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**Ministry of Energy and Mines
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Geological Survey Branch**

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**REGIONAL LAKE WATER
GEOCHEMISTRY OF PARTS OF
THE NECHAKO PLATEAU,
CENTRAL BRITISH COLUMBIA
(NTS 93F/2, 3; 93K/9, 10, 15, 16;
93L/9, 16; 93M/1, 2, 7, 8)**

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ABSTRACT

Open File 1999-5 presents new analytical results for three regional lake water geochemical surveys conducted over parts of the Nechako Plateau in central British Columbia during the period 1993-1996. The surveys, which cover parts of the Nechako River (NTS 93F), Fort Fraser (NTS 93K), Smithers (NTS 93L) and Hazelton (NTS 93M) map areas, cover an area of almost 9000 square kilometres in a region where mineral exploration has previously been limited by extensive drift cover and poor exposure.

The surface waters were obtained over the course of regional lake sediment geochemical surveys, corresponding analytical data for which have been previously released. Lake water samples were collected from a combined total of 630 sites in 551 lakes, at an average sampling density of approximately one site per 14.1 square kilometres. Waters were analyzed for major elements and trace elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES; Fawnie survey) or inductively coupled plasma-mass spectrometry

(ICP-MS; Pinchi and Babine surveys). In all, 8, 48 and 58 ICP element determinations are given here for waters from the Fawnie, Pinchi and Babine surveys, respectively. Among the major elements are calcium, magnesium, potassium and aluminum; trace elements include copper, zinc, molybdenum, barium and antimony. The standard Regional Geochemical Survey (RGS) suite of elements (U, F, sulphate, pH) were also determined on most samples. Additional constituents including conductivity and total dissolved solids (TDS) were determined for waters of the Babine area.

Preliminary data discussion for several elements indicate that survey results confirm the locations of several currently known prospects and may outline areas for prospective porphyry-style mineralization. Element distribution maps for each survey area are complemented by a series of ratio maps which may assist in identifying areas of potential porphyry-style alteration and mineralization.

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INTRODUCTION

Open File 1999-5 presents new major element and trace element analytical data for surface waters from more than 500 lakes in the Nechako Plateau of central British Columbia. The data was collected by the British Columbia Geological Survey Branch over the course of regional lake sediment surveys conducted in parts of the Nechako River (NTS 93F), Fort Fraser (NTS 93K), Smithers (NTS 93L) and Hazelton (NTS 93M) map areas during the period 1993-1996. A total of 630 sites were sampled over an area of almost 9000 square kilometres at an average density of approximately one site per 14.1 square kilometres (Table 1).

Data for major elements such as potassium and aluminum, and trace elements such as copper, zinc, molybdenum and rare earth elements are provided here. Some total dissolved solids (TDS) and conductivity data are also included. In addition, previously-published data for pH, sulphate, uranium and fluoride is incorporated into this report. These results, together with those of the northern Kechika Trough (Cook *et al.*, 1999) represent the first application of ICP-AES and ICP-MS hydrogeochemistry to Regional Geochemical Survey (RGS) lake sediment surveys in British Columbia. This report is a companion volume to earlier Open File lake sediment geochemical reports on the Fawnie (Cook and Jackaman, 1994), Pinchi (Cook *et al.*, 1997) and Babine (Cook *et al.*, 1998) areas. Geochemical results presented here are intended to highlight regional geochemical trends for mineral exploration purposes, and should not be used as a substitute for site-specific environmental studies.

The subdued topography, poor drainage and abundance of lakes in this part of the Nechako Plateau make lake sediments and waters ideal sample media for geochemical exploration. Sediments are an effective tool to delineate regional geochemical patterns and anomalous metal concentrations related to mineral occurrences. Most examples of the successful application of lake sediment geochemistry to Cordilleran mineral exploration come from the Nechako Plateau. Lake waters, on the other hand, have not been widely used. A small suite of water determinations (U, F, sulphate, pH) is routinely included in regional lake sediment geochemical reports, and there are currently more than 40,000 sets of these stream and lake water analyses available in the RGS database. Analytical results and field observations compiled by the RGS program in British Columbia are used in the development of a high-quality geochemical database suitable for mineral exploration, resource assessment, geological mapping and regional environmental studies.

Open File 1999-5 is a contribution to the Nechako NATMAP Project, a joint project of the British Columbia Geological Survey Branch, the Geological Survey of Canada, and university researchers. It is a multidisciplinary investigation of bedrock geology, glacial history, and lake sediment geochemistry of this part of the Nechako Plateau. Mineral exploration of this area has been limited by extensive drift cover, poor exposure and, until recently, a relatively low-resolution geological database. Each of the water survey areas outlined here correspond to areas of recent bedrock mapping, surficial mapping and till geochemistry. Epithermal gold deposits and porphyry-style copper and molybdenum deposits are the primary exploration targets, and new baseline geochemical data should prove useful in stimulating new exploration for these and other mineral deposit types.

OPEN FILE FORMAT

Open File 1999-5 is divided into the following sections:

- Introduction, survey methodology and quality control
- Preliminary data interpretation and discussion
- Listings of field variables and analytical data (Appendix A)
- Listings of field duplicate data (Appendix B)
- Summary statistics (Appendix C)
- Element distribution, geology and sample location maps (Appendix D)

Analytical and field data are included as an ASCII file on a 3.5-inch high density diskette, located in the back pocket of this report. Data for each sample are listed in comma-delimited fields over one data record. Document files detailing format specifications and survey details are also included. Page-size sample location maps are included here in Appendix D, but corresponding lake sediment Open Files (Cook and Jackaman, 1994; Cook *et al.*, 1997, 1998) should be consulted for more detailed 1:100,000 scale sample location maps.

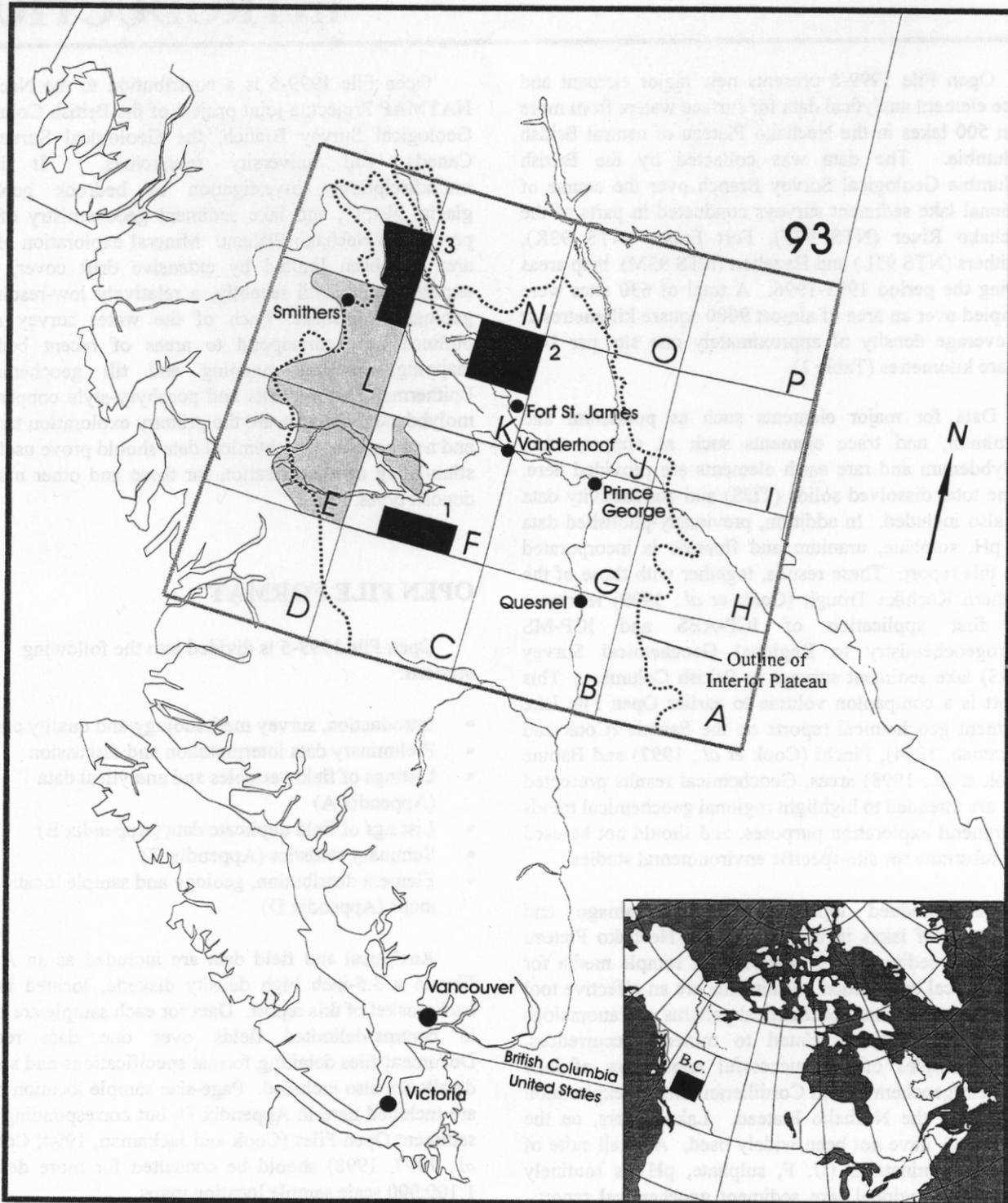


Figure 1. Location of regional lake water geochemistry survey areas (1993-1996) in the Nechako River (NTS 93F), Fort Fraser (NTS 93K), Smithers (NTS 93L) and Hazelton (NTS 93M) map areas of the Nechako Plateau, central British Columbia: 1) Fawnie survey, 2) Pinchi survey, and 3) Babine survey. Locations of other lake sediment and water geochemical surveys (lightly shaded areas) in the area, for which no data is presented here, are also shown. Physiographic outline of Interior Plateau (dotted line) after Holland (1976).

DESCRIPTION OF THE SURVEY AREAS

LOCATION AND ACCESS

The three survey areas are located in the Vanderhoof-Fort St. James-Smithers region of central British Columbia and are accessible from Highway 16, the main east-west corridor in the region.

The Fawnie survey area covers about 1880 square kilometres and is located approximately 90 kilometres south of Highway 16 and the town of Fraser Lake. There is only limited road access into the field area. The Kluskus-Ootsa and Kluskus-Malapat Forest Service roads provide access to much of the northern part of 93F/3 from Vanderhoof and Fraser Lake, while the Blue Road extends into the easternmost part of the survey area in 93F/2. Two of the major mineral occurrences, the Wolf and Blackwater-Davidson prospects, are road accessible.

The Pinchi Lake survey area (NTS map areas 93K/9, 10, 15, 16) covers about 3760 square kilometres and is located immediately north of the town of Fort St. James in central British Columbia, approximately 110 kilometres northwest of Prince George. An extensive network of logging roads provide good access into much of the survey area from Fort St. James. The Germansen North road runs northward through the eastern part of the survey area to Germansen Landing and Mackenzie, while the Tachie and Leo Creek roads provide access to the northwestern part of the survey area. The southwest corner of the survey area, on the southwest side of Stuart Lake, is accessed by the Whitefish-Cunningham road.

The Babine survey area (all or part of NTS map areas 93L/9, 16; 93M/1, 2, 7, 8) is located about 40-50 km east-northeast of Smithers in west-central B.C. Centred on northern Babine Lake, the survey area comprises a north-south trending strip, approximately 100 km long and 30-40 km wide, with an area of about 3406 square kilometres. It is bounded in the northwest by the Babine River, and in the northeast by a portion of Takla Lake. The village of Granisle, from which the survey was based, is the main population centre and is accessible from Highway 16 via both Topley and Smithers. Logging roads provide good road access within much of the survey area, particularly that area east of Babine Lake where access is provided by a private logging ferry. Access is limited, however, in the northern portion of the survey area.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

FAWNIE SURVEY AREA

Most of the Fawnie survey area lies within the Nechako Plateau, although a small area southeast of Tsacha Lake and the Blackwater River falls within the Fraser Plateau (Holland, 1976). Topography is dominated by the subparallel ridges of the Fawnie and Nechako ranges, with Mount Davidson (elev: 1852 m) and Kuyakuz Mountain (elev: 1781 m) forming maximum elevations, respectively. The Entiako Spur and Naglico Hills are also prominent topographic highs. A wide variety of physiographic regimes, ranging from rocky subalpine peaks to boggy lowlands along the Blackwater River and Fawnie Creek, occur throughout the area (Photos 1-3). Active first-order streams are relatively uncommon. Lakes are not uniformly distributed; they are numerous in parts of the Naglico Hills, but absent in large expanses of the Fawnie Range and Entiako Spur. The area within the Fraser Plateau is predominately flat lying and characterized by abundant bogs but few lakes.

The glacial history and surficial geology of the Fawnie Creek map area (NTS 93F/3) have been documented by Giles and Levson (1994) and Levson and Giles (1994, 1996). Ice flow was dominantly toward the east-northeast. Much of the region is drift covered although some areas, particularly the Naglico Hills, have considerable outcrop. Morainal diamicton, predominantly basal till, is the most widespread Quaternary deposit and covers much of the area to depths of up to several metres. Glaciofluvial outwash sediments occur in major valleys such as Fawnie Creek, and postglacial colluvial veneers and diamicton are common on steeper slopes.

PINCHI SURVEY AREA

The northeast and southwest portions of the Pinchi survey area lie within the bounds of the Nechako Plateau, but most of the area is within the Nechako Plain and parts of the Fraser Basin (Holland, 1976). This relatively flat-lying area of low relief lies (Photos 4-5) between 2500 to 3000 feet (762 to 914 m) elevation in most areas, well below that of the adjacent Nechako Plateau. Topography is dominated by Chuius Mountain (max. elevation: 1568 m) in the centre of the survey area, and by Mount Pope

and Murray Ridge (max. elevations: 1472 m and 1399 m, respectively) in the southeast. Tchentsut Mountain and Pinchi Mountain are also prominent topographic highs. Extensive lowland areas are centred around Grostete Creek, northwest of Tezzeron Lake, and to the southeast and northeast of Pinchi Lake. Active first-order streams are relatively uncommon. Lakes are relatively uniformly distributed throughout the survey area, but there is considerable local variation in their abundance. For example, lakes are particularly numerous as kettles in the area between Tezzeron and Trembleur lakes, but are almost absent on the north side of Stuart Lake and in the Tezzeron Creek-Tsilcoh River-Hyman Creek-Ocock Creek lowland in the southeast part of the survey area.

The surficial geology and glacial history of the survey area have been documented by Plouffe (1994, 1995), Armstrong and Tipper (1948) and Armstrong (1949). The area is extensively drift-covered, and till and glacial lake sediments are the most widespread Quaternary deposits; glaciofluvial sediments are not extensive. Plouffe (1994) indicates that most of the area is covered with a till blanket at least 1 m thick. Thicker hummocky till is most commonly found in the eastern part of the survey area; thin till veneers and associated postglacial colluvium are restricted to a few areas of higher relief. Ice flow was dominantly from west to east (Plouffe, 1995), with a significant deflection toward the northeast in the Tezzeron Creek map area (NTS 93K/16). Extensive deposits of glacial lake sediments in the area are erosional remnants of what Armstrong and Tipper (1948) referred to as the Fort St. James basin, one of three short-lived glacial lake basins which formed in the Prince George region upon stagnation and retreat of the Cordilleran ice sheet. Recent mapping (Plouffe, 1994) has shown that the distribution of these light-coloured silts, with minor sand and clay, is less extensive than previously thought. They are confined to a discontinuous northwest-trending corridor extending from the southeastern corner of the survey area to Trembleur Lake. Stuart, Pinchi and Tezzeron lakes are present-day remnants of these lake basins, which lie between about 2200 and 2600 feet (670 and 792 m; Armstrong, 1949) elevation. Maximum thickness of the Fort St. James basin is at least 30 m (Armstrong, 1949), but most glacial lake sediments form a discontinuous veneer of about 1 m (Plouffe, 1994) over the underlying till moraine. Thicker (generally 2-4 m) silt blankets are restricted to the north side of Stuart Lake and to the area between Tezzeron and Trembleur lakes.

BABINE SURVEY AREA

The Babine survey area is located at the northern terminus of the Interior Plateau (Holland, 1976), where

the rolling hills of the Nechako Plateau grade into the rugged peaks of the Skeena Mountains, to the north, and the Hazelton Mountains, to the west. The Nechako Plateau generally lies between about 2500 to 3500 feet (approx. 762 to 1067 m) elevation here. Lowest topography is near the shorelines of major lakes, and in the marshy southern part of the survey area near Lennac Lake. In more rugged areas (Photo 6), elevations up to 5148 feet (1569 m) are attained at Old Fort Mountain, and in excess of 4500 feet (1372 m) at Hearne Hill.

Elevations in excess of 3500 feet are common in the mountainous northern part of the survey area, where the southern part of the Bait Range (Skeena Mountains) overlooks the Nechako Plateau, reaching a maximum elevation of 6377 feet (1944 m) at Frypan Peak. Trail Peak, at 5313 feet (1619 m) is another prominent point in this area. In the far southeastern end of the survey area, topography is dominated by Matzehtzel Mountain (5758 feet/1755 m).

The surficial geology and glacial history of the Babine porphyry belt area have been described by Tipper (1971) and, more recently, by Levson *et al.* (1997b) and Huntley *et al.* (1996) at 1:50 000 scale. The area is extensively drift-covered, with till and glaciolacustrine sediments the most widespread Quaternary deposits. Glacial movement was dominantly to the southeast, and resulting morainal sediments vary from less than a metre to several metres in thickness, often occurring as fluted or drumlinized topography. Overlying glaciolacustrine sediments are exposed in the lower-lying parts of the survey area, generally near the shorelines of large modern lakes such as Babine Lake (elev: 2335 feet/711 m), which is a remnant of a postglacial lake. These sediments are generally restricted to elevations less than 950 m.

BEDROCK GEOLOGY AND MINERAL DEPOSITS

Two of the survey areas, Fawnie and Babine, lie within the bounds of the Stikine Terrane, which underlies much of this part of central British Columbia. The third, Pinchi, survey area is underlain by the Cache Creek and Quesnel Terranes.

FAWNIE SURVEY AREA

Bedrock geology of the Fawnie survey area has been mapped by Tipper (1963) and Diakow *et al.* (1994, 1995, 1996). The recent compilation of Diakow and Levson (1997) is the most up-to-date account of the bedrock and

surficial geology of the area. Most of the area is underlain by volcanic flows, volcanoclastics and sedimentary rocks of the Middle Jurassic Hazelton Group. The informal name Naglico formation has been applied to these rocks in NTS 93F/3 (Diakow and Webster, 1994). These are intruded by the Late Cretaceous Capoose batholith and locally overlain by Eocene rhyolite, dacite and conglomerate of the Ootsa Lake Group. Miocene-Pliocene Chilcotin Group basalt flows occur in low-lying regions in the south and eastern parts of the study area. Diakow and Webster (1994) have inferred the Jurassic rocks exposed in the survey area to be part of a regional east-trending horst, the Nechako uplift.

The metallogeny and mineral deposits of the Fawnie area have been outlined by Lane and Schroeter (1997). Epithermal precious metal deposits in Ootsa Lake Group volcanics, epithermal precious metal/magnetite skarn occurrences associated with the Capoose batholith, and transitional base and precious metal deposits are the most common exploration targets. Interest in the potential for epithermal deposits has increased in recent years, and both the Wolf and Blackwater-Davidson prospects occur within the Fawnie survey area. The Wolf prospect, a low sulphidation adularia-sericite epithermal gold-silver deposit (Lane and Schroeter, 1997) currently under exploration, is hosted by felsic flows, tuffs and subvolcanic porphyries. Mineralization occurs in quartz-carbonate veins, silicified stockworks and hydrothermal breccia zones. Anomalous silver, zinc, arsenic and molybdenum concentrations in sediment of a nearby lake led to the discovery of the prospect (Dawson, 1988). The Blackwater-Davidson prospect is a structurally controlled gold-silver-zinc-lead-copper occurrence located on the north side of Mount Davidson in the Fawnie Range. The Tsacha (Tommy) occurrence, discovered by the Geological Survey Branch during the 1993 field program, is a system of quartz veins and stockwork veinlets in Hazelton Group Naglico Formation rhyolitic flows and ash-flow tuff near the southern border of the survey area. Assay results of grab samples (fire assay-ICP) returned concentrations of up to 3.7 ppm gold at this locality (Diakow *et al.*, 1994; Pautler, 1995).

PINCHI SURVEY AREA

Bedrock geology of the Fort St. James region was first mapped by Armstrong (1941, 1949), and has been partially re-mapped to modern standards over the intervening half-century. Within the survey area, the Tezzeron Creek map area (NTS 93K/16) was mapped by Nelson *et al.* (1991a,b), while an area southwest of Stuart Lake (parts of NTS 93K/7, 8, 10 and 11) was mapped by Ash and Macdonald (1993a,b). Paterson (1973, 1977) mapped in the Pinchi Lake area, and a new bedrock

mapping project over the survey area (Struik, in prep.) has recently been completed. The compilation of Bellefontaine *et al.* (1995) is used here as the geological base for this survey (Appendix D-3).

The survey area straddles the boundary between the Quesnel and Cache Creek Terranes, which are separated by the northwest-southeast trending Pinchi Fault zone. To the northeast of the Pinchi fault zone are Early Mesozoic Takla Group island arc rocks of the Quesnel Terrane (Nelson *et al.*, 1991a,b). This assemblage of sedimentary, volcanic, pyroclastic and epiclastic rocks has been informally subdivided by Nelson *et al.* (1991a,b) and Nelson and Bellefontaine (1996) in this area into four informal successions: the Slate Creek, Inzana Lake, Witch Lake and Chuchi Lake successions. Of these, the Inzana Lake succession and, to a lesser extent, the underlying Slate Creek succession are most extensive within the survey area. The Inzana Lake succession largely comprises interlayered argillite and epiclastic volcanic units. The Slate Creek (formerly Rainbow Creek) succession comprises interbedded black argillite, greywacke, siltstone and other sedimentary units. Augite porphyry flows and agglomerate typify the Witch Lake succession, exposed in the northeastern part of the survey area. Coeval plutonic rocks, primarily Early Jurassic diorite intrusives such as the Kalder pluton and the Tas intrusive complex, are also exposed in this area. Miocene-Pliocene Chilcotin Group basalt flows occur in low-lying regions in the eastern part of the survey area.

To the southwest of the Pinchi fault zone are Late Paleozoic to Early Mesozoic pelagic sediments, carbonates, metabasalts and ultramafic rocks of the Cache Creek Terrane (Paterson, 1977; Ash and Macdonald, 1993a,b). A belt of glaucophane-lawsonite blueschist-facies metamorphism parallels the fault zone (Paterson, 1977) within the survey area. Pelagic sedimentary rocks are the most common units of this northwest-trending belt of Cache Creek Group oceanic rocks, named the Stuart Lake belt by Armstrong (1949). These are intruded north of Stuart Lake by a Middle Jurassic-Early Cretaceous Francois Intrusion. Felsic intrusive rocks of the Middle Jurassic Shass Mountain Pluton, which separates the Cache Creek and Stikine Terranes, are also exposed in the extreme southwestern corner of the survey area.

The mineral deposits of the Pinchi Lake survey area and surrounding region include: (i) porphyry copper-gold deposits, (ii) epithermal mercury deposits, (iii) mesothermal gold-antimony-quartz vein deposits, and (iv) podiform chromite showings.

Porphyry copper-gold deposits have been the main focus of exploration in the area since the mid-1980's. They are associated with coeval alkaline intrusions in

Late Triassic-Early Jurassic rocks of the Takla arc. The most prominent example in the region is the Mt. Milligan deposit, discovered in 1987, which is located just north of the survey area. Nelson and Bellefontaine (1996) have summarized the geological setting of the alkalic intrusives associated with these deposits. They are typically small, high-level to subvolcanic, contain densely-crowded, blocky plagioclase phenocrysts, and exhibit associated potassic-propylitic-pyritic alteration haloes. There are seven known porphyry prospects in Takla Group rocks within the survey area, all within the Tezzeron Creek map area (NTS 93K/16). The most significant of these are the Max copper-gold prospect (MINFILE 93K 020), and the Tas gold-copper prospect (MINFILE 93K 080).

Epithermal mercury deposits associated with the Pinchi fault zone are, historically, the most important economic mineralization within the survey area. The Pinchi Lake Mercury mine (MINFILE 93K 049) produced approximately 6.2 million kilograms of mercury during the periods 1940-1944 and 1968-1975 (MINFILE, 1995). Seven epithermal mercury deposits and showings occur along the Pinchi fault zone within the survey area, forming part of what Armstrong (1942a,b) named the Pinchi Lake mercury belt. They are found from the northwest side of Tezzeron Lake to Murray Ridge, near Fort St. James. Most, including the former Pinchi Lake Mercury mine, occur within a relatively small area between Pinchi and Tezzeron lakes. These deposits are hosted within metamorphosed sedimentary, volcanic and ultramafic rocks of the Cache Creek Group, where they typically occur as quartz-carbonate-cinnabar veins, stockworks, breccia zones and disseminations within carbonatized alteration zones (Armstrong, 1942a,b, 1949; Stevenson, 1940).

There are no mesothermal vein deposits within the bounds of the survey area. However, the Snowbird Au-Sb deposit (MINFILE 93K 036) is located just south of the survey area near the southwest end of Stuart Lake. It is a mesothermal quartz-carbonate-stibnite vein deposit hosted in a shear zone within carbonatized serpentinite of the Cache Creek Group, and was briefly mined for antimony during 1938-1940 (Armstrong, 1949). No similar gold-quartz vein mineralization is known in Cache Creek Group rocks of the survey area. Ash and Macdonald (1993a) attributed this to the rarity of exposed remnants of crustal and upper mantle ophiolitic rocks in the rest of the pelagic sedimentary sequence, although much of this area is obscured by a blanket of till and glaciolacustrine silt.

Chromite occurs as disseminations, wispy layers and rare lenses in obducted ultramafic rocks of the Cache Creek Group (Whittaker and Watkinson, 1981) at the

Murray Ridge showing (MINFILE 93K 012) northeast of Fort St. James.

BABINE SURVEY AREA

Bedrock geology of the Smithers and Hazelton map areas was first mapped by Armstrong (1944a,b), and later mapped at 1:250,000 scale by Tipper and Richards (1976) and Richards (1990), respectively. The Babine porphyry belt, first mapped by Carter (1973), has recently been remapped at 1:50,000 scale by MacIntyre (1998) and MacIntyre *et al.* (1997, 1996a,b) as part of the Nechako NATMAP Project. The geological compilation of the Skeena-Nass area (MacIntyre *et al.*, 1994) provides the most recent published geological account of the entire Babine porphyry belt, and is used as the geological base for this report.

The Babine survey area traces the distribution of Eocene intrusives within a largely Jurassic-Eocene volcano-sedimentary package. The Eocene intrusives are the most significant unit in this belt for hosting porphyry-style copper deposits, the primary exploration target in the area. The following account of the regional geology of the Babine porphyry belt is summarized from MacIntyre *et al.* (1997):

Layered rocks of the survey area range in age from Pennsylvanian-Permian limestones to Tertiary basalts of the Endako Group. Most of the area, however, is underlain by Lower to Middle Jurassic volcanic and sedimentary rocks of the Hazelton Group, a calc-alkaline island arc assemblage which has long been a focus of mineral exploration in British Columbia. These units are intruded by plutonic rocks of varying ages, most notably the Eocene Babine intrusions and Late Cretaceous Bulkley intrusions which host economic copper mineralization at many localities within the survey area and elsewhere in central B.C. The structural framework of the area is defined by uplifted and tilted fault blocks, and north to north-west trending grabens preserving younger Eocene rocks.

MacIntyre *et al.* (1997) provide detailed descriptions of lithological units within the Babine porphyry belt, together with their tectonic history and depositional environments. There are five main stratigraphic packages within the survey area:

i) Pennsylvanian-Permian limestone, exposed to the west of Babine Lake, and tentatively correlated with the Asitka Group by MacIntyre *et al.* (1997);

ii) Triassic Takla Group volcanic and sedimentary rocks, dominantly augite porphyry flows and marine

sediments, restricted to the west shore of Babine Lake north of Granisle;

(iii) Lower to Middle Jurassic rocks of the Hazelton Group, the most common sedimentary and volcanic units within the Babine porphyry belt, including subaerial calc-alkaline arc volcanics of the Telkwa Formation, shallow marine clastic sediments of the Nilkitkwa Formation, basaltic flows, pyroclastic and volcanoclastic rocks of the Saddle Hill Formation, and shallow-water sandstone, siltstone and conglomerate of the Smithers Formation.

(iv) shallow marine greywackes to mudstones of the Lower Cretaceous Skeena Group, and feldspar porphyry flows and breccia of the Lower to Upper Cretaceous Kasalka Group are present within the survey area. MacIntyre *et al.* (1997) noted that Skeena Group rocks are generally poorly exposed due to their preservation in low-lying areas in downdropped fault blocks or grabens.

(v) Early-Eocene-age units in the Babine porphyry belt include the Babine Intrusions, their extrusive equivalents the Newman Volcanics, and the Ootsa Lake Group. The Babine Intrusions (50.2-55.8 Ma) are the most economically-significant intrusive unit in the Babine porphyry belt. The Babine intrusions are exposed in a north-trending belt which extends from Fulton Lake in the south to Trail Peak in the north (MacIntyre *et al.*, 1997). They comprise plugs and dikes of biotite-feldspar porphyry, rhyolite dikes and domes and, less abundantly, granodiorite to quartz diorite. Rhyolite dikes and domes are best exposed near Old Fort Mountain, where they form an arcuate belt of resistant siliceous rocks which MacIntyre *et al.* (1997) likened to the remnants of a ring dike structure. MacIntyre *et al.* (1997) noted that the compositional similarity between the Babine Intrusions, and the older Bulkley Intrusions and Kasalka volcanics to the west, suggested that similar volcanic environments prevailed during Late Cretaceous and Eocene time.

The Newman volcanics, best exposed along the shores of the Newman Peninsula in Babine Lake, comprise calc-alkaline biotite-feldspar porphyry flows, breccias and lahars which are extrusive equivalents to the Babine intrusions. They are correlable to the Ootsa Lake Group, widespread in other parts of central B.C., which here form Eocene-age flows, breccias and lahars. Overlying the Ootsa Lake Group are vesicular basalt of the Buck Creek formation, Endako Group. These are the youngest rock units in the Babine survey area.

Intrusive units exposed in the Babine survey area include, in addition to the Babine intrusions, the late Triassic-Early Jurassic Topley intrusions (199-210 Ma) and the Late Cretaceous Bulkley intrusions (70-84 Ma). The Topley Intrusions, predominantly granite and

monzonite, are widely exposed in the southeastern part of the survey area. The Bulkley intrusions here are part of a north to northwestward-trending belt of intrusive bodies which extends from the Eutsuk Lake area of the Ootsa Reservoir to north of the Babine River. Here, they comprise hornblende-biotite-quartz-feldspar porphyry and granodiorite, and are restricted to the Lennac Lake area in the southern part of the survey area. Although secondary in economic significance to the Eocene Babine intrusions in this area, they are an important host for porphyry-style copper-molybdenum mineralization at other localities in central B.C. (Carter, 1981).

Past and current exploration in this region has centred primarily on porphyry copper targets, and the survey area includes the past-producing Bell (MINFILE 93M 001) and Granisle (MINFILE 93L 146) copper mines. Porphyry copper prospects such as the Hearne Hill (MINFILE 93M 006), Nak (MINFILE 93M 010) and Trail Peak (MINFILE 93M 011) deposits remain the primary exploration targets in the region. Porphyry-style copper deposits are the most important mineral deposit type within the bounds of the Babine survey area, and have been the focus of mineral exploration in this area for several decades. They include those deposits associated with: (i) Eocene Babine intrusives, and (ii) Late Cretaceous Bulkley intrusives. Only a short commentary on these mines and mineral localities is given here; more detailed descriptions are provided by sources such as MacIntyre *et al.* (1997), Carter *et al.* (1995), Dirom *et al.* (1995) and relevant assessment reports.

The former Bell and Granisle copper-gold mines are located on or near the Newman Peninsula in the northern part of Babine Lake. They operated during the periods 1972-1992 and 1966-1982, respectively. These, and other porphyry copper \pm gold prospects such as the Hearne Hill (MINFILE 93M 006), Nak (MINFILE 93M 010) and Trail Peak (MINFILE 93M 011) deposits, are hosted by Eocene biotite-feldspar porphyry Babine Intrusives. These deposits typically exhibit potassic and propylitic alteration zones around a smaller central ore zone of copper-sulphide minerals, as well as extensive pyrite halos with marginal polymetallic veins.

Porphyry copper-molybdenum mineralization is associated with Late Cretaceous Bulkley intrusions at the Lennac Lake Prospect (MINFILE 93L 190) in the southern part of the survey area. Here, copper and molybdenum mineralization is associated with a quartz diorite porphyry stock and dikes within Hazelton Group volcanics. There are no other porphyry copper prospects associated with the older Bulkley Intrusions within the Babine porphyry belt, but numerous similar deposits including the Bear, Huckleberry and Ox Lake deposits occur to the south and west of the survey area.

OTHER GEOCHEMICAL SURVEYS IN THE REGION

Several other publicly-available Regional Geochemical Surveys (RGS) have been conducted in this part of the Interior Plateau, most notably a series of corresponding lake sediment surveys in the Fawnie (Cook and Jackaman, 1994), Pinchi (Cook *et al.*, 1997) and Babine (Cook *et al.*, 1998) areas. However, there are also considerable data from stream sediment and till geochemical surveys conducted over the past fifteen years.

A regional stream and lake sediment survey of the Smithers map area (NTS 93L) was conducted during 1986 (Johnson *et al.*, 1987b), incorporating the southernmost part of the present Babine survey area. This, and an adjacent survey of the neighbouring Whitesail Lake map area (NTS 93E; Johnson *et al.*, 1987a), were primarily stream sediment surveys; low-density lake sediment and surface water sampling (one site per 30-35 square kilometres) was confined to the eastern parts of the map sheets. The northern part of the Babine porphyry belt also falls within the bounds of the 1983 RGS stream sediment survey of the Hazelton map area (NTS 93M; McMillan *et al.*, 1984). Stream sediment INAA data for gold, arsenic, antimony and a range of other elements has recently been released for this area (Jackaman, 1998).

The Geological Survey Branch also conducted surficial mapping and regional till geochemical surveys over parts of the southern Nechako Plateau and the entire Babine porphyry belt during the period 1993-1996. Till geochemical data for the Fawnie area and adjacent regions have been given by Levson *et al.* (1994), Weary *et al.* (1997), and Levson *et al.* (in preparation). Preliminary information on Babine till surveys has been reported by Stumpf *et al.* (1996), Huntley *et al.* (1996) and Levson *et al.* (1997a). Till geochemical data for the Old Fort Mountain area (NTS 93M/1), in the central part of the Babine belt, was released in May 1997 (Levson *et al.*, 1997c), and release of the remaining data is pending. Regional till geochemical data for the Pinchi area has been reported by the Geological Survey of Canada (Plouffe, 1995).

Mineral exploration industry surveys preceded government-funded regional lake sediment surveys in the Nechako Plateau during the 1960's and 1970's, but this data is not generally available in the public domain. Accounts of some industry surveys are described in the literature (*e.g.* Hoffman and Fletcher, 1976; Gintautas, 1984).



Photo 1. Regional lake sediment and water sampling in the Interior Plateau using a float-equipped helicopter (Fawnie Range, southern Nechako Plateau, June 1993).



Photo 2. Typical landscape in southern Nechako Plateau, showing extensive drift cover and poor exposure.



Photo 3. View of small pond (site 931143) draining altered Eocene felsic volcanic rocks exposed on adjacent hills at the Wolf epithermal gold prospect in the Fawnie Creek (NTS 93F/3) map area. Neutral (pH=7.10) surface waters here are among the lowest-pH waters in the Fawnie survey area, and have elevated aluminum (220 ppb) and SO_4/Ca levels. Sediments have elevated levels of gold, silver, arsenic, antimony, mercury, zinc, copper and molybdenum (June, 1993).



Photo 4. Preparing for a lake sediment and water sampling traverse in the Pinchi survey area (October, 1995)

SURVEY METHODOLOGY

COLLECTION OF WATER SAMPLES

Helicopter-supported regional water sampling was conducted by the authors in conjunction with lake sediment sample collection over the period 1993-1996. A sediment and water sample were systematically collected at each site using a float-equipped Bell 206 helicopter (Photo 1). Results reported here are based on an additional water sample which was collected at every second site or, in some cases, at every site for ICP multi-element determination of trace and major elements. In all, surface water samples for multi-element analysis were obtained from 630 sites in more than 500 different lakes (Table 1), at an average sampling density of approximately 1 site per 14.1 square kilometres. Details of sediment collection using the Hornbrook-type sampler have been described in previous Open File reports.

Survey	Collection Year	Area (square km)	Site Density	Lakes	Sites
Fawnie	1993	1862.6	7.9	189	237
Pinchi	1995	3584.2	16.5	199	217
Babine	1996	3406	19.4	163	176
<i>Totals:</i>		8852.8	14.1	551	630

Table 1. Summary of lake water multi-element geochemical surveys conducted in the Nechako Plateau area of central British Columbia during the period 1993-1996. Sampling density is in sites per square kilometre.

REGIONAL SAMPLING STRATEGIES

On the basis of results of prior orientation studies (Cook, 1993a,b), standard regional lake sediment and water surveys in British Columbia incorporate some departures from standard sampling strategies used elsewhere in Canada for the National Geochemical Reconnaissance (NGR) program (Friske, 1991; Friske and Hornbrook, 1991), particularly pertaining to overall site density and the number of sites sampled in each lake. First, every lake in each survey area was sampled, rather

than sampling only a selection of lakes at a fixed density (*i.e.* one site per 13 km²). In practice, some small ponds were not sampled due to unfavourable landing conditions. Samples are not usually collected from the centres of very large lakes (>10 km²; >40 m deep), such as Babine Lake.

Secondly, centre-basin sediments and waters are typically obtained from all major known or inferred sub-basins to investigate the considerable sediment trace element variations which may exist among sub-basins of the same lake. Consequently, sediment and water data is reported for more than one site in some of the larger lakes. Lake bathymetry maps in unpublished reports of the Fisheries Branch, B.C. Ministry of Environment, Lands and Parks (Balkwill, 1991) are routinely consulted prior to sampling these types of lakes in order to aid in site location.

SITE COLLECTION PROCEDURES

Lake water samples were collected at each site in 250-millilitre high-density polyethylene (HDPE) Nalgene bottles using a custom-designed sampling apparatus consisting of two HDPE water bottle holders secured to a 1-metre length of wooden dowel (Photo 2). Waters were sampled from approximately 15 centimetres below the lake surface to avoid collection of surface scum, and precautions were taken to minimize the collection of suspended solids. For example, sediment and water samplers worked from opposite sides of the helicopter to prevent the accidental collection of any water fouled by retrieved sediment. In small shallow ponds, the sediment was not collected until the water samples were obtained.

Two 250-millilitre water samples were collected:

- 1) One sample, at each site, for the determination of the standard RGS analytical suite (pH, uranium, fluoride, sulphate), which is determined for all routine RGS stream and lake water samples in British Columbia. These have been previously reported for this area by Cook and Jackaman (1994) and Cook *et al.* (1997, 1998).
- 2) A second lake water sample for more extensive multi-element ICP-AES or ICP-MS analysis of trace and major element constituents. This additional water sample was collected at every site in the Fawnie survey, and at every second site in the Pinchi and Babine surveys.

FIELD OBSERVATIONS

A variety of field variables and observations pertaining to sample media, site and local terrain were recorded at each site using Geological Survey of Canada lake sediment cards (Garrett, 1974). A rough estimate of the amount of suspended solids in water samples was noted. Other observations included sediment sample depth, colour and composition, as well as the general relief of the area and any potential sources of anthropogenic contamination. Depth was measured by means of graduated markings on the sampling rope or, in the case of the Pinchi survey, a float-mounted depth sounder. Field observations are reproduced here as part of Appendix A.

Site locations were marked on 1:50,000 scale NTS topographic maps in the field, transferred to master basemaps, and later digitized at the British Columbia Geological Survey Branch to obtain Universal Transverse Mercator (UTM) site coordinates (NAD27). Variables such as site geology, which reflects the dominant geological unit of the lake catchment, and lake area were coded after sample collection. Site geology was taken from Diakow and Levson (1997; Fawnie survey), Bellefontaine *et al.* (1995; Pinchi survey) and MacIntyre *et al.* (1994; Babine survey), and were manually verified to ensure that lake watersheds corresponded to the coded geological unit. Common lake names used on NTS topographic maps and British Columbia Forest Service maps were included where applicable. Element maps in Appendix D incorporate a NAD83 topographic base, and both NAD27 and NAD83 UTM site coordinates are included in the data listings in Appendix A.

PREPARATION OF WATER SAMPLES

Preparation procedures used for water samples over the course of the three surveys are summarized in Table 2. All lake water samples were kept cool following collection, and shipped to the Analytical Sciences Laboratory, Victoria, for insertion of control reference standards and distilled water blanks into the sample suite. No additional preparation procedures were performed on routine raw lake water samples collected for analysis of the RGS suite of elements.

Surface water samples for major and trace element analysis were filtered to 0.45 microns using cellulose nitrate filters (47 mm) and a Nalgene filtration apparatus with hand pump, in order to remove organic and inorganic particulate matter. In the case of Babine survey waters, only half the sample (125 ml) was filtered for

subsequent analysis; the remaining unfiltered portion was retained for field determination of TDS and conductivity.

Filtered waters were transferred to new 250-millilitre high-density polyethylene (HDPE) bottles and acidified to approximately pH=2 with concentrated nitric acid as per standard methods for analysis of metals (APHA/AWWA/WEF, 1992). Note that Fawnie water samples were filtered, but not acidified. Samples were transported from the field to the Analytical Sciences Laboratory, Victoria, in sealed plastic bags to ensure a high level of cleanliness prior to analysis. Further comments regarding bottles, filtration and acidification are provided in Table 2. Note that acid-washed bottles were used in the Pinchi and Babine survey, while those used in the Fawnie survey were rinsed three times in distilled water prior to use. Analytical tests conducted on acidified and unacidified distilled water blanks prior to the Fawnie survey showed no measurable contamination of the waters by the containing bottles.

ANALYSIS OF WATER SAMPLES

RGS-SUITE WATERS

Analysis of routine unfiltered lake water samples was conducted by CanTech Laboratories, Inc., Calgary in accordance with established National Geochemical Reconnaissance (NGR) analytical methods. Waters were analyzed for the standard RGS water analytical suite of pH, uranium, fluoride and sulphate (Pinchi and Babine surveys only). Note that uranium and fluoride were not determined for Fawnie-area waters. Analytical methods and stated detection limits are given in Tables 2 and 3, respectively.

- Hydrogen ion activity (pH) was measured, on a separate sample aliquot, with a pH meter with glass-calomel combination electrode (GCE). In the case of Fawnie-area waters, pH determinations were conducted in-house at the Analytical Sciences Laboratory, Victoria.

- Uranium was determined by laser-induced fluorescence (LIF) using a Scintrex UA-3 uranium analyzer. A complexing agent, known commercially as Fluran and composed of sodium pyrophosphate and sodium monophosphate (Hall, 1979), is added to produce a uranyl pyrophosphate species which fluoresces when exposed to the laser. As organic matter in the sample can cause unpredictable behaviour, a standard addition method is used. A total of 500 microlitres of Fluran solution was added to a 5 millilitre sample and allowed to stand for 24

hours, as the reaction of uranium with the complexing agent may be delayed or sluggish. At the end of this period fluorescence readings were made with the addition of 0.0, 0.2 and 0.4 ppb uranium. For high-concentration samples, the additions were 0.0, 2.0 and 4.0 ppb uranium. All readings are taken against a sample blank.

- Fluoride was determined by ion selective electrode (ION). A 20 millilitre aliquot of the sample was mixed with 20 millilitres of TISAB II (total ionic strength adjustment buffer) buffer solution. Fluoride was determined with an Orion fluoride electrode in conjunction with a Corning ion meter.
- Sulphate was determined by a turbidimetric method (TURB). A 50 millilitre aliquot (20 millilitres, in the case of Fawnie-area waters) was mixed with barium chloride and an isopropyl alcohol-HCl-NaCl reagent, and turbidity of the resulting barium sulphate solution measured with a spectrophotometer at 420 nanometres.

ICP SUITE WATERS

Filtered waters were analyzed for trace and major elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES; Fawnie) or inductively coupled plasma-mass spectrometry (ICP-MS; Pinchi and Babine). Reported analytical detection limits and calculated method detection limits (MDL) are listed in Table 3. MDL are defined as mean + 3s values determined from replicate analyses of distilled water blanks.

FAWNIE SURVEY

Filtered water samples from the Fawnie survey area were analyzed for a suite of major elements and trace elements by ICP-AES at Eco-Tech Laboratories Ltd., Kamloops, B.C. Only data for 7 major elements (aluminum, calcium, iron, magnesium, potassium, silicon and sodium) and one trace element (barium) are reported here. Most trace element results are not included here because of the relatively high detection limits available at the time of analysis in 1994. The sample is digested to near dryness in aqua regia, and brought to volume with 30% aqua regia. The resulting 25 ml solution, concentrated by a factor of five, is then analyzed by ICP-AES using a Jarrel-Ash 61E inductively coupled plasma-emission spectrometer.

PINCHI AND BABINE SURVEYS

Filtered and acidified water samples from the Pinchi and Babine survey areas were analyzed for a suite of 66

elements at Activation Laboratories Ltd., Ancaster, Ontario using a Perkin Elmer Elan 6000 inductively coupled plasma-mass spectrometer and a Perkin Elmer AS91 autosampler. Both major and trace elements are determined on this system. Data for 48 elements are reported here for the Pinchi area, and data for 58 elements are reported for the Babine area; these include 7 major elements (aluminum, calcium, iron, magnesium, potassium, silicon and sodium) and trace elements such as copper, zinc, molybdenum, arsenic, antimony and nickel.

Use of ICP-MS technology for water analysis allows elements to be determined to lower concentration levels than is obtainable with ICP-AES. Nevertheless, ICP-MS results for eight elements (ruthenium, palladium, indium, silver, rhenium, osmium, platinum and mercury) are not reported here for either survey as they occur at concentrations below detectable levels. Results for ten additional elements (germanium, tellurium, samarium, europium, gadolinium, dysprosium, holmium, erbium, thulium and gold) are reported here for the Babine area but not for the Pinchi area, where all or nearly all of these determinations are below detectable levels.

To determine trace and major elements by ICP-MS, a 10 ml aliquot of each water sample is spiked with an internal standard. The sample is introduced through a nebulizer into an argon plasma where elements are ionized at a temperature near 7500°K. Part of the plasma is transferred to a low-pressure region (1 Torr) by a water-cooled sampler. A skimmer allows the gas to pass into a high-vacuum chamber (10^{-6} Torr) where electrostatic lenses focus ions from the plasma. The focused ion beam is introduced into a quadrupole mass spectrometer where the ions are deflected onto a detector depending on their mass to charge ratio. A channel electron multiplier (CEM) counts the ions for a given element and provides an estimate of ion concentrations. The waters were analyzed using external calibration with internal standards. Two in-house reference standards were prepared using fully certified and traceable standards which contained all elements of interest. These standards are used to prepare calibration curves. Each group of standards analyzed also contained a certified reference standard (SLRS-3) and a reagent blank (18.2m deionized water). The data were calculated from the in-house standard calibration curves and results for the SLRS-3 certified values.

Interferences in ICP-MS are either spectral or sample-matrix induced, and the following account is taken largely from a review of ICP-MS techniques by Hall (1992). In case of the former, two mass spectral interferences are caused by species formed in the plasma gas and entrained air (*e.g.* Ar⁺) and in the acids added for sample preservation (*e.g.* ArCl⁺). The second of these can

be minimized by using nitric, rather than hydrochloric, acid as a preservative. In addition, commonly associated matrix elements (e.g. TiO^+ on $^{63}\text{Ni}^+$, $^{63}\text{Cu}^+$, $^{65}\text{Cu}^+$) are also potential sources of matrix interference. These can be minimized by selecting an element isotope free from spectral overlap, or by mathematically correcting for its presence. Some examples of interfering species are the formation of REE (rare earth element), tungsten and molybdenum oxides, the interference by molybdenum oxide on cadmium, and the interference by ArCl^+ on arsenic and selenium isotopes. These interferences can be reduced by various measures such as adding an organic solvent to the sample, which suppresses the influence of ArCl^+ and ArAr^+ . Non-spectral interference is caused by differences in transport efficiency of heavy and light ions in the ion beam leading, generally, to suppression of the analyte signal. Consequently suppression of lithium could be expected in a solution with high uranium. Non-spectral interferences can be reduced by appropriate instrument tuning to enhance the analyte signal and by maintaining the total salt solution below 0.1%.

OTHER DETERMINATIONS

Conductivity and total dissolved solids (TDS) were determined on a 125 ml aliquot of raw unfiltered Babine-area lake water samples using a Corning Checkmate 90 conductivity/TDS meter. No conductivity or TDS measurements were made on waters from the other survey areas. Hardness (see p. 48) was also calculated from calcium and magnesium concentrations at each site: Hardness (mg/L equivalent CaCO_3) = 2.497 Calcium (mg/L) + 4.118 Mg (mg/L) (APHA/AWWA/WEF, 1992).

Details of the preparation and analysis of corresponding lake sediment samples by atomic absorption spectroscopy (AAS) and instrumental neutron activation analysis (INAA) methods are given in earlier Open File reports (Cook and Jackaman, 1994; Cook *et al.*, 1997, 1998).

TABLE 2. SUMMARY TABLE OF SURVEY SAMPLING, PREPARATION AND ANALYTICAL PROCEDURES

Survey Sample Collection	Fawnie June, 1993	Pinchi Oct, 1995	Babine June, 1996	Totals:
Lakes	189	199	163	551
Sites	237	217	176	630
Total Samples	279	239	231	749
Field Samples	251	217	176	644
Field Duplicates: ICP	14*	-	-	14
Field Duplicates: RGS	-	25	19	44
Standards: ICP	-	8	20	28
Standards: RGS	14	25	23	62
DW Blanks: ICP	-	14	35	49
DW Blanks: RGS	14	-	20	34
Filtration (0.45 μ)	MSI MicronSep	MSI MicronSep	Sartorius	
Acidification	None	Merck Suprapure conc. nitric	Merck Suprapure conc. nitric	
Bottles	HDPE	Nalge I-Chem HDPE	Nalge I-Chem HDPE	
Bottle treatment	Distilled water rinse	(pre acid-washed)	(pre acid-washed)	
ICP Determinations	8 elements	48 elements	58 elements	
Major Elements	ICP-AES	ICP-MS	ICP-MS	
Trace Elements	-	ICP-MS	ICP-MS	
pH	GCE	GCE	GCE	
Uranium	-	LIF	LIF	
Fluoride	-	ION	ION	
Sulphate	TURB	TURB	TURB	
Suspended Load	X	X	X	
Water Colour	-	X	X	
TDS	-	-	X	
Conductivity	-	-	X	
pH Meter	Corning Checkmate 90	Fisher Accumet	Fisher Accumet	
Survey Reference	Cook & Jackaman, 1994	Cook <i>et al.</i> , 1997	Cook <i>et al.</i> , 1998	

* Only 13 field duplicate pairs used for most determinations

TABLE 3. ANALYTICAL AND METHOD DETECTION LIMITS: MAJOR AND TRACE ELEMENTS

	Element	Symbol	Analytical Detection Limit			Method Detection Limit		
			Fawnie ICP-AES ppm	Pinchi ICP-MS ppb	Babine ICP-MS ppb	Fawnie (N=14)* ppm	Pinchi (N=11)* ppb	Babine (N=19)** ppb
Major Elements	Aluminum	Al	0.01	0.2	0.2	0.04	14.53	4.22
	Calcium	Ca	0.01	1	1	0.20	326.9	115.2
	Iron	Fe	0.005	0.2	0.2	0.076	19.54	11.67
	Magnesium	Mg	0.01	0.5	0.5	0.19	28.71	27.66
	Potassium	K	0.01	1	1	0.67	99.5	21.9
	Silicon	Si	0.01	1	1	0.54	365.5	110.4
	Sodium	Na	0.01	0.8	0.8	0.76	37.41	110.4
Trace Elements	Antimony	Sb	-	0.02	0.02	-	0.02	0.03
	Arsenic	As	-	0.02	0.02	-	0.06	0.03
	Barium	Ba	0.01	0.002	0.002	0.08	0.474	0.374
	Bismuth	Bi	-	0.002	0.002	-	0.002	0.004
	Bromine	Br	-	1	1	-	2.4	2.5
	Cadmium	Cd	-	0.002	0.002	-	0.436	0.054
	Cerium	Ce	-	0.002	0.002	-	0.008	0.018
	Cesium	Cs	-	0.002	0.002	-	0.002	0.003
	Chromium	Cr	-	0.1	0.1	-	0.35	2.0
	Cobalt	Co	-	0.002	0.002	-	0.032	0.052
	Copper	Cu	-	0.002	0.002	-	n/r	0.944
	Dysprosium	Dy	-	-	0.002	-	-	0.003
	Erbium	Er	-	-	0.002	-	-	0.002
	Europium	Eu	-	-	0.002	-	-	0.002
	Gadolinium	Gd	-	-	0.002	-	-	0.003
	Gallium	Ga	-	0.002	0.002	-	0.003	0.019
	Germanium	Ge	-	-	0.002	-	-	0.013
	Gold	Au	-	-	0.002	-	-	0.010
	Hafnium	Hf	-	0.002	0.002	-	0.220	0.027
	Holmium	Ho	-	-	0.002	-	-	0.002
	Iodine	I	-	0.04	0.04	-	0.65	5.74
	Lanthanum	La	-	0.002	0.002	-	0.002	0.009
	Lead	Pb	-	0.02	0.02	-	0.44	0.38
	Lithium	Li	-	0.1	0.1	-	2.18	7.66
	Lutetium	Lu	-	0.002	0.002	-	0.002	0.003
	Manganese	Mn	-	0.02	0.02	-	1.63	0.10
	Molybdenum	Mo	-	0.02	0.02	-	0.02	0.10
	Neodymium	Nd	-	0.002	0.002	-	0.002	0.014
	Nickel	Ni	-	0.002	0.002	-	3.599	0.405
	Niobium	Nb	-	0.002	0.002	-	0.011	0.055
	Praseodymium	Pr	-	0.002	0.002	-	0.002	0.003
	Rubidium	Rb	-	0.002	0.002	-	0.028	0.031
	Samarium	Sm	-	-	0.002	-	-	0.002
	Scandium	Sc	-	0.02	0.02	-	3.90	0.64
	Selenium	Se	-	0.02	0.02	-	2.06	0.46
	Strontium	Sr	-	0.002	0.002	-	1.437	0.610
	Tantalum	Ta	-	0.002	0.002	-	0.023	0.005
	Tellurium	Te	-	-	0.02	-	-	0.02
	Terbium	Tb	-	0.002	0.002	-	0.002	0.002
	Thallium	Tl	-	0.002	0.002	-	0.002	0.014
	Thorium	Th	-	0.002	0.002	-	0.016	0.010
	Thulium	Tm	-	-	0.002	-	-	0.002
Tin	Sn	-	0.002	0.002	-	0.261	0.106	
Titanium	Ti	-	0.02	0.02	-	0.02	0.02	
Tungsten	W	-	0.002	0.002	-	0.437	0.017	
Uranium	U	-	0.002	0.002	-	0.008	0.013	
Vanadium	V	-	0.02	0.02	-	0.12	0.03	
Ytterbium	Yb	-	0.002	0.002	-	0.002	0.002	
Yttrium	Y	-	0.002	0.002	-	0.005	0.016	
Zinc	Zn	-	0.002	0.002	-	n/r	5.244	
Zirconium	Zr	-	0.002	0.002	-	10.234	1.380	

n/r: Cu and Zn data for Pinchi distilled water blanks not reported due to contamination during production

* unfiltered/unacidified blanks ** filtered/acidified blanks

TABLE 4. ANALYTICAL AND METHOD DETECTION LIMITS: RGS SUITE OF ELEMENTS

	Element	Symbol	Analytical Detection Limit			Method Detection Limit		
			Fawnie	Pinchi	Babine	Fawnie (N=14)	Pinchi	Babine (N=20)
RGS Suite	Uranium	U (ppb)	-	0.05	0.05	-	<i>n.a.</i>	0.08**
	Fluoride	F (ppb)	-	20	20	-	<i>n.a.</i>	10**
	Sulphate	SO ₄ (ppm)	1	1	1	2.73*	<i>n.a.</i>	1
	pH		0.01	0.1	0.1	-	-	-

Fawnie method detection limits: $x \pm 3s$ of unacidified distilled water blanks

Pinchi method detection limits: not available

Babine method detection limits: $x \pm 3s$ of filtered acidified distilled water blanks

* Fawnie sulphate values reported as < det.limit set to one-half det.limit (0.5 ppm)

** Babine U and F values reported as < det.limit set to one-half det.limit (0.02 and 10 ppb, respectively)

QUALITY CONTROL PROCEDURES AND RESULTS

METHODOLOGY

Variations in element concentrations in lake waters and sediments may be due to regional geological and geochemical variations (different bedrock lithologies and surficial materials, absence or presence of mineralization, limnological variations), within-site variations (combined sampling, preparation and analytical variations), or analytical variation alone. As noted by Fletcher (1981), a high degree of analytical precision is of limited importance if the sample collection and preparation error is so great as to be indistinguishable from the regional geochemical variation.

The ability to discriminate real geochemical trends from those resulting from sampling, preparation and analytical variation is of considerable importance in the interpretation of all geochemical data. It is particularly so in the case of water samples, where absolute concentrations and analytical detection levels of trace elements are often in the 0.001 ppb range. These low concentration levels offer a much greater scope for potential contamination during sample collection, transport, preparation and analysis than exists with sediments, where natural element concentrations may be several orders of magnitude greater.

Control reference standards are routinely inserted into (i) RGS-suite and (ii) ICP water sample suites to monitor and assess accuracy and precision of analytical results. Combined sampling and analytical variation can be quantified using estimates of precision from field duplicate data. In accordance with standard National Geochemical Reconnaissance (NGR) and Regional Geochemical Survey (RGS) quality control procedures, each block of 20 water samples (Figure 2) to be analyzed for the routine RGS analytical suite (uranium, fluoride, sulphate, pH) contains:

- Seventeen routine samples,
- One field duplicate sample,
- One distilled water blank,
- One control reference standard

This is a modification of the protocol typically used for lake and stream sediments (*e.g.* Cook *et al.*, 1997, 1998; Cook and Jackaman, 1994). Locations of blanks and control reference standards are selected prior to sampling. Field duplicate sites, however, are chosen randomly during fieldwork. At these sites two water samples are

collected simultaneously by the sampler, while sediment duplicates are obtained from the rear of the helicopter with successive drops of the torpedo sampler. Field duplicate samples are used to monitor combined sampling, preparation and analytical precision, and are a measure of within-site variation. After collection, distilled water blanks are inserted into the sample suite prior to analysis to monitor for analytical contamination. These are inserted into the locations otherwise occupied by blind, or analytical, duplicates in the corresponding sediment analytical suites.

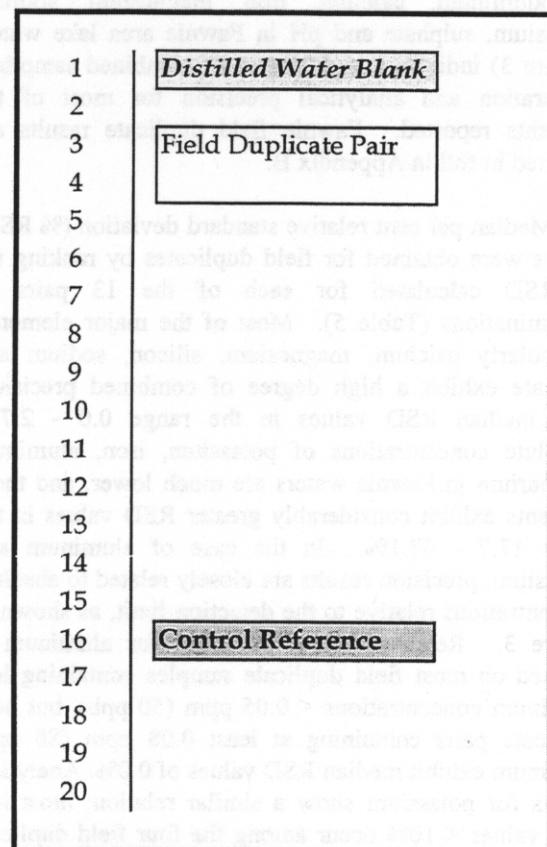


Figure 2. Typical Regional Geochemical Survey sample collection and analytical scheme used for routine waters (RGS suite) during combined lake sediment and water surveys. The 20-sample collection block incorporates 17 routine samples, a field duplicate sample, a distilled water blank and a control reference standard. Modifications to this scheme for water samples for ICP-AES and ICP-MS analysis of major and/or trace elements are outlined in the text. For example, field duplicates were collected only in the Fawnie area.

Adaptation of these protocols for ICP-AES and ICP-MS analysis of major and trace elements were similar, but more varied in their detail. Water samples for ICP-MS analysis were collected at only every second site in the Pinchi and Babine surveys, rather than at every site as for the Fawnie area and routine RGS analytical suites. No field duplicate samples were obtained in these two surveys. Blanks and control standards were sometimes inserted at more irregular intervals.

COMBINED SAMPLING AND ANALYTICAL PRECISION: FIELD DUPLICATE SAMPLES

Paired ICP-suite field duplicate samples were obtained only during the Fawnie survey. Scatterplots of field duplicate pairs (N=14 for pH; N=13 for all others) for aluminum, calcium, iron, magnesium, sodium, potassium, sulphate and pH in Fawnie area lake waters (Figure 3) indicate a high degree of combined sampling, preparation and analytical precision for most of the elements reported. Fawnie field duplicate results are reported in full in Appendix B.

Median per cent relative standard deviation (% RSD) values were obtained for field duplicates by ranking the % RSD calculated for each of the 13 pairs of determinations (Table 5). Most of the major elements, particularly calcium, magnesium, silicon, sodium and sulphate exhibit a high degree of combined precision, with median RSD values in the range 0.0 - 2.7%. Absolute concentrations of potassium, iron, aluminum and barium in Fawnie waters are much lower, and these elements exhibit considerably greater RSD values in the range 17.7 - 47.1%. In the case of aluminum and potassium, precision results are closely related to absolute concentrations relative to the detection limit, as shown in Figure 3. Relatively poor precision for aluminum is attained on most field duplicate samples containing low aluminum concentrations < 0.05 ppm (50 ppb), but both duplicate pairs containing at least 0.08 ppm (80 ppb) aluminum exhibit median RSD values of 0.0%. Analytical results for potassium show a similar relation; most low RSD values < 10% occur among the four field duplicate pairs containing at least 0.7 ppm (700 ppb) potassium.

Routine RGS-suite field duplicate water samples in the Pinchi and Babine area also show precise results (Table 5). Median per cent RSD values for sulphate are 0.0% for all three surveys, and do not exceed 3.4% for fluoride. Median per cent RSD values for field duplicate pH determinations are in the range 0.8 - 1.0%. Scatterplots of all Pinchi and Babine field duplicate data for U, F, SO₄, and pH are shown in Figure 4.

TABLE 5. MEDIAN RSD AND PRECISION RESULTS FOR FIELD DUPLICATE PAIRS

	Fawnie (N=13)*		Pinchi (N=25)		Babine (N=19)	
	Median % RSD	Median Precision	Median % RSD	Median Precision	Median % RSD	Median Precision
Al	47.1	94.3	-	-	-	-
Ba	35.4	70.7	-	-	-	-
Ca	2.3	4.6	-	-	-	-
Fe	23.7	47.4	-	-	-	-
Mg	2.4	4.9	-	-	-	-
K	17.7	35.4	-	-	-	-
Si	2.7	5.5	-	-	-	-
Na	1.9	3.7	-	-	-	-
U	-	-	0.0	0.0	0.0	0.0
F	-	-	3.4	6.9	1.9	3.9
Sulphate	0.0	0.0	0.0	0.0	0.0	0.0
pH	0.8	1.5	0.9	1.9	1.0	2.0

*N=14 for pH

ANALYTICAL ACCURACY AND PRECISION: CONTROL REFERENCE STANDARDS

Per cent relative standard deviation (% RSD) values calculated from replicate analyses of several control reference standards for the Fawnie, Pinchi and Babine surveys are presented in Tables 6 - 8. These results convey the levels of analytical precision achieved at various concentration levels for all elements. Mean \pm 1s results are also shown, and where possible are compared to accepted values.

FAWNIE SURVEY

Fourteen insertions of three synthetic water standards, prepared in the Analytical Sciences Lab, Victoria, were inserted into the Fawnie suite. Two of the standards were created to monitor the trace element, rather than major element, content of the lake waters and consequently are not included here. The third standard (93-C) was spiked with 50 ppm sulphate, 40.7 ppm potassium and 60.5 ppb sodium. Four replicate analyses of this standard returned mean concentrations of 51.3 ± 3.4 ppm sulphate and 34.5 ± 1.8 ppm potassium (Tables 6 and 8). Corresponding relative standard deviation (% RSD) values for sulphate and potassium were 6.6% and 5.2%, respectively, indicating a relative high degree of accuracy and precision for the determination of these elements. Less accurate results were obtained for sodium (Table 6), likely due to the relatively low concentration of this element in the control standard. The spiked concentration of 60.5 ppb (\sim 0.06 ppm) sodium is

considerably below both the calculated method detection limit and the median sodium concentration of distilled water blanks (Tables 3 and 9).

PINCHI SURVEY

Eight insertions of two separate water standards were inserted into the Pinchi ICP-MS suite. One, 95-B, was prepared in the Analytical Sciences Laboratory, Victoria for monitoring of trace elements, and spiked with 40 ppb of several elements, including iron, cobalt, nickel copper and zinc. Five replicate analyses of this standard returned mean concentrations of 40.5 ± 5.1 ppb iron, 42.91 ± 1.59 ppb copper and 38.42 ± 2.37 ppb zinc, among other relevant elements (Table 6). Corresponding relative standard deviation (% RSD) values for these three elements are 12.7%, 3.7% and 6.2%, respectively, indicating a high degree of analytical precision at these concentration levels.

The second standard is an unacidified Geological Survey of Canada natural water standard from Meech Lake in western Quebec. No accepted values are available for this water, which is collected annually and subject to seasonal geochemical variations. However, three replicate analyses returned good precision ($RSD < 7\%$) for most major elements including sodium, magnesium, calcium and potassium, as well as a small number of trace elements such as molybdenum, barium and rubidium (Table 6). The relatively high RSD values reported for most REEs here indicate that the precision and detection limits obtained by direct ICP-MS analysis without preconcentration are less than ideal for such low-concentration samples.

Three Geological Survey of Canada internal water standards, all natural waters from the Ottawa-Hull region, were used in the RGS analytical suite. Seven to ten replicate analyses of each standard returned relative standard deviation (% RSD) values of 3.5 - 10.9% for uranium, 4.3 - 7.0% for fluoride and 15.5 - 19.7% for sulphate.

BABINE SURVEY

Four natural waters, consisting of three internal water standards and a National Research Council certified reference standard (SLRS-3), were used as ICP-MS control standards (N=20 insertions) for the Babine survey.

Analytical data for the NRC standard SLRS-3 compare favourably with available certified values for both major and trace elements, indicating a high degree of

analytical accuracy for most constituents. For example, Babine ICP-MS analyses of SLRS-3 (n=5 insertions) returned mean concentrations of 1.57 ± 0.03 ppm magnesium and 0.67 ± 0.02 ppm potassium relative to certified values of 1.6 ± 0.2 ppm and 0.7 ± 0.1 ppm, respectively (Table 7; *Babine results converted here from original ppb*). Among other major constituents, mean SLRS-3 aluminum results of 29.30 ± 0.85 ppb and iron results of 105.64 ± 10.30 ppb compare favourably to certified values of 31 ± 3 ppb aluminum and 100 ± 2 ppb iron. Babine trace element results for SLRS-3 also agree closely with most certified values. For example, mean determinations of 0.15 ± 0.06 ppb antimony, 0.70 ± 0.03 ppb arsenic and 13.363 ± 0.221 ppb barium (Table 7) compare closely with certified values of 0.12 ± 0.01 ppb, 0.72 ± 0.05 ppb, and 13.4 ± 0.6 ppb, respectively. Mean copper and zinc concentrations of 1.163 ± 0.063 ppb and 0.826 ± 0.117 ppb, respectively, compare favourably with the slightly higher certified values of 1.35 ± 0.07 ppb copper and 1.04 ± 0.09 ppb zinc. Established certified values for SLRS-3 are taken from NRC (1994).

The three internal water standards (Chutanli, CH-1, 3031) were obtained in 1996 from Interior Plateau lakes and have not yet been fully characterized. However, standards results reported here for the Babine survey are in general agreement with other ICP-MS determinations on the same waters. For example, replicate analyses of standards Chutanli and CH-1 from a different laboratory during the same year returned mean results of 2 ppb and 4.3 ppb aluminum, respectively versus mean results of 2.32 ppb and 5.58 ppb aluminum achieved here (Table 7). Similarly, replicate analyses of the same two standards returned mean arsenic concentrations of 1.83 ppb and 0.1 ppb, respectively, versus mean results of 1.64 and 0.10 ppb arsenic reported here. As a further example, mean barium concentrations of 15.0 ppb and 2.8 ppb reported by the other laboratory for standards Chutanli and CH-1 compared well with mean values of 13.314 ppb and 2.977 ppb barium reported here in Table 7.

As a measure of the analytical precision of control standards results, relative standard deviation (% RSD) values determined from five replicate analyses of each of the four standards are shown in Table 7. The most precise results are, not surprisingly, associated with the major elements. Per cent RSD values for magnesium, sodium and potassium for example, do not exceed the 9-10% level for any of the four standards. Results are much more variable for trace elements; higher RSD values, and correspondingly poorer precision, are associated with those elements which commonly occur near the limits of analytical detection. In the case of copper, for example, per cent RSD was only 5.4% for NRC standard SLRS-3, which has a relatively high copper concentration (x: 1.163 ppb), but varies between 17.7-66.7% for the other three

standards, all of which have much lower copper concentrations. Among those elements determined with the greatest precision in the Babine ICP-MS suite are barium (% RSD: 1.7-4.3% for all four standards), strontium (% RSD: 2.3-9.2% for all four standards), arsenic (% RSD: 4.1-5.9% for three of four standards) and molybdenum (% RSD: 6.3-10.5% for three of four standards).

Four natural waters and a spiked internal standard were used as RGS suite control standards (N=23 insertions) for the Babine survey. Three of the natural water standards were also used in the ICP-MS analytical suite. Although accepted values have not yet been formally defined for these standards, as mentioned above, summary analytical results (Table 8) compare favourably with results for the same standards achieved in other analytical batches. For example, replicate analyses of standards CH-1, 3031 and Chutanli in a separate batch during the same year returned mean results of 25.8 ppm, 9.6 ppm and 5.6 ppm sulphate, versus mean results of 26.8 ppm, 11.0 ppm and 2.8 ppm sulphate, respectively achieved here (Table 8). Similarly, replicate analyses of the same three standards returned mean fluoride concentrations of 108 ppb, 292 ppb and 47.2 ppb versus mean results of 92.8 ppb, 290 ppb and 46.0 ppb fluoride reported here.

Regarding analytical precision for the RGS suite of elements, 3 - 5 replicate analyses of each of five standards returned relative standard deviation (% RSD) values of 3.3 - 30.5% for uranium, 0.0 - 36.5% for fluoride and 6.6 - 21.3% for sulphate (Table 8). As with sediment results, precision is generally poorer for those results near the analytical detection limits.

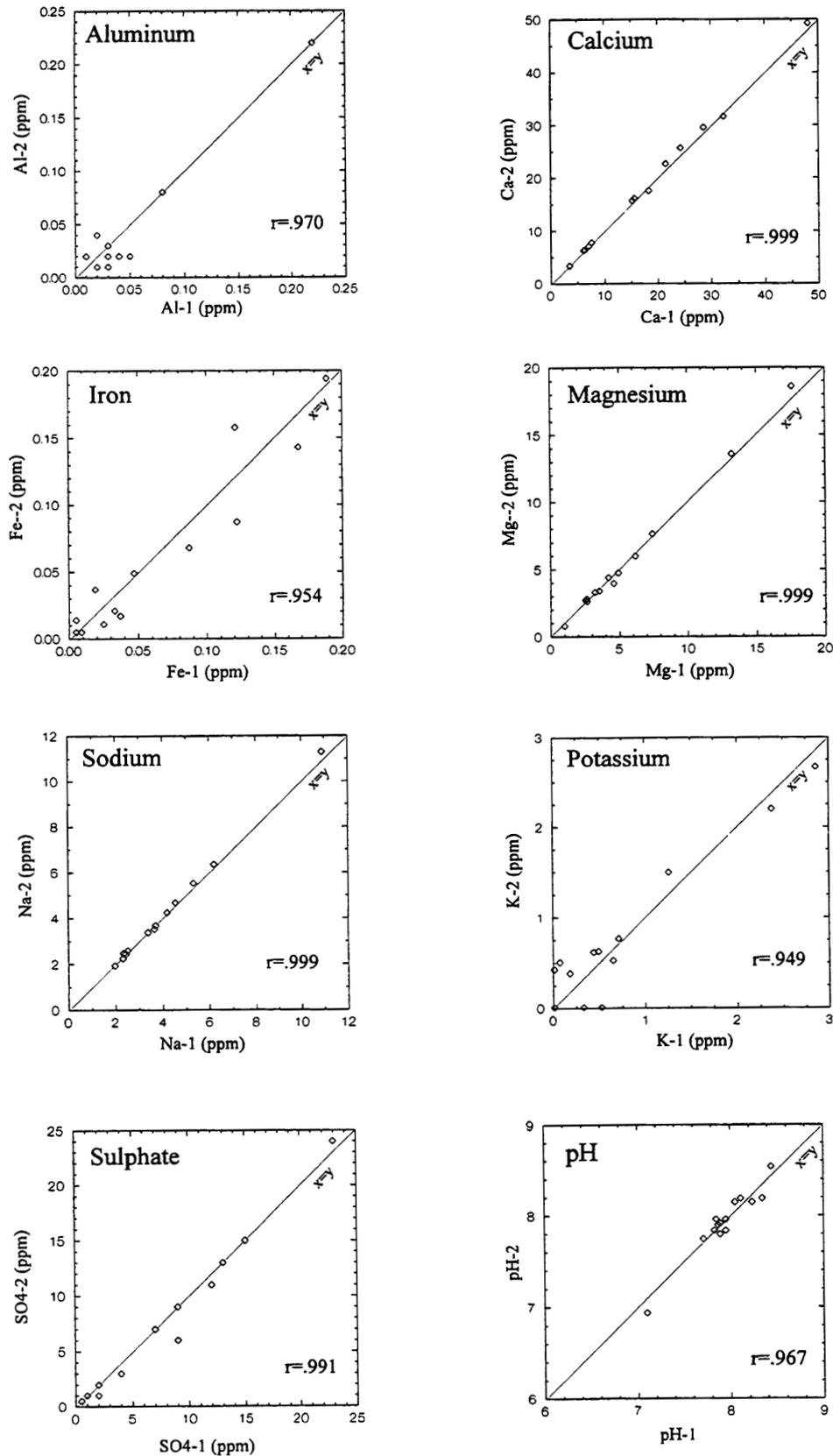
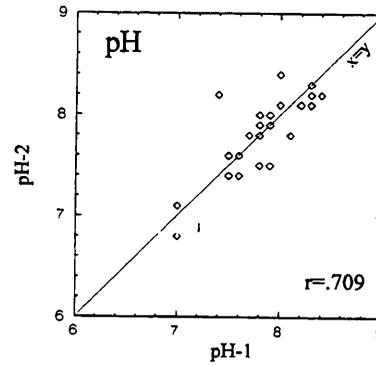
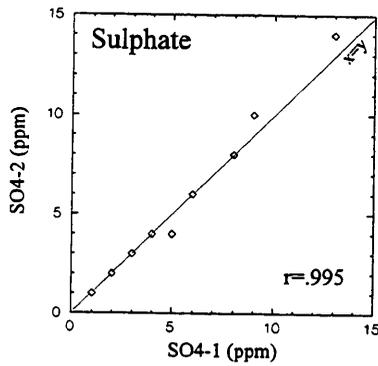
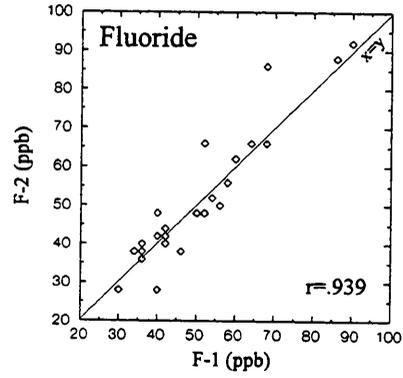
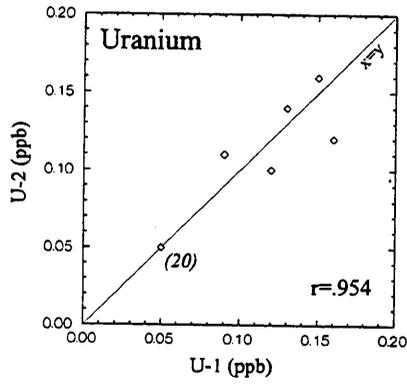


Figure 3. Scatterplots of field duplicate pairs (N=14 for pH; N=13 for all others) for Fawnie area lake waters: aluminum, calcium, iron, magnesium, sodium, potassium, sulphate and pH. Refer to data listings, and Appendix B, for full listings of Fawnie-area field duplicate data. Data for sulphate and pH has previously been reported by Cook and Jackaman (1994) in Open File 1994-19.

PINCHI SURVEY



BABINE SURVEY

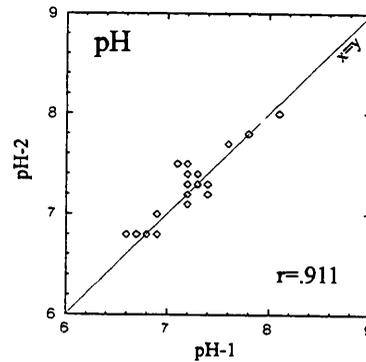
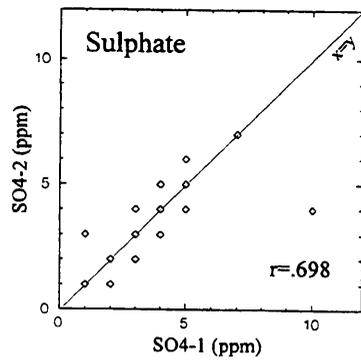
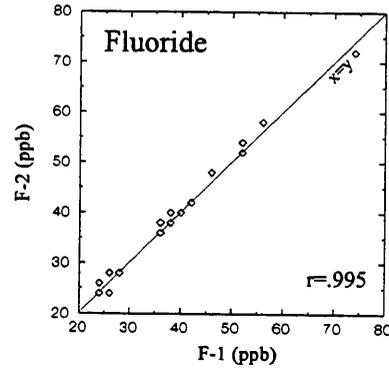
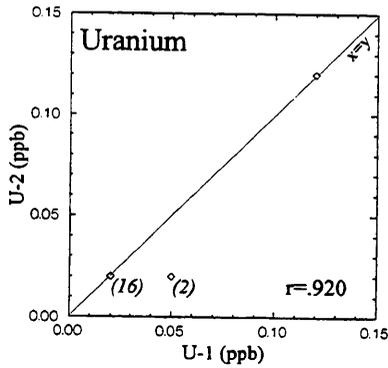


Figure 4. Scatterplots of routine field duplicate pairs for Pinchi (N=25 pairs) and Babine (N=19 pairs) area lake waters: uranium, fluoride, sulphate and pH. This data has previously been reported by Cook *et al.* (1997, 1998), respectively.

TABLE 6. CONTROL STANDARDS RESULTS - FAWNIE/PINCHI SURVEYS: MAJOR AND TRACE ELEMENTS

Element	Symbol	Fawnie Survey		Pinchi Survey		Meech Lake (n=3)	
		93-C (n=4) x ± 1s (ppm)	RSD (%)	95-B (n=5) x ± 1s (ppb)	RSD (%)	x ± 1s (ppb)	RSD (%)
Major Elements							
Aluminum	Al	-	-	41.94 ± 5.60	13.36	12.70 ± 6.72	52.90
Calcium	Ca	-	-	-	-	17108.3 ± 1089.4	6.37
Iron	Fe	-	-	40.50 ± 5.14	12.68	6.53 ± 5.91	90.45
Magnesium	Mg	-	-	-	-	2263.27 ± 86.14	3.81
Potassium	K	34.5 ± 1.8	5.24	-	-	423.3 ± 18.2	4.31
Silicon	Si	-	-	-	-	1149.3 ± 209.9	18.26
Sodium	Na	0.39 ± 0.16	40.93	137.24 ± 16.33	11.90	1243.67 ± 38.91	3.13
Trace Elements							
Antimony	Sb	-	-	-	-	0.03 ± 0.02	45.83
Arsenic	As	-	-	-	-	0.21 ± 0.06	29.17
Barium	Ba	-	-	3.44 ± 0.18	5.28	26.934 ± 0.514	1.91
Bismuth	Bi	-	-	-	-	0.002 ± 0.000	0.00
Bromine	Br	-	-	-	-	6.7 ± 0.6	8.66
Cadmium	Cd	-	-	34.60 ± 1.05	3.04	0.066 ± 0.105	157.65
Cerium	Ce	-	-	-	-	0.012 ± 0.009	73.90
Cesium	Cs	-	-	1.55 ± 0.07	4.40	0.004 ± 0.002	41.66
Chromium	Cr	-	-	-	-	0.1 ± 0.0	0.0
Cobalt	Co	-	-	36.50 ± 1.06	2.91	0.042 ± 0.015	35.95
Copper	Cu	-	-	42.91 ± 1.59	3.71	0.722 ± 0.270	37.41
Dysprosium	Dy	-	-	-	-	-	-
Erbium	Er	-	-	-	-	-	-
Europium	Eu	-	-	-	-	-	-
Gadolinium	Gd	-	-	-	-	-	-
Gallium	Ga	-	-	-	-	0.008 ± 0.006	66.09
Germanium	Ge	-	-	-	-	-	-
Gold	Au	-	-	-	-	-	-
Hafnium	Hf	-	-	-	-	0.057 ± 0.072	125.67
Holmium	Ho	-	-	-	-	-	-
Iodine	I	-	-	-	-	1.41 ± 0.40	27.95
Lanthanum	La	-	-	-	-	0.005 ± 0.003	47.19
Lead	Pb	-	-	35.35 ± 4.50	12.72	0.05 ± 0.05	98.97
Lithium	Li	-	-	-	-	1.07 ± 0.61	57.28
Lutetium	Lu	-	-	-	-	0.002 ± 0.000	0.00
Manganese	Mn	-	-	-	-	0.33 ± 0.25	76.24
Molybdenum	Mo	-	-	-	-	0.53 ± 0.04	6.58
Neodymium	Nd	-	-	-	-	0.007 ± 0.005	69.98
Nickel	Ni	-	-	56.64 ± 16.84	29.72	0.409 ± 0.218	53.36
Niobium	Nb	-	-	-	-	0.002 ± 0.000	0.00
Praseodymium	Pr	-	-	-	-	0.002 ± 0.001	24.74
Rubidium	Rb	-	-	-	-	1.447 ± 0.062	4.31
Samarium	Sm	-	-	-	-	-	-
Scandium	Sc	-	-	-	-	1.12 ± 1.26	112.66
Selenium	Se	-	-	-	-	0.06 ± 0.07	115.47
Strontium	Sr	-	-	1.48 ± 0.20	13.46	94.618 ± 4.749	5.02
Tantalum	Ta	-	-	-	-	0.007 ± 0.006	96.44
Tellurium	Te	-	-	-	-	-	-
Terbium	Tb	-	-	-	-	0.002 ± 0.000	0.00
Thallium	Tl	-	-	-	-	0.004 ± 0.001	25.00
Thorium	Th	-	-	-	-	0.005 ± 0.003	65.47
Thulium	Tm	-	-	-	-	-	-
Tin	Sn	-	-	-	-	0.013 ± 0.009	73.35
Titanium	Ti	-	-	-	-	0.33 ± 0.05	15.10
Tungsten	W	-	-	-	-	0.139 ± 0.144	103.85
Uranium	U	-	-	-	-	0.334 ± 0.278	83.23
Vanadium	V	-	-	-	-	0.14 ± 0.03	18.90
Ytterbium	Yb	-	-	-	-	0.002 ± 0.000	0.00
Yttrium	Y	-	-	-	-	0.008 ± 0.003	43.30
Zinc	Zn	-	-	38.42 ± 2.37	6.18	3.584 ± 3.099	86.45
Zirconium	Zr	-	-	-	-	3.545 ± 4.497	126.85

RSD < 10%

TABLE 7. CONTROL STANDARDS RESULTS - BABINE SURVEY: MAJOR AND TRACE ELEMENTS

Element	Symbol	Babine Survey		Chutanli Lake (n=5)		Lake CH-1 (n=5)		Lake 3031 (n=5)	
		$x \pm 1s$ (ppm)	RSD (%)	$x \pm 1s$ (ppb)	RSD (%)	$x \pm 1s$ (ppb)	RSD (%)	$x \pm 1s$ (ppb)	RSD (%)
Major Elements									
Aluminum	Al	29.30 ± 0.85	2.89	2.32 ± 1.22	52.47	5.58 ± 0.61	10.93	66.10 ± 4.05	6.12
Calcium	Ca	5850.0 ± 120.8	2.06	20111.2 ± 2119.0	10.54	10439.4 ± 837.2	8.02	7881.0 ± 445.1	5.65
Iron	Fe	105.64 ± 10.30	9.75	7.96 ± 2.14	26.92	8.04 ± 1.94	24.16	139.98 ± 11.05	7.89
Magnesium	Mg	1568.32 ± 31.37	2.00	5445.32 ± 501.00	9.20	3066.42 ± 225.40	7.35	2007.50 ± 110.78	5.52
Potassium	K	667.2 ± 19.4	2.91	929.8 ± 93.6	10.07	2090.6 ± 153.4	7.34	774.8 ± 70.1	9.05
Silicon	Si	1723.8 ± 25.2	1.46	2881.0 ± 228.4	7.93	4792.8 ± 287.4	6.00	4347.4 ± 165.5	3.81
Sodium	Na	2190.5 ± 48.9	2.23	2845.52 ± 277.19	9.74	2577.38 ± 193.21	7.50	11335.34 ± 692.52	6.1
Trace Elements									
Antimony	Sb	0.15 ± 0.06	40.11	0.08 ± 0.04	55.44	0.03 ± 0.01	40.75	0.20 ± 0.07	32.81
Arsenic	As	0.70 ± 0.03	4.08	1.64 ± 0.10	5.91	0.10 ± 0.03	28.07	3.00 ± 0.17	5.68
Barium	Ba	13.363 ± 0.221	1.65	13.314 ± 0.517	3.88	2.977 ± 0.090	3.04	5.923 ± 0.256	4.33
Bismuth	Bi	0.003 ± 0.002	67.75	0.007 ± 0.011	148.22	0.002 ± 0.000	0.00	0.003 ± 0.002	55.90
Bromine	Br	29.6 ± 2.1	7.01	7.0 ± 0.0	0.00	6.0 ± 0.7	11.79	11.2 ± 0.8	7.47
Cadmium	Cd	0.010 ± 0.006	58.58	0.005 ± 0.006	126.39	0.017 ± 0.017	96.89	0.004 ± 0.004	111.80
Cerium	Ce	0.316 ± 0.005	1.48	0.022 ± 0.020	87.46	0.016 ± 0.008	49.08	0.900 ± 0.073	8.09
Cesium	Cs	0.006 ± 0.002	26.15	0.003 ± 0.001	47.14	0.004 ± 0.000	11.77	0.015 ± 0.001	3.75
Chromium	Cr	0.44 ± 0.18	41.29	0.72 ± 0.85	118.42	0.66 ± 0.74	112.67	0.72 ± 0.58	80.63
Cobalt	Co	0.035 ± 0.010	28.85	0.039 ± 0.018	46.84	0.020 ± 0.006	29.88	0.044 ± 0.006	14.39
Copper	Cu	1.163 ± 0.063	5.41	0.309 ± 0.125	40.32	0.426 ± 0.075	17.68	0.194 ± 0.129	66.69
Dysprosium	Dy	0.022 ± 0.001	6.21	0.002 ± 0.000	20.33	0.003 ± 0.001	33.33	0.259 ± 0.009	3.56
Erbium	Er	0.010 ± 0.003	27.16	0.002 ± 0.000	20.33	0.003 ± 0.001	34.40	0.132 ± 0.008	6.33
Europium	Eu	0.010 ± 0.001	12.78	0.005 ± 0.002	47.51	0.002 ± 0.000	20.33	0.044 ± 0.005	11.55
Gadolinium	Gd	0.035 ± 0.003	7.89	0.002 ± 0.001	37.27	0.003 ± 0.001	39.46	0.306 ± 0.016	5.32
Gallium	Ga	0.014 ± 0.007	48.38	0.013 ± 0.014	105.89	0.008 ± 0.003	41.19	0.018 ± 0.005	27.34
Germanium	Ge	0.009 ± 0.003	37.17	0.005 ± 0.002	45.08	0.004 ± 0.002	58.63	0.008 ± 0.006	71.73
Gold	Au	0.011 ± 0.009	84.54	0.004 ± 0.002	65.53	0.002 ± 0.000	20.33	0.005 ± 0.004	80.76
Hafnium	Hf	0.012 ± 0.009	68.81	0.009 ± 0.011	130.41	0.006 ± 0.005	79.34	0.037 ± 0.008	22.74
Holmium	Ho	0.004 ± 0.001	12.45	0.002 ± 0.000	0.00	0.002 ± 0.000	0.00	0.049 ± 0.003	6.80
Iodine	I	5.65 ± 1.03	18.27	2.61 ± 0.32	12.39	1.93 ± 0.34	17.72	4.69 ± 0.79	16.84
Lanthanum	La	0.255 ± 0.011	4.24	0.010 ± 0.008	76.49	0.006 ± 0.003	53.70	1.040 ± 0.046	4.39
Lead	Pb	0.08 ± 0.02	25.00	0.04 ± 0.03	63.74	0.02 ± 0.00	0.00	0.04 ± 0.02	60.86
Lithium	Li	1.1 ± 1.5	135.91	1.2 ± 1.3	107.08	2.1 ± 0.6	30.28	6.1 ± 1.2	19.59
Lutetium	Lu	0.003 ± 0.001	40.82	0.003 ± 0.002	67.75	0.003 ± 0.002	67.75	0.020 ± 0.001	4.56
Manganese	Mn	3.78 ± 0.19	4.91	5.32 ± 0.61	11.52	0.08 ± 0.05	68.08	2.23 ± 0.11	4.78
Molybdenum	Mo	0.26 ± 0.02	8.99	0.65 ± 0.07	10.49	0.07 ± 0.01	18.11	0.76 ± 0.05	6.29
Neodymium	Nd	0.223 ± 0.013	5.85	0.012 ± 0.006	46.51	0.013 ± 0.006	49.84	1.445 ± 0.057	3.93
Nickel	Ni	0.611 ± 0.314	51.38	0.165 ± 0.130	78.99	0.161 ± 0.157	97.28	0.451 ± 0.228	50.66
Niobium	Nb	0.047 ± 0.014	30.27	0.030 ± 0.022	74.24	0.008 ± 0.003	44.23	0.032 ± 0.004	13.98
Praseodymium	Pr	0.061 ± 0.004	5.79	0.004 ± 0.002	49.79	0.005 ± 0.003	67.82	0.327 ± 0.017	5.35
Rubidium	Rb	1.718 ± 0.039	2.27	0.500 ± 0.052	10.32	2.795 ± 0.185	6.62	1.471 ± 0.099	6.75
Samarium	Sm	0.046 ± 0.009	19.89	0.003 ± 0.002	57.74	0.004 ± 0.002	42.13	0.340 ± 0.032	9.34
Scandium	Sc	2.81 ± 0.12	4.32	4.66 ± 0.31	6.62	7.99 ± 0.84	10.54	7.36 ± 1.14	15.46
Selenium	Se	0.27 ± 0.20	74.86	0.13 ± 0.11	84.79	0.15 ± 0.14	88.99	0.60 ± 0.88	145.21
Strontium	Sr	33.800 ± 0.783	2.32	140.934 ± 12.990	9.22	40.472 ± 3.302	8.16	66.665 ± 3.446	5.17
Tantalum	Ta	0.003 ± 0.001	33.33	0.004 ± 0.003	72.44	0.003 ± 0.001	51.60	0.006 ± 0.001	16.67
Tellurium	Te	0.03 ± 0.02	64.44	0.02 ± 0.00	0.00	0.02 ± 0.00	20.33	0.02 ± 0.00	20.33
Terbium	Tb	0.005 ± 0.001	24.85	0.003 ± 0.002	57.74	0.003 ± 0.002	74.54	0.051 ± 0.003	6.03
Thallium	Tl	0.007 ± 0.002	22.82	0.004 ± 0.002	57.60	0.002 ± 0.001	22.82	0.004 ± 0.001	20.33
Thorium	Th	0.029 ± 0.013	46.07	0.052 ± 0.048	92.16	0.018 ± 0.023	128.76	0.122 ± 0.033	27.36
Thulium	Tm	0.002 ± 0.000	20.33	0.002 ± 0.000	0.00	0.002 ± 0.000	0.00	0.019 ± 0.001	6.79
Tin	Sn	0.041 ± 0.016	40.00	0.030 ± 0.016	54.52	0.041 ± 0.008	20.34	0.037 ± 0.006	17.31
Titanium	Ti	0.54 ± 0.05	8.59	1.57 ± 0.26	16.40	1.10 ± 0.17	15.71	0.73 ± 0.07	9.95
Tungsten	W	0.006 ± 0.003	61.34	0.005 ± 0.003	69.72	0.002 ± 0.001	37.27	0.002 ± 0.000	20.33
Uranium	U	0.059 ± 0.022	37.86	0.053 ± 0.018	33.60	0.003 ± 0.002	63.89	0.174 ± 0.067	38.71
Vanadium	V	0.35 ± 0.03	7.35	0.58 ± 0.06	10.53	0.33 ± 0.05	16.18	0.22 ± 0.05	20.36
Ytterbium	Yb	0.010 ± 0.003	28.32	0.003 ± 0.001	46.57	0.004 ± 0.002	57.05	0.122 ± 0.006	4.55
Yttrium	Y	0.129 ± 0.008	5.89	0.017 ± 0.006	34.86	0.024 ± 0.004	17.92	1.550 ± 0.072	4.63
Zinc	Zn	0.826 ± 0.117	14.19	0.169 ± 0.190	112.49	1.358 ± 0.751	55.33	0.466 ± 0.434	93.01
Zirconium	Zr	0.301 ± 0.244	81.12	0.414 ± 0.600	145.07	0.311 ± 0.292	94.07	1.086 ± 0.282	25.94

TABLE 8. STANDARDS RESULTS: RGS SUITE OF ELEMENTS

Fawnie Survey (N=4 insertions)

Element	Method	93-C (n=4) x ± 1s	RSD (%)
Uranium U	-	-	-
Fluoride F	-	-	-
Sulphate SO4 (ppm)	TURB	51.3 ± 3.4	6.64
pH	GCE	5.46 ± 0.13	2.29

Pinchi Survey (N=25 insertions)

Element	Method	Std. 1 (n=8)		Std. 2 (n=7)		Std. 3 (n=10)	
		x ± 1s	RSD (%)	x ± 1s	RSD (%)	x ± 1s	RSD (%)
Uranium U (ppb)	LIF	0.26 ± 0.01	4.19	0.15 ± 0.02	10.89	0.97 ± 0.03	3.49
Fluoride F (ppb)	ION	66.8 ± 4.7	6.97	84.3 ± 4.1	4.83	182.0 ± 7.9	4.33
Sulphate SO4 (ppm)	TURB	5.3 ± 1.0	19.7	10.4 ± 1.6	15.52	12.2 ± 2.2	17.60
pH	GCE	7.95 ± 0.05	0.67	8.33 ± 0.10	1.14	8.15 ± 0.11	1.33

Babine Survey (N=23 insertions)

Element	Method	Babine STD-3 (n=5)		Chutanli Lake (n=5)		Lake CH-1 (n=5)		Lake 3031 (n=5)		Meech L. 1993 (n=3)	
		x ± 1s	RSD (%)	x ± 1s	RSD (%)	x ± 1s	RSD (%)	x ± 1s	RSD (%)	x ± 1s	RSD (%)
Uranium U (ppb)	LIF	0.14 ± 0.01	7.14	0.08 ± 0.00	5.73	0.04 ± 0.01	30.49	0.12 ± 0.01	5.89	0.47 ± 0.02	3.27
Fluoride F (ppb)	ION	22.8 ± 1.8	7.85	46.0 ± 0.0	0.00	92.8 ± 33.9	36.53	290.0 ± 7.1	2.44	62.7 ± 2.3	3.69
Sulphate SO4 (ppm)	TURB	6.8 ± 0.5	6.58	2.8 ± 0.5	15.97	26.8 ± 5.7	21.34	11.0 ± 1.2	11.13	5.3 ± 0.6	10.83
pH	GCE	6.52 ± 0.11	1.68	1.82 ± 0.04	2.46	7.06 ± 0.34	4.87	1.82 ± 0.04	2.46	7.57 ± 0.40	5.34

LIF: laser-induced fluorescence

ION: ion selective electrode

TURB: turbidimetry

GCE: glass-calomel combination electrode

RSD < 10%

$$RSD = \frac{S.D.}{Mean} \times 100\%$$

MONITORING ANALYTICAL CONTAMINATION: DISTILLED WATER BLANKS

Distilled water blanks are inserted into analytical suites to monitor potential analytical contamination of the samples. Median results for major elements, trace elements and the RGS suite of elements are reported in Table 9 for each of the three surveys. Blank results are also used in the calculation of method detection limits (MDL) for each element (Table 3). Refer to page 50 for further comments on method detection limits and their relation to regional median values for each survey.

FAWNIE SURVEY

Analysis of distilled water blanks (N=14 insertions) inserted in the Fawnie analytical suite returned median aluminum, calcium, iron, magnesium, sulphate and barium values at or near the stated analytical detection limits for these elements (Table 9). Median results for potassium, silicon and sodium in the blanks were somewhat greater at 0.07, 0.13 and 0.24 ppm, respectively. The blanks were not re-filtered or acidified prior to insertion in the analytical suite.

PINCHI SURVEY

Eleven unfiltered unacidified distilled water blanks inserted in the Pinchi ICP-MS suite returned median concentrations below or near the limits of analytical detection for most elements (Table 9). Among trace elements, for example, median concentrations of barium, cobalt, rubidium and selenium in blanks are 0.154 ppb, 0.002 ppb, 0.007 ppb and 0.02 ppb, respectively. Method detection limits were also calculated from these samples (Table 3). No median results or method detection limits are reported here for copper or zinc, as high concentrations of these elements in the distilled water were found to have resulted from contamination at the source. No blanks were included in the routine RGS analytical suite.

BABINE SURVEY

Nineteen filtered and acidified distilled water blanks inserted in the Babine ICP-MS suite returned median concentrations below or near the limits of analytical detection for most elements (Table 9). Among trace

elements, for example, median concentrations of barium, cobalt, nickel and copper in blanks are 0.107 ppb, 0.002 ppb, 0.049 ppb and 0.358 ppb, respectively. Sixteen additional unfiltered/unacidified and unfiltered/acidified blanks were also included in the analytical suite, but are not reported on here.

Median results of 0.04 ppb uranium, 10 ppb fluoride and 1 ppm sulphate were obtained for unacidified distilled water blanks (N=20 insertions) in the routine RGS analytical suite. These results are all at or below the stated analytical detection limits (Table 9).

FURTHER COMMENTS ON ANALYTICAL METHODS

As a further comment on analytical methods, gold in waters of the Babine area was determined here by direct ICP-MS analysis following filtration and acidification alone. No preconcentration methods were employed. Owing to the very low background gold content of natural waters of <0.001-0.005 ppb (1-5 parts per trillion, or ng/l; McHugh, 1988), sample preconcentration is recommended for hydrogeochemical exploration surveys for gold in order to lower detection limits and improve analytical precision. Preconcentration techniques may involve (i) adsorption on to activated charcoal (Hamilton *et al.*, 1983; Hall *et al.*, 1986) prior to analysis by, for example, graphite furnace-atomic absorption spectrometry (GF-AAS), (ii) sample evaporation and solvent extraction following leaching of container walls with a bromine-hydrochloric acid solution (Hall *et al.*, 1986), or (iii) preconcentration by hydrochloric acid-MIBK prior to ICP-MS analysis (Cidu and Edmunds, 1990). Readers are referred to Hall *et al.* (1986) and Cidu and Edmunds (1990) for further information on sampling and analytical requirements for determining gold in natural waters.

Similarly, determination of REEs in lake waters may be improved by preconcentration prior to analysis. Hall *et al.* (1996) and Hall and McConnell (1994) have described a method for preconcentrating REEs and other elements in Newfoundland lake and stream waters with MetPac CC-1 chelating resin prior to nebulisation ICP-MS analysis. Concentrations of REEs reported here are generally quite low. Comparison of standards results (Tables 6 and 7) and the element distribution maps (Appendix D) with both analytical and method detection limits (Table 3) show that there is a need for better detection limits and low-concentration precision than can be obtained with direct ICP-MS analysis.

TABLE 9. MEDIAN ANALYTICAL RESULTS: DISTILLED WATER BLANKS

Element	Symbol	Fawnie	Pinchi	Babine	Element	Symbol	Fawnie	Pinchi	Babine
		(ppm) (N=14)*	(ppb) (N=11)*	(ppb) (N=19)**			(N=14)	(N=20)	
Major Elements					RGS Suite				
Aluminum	Al	0.01	1.4	0.6	Uranium	U (ppb)	-	-	0.04
Calcium	Ca	0.02	115	30	Fluoride	F (ppb)	-	-	10
Iron	Fe	0.005	2.1	2.3	Sulphate	SO ₄ (ppm)	0.5	-	1
Magnesium	Mg	0.01	13.6	9.0	pH		-	-	-
Potassium	K	0.07	19	5					
Silicon	Si	0.13	1	28					
Sodium	Na	0.24	11.5	45.3					
Trace Elements									
Antimony	Sb	-	0.02	0.02					
Arsenic	As	-	0.02	0.02					
Barium	Ba	0.01	0.154	0.107					
Bismuth	Bi	-	0.002	0.002					
Bromine	Br	-	1.0	1.0					
Cadmium	Cd	-	0.008	0.002					
Cerium	Ce	-	0.002	0.006					
Cesium	Cs	-	0.002	0.002					
Chromium	Cr	-	0.1	0.2					
Cobalt	Co	-	0.002	0.002					
Copper	Cu	-	n/r	0.358					
Dysprosium	Dy	-	-	0.002					
Erbium	Er	-	-	0.002					
Europium	Eu	-	-	0.002					
Gadolinium	Gd	-	-	0.002					
Gallium	Ga	-	0.002	0.005					
Germanium	Ge	-	-	0.002					
Gold	Au	-	-	0.002					
Hafnium	Hf	-	0.002	0.002					
Holmium	Ho	-	-	0.002					
Iodine	I	-	0.04	2.21					
Lanthanum	La	-	0.002	0.003					
Lead	Pb	-	0.21	0.04					
Lithium	Li	-	0.3	0.1					
Lutetium	Lu	-	0.002	0.002					
Manganese	Mn	-	0.39	0.02					
Molybdenum	Mo	-	0.02	0.02					
Neodymium	Nd	-	0.002	0.003					
Nickel	Ni	-	0.577	0.049					
Niobium	Nb	-	0.002	0.014					
Praseodymium	Pr	-	0.002	0.002					
Rubidium	Rb	-	0.007	0.008					
Samarium	Sm	-	-	0.002					
Scandium	Sc	-	0.02	0.02					
Selenium	Se	-	0.02	0.08					
Strontium	Sr	-	0.328	0.233					
Tantalum	Ta	-	0.002	0.002					
Tellurium	Te	-	-	0.02					
Terbium	Tb	-	0.002	0.002					
Thallium	Tl	-	0.002	0.002					
Thorium	Th	-	0.002	0.002					
Thulium	Tm	-	-	0.002					
Tin	Sn	-	0.107	0.029					
Titanium	Ti	-	0.02	0.02					
Tungsten	W	-	0.067	0.002					
Uranium	U	-	0.002	0.002					
Vanadium	V	-	0.02	0.02					
Ytterbium	Yb	-	0.002	0.002					
Yttrium	Y	-	0.002	0.004					
Zinc	Zn	-	n/r	0.836					
Zirconium	Zr	-	0.007	0.091					

* Fawnie/Pinchi method detection limit: $x + 3s$ of unfiltered unacidified distilled water blanks

** Babine method detection limit: $x + 3s$ of filtered acidified distilled water blanks

n/r: Cu and Zn data for Pinchi distilled water blanks not reported due to contamination during production

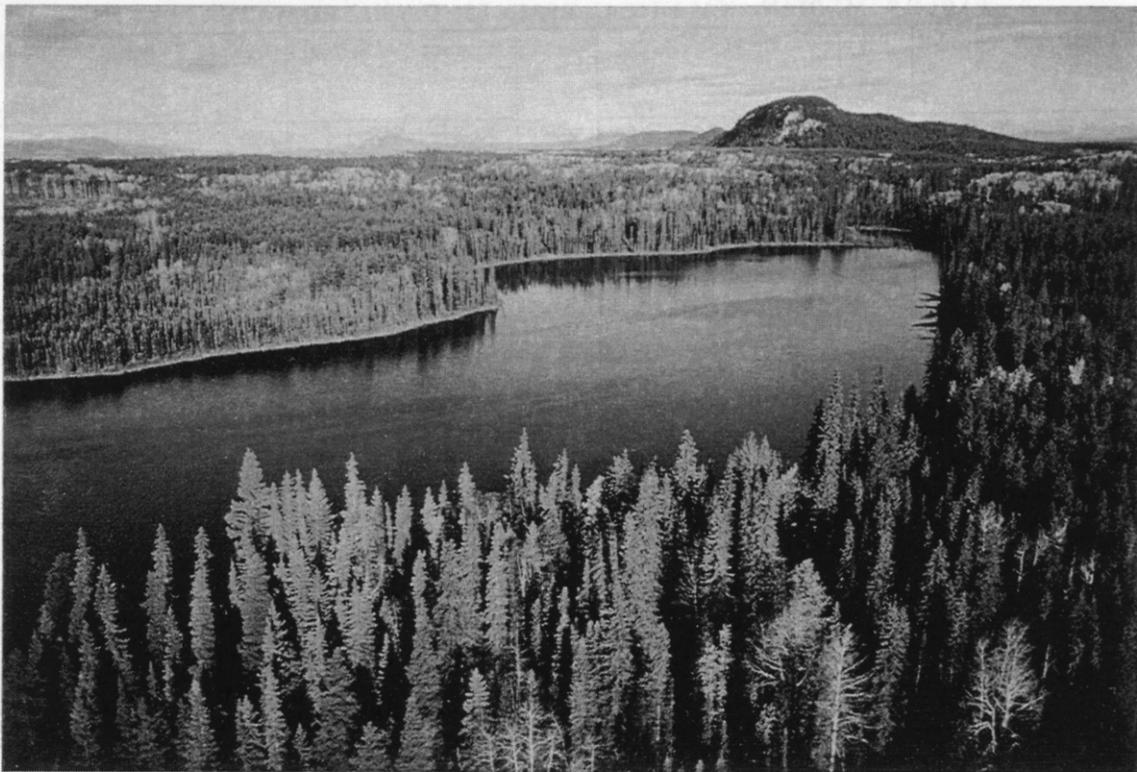


Photo 5. Typical landscape in the western part of the Pinchi survey area, above Cache Creek Terrane rocks west of Tezzeron Lake (October, 1995)



Photo 6. View of a lake on the flank of Matzehtzel Mountain, looking southwest toward Tacheh Mountain, at the southern margin of the Babine survey area. Surface waters here (site 962044) have elevated concentrations of zinc (2.772 ppb); sediments have elevated levels of zinc, lead, silver and cadmium (June, 1996).

PRELIMINARY DATA INTERPRETATION

This section presents summary data and preliminary interpretations for field variables and selected water geochemical results for each survey area. Data interpretation is of a preliminary nature only. Discussions on the distribution and abundance of major elements such as potassium and aluminum, and of trace elements such as copper and zinc are intended to highlight regional geochemical patterns that may be of interest to mineral explorationists. They are not intended to replace detailed environmental studies for site-specific areas. Refer to the appropriate 1:50,000 scale NTS topographic maps for lake and place names.

FIELD VARIABLES

FAWNIE SURVEY

All sites in the Fawnie survey area are within the Stikine Terrane. The majority of sites (60%) are of pond size or smaller ($< 0.25 \text{ km}^2$). Only 8% of sites are in large lakes ($> 5 \text{ km}^2$), while 17% are in small lakes of 0.25 - 1 square kilometre.

Median sample depth is 4 metres in the Fawnie area (Figure 5). Very shallow lakes are common; one-third of all sites are from ponds with depths of 2 metres or less. Most sites (71-76%) are from depths of 8 metres or less. Deepest site sampled was 33 metres, but less than 3% of Fawnie sites are deeper than 20 metres. It should be noted that sample depth measures the distance from the water surface to the sample location within the sediment column. It is *not* synonymous with lake depth (distance from water surface to the sediment-water interface), because the sampler typically penetrates a few metres into the sediment before coming to a stop. Generally, depth of penetration increases with increasing lake depth; it may be negligible in small ponds, but up to 3 or 4 metres in large, deep lakes.

The proportion of sites classed as being in areas of low relief is approximately equal (41-42%) in both survey areas. However, there is a greater proportion of high-relief sites in the Fawnie area (5%) than in the Ootsa area (1%). Field observations indicate that potential sources of anthropogenic contamination are negligible. Work or camp sites were seen on the shores of only 4 to 5% of sites sampled.

PINCHI SURVEY

By terrane, approximately 55% of the sites in the Pinchi area are within Quesnellia; most of the remainder are in the Cache Creek Terrane (40%). The majority of sites in the survey area (65%) are in lakes of pond size or smaller (*e.g.* $< 0.25 \text{ km}^2$). This is similar to the proportion of pond-sized sites recorded to the south in the Fawnie and Ootsa lake sediment surveys of the Nechako River map area (NTS 93F; Cook and Jackaman, 1994b). Almost 21% of sites are in lakes in the range 0.25 to 1 km^2 , but only 8.5% of sites are in large lakes (*e.g.* $> 5 \text{ km}^2$). Median lake depth in the Pinchi Lake survey area is 4 metres. Shallow lakes are very common, and more than one-third of all sites are ponds with depths of 2 metres or less (Figure 5). More than three-quarters (78%) of the sites have depths of 10 metres or less. The deepest site recorded was 35 metres, but only 4% of the sites have depths of more than 20 metres. Lake depth, measured here with a float-mounted depth sounder, is not synonymous with sample depth, as mentioned in the preceding paragraph.

Approximately 43% of sites were classed as being in areas of low relief, with a further 49% classed as areas of medium relief. Only 8% of lake sediment sites were categorized as being in areas of high relief. Field observations indicate that potential sources of anthropogenic contamination are likely minimal in spite of extensive logging activity in some parts of the survey area. Work or camp sites were recorded on the shores of 14% of sites sampled.

BABINE SURVEY

The watersheds of most lake sediment sites in the Babine area are underlain by Cretaceous to Triassic sedimentary and volcanic units. Of these, the Telkwa Formation of the Lower to Middle Jurassic Hazelton Group contains the greatest number of sample sites (96 sites; 28.9%). Comparatively few sites are within the watersheds of intrusive units due to their relatively small size. Of these, only the Early Jurassic Topley Intrusions (19 sites; 5.7%) host a substantial number of sites. Geological unit designations are those of MacIntyre *et al.* (1994).

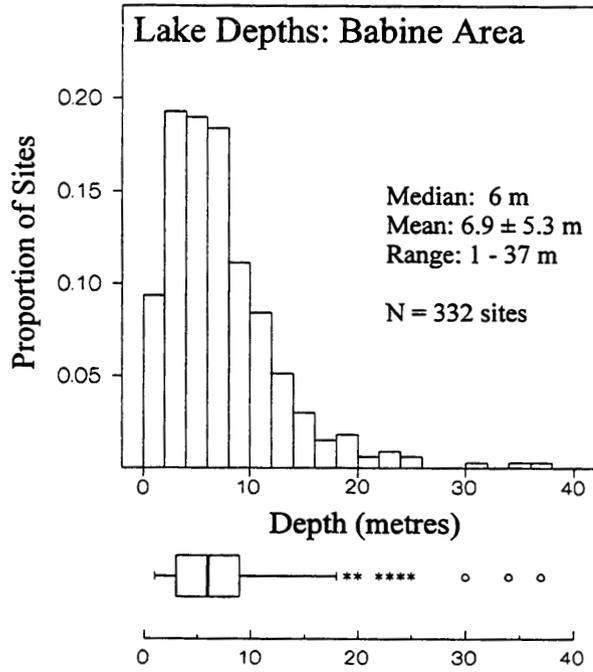
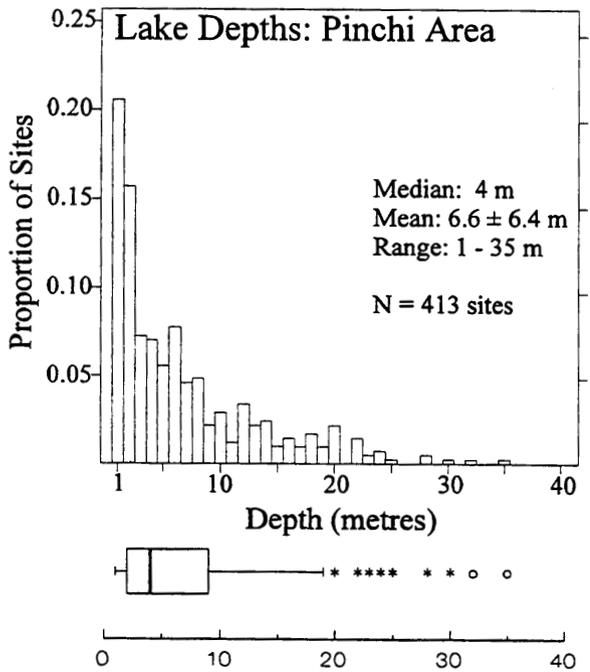
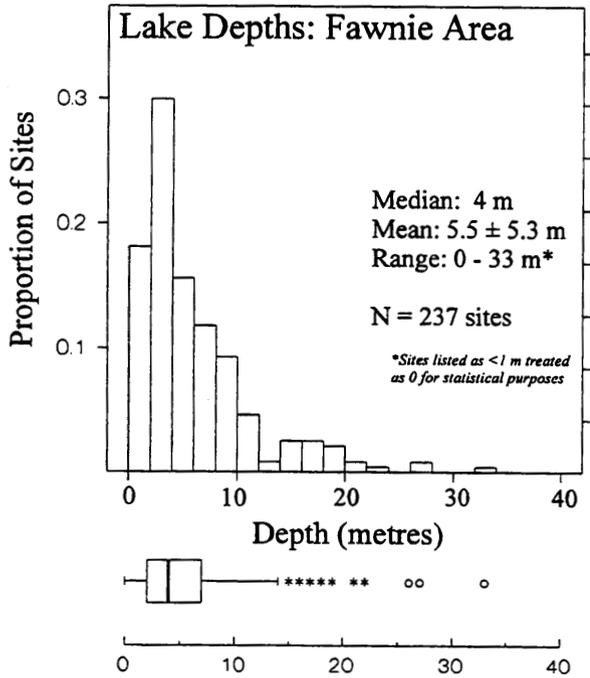


Figure 5. Histograms and box plots showing lake depths in the Fawnie, Pinchi and Babine survey areas. Note that Fawnie and Babine data record depth of the underlying sediment sample rather than the depth to the sediment-water interface. Nevertheless, median depths are in the range 4-6 metres for all areas.

The majority of sites in the Babine survey area (66%) are in lakes of pond size or smaller (e.g. < 0.25 km²). This is similar to the proportion of pond-sized sites recorded in prior surveys of the Nechako Plateau area (Cook and Jackaman, 1994; Cook *et al.*, 1997a). Approximately 21% of the sites are in lakes in the range 0.25 to 1 km², but only 14 sites (4.2%) are in large lakes (e.g. > 5 km²). Samples obtained from such large lakes are often from restricted bays and other relatively shallow areas. Median sample depth in the Babine survey area is 6 metres (Figure 5). Shallow lakes are very common, and more than one-quarter (29%) of all sites have depths of 3 metres or less. A majority of the sites (82%) have depths of 10 metres or less. The deepest site recorded was 37 metres, but overall deep lakes are relatively rare; only 8 sites in the entire survey area (2.4%) have sample depths of more than 20 metres. Sample depth was determined here using a marked sampling rope, and is a measure of the distance from the water surface to the sample location within the sediment column.

The proportion of sites classed as being in areas of low relief (approximately 41%), is very similar to that encountered elsewhere in the Nechako Plateau (Cook and Jackaman, 1994; Cook *et al.*, 1997a). A further 52% of sites were classed as being in areas of medium relief. Just over 7% of sediment sites were categorized as being in areas of high relief. The Babine belt has a history of mining and mineral exploration and is presently the site of active logging activity. Potential sources of anthropogenic contamination (work or camp sites) were limited, however, to the shores of 27 (8.1%) sites.

WATER GEOCHEMISTRY: RGS SUITE

pH

A pH boxplot for the Fawnie area (Figure 6) shows that lake waters are predominantly of near-neutral to alkaline pH, with a median value of 7.91 (range: 6.80 to 9.95). One pond with an extremely alkaline pH of 9.95 is located on a hillside overlooking the Fawnie Creek valley near Top Lake. Most of the lowest pH values (6.80-7.63) occur in small lakes and ponds to the west of Kuyakuz Lake, on the northeast flanks of the Fawnie Range and extending to the summit areas of Tsacha Mountain and Mt. Davidson. Some of these sites also have elevated aluminum concentrations, and coincide with relatively high SO₄/Ca in water ratios. Many of these sites overlie Quaternary sediments with little or no bedrock exposure (Diakow and Levson, 1997), but receive upslope drainage from Hazelton Group and Ootsa Lake Group rhyolitic

tuffs and flows exposed at higher elevations in the Fawnie Range.

The pH of raw surface lake waters in the Pinchi survey area are in the range 5.6 - 8.5. Most lake waters are slightly alkaline; median pH is 7.8, and only a small proportion of sites (18 of 413; 4.4%) exhibit a pH < 7.0. Carbonate units of the Cache Creek Group are the likely source of the slightly alkaline lake waters. Median pH of lakes underlain by these units (PTrCCI) is 8.0 (max: 8.5). Elevated pH values are also present in areas underlain by lowermost Takla Group (muTrTs) sedimentary rocks (median: 7.9; max: 8.5), and by several other units. Acidic pH values are most common in areas underlain by pelagic sediments and blueshists of the Cache Creek Group (PTrCCs, PTrCCb), particularly between Tezzeron and Trembleur lakes. Four of the five lowest pH values < 6.5 occur here, three of which (sites 1169-1171) are just west of Tezzeron Lake. Just west of here, relatively low pH values are also found in the area of several sites with elevated metal concentrations in sediments and/or waters. Furthermore, several sites with relatively acidic pH values coincide with the location of a previously-unrecognized Middle Jurassic pluton east of Trembleur Lake which was recently mapped by Struik (in preparation). Slightly acidic pH values < 7.0 are also present above Takla Group sedimentary rocks (uTrTt) east of Tezzeron Lake.

The pH of raw surface lake waters in the Babine survey area are in the range 6.1 - 8.1. Most lake waters are neutral, and the median pH is 7.2. Subdivided by geology, median lake water pH values of those units with at least ten sample sites are in the range 7.0 - 7.3. Lakes above the Early Jurassic Topley Intrusions (EJT) have the lowest median pH (7.0). In general, more acidic pH values of 6.8 or lower occur in three areas:

- The relatively flat-lying southwestern part of the survey area, in the region of Findlay, Baboon and Lennac lakes (NTS 93L/9). Lake water pH values as low as 6.4 (site 2022) occur in this area, which is underlain by Telkwa Formation (IJT) rocks of the Hazelton Group.
- The east side of Babine Lake (NTS 93L/16), opposite the village of Granisle, in a region underlain by the Topley Intrusions (EJT). Lake water pH values as low as 6.1 (site 2065) are present here.
- The Clota Lake-Nilkitkwa River area in the northeastern corner of the survey area (NTS 93M/7). This region is underlain by Lower Cretaceous Skeena Group rocks of the Red Rose (IKRR) and Kitsuns Creek (IKK) Formations. Of the only seven of 332 sites in the Babine survey area (2.1% of the total) which exhibit lake water pH values < 6.5, three of them are in this area. One site (2291) has a pH of 6.1.

Conversely, six lake water sites in the survey area (1.8% of the total) have a more alkaline pH of 8.0 or greater. Most of these are associated with Ashman Formation (muJA) and Telkwa Formation (IJT) rocks; many are coincident with elevated lake water sulphate concentrations as discussed in the following section.

SULPHATE

In a study of drill-hole and spring waters from the Eustis copper-zinc mine, Quebec, Hoag and Webber (1976) proposed that sulphate concentrations > 28 mg/l (28 ppm) were indicative of sulphide mineralization. Furthermore, sulphate concentrations > 160 mg/l (160 ppm) were considered to be indicators of extensive bacterial surface oxidation of sulphide minerals. In this study, three sites in the Fawnie area, none in the Pinchi area and one site in the Babine area have sulphate concentrations in the range 28-160 ppm. An additional single site in the Fawnie area has a sulphate concentration greater than 160 ppm. High sulphate concentrations in surface waters may have a variety of potential sources, including the oxidation of potentially economic sulphide occurrences (Cameron, 1977), oxidation of disseminated pyrite in coal, or from the dissolution of sedimentary gypsum horizons (Rose *et al.*, 1979). Ratioing of sulphate with calcium and TDS to differentiate sulphate sources is discussed in a later section.

Median sulphate concentration in Fawnie-area lake waters is 4 ppm, somewhat greater than the median result of 0.6 ppm reported for the Ootsa Lake area to the north (Cook and Jackaman, 1994), but similar to median results for the other surveys here documented here. Maximum sulphate concentration in the Fawnie survey area is 168 ppm. Eleven sites have sulphate concentrations > 20 ppm (95th percentile), well in excess of background values. Elevated sulphate concentrations primarily occur in areas underlain by Naglico Formation rocks of the Hazelton Group.

In the Pinchi area, median sulphate concentration in lake waters is 3 ppm, similar to the median values of 3 - 4 ppm sulphate reported here for the Fawnie and Babine surveys. Maximum sulphate concentration in the Pinchi Lake survey area is 55 ppm. Thirteen sites have sulphate concentrations > 10 ppm (95th percentile), well in excess of background values. Elevated sulphate concentrations occur in areas underlain by Takla Group sediments (uTrTt) in the eastern part of the survey area, and in the Pinchi fault area between Pinchi and Tezzeron lakes. However, lakes with elevated sulphate are most common above pelagic sedimentary units of the Cache Creek Group (PTrCCs) to the southwest of Stuart Lake. Lake

waters at numerous sites in this area near the contact with the Shass Mountain pluton contain at least 8 ppm sulphate (>90th percentile). Two of the three highest sulphate concentrations in the Pinchi Lake survey area (site 1472: 27 ppm; site 1488: 55 ppm) occur here just upslope of Stuart Lake.

Median sulphate concentration in Babine-area lake waters is 3 ppm, similar to median values of 3 - 4 ppm sulphate reported here for the Fawnie and Pinchi surveys areas. Subdivided by geological unit, median sulphate values do not vary beyond 2-4 ppm for those units with at least ten sample sites. Maximum sulphate concentration is 47 ppm. Fourteen sites have sulphate concentrations > 7 ppm (95th percentile); concentrations at seven of these sites (2.1%) exceed 9 ppm (98th percentile).

Babine-area lakes with elevated sulphate concentrations are most common in areas underlain by Hazelton Group Telkwa Formation (IJT) and Bowser Lake Group Ashman Formation (muJA) rocks. The site with the highest sulphate concentration (site 2338; 47 ppm), for example, is situated above Telkwa Formation rocks just northeast of Tahlo Lake in the Nakinilerak Lake map area (NTS 93M/8). Groupings of lakes with elevated sulphate values > 95th percentile occur in two main areas:

- The northwest corner of the Old Fort Mountain map area (NTS 93M/1), where waters at three sites in small ponds and lakes located about 7 kilometres west of Morrison Lake contain 13-44 ppm sulphate. These sites, which drain Bowser Lake Group Ashman Formation (muJA) sedimentary rocks, are also adjacent to two other sites with elevated sediment antimony concentrations.
- The northeast margin of the survey area, between the two arms of Takla Lake (NTS 93M/8). Waters at three sites above Eocene Ootsa Lake Group (EO) felsic volcanics contain 8-9 ppm sulphate.

In addition to the foregoing, elevated sulphate concentrations in lake waters also reflect the presence of porphyry copper mineralization at both the Morrison and Lennac Lake prospects. Waters from two sites located at the base of Hearne Hill, near the Morrison prospect, contain 10-19 ppm sulphate. In the case of Lennac, a single water sample from a small lake adjacent to bedrock copper mineralization in Bulkley intrusive rocks (LKBp) contains 9 ppm sulphate.

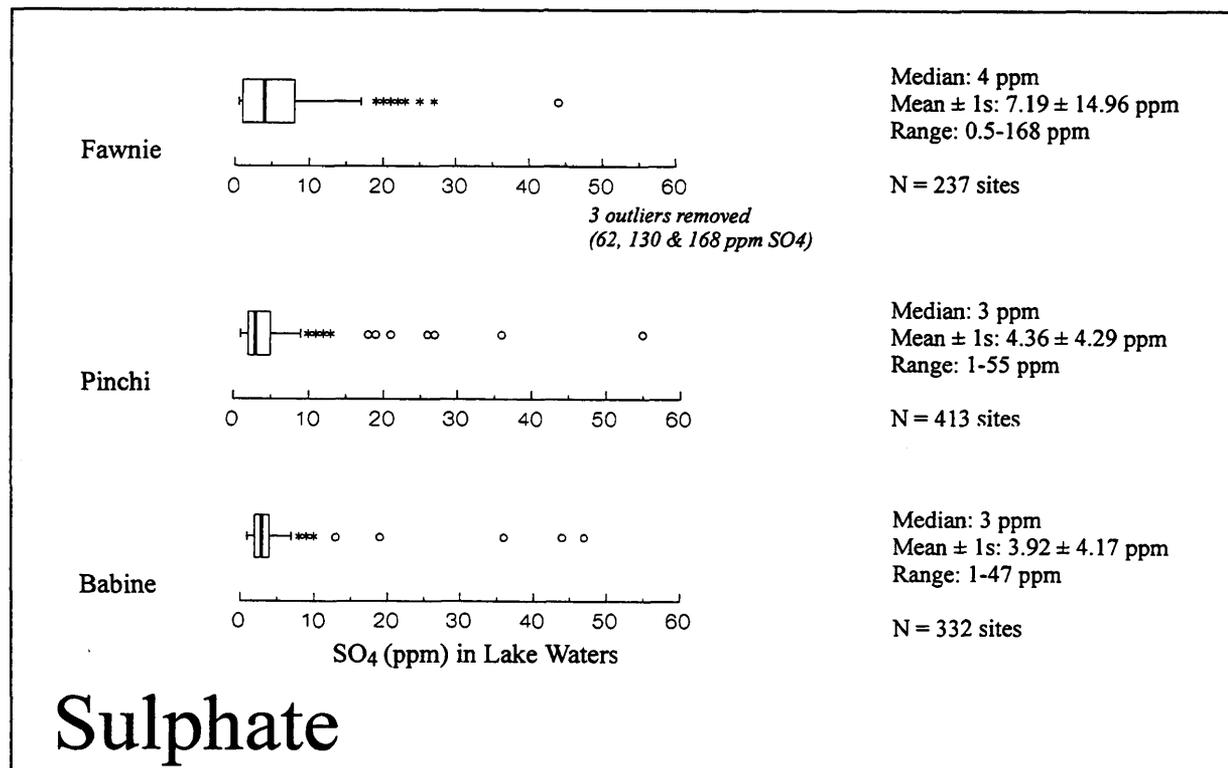
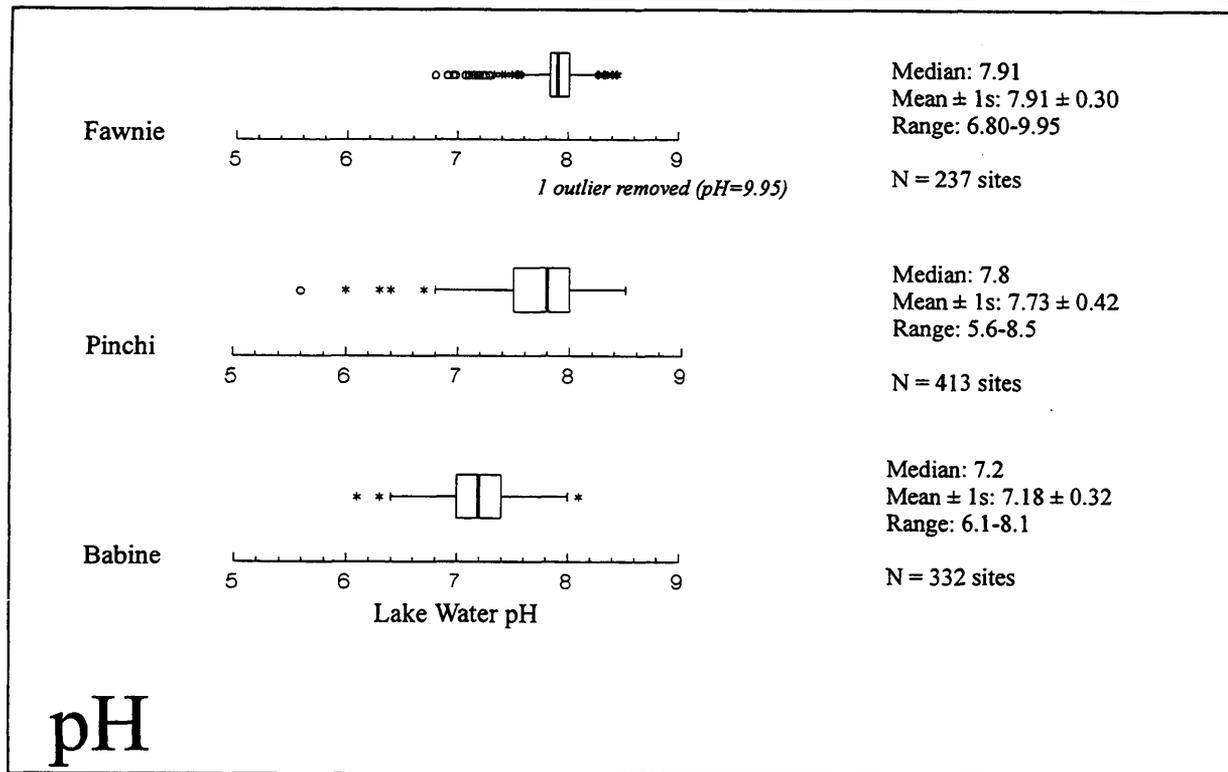


Figure 6. Boxplots showing distribution of pH and sulphate in unfiltered lake waters of the Fawnie, Pinchi and Babine survey areas. This data was obtained at every sediment site in the three survey areas, and was previously reported by Cook *et al.* (1997, 1998) and Cook and Jackaman (1994) Fifty per cent of the data lies within the box; the lower and upper bounds of each box define the first quartile and third quartile of data, respectively.

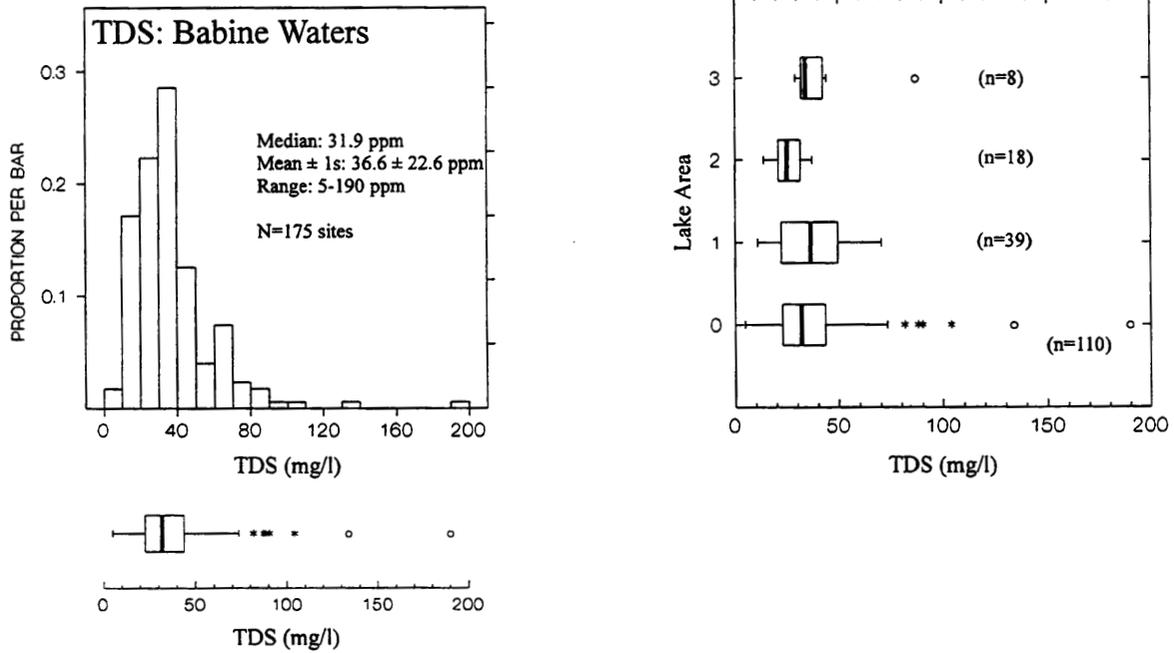


Figure 7. Histogram and boxplot showing distribution of total dissolved solids (TDS) in Babine-area lake waters (N=175 sites). Subdivision by lake area (see Table 4 in Appendix A for explanation of units) shows that most elevated TDS concentrations are in ponds and small lakes < 0.25 km². Note that there is no TDS data for site 962293.

USE OF LAKE WATERS IN MINERAL EXPLORATION

ORIGIN OF LAKE WATERS

Lake waters originate from a combination of sources including groundwater seepage, stream water input, sheet runoff and snow melt. Several factors influence the composition of natural lake waters (Rose *et al.*, 1979):

- 1) dissolution of rock and unconsolidated surficial materials in the watershed;
- 2) presence or absence of oxidizing sulphide minerals, or their dispersed remnants in till or other surficial materials;
- 3) seasonal and within-lake limnological variations, such as thermal stratification of the water column and the depletion of oxygen at depth in eutrophic lakes;
- 4) rain water composition;
- 5) climatic factors;
- 6) age, or residence time, of both lake water and inflowing ground waters;
- 7) geochemical environment, such as pH, which affects whether trace elements remain in solution or are adsorbed onto suspended organic matter, clay-sized particles or iron oxides;

LAKE WATERS AND REGIONAL GEOCHEMICAL EXPLORATION

Lake waters have been used as a regional geochemical exploration medium in northern North America for forty years since Kleinkopf (1960) showed that the distribution of elevated levels of copper and molybdenum in Maine lake waters coincided with known copper-molybdenum mineralization. Nevertheless, lake waters have not been widely used in mineral exploration in glaciated regions of northern or western Canada. Until recently this has been due, at least in part, to the inability of commercially-available analytical methods to accurately determine trace elements at the ppb and sub-ppb levels at which they typically occur in surface waters. Furthermore, the very low levels of trace elements in most water samples are prone to external contamination if not handled with care in the field environment, and the samples must be analyzed relatively soon after collection in order to minimize compositional changes during storage (Miller, 1979).

Nevertheless, collection of lake waters in regional-scale helicopter-borne geochemical surveys offer several advantages over collection of stream or lake sediments. Several benefits of lake water geochemical surveys were recently outlined by Cameron *et al.* (1997) for parts of the Northwest Territories, and these are largely applicable to British Columbia as well. Lakes are abundant in the Interior Plateau of British Columbia, and they are relatively quick and simple to sample with a float-equipped helicopter. Necessary preparation in the form of filtering and acidification can be completed in the field, negating the need for commercial sample preparation, and the advent of commercially-available multi-element ICP-MS instrumentation has increased the range of available trace elements and reduced their detection levels to much more useful levels. Sources of variation in regional lake water geochemical surveys over any given area may be minimized by sampling only surface waters, which are typically dilute and oxidizing, and by filtering all samples to 0.45 microns to remove the ubiquitous suspended mineral and organic particulate matter, which may have very variable metal contents. In addition, acidification of the filtered water keeps dissolved metals in solution rather than being adsorbed to the sides of the sample container.

Lake water geochemical surveys were widely used for uranium exploration during the 1970's (Rose *et al.*, 1979; Dyck, 1979; Taufen, 1997), and have also been successfully applied in case studies and regional exploration surveys for base metals in the Northwest Territories (Cameron, 1977; Cameron *et al.*, 1997). There is however only limited regional water geochemical data available in the Cordillera. Most publicly-funded regional lake sediment geochemical surveys in both British Columbia (*e.g.* Cook *et al.*, 1998) and the rest of Canada (*e.g.* Friske and Hornbrook, 1991), in which lake waters are also sampled, have been restricted to determination of only a few constituents such as pH, uranium, fluoride and sulphate. Development of ICP-MS preconcentration techniques such as those outlined for REEs and trace elements by Hall and McConnell (1994) and Hall *et al.* (1996) for regional water surveys in Newfoundland and Nova Scotia will likely lead to more widespread use of lake water geochemistry in mineral exploration.

Those readers further interested in the use of surface water geochemistry in mineral exploration should consult reviews of Rose *et al.* (1979), Miller (1979) and Taufen (1997). A brief discussion of the major element and trace element composition of Nechako Plateau-area lake waters is given in the following sections.

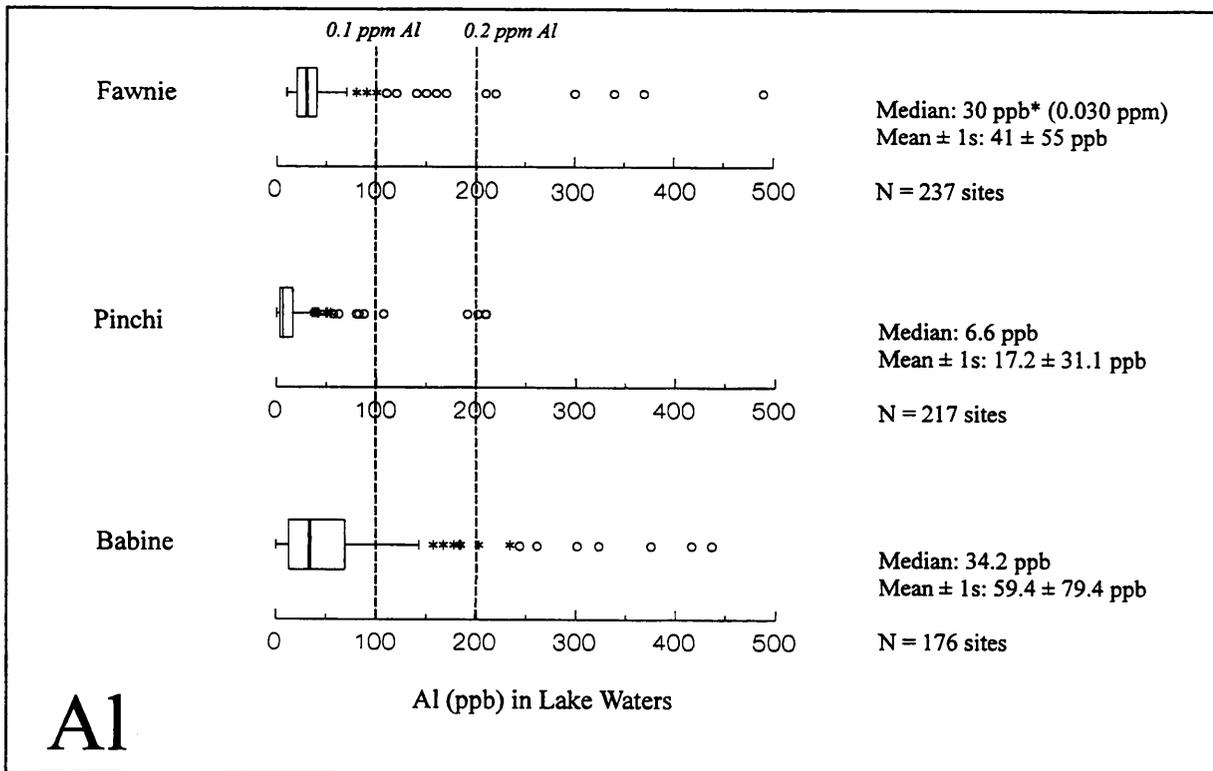
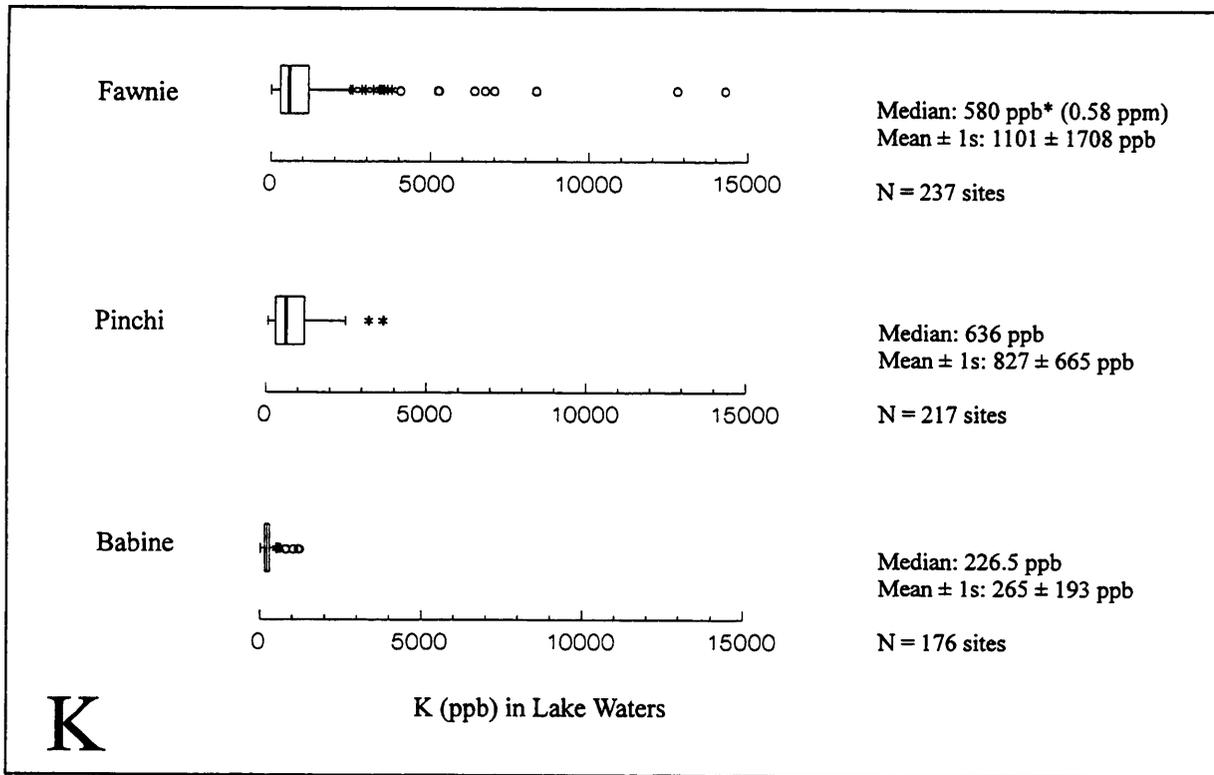


Figure 8. Boxplots showing distribution of potassium and aluminum in lake sediments of the Fawnie, Pinchi and Babine survey areas. Fifty per cent of the data lies within the box; the lower and upper bounds of which define the first quartile and third quartile of data, respectively.

WATER GEOCHEMISTRY: MAJOR ELEMENTS

The following discussion highlight significant trends in the distribution of the major elements calcium, magnesium, silicon, sodium, potassium, iron and aluminum in Nechako-area waters, and is not intended as exhaustive. A brief synopsis of the bedrock sources, dominant aqueous species and lake water stability constraints for each is provided. Only major element cations are reported here; with the exception of sulphate, no major anions such as chloride or bicarbonate were determined. For purposes of comparison, Fawnie results, reported as ppm in data listings, are referred to here in ppb. Iron and aluminum, although often present in trace amounts (<100 ppb), are grouped here for convenience.

Major element cation composition of Nechako-area lake waters, based on median concentrations, generally follows the trend $Ca > Si > Mg > Na > K > Fe > Al$. There are a few exceptions; median concentrations of magnesium exceed those of silicon in the case of the Pinchi area, and median sodium and magnesium concentrations are equal in the Fawnie area.

Geochemical results here are compared with Canadian and British Columbia water quality guidelines for protection of aquatic life. Readers are referred to Environment Canada (1987) and Nagpal *et al.* (1995) for further information on approved and working criteria for drinking water, freshwater aquatic life and livestock.

CALCIUM AND MAGNESIUM

Calcium is one of the most abundant constituents of natural waters, and is primarily derived from the weathering of sedimentary carbonate rocks such as limestone and dolomite, gypsum and, to a lesser extent, from calcium silicate minerals such as anorthite (Berner and Berner, 1987), which are less susceptible to weathering than sedimentary carbonates. Magnesium in waters is chiefly derived from the weathering of magnesium silicate minerals such as amphiboles, pyroxenes and olivine, with a lesser proportion derived from dolomite weathering. Together, dissolved calcium and magnesium in water are the primary controls on hardness. Calcium concentrations in hard-water lakes typically decrease during the warm summer months, as $CaCO_3$ is precipitated with rising water temperatures (Environment Canada, 1987). However, the more-soluble dissolved magnesium compounds are less likely to be precipitated.

Median calcium concentrations in Nechako-area lake waters for the three survey areas are in the range 9157 -

20411 ppb, with highest concentrations occurring in Pinchi-area waters and lowest in Babine-area waters. Median magnesium concentrations, in the range 1828.1 - 4241.7 ppb, show a trend among the three survey areas. Elevated calcium concentrations > 95th percentile (35800 ppb) in the Fawnie survey area occur mostly in the southern part of the survey area. Most higher calcium concentrations show a strong association with bedrock lithology, in particular the distribution of Lower to Middle Jurassic Naglico Formation basalt and andesite flows. Elevated lake water magnesium concentrations > 95th percentile (13800 ppb) are also associated with mafic volcanic rocks, in this case with Chilcotin Group olivine basalt flows near Tsacha Lake in the southeastern part of the survey area, as well as with Naglico Formation rocks. Those lakes with the highest calcium (max: 64,700 ppb) and magnesium (max: 29,800 ppb) concentrations occur west of Tsacha Lake, just north of the Blackwater River.

Elevated calcium concentrations > 95th percentile (50032 ppb) in the Pinchi area (max: 62858 ppb) show a rough association with the mapped distribution of limestone units of the Cache Creek Group. In contrast, elevated magnesium concentrations > 95th percentile (23449 ppb) here (max: 56086.2 ppb) are associated with the distribution of Cache Creek Group ultramafic rocks, such as those of Murray Ridge, and Middle to Upper Triassic Takla Group sedimentary rocks (muTrTs) exposed north of Fort St. James. In the Babine area, relationships between elevated calcium and magnesium concentrations and bedrock lithology are less clear. Most elevated calcium concentrations > 95th percentile occur as isolated scattered sites, but one area of elevated and moderately-elevated calcium occurs in a group of lakes between Fulton Lake and the Lennac prospect. The greatest clustering of elevated magnesium values is near the northwest corner of the Old Fort Mountain (NTS 93M/1) map area, in an area between Babine and Morrison lakes.

There are no Canadian or British Columbia water quality guidelines for calcium, magnesium and protection of freshwater aquatic life. No sites reported here exceed the 500 mg/L (500 ppm) magnesium taste threshold for average people (Environment Canada, 1987; Nagpal *et al.*, 1995), or the 1000 mg/L (1000 ppm) limit for livestock watering.

SILICON

Silicon is the second most common element in the crust, but its abundance in natural waters is limited by the weathering resistance of silica, or quartz (SiO_2), a common constituent of many rocks. Consequently most dissolved silicon, as silicic acid (H_4SiO_4), is instead derived from weathering of aluminosilicate minerals such

as feldspars, micas and clay minerals (Environment Canada, 1987). It follows that geological variations may control differences in the silicon content of natural waters. Berner and Berner (1987) reported that the weathering of recent volcanic rocks released twice the silicon, as silica, of crystalline intrusive and metamorphic rocks, and almost four times the silica of detrital sedimentary rocks. This was attributed to the presence of more readily-weathered anorthite, pyroxenes and glass in the volcanics. Seasonal assimilation and sedimentation of dissolved silicon by lacustrine diatoms is the primary control on its removal from the water column (Wetzel, 1983).

Median silicon concentrations are greatest here in Fawnie-area lake waters (3740 ppb; max: 14800 ppb). Median silicon concentrations in Pinchi and Babine-area lake waters are roughly equivalent at 2158 ppb (max: 11091 ppb) and 2036 ppb (max: 6838 ppb), respectively. There are no Canadian or British Columbia water quality standards for silicon.

SODIUM

Most lake water sodium of natural origin is derived from weathering of sodium plagioclase, feldspathoids and evaporitic minerals such as halite (NaCl). Sodium concentrations in natural waters are greater than those of potassium because, in part, sodium-plagioclase feldspars weather more readily than potassium feldspars. Furthermore, highly soluble dissolved sodium compounds tend to remain in solution and resist adsorption (Environment Canada, 1987).

Median sodium concentrations in Nechako-area waters display a similar trend to those of silicon. Median sodium concentrations are greatest in Fawnie-area lake waters (3380 ppb). This is approximately 2x that of the median sodium concentrations of Pinchi and Babine-area lake waters, which are roughly equivalent at 1675.4 ppb and 1490.5 ppb, respectively. Elevated lake water sodium concentrations > 95th percentile (9240 ppb) in the Fawnie area (max: 42400 ppb) have a similar distribution to that of elevated magnesium concentrations, showing a particularly strong association with underlying Chilcotin Group olivine basalt flows in the southeastern part of the survey area. Elevated sodium levels in the Pinchi area (max: 7313.5 ppb) are most common in lakes overlying Takla Group sedimentary rocks in the southeast corner of the survey area, and are similar to the maximum sodium concentrations in Babine-area waters (5912.1 ppb).

There are no Canadian or British Columbia water quality guidelines for sodium dealing with the protection of freshwater aquatic life (Environment Canada, 1987; Nagpal *et al.*, 1995), but concentrations in drinking water

should not exceed 200 mg/L (200 ppm). No sites reported here exceed this level.

POTASSIUM

Almost 90% of potassium in natural waters is derived from the weathering of silicate minerals, particularly potassium feldspars and biotite (Berner and Berner, 1987). Potassium abundance in natural waters is lower than that of calcium, magnesium and sodium because (i) primary potassium silicate minerals are more resistant to chemical weathering, and (ii) once liberated, potassium ions are relatively more likely to be adsorbed onto surfaces of clay minerals such as illite and vermiculite (Environment Canada, 1987; Hem, 1989). Consequently, the sodium:potassium ratio in natural waters is typically in the range 2:1 to 3:1 (Environment Canada, 1987). Potassium in waters does not reflect underlying bedrock lithologies to the same extent as the other major cations because there is little overall difference between average potassium concentrations of sedimentary and igneous rocks. From a geochemical exploration perspective, weathering of potassium-rich minerals such as biotite, K-feldspar and sericite in extensive potassic or phyllic hydrothermal alteration zones associated with porphyry copper deposits might be expected to be an important local source of potassium in surface waters. The use of K/Na ratios in locating epigenetic mineralization (Boyle, 1974) is described in a later section.

Median potassium concentrations in Nechako-area lake waters for the three survey areas are in the range 226 - 636 ppb. As with calcium and magnesium, the highest median potassium concentrations occur in Pinchi-area waters, and the lowest in Babine-area waters. Median potassium concentration of Fawnie-area lake waters (580 ppb) are only marginally less than those of Pinchi waters (636 ppb). Boxplots showing the distribution of potassium in the three survey areas (Figure 8) indicate that the greatest number of lake sites with high-potassium waters occur in the Fawnie area (max: 14300 ppb). Eighteen sites here have potassium concentrations in excess of 3000 ppb. In contrast, Babine-area waters show the least variation in regional potassium distribution among the three survey areas, and only 4 sites contain >1000 ppb potassium.

Distribution of elevated potassium concentrations > 95th percentile (3570 ppb) in Fawnie-area lake waters (max: 14300 ppb) is roughly similar to that of magnesium, and occurs in two general areas of the Tsacha Lake map area (NTS 93F/2): (i) several small areas immediately west, south and southwest of Tsacha Lake, and (ii) the area between Kluskus Lake and the Euchiniko lakes at the eastern margin of the survey area. In the case of the former, potassium concentrations of 4070 - 14300

ppb occur in five small lakes and ponds overlying Chilcotin Group basalts on the south side of Tsacha Lake; a sixth site (5280 ppb) overlies Hazelton Group Naglico Formation volcanics to the west of Tsacha Lake. In the case of the latter, four small lakes and ponds containing 3790 - 6730 ppb potassium in water are situated above Middle and Upper Jurassic Bowser Lake Group Ashman Formation sandstones and siltstones intruded by Late Cretaceous diorite sills and dikes. Elevated sediment silver concentrations of 0.4-0.5 ppm were reported for some of these lakes by Cook and Jackaman (1994).

Elevated potassium concentrations > 95th percentile (1961 ppb) in Pinchi-area lake waters (max: 3679 ppb) are largely confined to the southwest part of the survey area west of Stuart Lake, where seven sites containing up to 3646 ppb potassium overlie pelagic sedimentary rocks of the Cache Creek Group near the margin of the Shass Mountain Pluton. Lake water potassium concentrations of up to 3679 ppb are also present at two additional sites along the margin of the Francois Intrusive body exposed between Stuart and Trembleur Lakes.

Elevated potassium concentrations > 95th percentile (549 ppb) in Babine-area lake waters are the lowest of the three survey areas. These occur largely in the Granisle area, on both the west and east sides of Babine Lake, and in a lake on the Newman Peninsula located immediately south of the former Bell mine. The two highest potassium concentrations in the survey area (1207-1243 ppb) occur in this Newman Peninsula lake, which is adjacent to units of the Newman Volcanics.

There are no Canadian water quality guidelines for permissible potassium levels in natural waters with respect to freshwater aquatic life.

IRON

Iron is the fourth most abundant element in the crust, and is present in a wide variety of silicate, oxide and sulphide minerals in most igneous, sedimentary and metamorphic rocks. It may be released into the surficial environment from, among these many other sources, the weathering of pyrite (FeS₂). Pyrite occurs in coal, black shales and a wide variety of mineral deposit types, including the pyritic haloes associated with phyllic alteration zones of porphyry-style deposits, and it oxidizes rapidly under surficial weathering conditions. The behaviour of iron in natural waters is governed, in part, by pH and redox conditions. In oxic surface waters iron is generally present in the ferric (Fe³⁺) state, but at relatively low concentrations levels owing to its low solubility at the pH range 5-8 typical of many surface lake waters (Wetzel, 1983; Environment Canada, 1987; Hem, 1989). Nevertheless, much of the total iron present in

lake waters occurs as suspended particles of hydrated ferric hydroxide (Fe(OH)₃). These are removed by filtering the sample to 0.45 microns prior to analysis.

Median iron concentrations in Nechako-area lake waters are in the range 35 - 78.5 ppb. Highest median concentrations occur in Babine-area waters (med: 78.5 ppb), while Fawnie and Pinchi lake waters have roughly similar iron concentrations at 35 ppb and 39.1 ppb, respectively. Maximum iron concentrations, however, are greatest in lakes in the Fawnie (max: 3520 ppb) and Pinchi (max: 2213.7 ppb) survey areas; the maximum iron level in Babine-area lakes is considerably lower at 646.4 ppb.

Canadian and British Columbia water quality guidelines for the protection of freshwater aquatic life (Environment Canada, 1987; Nagpal *et al.*, 1995) specify that iron levels should not exceed 0.3 mg/L (300 ppb). Lake water iron levels reported here exceed 300 ppb at seven sites in the Fawnie area, seventeen sites in the Pinchi area, and two sites in the Babine area.

ALUMINUM

Aluminum is the third most abundant element in the crust, and aluminosilicate minerals are common constituents of all types of rocks. Among these are clay minerals associated with the hydrothermal alteration zones which accompany many types of epigenetic mineral deposits. Aluminum speciation in natural waters is governed partly by pH, and aluminum hydroxide (Al(OH)₃) is the dominant species in lakes with pH >6.5, a range which would include most central British Columbia lakes. Aluminum solubility increases greatly, however, at more acidic pH levels of 5-6 (Environment Canada, 1987).

Median aluminum concentrations among the three Nechako-area lake water surveys are in the range 6.6 - 34.2 ppb. Highest median aluminum concentrations, as with iron, occur in Babine-area waters; median concentration in the Fawnie area is only slightly lower at 30 ppb. The much lower median aluminum concentrations in Pinchi-area waters (6.6 ppb) are likely a result of the more alkaline pH values which are present in these lakes.

Boxplots (Figure 8) show the distribution of aluminum concentrations among the three survey areas. Pinchi-area waters (max: 209.9 ppb) show the least variation among aluminum concentrations, but there are numerous sites in both the Fawnie (max: 490 ppb) and Babine (max: 436.5 ppb) survey areas with relatively high aluminum concentrations. In the Fawnie area, most of the elevated aluminum concentrations > 95th percentile (120

ppb) occur in eight small lakes and ponds to the west of Kuyakuz Lake, on the northeast flanks of the Fawnie Range and extending to the summit areas of Tsacha Mountain and Mt. Davidson. These sites also exhibit relatively low pH levels, and several additional sites with higher aluminum concentrations also occur in the area. The three sites with the highest aluminum concentrations (300-490 ppb) form a triangular pattern in the north-central part of the Tsacha Lake map area (NTS 93F/2), and coincide with relatively high SO_4/Ca in water ratios. These, like most of the other sites with elevated aluminum concentrations, overlie Quaternary sediments with little or no bedrock exposure (Diakow and Levson, 1997), but receive upslope drainage from Hazelton Group and Ootsa Lake Group rhyolitic tuffs and flows exposed at higher elevations in the Fawnie Range. Aluminum-rich lake waters on Tsacha Mountain occur near pyrite associated with a buried pluton in Hazelton Group rocks exposed just south of the summit. More critically, gossaneous and clay-altered Ootsa Lake Group felsic flows are exposed about 5 km northwest of Mt. Davidson (L.J. Diakow, personal communication, 1998), upslope and upstream of those sites with the highest aluminum concentrations. Whether or not these high-aluminum lake waters might also denote the presence of additional similar zones of buried intrusive-related hydrothermal alteration at lower elevation is unknown. Elsewhere in the Fawnie area, two water sites with elevated aluminum concentrations in the range 140-220 ppb are also present in the northwestern part of the survey area, where they draining the Eocene Ootsa Lake Group felsic volcanics hosting the Wolf epithermal gold-silver prospect. Water from the site nearest the Wolf prospect also exhibits an elevated SO_4/Ca signature.

In the Pinchi area, most of the elevated aluminum concentrations $> 95^{\text{th}}$ percentile (54.3 ppb) occur near the margins of the Shass Mountain Pluton and, to a lesser extent, the Kalder Pluton. However, isolated lake sites with elevated aluminum concentrations in the range 191.0-209.9 ppb occur in the southeastern corner of the survey area, to the west of the Tas intrusive complex, and in the valley between Tezzeron and Trembleur lakes.

Most elevated lake water aluminum concentrations $> 95^{\text{th}}$ percentile (184.9 ppb) in the Babine area occur as single scattered sites forming no discernible patterns. Of these, the highest aluminum concentration in the survey area (site 2117; 436.5 ppb) occurs in a small pond just northeast of Macdougall Lake near the Northwest Arm of Takla Lake. However, four sites with aluminum concentrations in the range 234.0-323.1 ppb do form, together with other sites with elevated aluminum levels, a northwest-trending belt of relatively aluminum-rich waters in the northwestern corner of the survey area. This area, centred on Clota Lake in the Netalzul Mountain map

area (NTS 93M/8), extends roughly from Tahlo Lake to the Nilkitkwa River. It is underlain by Lower Cretaceous Skeena Group sedimentary rocks of the Kitsuns Creek and Red Rose formations.

Canadian and British Columbia water quality guidelines for the protection of aquatic life specify that dissolved aluminum levels should not exceed 0.1 mg/L (100 ppb) in waters with pH of 6.5 or greater (Environment Canada, 1987; Nagpal *et al.*, 1995). Without any reference to sites with low pH values < 6.5 , lake water aluminum levels reported here exceed 100 ppb at fifteen sites in the Fawnie area, six sites in the Pinchi area, and thirty-one sites in the Babine area.

WATER GEOCHEMISTRY: TRACE ELEMENTS

Trace elements are, by convention, considered as those elements which are usually present at concentration levels of < 0.1 mg/L (< 0.1 ppm, or < 100 ppb). Trace element data for Nechako lake waters are only available, in most cases, for the Pinchi and Babine areas. No trace element data other than barium for the Fawnie area, concentrations of which are referred to here in ppb rather than ppm to facilitate comparisons with other data.

The following discussion highlight significant trends in the distribution of selected trace elements (copper, molybdenum, zinc, lead, arsenic, antimony, barium, nickel and selenium) in Nechako-area waters, and is not intended as exhaustive. In general, median concentrations of barium, arsenic, antimony and, to a lesser extent, copper are roughly similar in both the Pinchi and Babine survey areas. However, median concentrations of zinc, molybdenum, lead and nickel are 3-4x greater in the generally harder Pinchi-area waters than Babine-area waters.

A brief synopsis of the bedrock sources, dominant aqueous species and lake water stability constraints for each of the selected elements is provided. Readers are referred to Canadian and British Columbia water quality guidelines of Environment Canada (1987) and Nagpal *et al.* (1995), respectively, for further information on approved and working criteria for drinking water, freshwater aquatic life, livestock and irrigation for these and other elements. Note that guidelines cited here may be for the total concentration of an element in a raw sample; all water data reported here are for filtered samples.

COPPER

Copper derived from the weathering and oxidation of copper ore minerals, principally the sulfides chalcopyrite (CuFeS_2), bornite (Cu_5FeS_4) and chalcocite (Cu_2S), is of intermediate mobility in the surficial environment at $\text{pH} < 6.5$ (Environment Canada, 1987). Dissolved copper may occur as simple cations or as various hydroxide, carbonate or chloride complexes. However, their mobility is tempered by an affinity to adsorption by hydrous iron and manganese oxides and clays, and complexing with organic matter (Kabata-Pendias and Pendias, 1992). Rose *et al.* (1979) stated that dissolved copper content of fresh waters was only rarely effective as a geochemical exploration method because of its limited solubility at typical pH levels.

Median copper concentrations in Nechako-area lake waters are 1.336 ppb for Pinchi-area waters and 0.811 ppb for Babine-area waters. Many elevated copper concentrations $> 95^{\text{th}}$ percentile (4.008 ppb) in the Pinchi survey area (max: 12.223 ppb) occur as scattered sites showing few discernible patterns. The largest grouping of sites with elevated copper concentrations, however, are four sites near the margin of the Shass Mountain Pluton in the southwestern corner of the survey area. Copper in water concentrations here are in the range 5.705-7.166 ppb; they roughly correspond to an area of moderately-elevated to elevated copper in lake sediments reported by Cook *et al.* (1997). In addition to the foregoing, elevated copper concentrations are also present at two sites (5.509-8.582 ppb) above Middle to Upper Triassic Takla Group sedimentary rocks in the southeastern corner of the survey area, and at two sites (5.944-12.223 ppb) above or near Chilcotin Group basalt flows along the eastern margin of the survey area.

The largest single grouping of elevated copper concentrations $> 95^{\text{th}}$ percentile (1.829 ppb) in the Babine area (max: 3.867 ppb) are in the vicinity of the Lennac Lake porphyry copper prospect south of Fulton Lake. Five sites with copper concentrations in the range 1.837-3.867 ppb, in addition to several other sites with moderately-elevated copper values, occur in a roughly 16 km-long zone between the Lennac prospect and the Port Arthur-Deasy Creek area. The zone also extends southward beyond Baboon Lake to the Strimboldh Creek area. Lake water at a site immediately adjacent to porphyry-style copper mineralization hosted within Bulkley Intrusive and Hazelton Group Telkwa Formation rocks on the Lennac property (Leary and Allan, 1972) contains 2.392 ppb copper, one of the highest concentrations reported here. This lake also has the highest sediment copper concentration (230 ppm) in the Babine porphyry belt (Cook *et al.*, 1998).

A few examples of other scattered sites with elevated copper concentrations are those in the Skinhead-Bonehead lakes area west of Granisle, at the end of Hagan Arm of Babine Lake just north of the former Bell copper mine, and near the Nilkitkwa River in the northwestern corner of the survey area. These sites are not necessarily coincident with elevated copper levels in lake sediments.

Canadian and British Columbia water quality copper guidelines for freshwater aquatic life vary with increasing water hardness. For example, Environment Canada (1987) recommended guidelines specify a range of maximum concentrations, from 2 $\mu\text{g/L}$ (2 ppb) total copper in soft and medium water (0-60 and 60-120 mg/L , respectively, as CaCO_3) up to 6 $\mu\text{g/L}$ (6 ppb) total copper in very hard water ($>180 \text{ mg/L}$ as CaCO_3). Maximum British Columbia guidelines are based on an equation of $(0.094 \cdot \text{Hardness}) + 2$ for all waters (Nagpal *et al.*, 1995). A total of 54 sites in the Pinchi area and 8 sites in the Babine area exceed the 2 ppb Environment Canada maximum, although Pinchi-area lake waters are much harder than those of the Babine area.

MOLYBDENUM

Molybdenum is a relatively rare element in natural waters, with an average surface concentration of about 0.8 ppb in lakes and rivers (Wetzel, 1983). It occurs as the sulphide molybdenite (MoS_2) in porphyry-style molybdenum and copper deposits, and is also a constituent of skarns, pegmatites, quartz veins and several other deposit types (Boyle, 1974), as well as black shales. Although molybdenite oxidizes slowly during surficial weathering (Kabata-Pendias and Pendias, 1992), dissolved molybdenum is highly mobile, staying in solution under a wide range of surface conditions. Unlike copper, for example, molybdenum is soluble at more alkaline pH levels, and at $\text{pH} > 5$ occurs in oxic lake waters as the molybdate anion (MoO_4^{2-}). Its stability here is controlled by adsorption and coprecipitation by suspended hydrous iron and aluminum oxides present in the water column (Environment Canada, 1987; Hem, 1989).

Median molybdenum concentrations in Pinchi-area lake waters (0.27 ppb) are somewhat greater than those of Babine-area lake waters (0.08 ppb). Elevated molybdenum concentrations $> 95^{\text{th}}$ percentile (0.94 ppb) in the Pinchi survey area (max: 3.50 ppb) occur for the most part as scattered sites above Quesnel Terrane rocks, and show few discernible patterns. The maximum molybdenum concentration in lake waters occurs near the southern margin of a small Late Cretaceous-Early Tertiary rhyodacite/dacite intrusive located just east of the Dem arsenic-antimony-gold prospect. Elevated concentrations of antimony and uranium are also present

in waters of this lake, and elevated levels of gold, antimony, copper, molybdenum, bismuth and uranium occur in sediments (Cook *et al.*, 1997). Single sites with elevated molybdenum concentrations also occur near the margins of the Kalder Pluton, the Shass Mountain Pluton, and a Late Triassic-Early Jurassic diorite body located along the Pinchi Fault Zone between Pinchi and Tezzeron lakes. Among those sites with no apparent source of elevated molybdenum in waters are four widely-spaced sites located above, or near the margins of, Chilcotin Group basalt flows near the eastern margin of the survey area. These sites, in the range 0.97-2.24 ppb molybdenum, coincide in part with elevated levels of arsenic, barium, cadmium and uranium in waters, and with elevated levels of molybdenum and arsenic in sediments. They form the periphery of an approximately 20 km x 12 km area, numerous lakes in the centre of which have relatively low pH values. In addition to the foregoing, there are several sites with moderately-elevated molybdenum levels in the upper 20 percentiles of the Pinchi data set which are coincident with a zone of very high sediment molybdenum concentrations up to 38 ppm reported by Cook *et al.* (1997). This zone, underlain by Cache Creek Group pelagic sedimentary rocks, is located within a narrow glaciolacustrine plain which occupies the valley between Tezzeron and Trembleur lakes. The plain is characterized by a generally 2-4 metre thick blanket of glacial lake sediments and numerous lakes and small kettle holes (Plouffe, 1994). Coincident anomalous zones of molybdenum and arsenic in sediments here occur within a larger peripheral zone of elevated sediment zinc \pm silver concentrations; in waters, elevated levels of arsenic, barium and fluoride are present. Readers should refer to Cook *et al.* (1997) for further discussion of anomalous metal concentrations in this area.

Most elevated molybdenum concentrations > 95th percentile (0.34 ppb) in the Babine survey area (max: 1.26 ppb) occur in the Lennac-Deasy Creek area. They form a narrow east-west trending, approximately 5 km long, belt of five sites (range: 0.36-1.26 ppb molybdenum) extending from the area near the Lennac Lake porphyry copper prospect in the west, to Deasy Creek on the west side of Babine Lake. The maximum molybdenum concentration in the Babine porphyry belt (1.26 ppb) occurs here in a lake about 2 km west of three MINFILE copper-molybdenum showings, and located between the Granisle-Topley highway and the forestry hauling road. Among other lakes with elevated molybdenum levels are sites in Hagan Arm of Babine Lake near the former Bell mine, and in the Skinhead-Bonehead lakes area near Granisle.

British Columbia water quality standards for molybdenum specify a limit of 2 mg/L (2000 ppb) for

protection of freshwater aquatic life (Nagpal *et al.*, 1995). No sites in either the Pinchi or Babine survey areas approach or exceed this concentration.

ZINC

Zinc entering the surficial environment from the weathering and oxidation of sphalerite (ZnS) may occur in both dissolved and suspended forms (Environment Canada, 1987). It is a relatively mobile element at lower pH, and generally occurs at higher concentrations in natural waters than copper and many other trace elements. In dissolved form, zinc may be present as the divalent cation Zn²⁺, or as zinc carbonate or hydroxide. However, zinc is readily adsorbed by soluble and insoluble organic matter, hydrous iron and manganese oxides and clay minerals, which serve to remove zinc from solution in the presence of suspended and colloidal particles (Rose *et al.*, 1979; Environment Canada, 1987, Kabata-Pendias and Pendias, 1992).

Median zinc concentrations in Pinchi-area waters, at 2.707 ppb, are approximately 4x that of Babine-area waters (0.696 ppb). Most elevated lake water zinc concentrations > 95th percentile (10.365 ppb) in the Pinchi area are clustered along the eastern margin of the survey area, in the region north of Fort St. James and east of Stuart, Pinchi and Tezzeron lakes. Most sites, which are in the range 10.794-18.488 ppb zinc and include the highest zinc concentration in the survey area, are associated with underlying Takla Group sedimentary rocks, and are situated in a low-lying area near the margin of mapped Chilcotin Group basalt flows. Among other scattered sites with elevated zinc levels are two water sites (10.381-11.634 ppb) east of Trembleur Lake within an area of elevated arsenic-zinc concentrations in lake sediments. Elevated zinc in sediments and waters here are not directly coincident. This zone is in the northwestern part of the glaciolacustrine plain between Tezzeron and Trembleur lakes, but metal concentrations in both sediment and water here are weaker than in the larger previously-noted sediment molybdenum-arsenic-zinc \pm silver zone closer to Tezzeron Lake.

Most elevated lake water zinc concentrations > 95th percentile (2.599 ppb) in the Babine area occur in either of two areas: (i) in a mostly flat-lying lowland area in the southern part of the survey area, and (ii) as scattered sites forming a weak linear trend in the northwestern corner of the survey area. In the first case, four sites containing 2.862-20.505 ppb zinc occur in a roughly north-south trending zone centred on Lennac and Baboon lakes which roughly parallels the forestry hauling road. One of the lakes is situated at the base of slope of Matzehtzel Mountain near Strimboldh Creek; a fifth site with 2.772 zinc in waters and coincident elevated zinc, silver and

lead in sediments is also found at higher elevation on the southern flank of Matzehtzel Mountain. Four of the five sites overlay calc-alkaline volcanic rocks of the Hazelton Group Telkwa Formation. In the case of the second group of sites, three widely separated sites (2.820-5.526 ppb zinc) occur together with other moderately-anomalous sites over an approximately 35 km-long area parallel to Babine and Nilkitkwa lakes, extending northwest from the base of Old Fort Mountain to the Nilkitkwa River.

Although the highest two of the four sites are also coincident with moderately-elevated zinc levels in sediments (Cook *et al.*, 1997), the occurrence of the highest zinc concentrations in the Babine survey area within the very first four sample sites analyzed may give rise to concerns of analytical contamination of the samples, perhaps instrumental carryover contamination from a previous suite of samples with higher zinc contents. However, a filtered and acidified distilled water blank inserted in the first position in the analytical suite, before the routine samples, returned a much lower zinc concentration of 0.492 ppb. This result is well below the mean zinc concentration of 1.287 ± 1.320 (median: 0.836 ppb; Table 9) for nineteen filtered acidified distilled water blanks inserted into the Babine analytical suite. It is also well below the median zinc concentration in the survey area (0.696 ppb), and well below the zinc values of 19.277 ppb and 20.505 ppb returned for subsequent lake water samples. Consequently, it is unlikely that these high zinc values can be attributed to analytical contamination of the samples. However, it does not rule out spurious contamination introduced elsewhere during sample collection or preparation, and readers are cautioned that no re-analyses were conducted on these sample. The first several samples collected in the Pinchi analytical suite have similarly high zinc concentrations. Background zinc levels in the Pinchi area are much higher than in the Babine area, but the potential of analytical contamination of initial Pinchi water samples cannot be definitively ruled out, as the distilled water employed in this survey was later found to be contaminated in zinc and copper. Nevertheless, the area of elevated zinc in the southeast corner of the Pinchi area, where the survey started, is defined by only six of some twenty-five sites, suggesting that geological variation should be a critical factor controlling zinc concentrations in water here.

Canadian and British Columbia water quality guidelines for protection of freshwater aquatic life specify a maximum level of 0.03 mg/L (30 ppb) total zinc (Environment Canada, 1987; Nagpal *et al.*, 1995). There are no sites in either survey area which exceed this concentration.

LEAD

Lead released into the surficial environment by the weathering of minerals such as galena (PbS) and, to a lesser extent, anglesite (PbSO₄) and cerrusite (PbCO₃) occurs dissolved in surface waters as soluble Pb²⁺ and hydroxide and carbonate complexes. Most, however, is associated with suspended sediments (Hem, 1989). Lead is relatively immobile; it is poorly soluble and is readily adsorbed from the water column by suspended particulate organic matter, manganese-iron oxides and clays (Rose *et al.*, 1979; Environment Canada, 1987).

Median lead concentrations in Pinchi-area lake waters, at 0.13 ppb, are roughly 3x that of Babine-area lake waters (0.04 ppb). Elevated lake water lead concentrations > 95th percentile (0.44 ppb) in the Pinchi area (max: 1.18 ppb) occur mostly as scattered sites showing few discernible trends. Three water sites containing 0.45-1.18 ppb lead, including the highest concentration, occur in the southeastern corner of the survey area above Takla Group sedimentary rocks and Cache Creek Group ultramafics. This area is just north of Fort St. James. In the southwestern part of the survey area, three sites with elevated lead in the range 0.57-1.13 ppb are present within and adjacent to the Shass Mountain Pluton and its contact with pelagic sedimentary rocks of the Cache Creek Group.

Elevated lake water lead concentrations > 95th percentile (0.17 ppb) in the Babine area (max: 0.41 ppb) occur, in part, in the low-lying Baboon Lake area, where two sites in the range 0.20-0.24 ppb with coincident elevated zinc concentrations drain underlying calc-alkaline arc volcanics of the Hazelton Group Telkwa Formation. Two other relatively closely-spaced sites in the Babine Lake-Morrison Lake-Haul Lake area in the northwest part of the survey area also contain 0.18-0.25 ppb lead.

As with copper, Canadian and British Columbia water quality lead guidelines for protection of freshwater aquatic life vary with increasing water hardness. For example, Environment Canada (1987) recommended guidelines specify a range of maximum concentrations, from 1 ug/L (1 ppb) total lead in soft water (0-60 mg/L as CaCO₃) up to 7 ug/L (7 ppb) total lead in very hard water (>180 mg/L as CaCO₃). Maximum British Columbia guidelines range from 3 ug/L (3 ppb) total lead in very soft water up to 330 ug/L (330 ppb) total lead in extremely hard water (Nagpal *et al.*, 1995). There are no sites in the Babine area, where waters are predominantly soft, which exceed the 1 ppb Environment Canada total lead limit. Only two water sites in the Pinchi area exceed 1 ppb; of these only one site (1004) is sufficiently soft (37 mg/L as CaCO₃) to exceed allowable freshwater aquatic life guidelines for lead.

ARSENIC

Arsenic is a natural constituent of many types of mineral deposits, and is widely used as a pathfinder element in geochemical exploration. The main sources of arsenic in waters and sediments are arsenic-bearing minerals such as sulphides (e.g. arsenopyrite FeAsS), arsenides (e.g. niccolite NiAs) or other sulphur minerals (e.g. orpiment As₂S₃) which are present in bedrock or surficial sediments. Arsenic concentrations in natural fresh waters are typically in the range 1.0-10 ppb (Azcue, 1995). The stable form of arsenic in oxygen-rich surface waters is arsenate (AsO₄³⁻). Arsenic concentrations in waters are generally very low, largely due to (i) its affinity for adsorption to hydrous iron and aluminum oxides, clays and organic matter, and (ii) its tendency to combine with sulphur to form metal sulphides in anoxic bottom sediments (Hem, 1989; Kabata-Pendias & Pendias, 1992).

Median arsenic concentrations in Pinchi and Babine-area lake waters are roughly equivalent at 0.30 ppb and 0.20 ppb, respectively. Almost all elevated lake water arsenic concentrations > 95th percentile (0.87 ppb) in the Pinchi area (max: 1.91 ppb) occur mostly within the Cache Creek pelagic sedimentary unit in a roughly 6 km x 3 km east-west trending zone of small lakes west of Tezzeron Lake. These six sites are among the numerous small lakes and kettle holes within a 2 to 4 m thick blanket of glaciolacustrine sediments (Plouffe, 1994) which occupies the valley between Tezzeron and Trembleur lakes. They are coincident with similar zones of elevated barium, fluoride and, to a lesser extent, molybdenum in these waters, and with highly elevated levels of arsenic and molybdenum in lake sediments. Elevated concentrations of zinc and, to a lesser extent, silver are also present in lake sediments peripheral to these sites. Two additional sites containing 1.17-1.26 ppb arsenic (± barium) also occur within a similar, but slightly smaller, zone of elevated sediment arsenic and zinc concentrations located near the east end of Trembleur Lake.

Most elevated lake water arsenic concentrations > 95th percentile (0.40 ppb) in the Babine area (max: 0.63 ppb) occur in the low-lying southwestern part of the survey area roughly bounded by Fulton and Baboon lakes and the forestry hauling road, where they are mostly associated with underlying Telkwa Group arc volcanics of the Lower to Middle Jurassic Hazelton Group. Six lake sites here contain 0.42-0.53 ppb arsenic in waters, and several sites with more moderately-elevated arsenic concentrations are also present. The highest arsenic concentration in the Babine survey area (0.63 ppb) occurs as an isolated site near the northeast end of Morrison Lake.

Canadian and British Columbia water quality guidelines for protection of freshwater aquatic life specify a maximum level of 0.05 mg/L (50 ppb) total arsenic (Environment Canada, 1987; Nagpal *et al.*, 1995). There are no sites in either survey area which either approach or exceed this concentration level.

ANTIMONY

Antimony is a relatively mobile element, and most antimony present in surface waters likely occurs in solution as stable antimonites and antimonates (Environment Canada, 1987). Median antimony concentrations in Pinchi and Babine-area lake waters are similar at 0.03 ppb and 0.02 ppb, respectively. Most elevated lake water antimony concentrations > 95th percentile (0.08 ppb) in the Pinchi area (max: 1.29 ppb) occur in either (i) Pinchi Lake, or (ii) the Dem-Hat lakes area northeast of Tezzeron Lake. In the first case, five sites covering the entire length of Pinchi Lake contain 1.09-1.29 ppb antimony. These antimony concentrations are approximately 40x greater than the 0.03 ppb background level for the remainder of the survey area, and include the highest concentrations reported here. The Pinchi lake sites drain various carbonate, blueschist and volcano-sedimentary units of the Cache Creek Group, and show a slight increase in antimony concentrations from southeast to northwest within the lake. In addition to antimony in waters, sediments of Pinchi Lake also contain elevated concentrations of antimony, mercury, cobalt, barium and several other elements (Cook *et al.*, 1997). In the second case, elevated antimony in water concentrations at four sites in the Dem-Hat lakes area roughly parallel zones of elevated antimony and gold in lake sediments near the Dem arsenic-antimony-gold and, to a lesser extent, Hat Lake copper prospects. Antimony concentrations here are in the range 0.09-0.13 ppb near Dem Lake, and in the range 0.12-0.13 in Hat and Chuzkeepah lakes, but are nevertheless an order of magnitude less than those of Pinchi Lake. They occur above Takla Group rocks near, and to the east of, the Dem Lake fault, and in two cases are adjacent to a Late Cretaceous-early Tertiary rhyodacite/dacite intrusive.

Elevated lake water antimony concentrations > 95th percentile (0.07 ppb) in the Babine area (max: 0.18 ppb) are of similar magnitude to those of the Pinchi area, but without the high levels of sites in Pinchi Lake. The largest single grouping of sites with elevated antimony concentrations is located between Morrison Lake and the Fort Babine area of Babine Lake, where three sites (0.08-0.18 ppb antimony) overlying a variety of Hazelton Group and Bowser Lake Group map units are roughly coincident with a larger zone of elevated antimony in lake sediments reported by Cook *et al.* (1997).

Among single scattered sites with anomalous antimony levels is a single lake (0.09 ppb antimony) on the eastern flank of Old Fort Mountain with coincident elevated antimony in lake sediment. Another single lake with elevated antimony (0.08 ppb) is located south of Fulton Lake and immediately east of the Lennac porphyry copper prospect. Unlike the aforementioned coincident zones of anomalous antimony in sediments and waters which are present west of Morrison Lake, the large zone of elevated antimony concentrations in lake sediment between the Lennac prospect and Babine Lake (Cook *et al.*, 1997) is not reflected in the surface waters of these lakes.

British Columbia water quality guidelines for protection of freshwater aquatic life specify a maximum level of 30 ug/L (30 ppb) total antimony (Nagpal *et al.*, 1995). There are no sites in either the Pinchi or Babine survey areas which either approach or exceed this concentration level.

BARIUM

Barium is released into the surficial environment by the weathering of barite (BaSO₄), witherite (BaCO₃) and potassium feldspar. However, its mobility in natural waters is limited by the relative insolubility of barium sulphates and carbonates, and by its adsorption by metal oxides and hydroxides (Environment Canada, 1987; Hem, 1989).

Median barium concentrations are greatest in Fawnie-area lake waters (0.03 ppm; 30 ppb). This is approximately 2x the level of median barium concentrations of Pinchi and Babine-area lake waters, which are roughly equivalent at 18.4 ppb and 15.0 ppb, respectively. This relation is similar to that of median sodium concentrations among the survey areas.

Elevated lake water barium concentrations > 95th percentile (60 ppb) in the Fawnie area (max: 360 ppb) occur mostly in the area immediately west and northwest of Tsacha Lake. Barium concentrations up to 160 ppb in this area are primarily associated with lakes overlying Hazelton Group basalt and andesite flows of the Lower and Middle Jurassic Naglico Formation, and have a similar distribution to that of elevated calcium in water concentrations. Two of the sites also occur near Late Cretaceous and Late Jurassic-Early Cretaceous (Capoose) intrusive rocks mapped by Diakow and Levson (1997). With the exception of sediment in a small bay on the northwest side of Tsacha Lake, there are no sites here with similarly-elevated levels of barium in sediments (Cook and Jackaman, 1994). Further to the northwest, three sites containing 70-360 ppb barium occur, in part, in Moose Lake and Laidman Lake, which drain quartz

monzonite and granodiorite of the Late Jurassic-Early Cretaceous Capoose batholith, as well as marginal porphyritic phases of the batholith. The highest barium concentration (360 ppm) in Laidman Lake coincides with several sites of elevated barium in Laidman Lake sediments reported by Cook and Jackaman (1994).

Almost all elevated lake water barium concentrations > 95th percentile (110.8 ppb) in the Pinchi area (max: 388.8 ppb) occur in the group of small lakes within the narrow glaciolacustrine plain which occupies the valley between Tezzeron and Trembleur lakes. Barium in lake waters at eight sites here are in the range 137.5-388.8 ppb, approximately 7-21x greater than the regional background of 18.4 ppb.

Elevated lake water barium concentrations > 95th percentile (36.8 ppb) in the Babine area (max: 106.6 ppb) occur in two main groupings: (i) the Lennac-Fulton Lake-Deasy Creek area south of Granisle on the west side of Babine Lake, and (ii) a large area of somewhat lower levels of elevated barium covering much of the northwestern part of the survey area. The first area, located east and northeast of the Lennac Lake porphyry copper prospect, is roughly coincident with elevated levels of copper, lithium and cadmium in waters, and elevated levels of antimony, molybdenum and copper in lake sediments (Cook *et al.*, 1998). These sites, in the range 38.8-49.4 ppb barium together with several slightly lower values, are associated with mostly Lower-Middle Jurassic Telkwa Formation, Upper Triassic Takla Group rocks and Eocene clastic sediments near the margin of the Topley Intrusions. The zone of elevated barium levels in the northwestern part of the survey area, extending from the Saddle Hill area north of the base of Old Fort Mountain to Clota Lake, also coincides with a zone of elevated barium, arsenic, antimony, nickel and zinc values in lake sediment. These sites occur above Lower Cretaceous Skeena Group sedimentary rocks of the Kitsuns Creek Formation, and with units of the Bowser Lake Group Ashman Formation and Hazelton Group Saddle Hill Volcanics and Smithers Formation. The two sites with barium concentrations in the upper five percentiles of Babine data are in the range 43.0-55.0 ppb. In addition to the foregoing, the single site with the maximum barium concentration here (106.6 ppb) occurs in the northeastern part of the survey area. This area of clastic sedimentary rocks has been mapped as part of the Sustut Group (MacIntyre *et al.*, 1994).

British Columbia water quality guidelines for protection of freshwater aquatic life specify a maximum level of 1 mg/L (1 ppm, or 1000 ppb) total barium (Nagpal *et al.*, 1995). There are no water sites in either the Fawnie, Pinchi or Babine survey areas which exceed this concentration level.

NICKEL

Nickel is released into surface waters by the weathering of iron-rich silicate minerals in mafic and ultramafic igneous rocks, and of nickel-bearing sulphide minerals such as pentlandite ((Fe,Ni)₉S₈) and niccolite (NiAs). However, nickel is relatively immobile in most near-neutral and alkaline surface waters above pH 6.0 due to its adsorption to and coprecipitation with hydrous oxides of iron and manganese (Environment Canada, 1987; Hem, 1989), resulting in higher concentrations in sediment relative to water.

Median nickel concentrations in Pinchi-area lake waters (1.752 ppb) are approximately 4-5x the median nickel concentration of Babine-area waters (0.361 ppb). Most elevated lake water nickel concentrations > 95th percentile (5.052 ppb) in the Pinchi area (max: 104.504 ppb) show a strong lithological association, and occur in lakes at or adjacent to the Pinchi Fault Zone in the southeastern corner of the survey area. Of these, five sites (5.287-22.506 ppb nickel) overlie various ultramafic, blueschist and volcano-sedimentary units of the Cache Creek Group. They are situated on or at the base of Murray Ridge to the north of Fort St. James, and between Pinchi and Tezzeron lakes, where they coincide with similar zones of highly elevated nickel in lake sediments (Cook *et al.*, 1997). Waters at two of these sites contain more than 20 ppb nickel, and there are also numerous additional sites here with more moderately-elevated nickel values. Two additional nearby sites with elevated nickel (5.931-7.196 ppb) are also present near Hyman Creek, where they overly Middle-Upper Triassic Takla Group sedimentary rocks. The single highest nickel concentration in the Pinchi area (104.504 ppb) was obtained from a small lake overlying Cache Creek pelagic sedimentary rocks on the west side of Stuart Lake. Two other sites with elevated nickel values (5.391-5.809 ppb) are also present in this region near the margin of the Shass Mountain Pluton.

Elevated lake water nickel concentrations > 95th percentile (1.087 ppb) in the Babine area (max: 1.509 ppb) are considerably less than those of the Pinchi area. The majority of these are located in the northwestern corner of the survey area, where six sites containing 1.217-1.333 ppb nickel occur within an extensive approximately 28 km x 5 km belt of elevated nickel which extends from near Saddle Hill in the southeast to the Nilkitkwa River in the northwest. This region is coincides with a somewhat larger area of elevated nickel in lake sediments. Whereas most of those sites with anomalous sediment nickel occur to the south of Haul Lake, the greatest clustering of sites with anomalous nickel in waters occurs to the north of Haul Lake. These four sites, in the range 1.261-1.333 ppb nickel, are all associated with Lower Cretaceous Skeena Group

sedimentary rocks of the Kitsuns Creek Formation. In addition to the foregoing, the two highest nickel values in the Babine porphyry belt (1.366-1.509 ppb) occur just south of Takla Lake in the northeastern corner of the survey area. These sites, underlain by Sustut Group and Ootsa Lake Group rocks, also largely coincide with a zone of elevated nickel in lake sediments reported by Cook *et al.* (1997).

As with copper and lead, Canadian and British Columbia water quality nickel guidelines for protection of freshwater aquatic life vary with increasing water hardness. For example, Environment Canada (1987) and British Columbia (Nagpal *et al.*, 1995) recommended guidelines specify a range of maximum concentrations, from 25 ug/L (25 ppb) total nickel in soft water (0-60 mg/L as CaCO₃) up to 150 ug/L (150 ppb) total nickel in very hard water (>180 mg/L as CaCO₃). There are no sites in the Babine area where nickel concentrations exceed or even approach the 25 ppb limit. There is one site in the Pinchi area (1470; 104.504 ppb) where nickel levels exceed 25 ppb. In fact, the nickel concentration here is sufficiently high to exceed allowable freshwater aquatic life guidelines (in this case, 65 ppb) for the medium water hardness (88.2 mg/L as CaCO₃) calculated for the site.

SELENIUM

Selenium is a chalcophile element, widely distributed in the crust at trace amounts, which may be concentrated in sulfide-rich mineral deposits and, to a lesser extent, in coal and shale. Selenium mobility in the weathering environment is dependent upon pH and redox conditions, with dissolved selenium occurring as the oxyanions selenite (SeO₃²⁻) and selenate (SeO₄²⁻) under oxygen-rich conditions. The more soluble selenates are the dominant species at neutral to alkaline pH, while selenites are dominant at neutral pH. Selenites are also more easily adsorbed from solution by iron and aluminum oxides and clay minerals. Under less aerobic conditions, reduction of soluble selenides to insoluble elemental selenium also serves to remove the element from the water column (Environment Canada, 1987; Hem, 1989; Kabata-Pendias and Pendias, 1992).

The median selenium concentration in Pinchi-area lake waters is 0.02 ppb, which is at the limit of analytical detection. In comparison, median selenium concentration of Babine-area waters (0.14 ppb) is 7x that of the Pinchi area, which is a reversal of the general trend toward trace elements such as zinc, molybdenum, lead and nickel occurring at higher background levels in the Pinchi area. Nevertheless, elevated selenium concentrations in the Pinchi area are still considerably greater than those in the Babine porphyry belt.

Most elevated lake water selenium concentrations > 95th percentile (1.74 ppb) in the Pinchi area (max: 3.29 ppb) occur in the northwestern part of the survey area, where all but one are associated with underlying carbonate or pelagic sedimentary units of the Cache Creek Group. In particular, two clusterings of two sites each (1.93-2.22 ppb, and 2.18-3.29 ppb) within a glaciolacustrine plain overlying the pelagic sedimentary map unit are roughly coincident with zones of various metal-rich sediments. Individual selenium-rich water sites do not necessarily coincide with those sites with the highest sediment metal concentrations. None of the selenium-rich lake waters correlate with selenium-rich lake sediments, which are predominantly associated with underlying Takla Group sedimentary rocks near the east end of Inzana Lake (Cook *et al.*, 1997). In addition to the foregoing, three additional water sites with elevated selenium in the range 2.33-2.53 ppb occur in the southwestern part of the survey area, near the contact of the Shass Mountain Pluton with adjacent Cache Creek Group pelagic sedimentary rocks.

Elevated lake water selenium concentrations > 95th percentile (0.45 ppb) in the Babine area (max: 0.63 ppb) are present mostly as single scattered sites throughout the survey area. One grouping of two sites with elevated selenium is near Haul Lake area (0.53-0.61 ppb) in the northern part of the survey area. Note that selenium data for five sites in the central and north-central part of the Babine survey area were removed from this data set on the basis of high selenium concentrations in accompanying distilled water blanks. A filtered acidified blank here returned 1.23 ppb selenium relative to a median value of 0.10 ppb obtained for 19 blanks insertions. Unfiltered acidified and unfiltered unacidified distilled water blanks returned similar selenium results of 1.91 ppb and 1.85 ppb, respectively.

Canadian and British Columbia water quality guidelines for protection of freshwater aquatic life specify a maximum level of 1 µg/L (1 ppb) total selenium (Environment Canada, 1987; Nagpal *et al.*, 1995). There are 39 sites in the Pinchi area where dissolved selenium concentrations exceed this level, but no such sites in the Babine area.

OTHER DETERMINATIONS

TOTAL DISSOLVED SOLIDS AND CONDUCTIVITY

TDS is the total amount of solids (in mg/L) remaining when a water sample is evaporated to dryness (Drever, 1988), and is an index of the amount of

dissolved constituents, regardless of origin (McNeely *et al.*, 1979). When used in the context of fresh waters (*e.g.* TDS < 1000 mg/L), it is roughly equivalent to salinity. Conductivity, expressed in uS, is the ability of a solution to pass an electrical current. It is an approximate measure of the salinity of a water sample (Drever, 1988), as conductivity increases with increasing ionic concentration.

Total dissolved solids (TDS) and conductivity were determined only for lakes in the Babine area (Appendix D). Median TDS of Babine-area waters is 31.9 mg/L (max: 190.0 mg/L; Figure 7a); median conductivity is 63.5 uS (max: 381.0 uS). Elevated TDS and conductivity levels are largely identical and, not surprisingly, have distributions similar to those of elevated concentrations of calcium and magnesium, the most-abundant and third-most abundant ions in Babine-area lake waters. Many sites are scattered and form no discernible pattern, but elevated and moderately-elevated TDS and conductivity levels are clustered (i) in the Fulton Lake-Lennac prospect-Skinhead/Bonehead lakes area of the Fulton Lake (NTS 93L/16) map area, where they underlie, in part, Hazelton and Takla Group volcanic rocks (MacIntyre *et al.*, 1996b), and (ii) near the northwest corner of the Old Fort Mountain (NTS 93M/1) map area, in an area between Babine and Morrison lakes, where elevated TDS and conductivity levels in small ponds are associated with mostly Ashman Formation sedimentary rocks of the Bowser Lake Group. TDS levels in Babine lake waters do not differ appreciably among different-sized lakes (Figure 7b), although there is a wider range of both lower and higher TDS concentrations among the many small ponds sampled. Note that neither TDS or conductivity data is available for one site (962293).

HARDNESS

Hardness of water refers to the concentration of ions, primarily of calcium and magnesium, that will react with a sodium soap to precipitate an insoluble residue (Drever, 1988). Hardness is determined here by calculation as the sum of the calcium and magnesium concentrations:
 Hardness (mg/L equivalent CaCO₃) = 2.497 Calcium (mg/L) + 4.118 Mg (mg/L) (APHA/AWWA/WEF, 1992).

Hardness is conventionally expressed as either soft (0-60 mg/L CaCO₃), moderately hard (61-120 mg/L CaCO₃), hard (121-180 mg/L CaCO₃) or very hard (>180 mg/L CaCO₃; Hem, 1989).

Waters in the Babine area are predominantly soft (median: 30.9 mg/L equivalent CaCO₃), although levels as high as 162.1 mg/L equivalent CaCO₃ are locally present. Elevated hardness levels > 95th percentile (71.0 mg/L equivalent CaCO₃) generally follow those of

calcium, magnesium, TDS and conductivity outlined above. Overall, Babine waters are the softest of the three survey areas.

Waters in the Pinchi area are mostly moderately hard (median: 73.7 mg/L equivalent CaCO_3). Waters here are the hardest of the three survey areas, and very hard levels up to 326.7 mg/L equivalent CaCO_3 are locally present. Elevated hardness levels > 95th percentile (195.7 mg/L equivalent CaCO_3) generally coincide with the distribution of elevated magnesium and, to a lesser extent, calcium.

Waters in the Fawnie area are predominantly soft, with a median hardness (median: 50.2 mg/L equivalent CaCO_3) intermediate between those of the Babine and Pinchi areas. Very hard water levels as high as 236.9 mg/L equivalent CaCO_3 are locally present, however. Elevated hardness levels > 95th percentile (135.4 mg/L equivalent CaCO_3) have a lithological origin and coincide with distributions of both calcium and magnesium.

ELEMENT RATIO MAPS

Several maps showing the distribution of various element in water ratios are shown at the end of Appendix D. These ratio maps may assist in identifying areas of porphyry-style alteration and mineralization (K/Na, Ba/Sr, Rb/Sr) or, more generally, areas of oxidizing sulphide minerals (SO_4/Ca , SO_4/TDS). Not all ratios are available for each survey area.

K/NA

Potassium-rich aluminosilicate minerals such as biotite, K-feldspar and sericite are commonly present in potassic and phyllic hydrothermal alteration zones associated with porphyry-style copper or copper-molybdenum deposits. Calcium-bearing primary silicates such as plagioclase are susceptible to alteration by these hydrothermal fluids, and Boyle (1974) suggested that use of potassium/sodium (K/Na) ratios might be helpful in gauging proximity to many types of epigenetic base and precious-metal ore deposits, provided that albitization was absent. Lake water K/Na distribution maps are given in Appendix D for each of the three survey areas.

In the Fawnie area, the distribution of elevated K/Na ratios in the upper five percentiles of data is similar to, but more restricted than, the distribution of potassium in water. Most elevated K/Na values in lake waters occur in the Tsacha Lake area, particularly in several small ponds at the west end of the lake which drain Hazelton Group Naglico Formation volcanic rocks. Two small clusters of

sites are also present on the southeast side of the lake, where they overlie Chilcotin Group basalts. A second small group of elevated K/Na ratios also occurs in the area between Kluskus Lake and the Euchiniko lakes at the eastern margin of the survey area, where they are associated largely with Middle and Upper Jurassic Bowser Lake Group Ashman Formation sandstones and siltstones intruded by Late Cretaceous diorite sills and dikes. Elevated sediment silver concentrations of 0.4-0.5 ppm were reported for some lakes in this area by Cook and Jackaman (1994).

Elevated K/Na ratios greater than the 95th percentile in the Pinchi area are almost entirely confined to lakes within the glaciolacustrine plain between Tezzeron and Trembleur lakes. They occur within two principal zones which roughly correspond to earlier-described zones of anomalous arsenic, molybdenum, zinc and other elements in lake sediments, and anomalous arsenic, barium, fluoride and strontium in waters, although not all of these elements are present in each zone. Zones of elevated K/Na here are more broadly distributed over wider areas than are the corresponding zones of elevated arsenic, barium and fluoride in waters. In fact, the spatial distribution of elevated K/Na ratios here more closely resembles the distribution of elevated zinc in lake sediments reported by Cook *et al.* (1997).

Most elevated K/Na ratios greater than the 95th percentile in the Babine area occur in the southern part of the survey area in the general vicinity of the former Bell and Granisle copper mines. One group of two sites occurs in a lake on the Newman Peninsula located immediately south of the Bell mine; a second group of three sites occurs in the Skinhead-Bonehead lakes area just west of Granisle village. Elevated concentrations of potassium, iodine and rubidium in waters are also present in both groups. Sediments of the Newman Peninsula sites contain elevated levels of antimony, lead and nickel, while those in the Bonehead-Skinhead lakes area contain elevated copper concentrations. A third grouping of two elevated K/Na ratios occurs in the northwestern corner of the survey area near the Nilkitkwa River. This area is underlain by Red Rose Formation rocks of the Lower Cretaceous Skeena Group. Among other scattered lakes with elevated K/Na ratios is a single site, southeast of Nakinilerak Lake, which is closest to the Nak porphyry copper prospect.

BA/SR

Elevated barium-strontium (Ba/Sr) ratios were reported by Olade *et al.* (1975) for rocks hosting the Valley Copper, Lornex and Bethlehem/JA copper-molybdenum deposits of the Highland Valley in south central British Columbia. Highest Ba/Sr ratios, in excess

of 1.0, were reported from mineralized zones relative to lower ratios in peripheral areas. Formation of these dispersion haloes were attributed by Olade *et al.* (1975) to the preferential destruction of plagioclase by hydrothermal fluids, and subsequent leaching of the relatively more soluble-strontium in those areas of most intense hydrothermal activity.

No Ba/Sr ratios are available for the Fawnie area lake waters, but in the Pinchi area most elevated Ba/Sr ratios greater than the 95th occur in two groups of lakes, most of which are associated with Cache Creek Group pelagic sedimentary rocks. The first group is in the glaciolacustrine plain between Tezzeron and Trembleur lakes, where a zone of elevated Ba/Sr ratios is largely coincident with elevated levels of arsenic, barium, K/Na and Rb/Sr in waters. The second group is situated in the northwestern corner of the survey area near the contact of the pelagic sediments with nearby carbonate rocks. Coincident elevated uranium concentrations are also present in these waters. In addition to the foregoing, two sites with elevated Ba/Sr are also present along the Pinchi Fault Zone south of Pinchi Lake.

In the Babine area, the largest single grouping of elevated Ba/Sr ratios in lake waters is in the Old Fort Mountain (NTS 93M/1) map area, adjacent to the Hearne Hill porphyry copper deposit near the south end of Morrison Lake. The sites comprise four small lakes and ponds located immediately east and northeast of the Hearne Hill summit which drain Lower-Middle Jurassic Hazelton Group rocks of the Saddle Hill Volcanics and the Telkwa Group. More recent mapping by MacIntyre *et al.* (in press) has assigned all rocks in this area to the Saddle Hill Volcanics, a bimodal suite of arc volcanic and sedimentary rocks.

RB/SR

Elevated rubidium and rubidium/strontium ratios in hydrothermally-altered rocks may also, like barium/strontium, be useful in porphyry copper deposit exploration (Rose *et al.*, 1979), as rubidium concentrations tend to increase toward mineralization in potassium-rich alteration zones (Boyle, 1974). Primary Rb/Sr haloes were described for Highland Valley porphyry copper-molybdenum deposits by Olade and Fletcher (1975). The presence of elevated rubidium concentrations and Rb/Sr ratios near mineralization is attributed to the preferential enrichment of rubidium in potassic alteration zones typically located near the centres of porphyry-style systems near mineralization. The preferential enrichment of strontium in calcium alteration minerals such as epidote and calcite in the more peripheral propylitic and argillic alteration assemblages is attributed to the concomitant alteration and destruction of

Ca-plagioclase, and the subsequent leaching of the associated strontium in those areas of most intense hydrothermal activity.

Rb/Sr ratio maps for the Pinchi and Babine areas are given in Appendix D. In the Pinchi area, elevated Rb/Sr greater than the 95th percentile have a distribution which is similar to, but not identical with, elevated Ba/Sr ratios. Foremost among similarities is the zone of elevated Rb/Sr in lakes above Cache Creek Group pelagic sedimentary rocks in the glaciolacustrine plain between Tezzeron and Trembleur lakes. This anomalous zone is largely coincident with elevated levels of arsenic, barium, fluoride, K/Na and Ba/Sr in waters, and with several metals in lake sediments such as molybdenum and arsenic. As with Ba/Sr, elevated Rb/Sr values are somewhat more widely distributed among lakes of this area than are elevated barium and arsenic concentrations. The second group is located in the northwestern part of the same glaciolacustrine plain, immediately east of Trembleur Lake. Many of the waters here have elevated concentrations of K/Na, aluminum, cerium, lithium, zinc and several other elements; lake sediments have elevated concentrations of zinc, lead and fluorine, among other elements. Unlike the case of Ba/Sr ratios, there are no elevated Rb/Sr values near the Cache Creek Group pelagic unit in the northwestern corner of the survey area.

In the Babine area, the distribution of elevated Rb/Sr ratios greater than the 95th percentile in lake waters is substantially similar to that of elevated Ba/Sr. Two of the four sites with elevated Ba/Sr adjacent to the Hearne Hill porphyry copper deposit, east and northeast of the Hearne Hill summit, are also coincident with elevated Rb/Sr. Several other sites with elevated Rb/Sr in water occur throughout the survey area, including one south of the Nak porphyry copper prospect. However, the only other grouping of more than a single site is in the northeast part of the survey area, where two sites near Takla Lake drain Sustut Group sedimentary rocks and Ootsa Lake Group rhyodacite. Elevated levels of aluminum, niobium, tungsten, sulphate and SO₄/Ca are also present in waters of at least one of the two sites.

SO₄/CA

High sulphate concentrations in surface waters may have a variety of potential sources. They may result from the oxidation of potentially economic sulphide occurrences (Cameron, 1977), but they may also originate from the oxidation of disseminated pyrite in coal, or from the dissolution of sedimentary gypsum horizons (Rose *et al.*, 1979), giving rise to apparent sulphate anomalies which may also be associated with elevated calcium concentrations. Sulphate derived from sulphide oxidation may be distinguished from those in more saline waters

derived from marine evaporites by their lower calcium and chlorine concentrations (Dall'Aglio and Tonani, 1973). To this end, SO_4/Ca ratio maps are shown in Appendix D for each survey area, and a SO_4/TDS ratio map is also given for the Babine area.

In the Fawnie area, elevated SO_4/Ca ratios > 95th percentile occur in four main areas. Lakes in two of these areas, (i) at the south side of Tsacha Lake, and (ii) the region between Kluskus Lake and the Euchiniko lakes, are in part coincident with elevated K/Na ratios also present at these sites. In the latter area, the two closely-spaced sites with elevated SO_4/Ca ratios here also have two of the three highest sulphate concentrations in the Fawnie survey area (168 ppm, 62 ppm). Lakes in the remaining two areas, (iii) four sites on the northeast flank of the Fawnie Range, and (iv) a single site draining the Wolf epithermal gold-silver prospect in Ootsa Lake Group rocks in the northwest corner of the survey area, are both distinguished by elevated concentrations of aluminum in water and relatively low pH levels. In addition to the foregoing, a few other scattered sites also have elevated SO_4/Ca ratios in this area. Among these is a single site, about 8 km west-southwest of the Tsacha epithermal gold prospect, with the second-highest sulphate concentration (130 ppm) in the survey area.

In the Pinchi area, most elevated SO_4/Ca ratios in lake water > 95th percentile occur as scattered sites, but there are three areas with loose groupings of 2-3 sites each. First, two sites with coincident elevated aluminum (80.2-201.3 ppb) and relatively low pH values occur in and adjacent to the Kalder Pluton in the northeastern part of the survey area. Elevated silver concentrations in the range 1.0-1.2 ppm in lake sediments at these sites were among several anomalous sediment silver values reported for this immediate area by Cook *et al.* (1997). In the other two cases, groupings of 2-3 sites with elevated SO_4/Ca at either end of the glaciolacustrine plain between Tezzeron and Trembleur lakes are roughly coincident with elevated levels of several elements in both sediments and waters, as previously discussed.

In the Babine area, most elevated SO_4/Ca and SO_4/TDS ratios > 95th percentile occur as scattered sites, with the exception of one grouping of 4-5 sites in the Netalzul Mountain (NTS 93M/7) map area in the northwestern corner of the survey area. This southeast-northwest trending zone, centred on Clota Lake, extends from the Haul Lake area to the Nilkitkwa River. It is underlain by Lower Cretaceous Skeena Group sedimentary rocks of the Kitsuns Creek and Red Rose Formations, and coincides in part with similar zones of

elevated aluminum and cerium in waters, among other elements, and relatively low pH values. Anomalous levels of zinc and mercury are present in sediments of some of the lakes here (Cook *et al.*, 1998).

METHOD DETECTION LIMITS AND REGIONAL BACKGROUND

Calculated method detection limits (MDL = mean + 3s of distilled water blanks; Table 3) were compared with median ICP element concentrations (Appendices C and D) for each survey area, with the notion that greater confidence may be placed in those element results where method detection limits are less than regional background values. Method detection limits are less than or equal to regional medians for 4 of 8 elements (50%) in the Fawnie area, 32 of 46 elements (74%) for which MDLs are available in the Pinchi area, and for 34 of 58 elements (59%) in the Babine area. For comparison, median element concentrations of the blanks are shown in Table 9.

In the case of major elements, median values exceed MDLs for almost all elements. Most of those which do not are lower-concentration Fawnie-area elements (Al, Fe, K) determined by ICP-AES. Major element method detection limits by ICP-MS, and for Babine-survey major elements in particular, are a great deal lower. In the case of some elements, such as calcium, MDLs are subordinate to even the lowest concentrations in natural waters reported here for each survey area.

A few generalizations can be made for trace elements determined by ICP-MS in the Pinchi and Babine surveys. Of those elements determined for both areas, MDLs for some (As, Ba, Br, Ce, La, Mn, Nd, Pr, Rb, Th, Ti, V, Y) are consistently lower than regional median values. Conversely, MDLs for several other elements (Cd, Cr, Hf, Pb, Li, Ni, Nb, Se, Ta, W, Zr) are consistently greater than regional median values in each survey area. Of these, method detection limits for some, such as lead, lithium, hafnium, selenium, tungsten and zirconium, are so high as to approach or exceed natural elevated concentration levels determined in each survey area. Less confidence should be placed on such results. For many elements however, particularly antimony, copper, molybdenum, nickel and uranium in the Babine area, the calculated MDLs only marginally exceed median background levels.

SUMMARY

Three regional lake water geochemical surveys were conducted over parts of the Nechako River (NTS 93F), Fort Fraser (NTS 93K), Smithers (NTS 93L) and Hazelton (NTS 93M) map areas in the Nechako Plateau of central British Columbia. Surface waters were obtained from 630 sites. The surveys, conducted during the period 1993-1996 in conjunction with regional lake sediment geochemical surveys (Cook *et al.*, 1997, 1998; Cook and Jackaman, 1994), are a contribution to the Nechako NATMAP Project and its predecessor, the Interior Plateau Project.

Survey results confirm the locations of several known mineral deposits and prospects and, together with results of corresponding lake sediment surveys, outline areas for prospective porphyry-style mineralization. A few examples of some areas of particular interest to explorationists include the following:

- In the Fawnie area, high aluminum, low pH and high SO₄/Ca are present in small lakes on the eastern flanks of the Fawnie Range which drain Hazelton and Ootsa Lake Group tuffs and flows exposed upslope.
- In the Pinchi area, a zone of elevated barium, arsenic and fluoride occur in waters above Cache Creek Group pelagic sedimentary rocks west of Tezzeron Lake. It coincides with a similar zone of elevated molybdenum, arsenic and other elements earlier outlined by lake sediment geochemical results.
- In the Babine area, a zone of elevated copper, molybdenum and barium is present in lake waters south of Fulton Lake, in the area between the Lennac copper prospect and Babine Lake. It coincides with a similar zone of elevated metals in lake sediments.

Geochemical results presented here are intended to highlight regional geochemical trends for mineral exploration purposes, and should not be used as a substitute for site-specific environmental studies. Owing to analytical imprecision which may result from the very low concentrations of many trace elements in lake waters, and to potential seasonal variations, it is recommended that re-sampling of the original water site be part of any follow-up exploration surveys.

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2) PINCHI SURVEY:

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(ICP-MS)
CanTech Laboratories Inc., Calgary, Alberta
(RGS Suite)

3) BABINE SURVEY:

Activation Laboratories Ltd., Ancaster, Ont.
(ICP-MS)
CanTech Laboratories Inc., Calgary, Alberta
(RGS Suite)

Survey duties were divided as follows:

Surveys Design: SC
Sample Collection: SC, WJ (Fawnie)
SC, WJ, MM, SD (Pinchi)
SC, RL (Babine)
Quality Control: SC
Data Interpretation: SC
Statistics: WJ
Geochemical Map Production: SC, WJ
Open File Production and Coordination: SC

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