dominant-subordinant

multiple distinct colours
dominant ; subordinate

BOTTOM PRECIPITATE

☐ No Yes ☐

_____

Colour(s)

Syntax

single colour
dominant-subordinant

multiple distinct colours
dominant ; subordinate

STREAM SEDIMENT SAMPLE COLOUR(S)

_____

Syntax

single colour
dominant-subordinant

multiple distinct colours
dominant ; subordinate

STREAM SEDIMENT COMPOSITION

Sand _____ % - particles between 0.0625 and 2 mm in size
- will fall apart when squeezed into a ball

Silt & Clay _____ % - particles smaller than 0.0625 mm
- holds together when squeezed, silt is fine grained with gritty feel, clay is very fine grained and has slippery feel

Organics _____ % - muck-like light weight sediment composed of organic materials

IN-SITU WATER

PH COND

If applicable

N A D

Datum, either NAD27 or NAD83

Decimal Degrees

Longitude
(decimal degrees to at least five decimal places)

Decimal Degrees

Latitude
(decimal degrees to at least five decimal places)

BULK SEDIMENT SITE

- ☐ Longitudinal Bar - elongated bodies of sediment parallel to stream flow
- ☐ Transverse Bar - lobate bodies of sediment oriented roughly perpendicular to stream flow
- ☐ Point Bar - elongated bodies of sediment that form on the inside of stream bend, often attached to the inside bank
- ☐ Diagonal Bar - elongated bodies of sediment orientated obliquely to the stream flow
- ☐ Boulder Trap - sediment on the down-stream side of a boulder
- ☐ Log Trap - sediment on the down-stream side of a log
- ☐ Vegetation Trap - sediment on the down-stream side of vegation
- ☐ Bedrock Step - sediment collects down-stream of break in bedrock slope
- ☐ Pool - sediment collects down-stream of waterfall or set of rapids
- ☐ Gravel Veneer - thin layer of gravel atop finer sediment
- ☐ Stream Bed - sediment taken from main stream channel
- ☐ Beaver Dam - course sediment exposed by flushing action adjacent or below dam

SITE RATING*

- ☐ Good - Clast supported, tightly packed, poorly sorted gravel in well formed bedrock depression, pothole or crevice. Clast sizes: boulders, cobbles, pebbles, granules. Matrix contains sand and silt. Excavation to bedrock and/or presence of abundant well-rounded clasts enhances site rating. Lack of boulders diminishes rating.
- ☐ Good to Moderate - Clast supported, tightly packed, poorly sorted gravel upstream or downstream of prominent rock bar or large boulder and preferably at a level well below the obstruction. Clast sizes: boulders, cobbles, pebbles, granules. Matrix contains sand and silt. Excavation to bedrock and/or presence of abundant well-rounded clasts enhances site rating.
- ☐ Moderate - Clast supported, poorly sorted gravel amongst boulders. Packing moderate to tight. Clast sizes boulders (mainly small), cobbles, pebbles, granules. Matrix contains sand and silt. Excavation to bedrock and/or presence of many well-rounded clasts and/or association with some kind of obstruction enhances site rating. Lack of boulders diminishes rating.
- ☐ Moderate to Poor - Matrix supported, generally losely packed gravel strewn on river bed and not associated with any prominent obstruction. Sorting is moderate to poor. Boulders are rare or absent. Main clast sizes: cobbles, pebbles, granules. Matrix contains sand and silt.
- ☐ Poor - Matrix supported, very loosely packed, fine gravel. Clasts are relatively rare and often form a thin surface veneer on sand or are confined to isolated lenses within a sand mass. Clast sizes: cobbles (rare), pebbles, granules. Matrix of sand and/or silt. No associated obstruction.

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PEBBLE SHAPE

Rounded _____ % - smooth and rounded clasts

Sub-Angular/ Sub-Rounded _____ % - rough and semi-rounded clasts

Angular _____ % - sharp edged angular clasts

Platy/Flat _____ % - disclike clasts, one dimension much shorter than other two

BULK SEDIMENT SITE COMPOSITION

Cobbles _____ % - particles between 64 and 256 mm in size

Pebbles _____ % - particles between 2 and 64 mm in size

Sand _____ % - particles between 0.0625 and 2 mm in size
- will fall apart when squeezed into a ball

Silt _____ % - particles between 0.02 and 0.0625 mm
- holds together when squeezed, silt is fine grained with gritty feel

Clay _____ % - particles smaller than 0.02 mm
- holds together when squeezed, clay is very fine grained and has slippery feel

Organics _____ % - muck-like light weight sediment composed of organic materials

PEBBLE LITHOLOGY(IES)

- Rough estimate of pebble lithology(ies)

_____ ____%

_____ ____%

_____ ____%

_____ ____%

BEDROCK EXPOSED

☐ No Yes ☐

_____

Type(s)

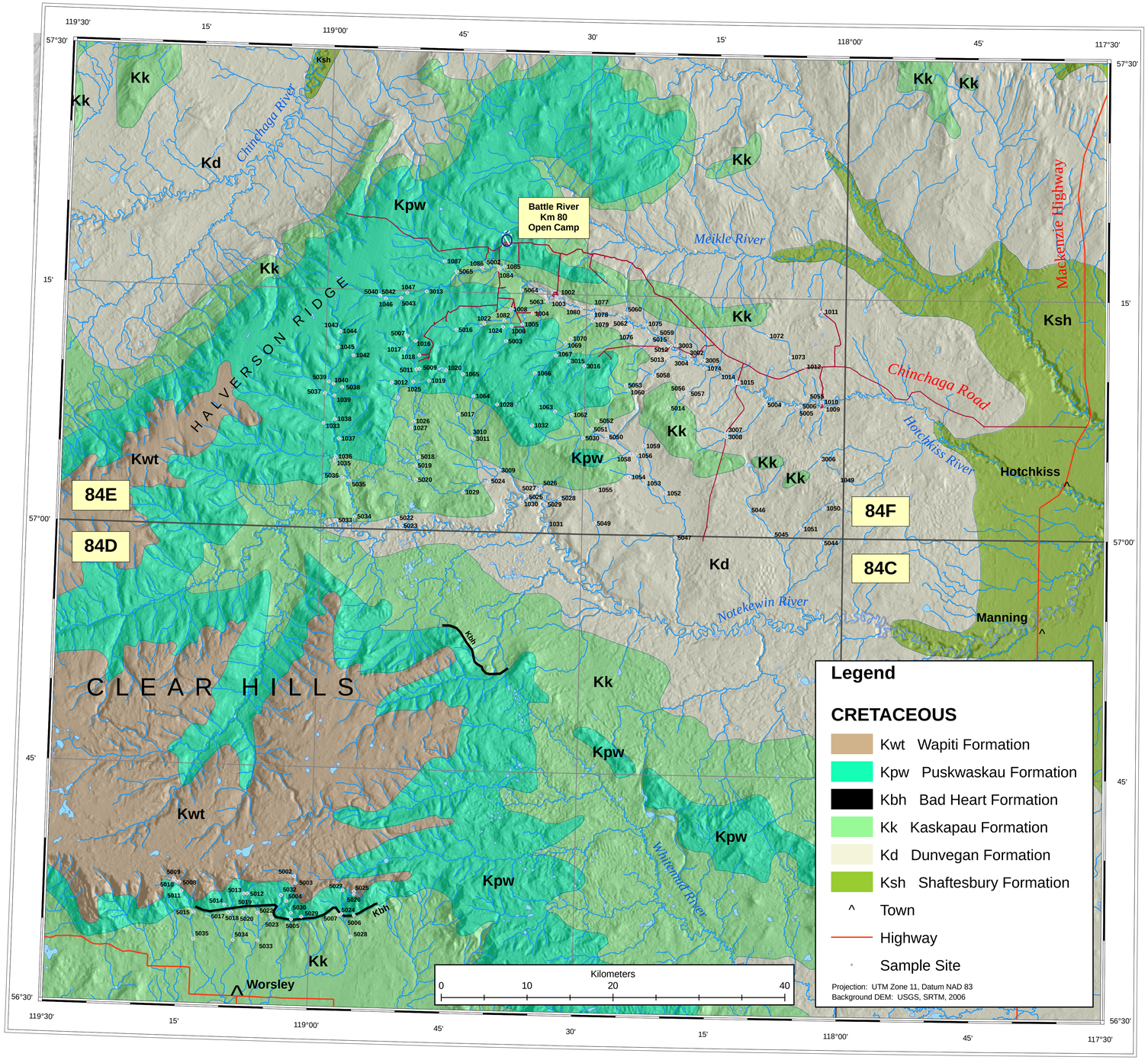
BOULDERS* PRESENT

☐ No Yes ☐

_____

Type(s)

* > 256 mm


Battle River
Km 80
Open Camp
Chinchaga River
Meikle River
Chinchaga Road
Hotchkiss River
Mackenzie Highway
Notekewin River
Whitemud River
HALVERSON RIDGE
CLEAR HILLS
Hotchkiss
Manning
Worsley
84E
84D
84F
84C
Kk
Kd
Kpw
Kwt
Ksh
Kbh
Legend
CRETACEOUS
Kwt Wapiti Formation
Kpw Puskwaskau Formation
Kbh Bad Heart Formation
Kk Kaskapau Formation
Kd Dunvegan Formation
Ksh Shaftesbury Formation
Town
Highway
Sample Site
Kilometers
0 10 20 40
Projection: UTM Zone 11, Datum NAD 83
Background DEM: USGS, SRTM, 2006
119°30'
119°00'
118°00'
117°30'
57°30'
57°00'
56°30'