Till Geochemistry and Clast Lithology Studies of the Bulkley River Valley, West-Central British Columbia (parts of NTS 093L)

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ABSTRACT

Regional till geochemistry and clast lithology studies were undertaken in the Bulkley River valley and adjacent areas (NTS map areas 093L/06, 07, 08, 09, 10, 11, 14, 15, 16) with the objectives of determining the background elemental concentrations in the till within the region and to locate new potential areas of mineralization in the bedrock. To achieve these objectives, 165 samples were collected and submitted for geochemical analyses and study of their clast lithologies.

The Quaternary geology of the Bulkley River valley area is characterized by an extensive cover of Late Wisconsinan deposits consisting of glacial, glaciofluvial, and glaciolacustrine sediments that in many places masks the bedrock surface. Where the bedrock outcrops, ice-flow indicators present on its surface document a complex glacial history comprising three main phases of glaciation. At the glacial maximum, glaciers overtopped the confining topography and ice flowed westward across the Skeena, Hazelton, and Coast Mountains to the Pacific Ocean. In some places, this direction of glacier flow was opposite in direction to ice movements that occurred during earlier and later phases of glaciation.

Elevated concentrations of copper, molybdenum, arsenic, and other elements were measured in till in the vicinity and down-ice of known mineral occurrences. Several others having anomalous concentrations for some elements were collected at sites far away from mapped bedrock mineralization. A high proportion of some pebble-sized clasts in the till also document dispersal of material down-ice of bedrock sources. Some dispersal trains are over 20 km long. Results of the clast lithology can also be used to predict the lithology of the underlying bedrock where glacial sediments completely cover the bedrock surface.

INTRODUCTION

Mineral exploration by traditional exploration techniques has been hindered in west-central BC because of a thick and nearly continuous cover of glacial sediment that masks the bedrock surface. The bedrock in the region has a high mineral potential; several active mines and past producers are located in the project area. Regional till geochemistry surveys have been used to determine the background mineral composition and identify anomalous concentrations that can be traced to bedrock sources. The geochemical composition of till is directly influenced by the bedrock geology and dominant direction of glacier flow during the last glaciation (Late Wisconsinan).

To assist the mining industry in locating new mineral prospects, a two-year project was undertaken in west-central BC in an area approximately 340 km east of Prince Rupert and 400 km west of Prince George (Fig. 1). This project was undertaken in an area that is within Geoscience BC's QUEST-West Project area and the Mountain Pine Beetle–Impacted Zone.

Specifically, this project delivers till geochemical and clast lithology data for the Bulkley River valley and adjacent areas (encompassing parts of NTS map areas 093L/07, /08, /09/, /10, /11, /15; Fig. 2); information that is not publically available. The data was collected for the British Columbia Geological Survey (BCGS) in 1996, as part of regional till sampling and Quaternary geology studies in the Babine porphyry copper belt of west-central BC (Levson, 2002). The BCGS project was a component of a program of multi-disciplinary and collaborative research with the Geological Survey of Canada (GSC), universities and the mining industry under the Nechako National Geoscience Mapping Program (NATMAP) in central BC. This till geochemical and clast lithology data has not been previously published. Its release will provide information about the background geochemistry and Quaternary geology of this part of west-central BC.

The goal of this project was to provide the mineral exploration community additional information characterizing the glacial materials, which in this region forms a near-continuous cover masking the bedrock surface. Combined with existing geological and geophysical data collected for Geoscience BC, and historical databases archived at the BCGS and GSC, this information will assist companies in identifying new exploration targets and re-evaluate known mineral occurrences. These activities will promote further investment in the resource exploration and development sector in this part of BC.

LOCATION AND ACCESS

The project area is centred along the Bulkley River valley from its headwaters located west of

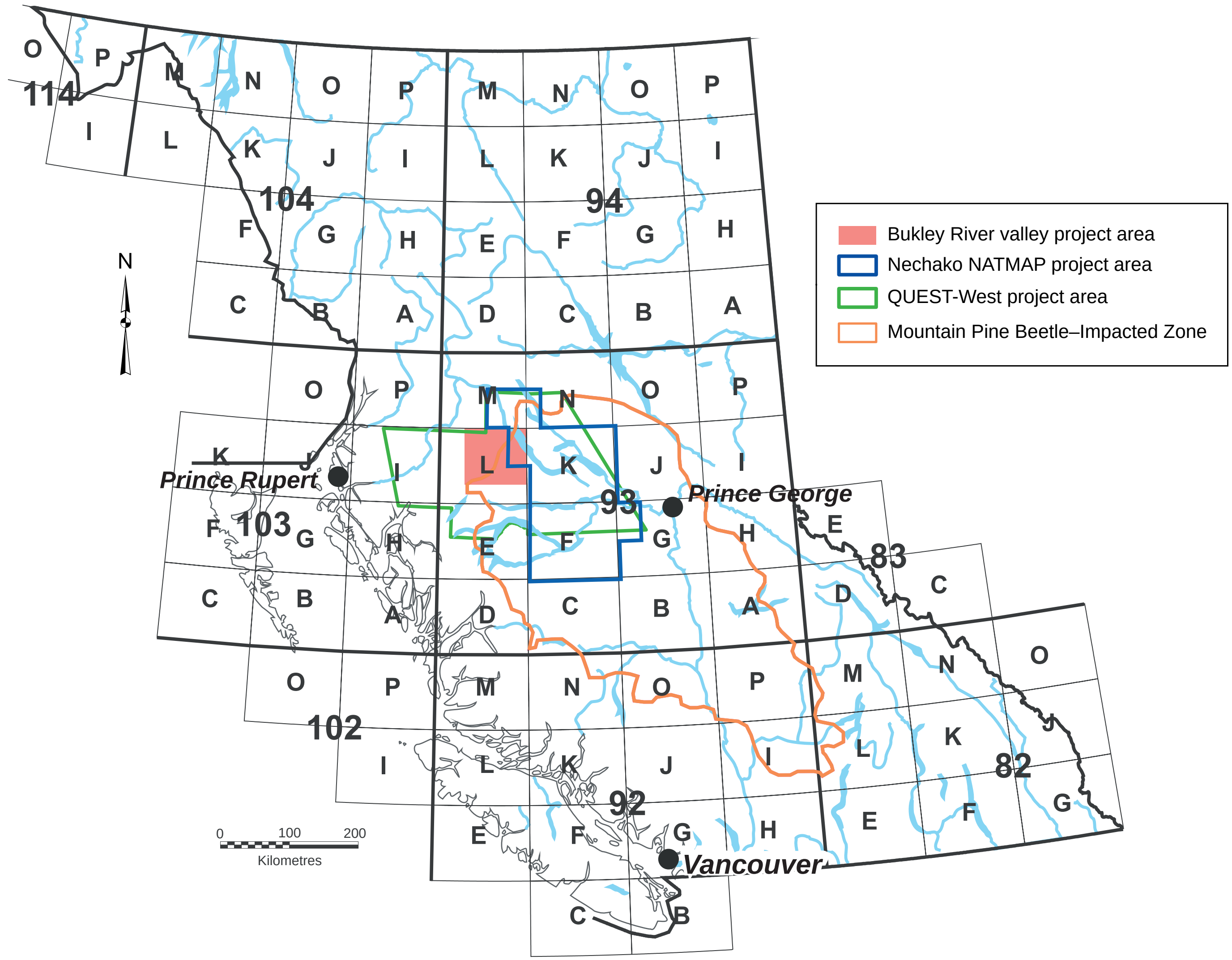


Figure 1. Location of project area in west-central BC. The grid of 1:250 000 scale NTS map areas is overlain on the map.

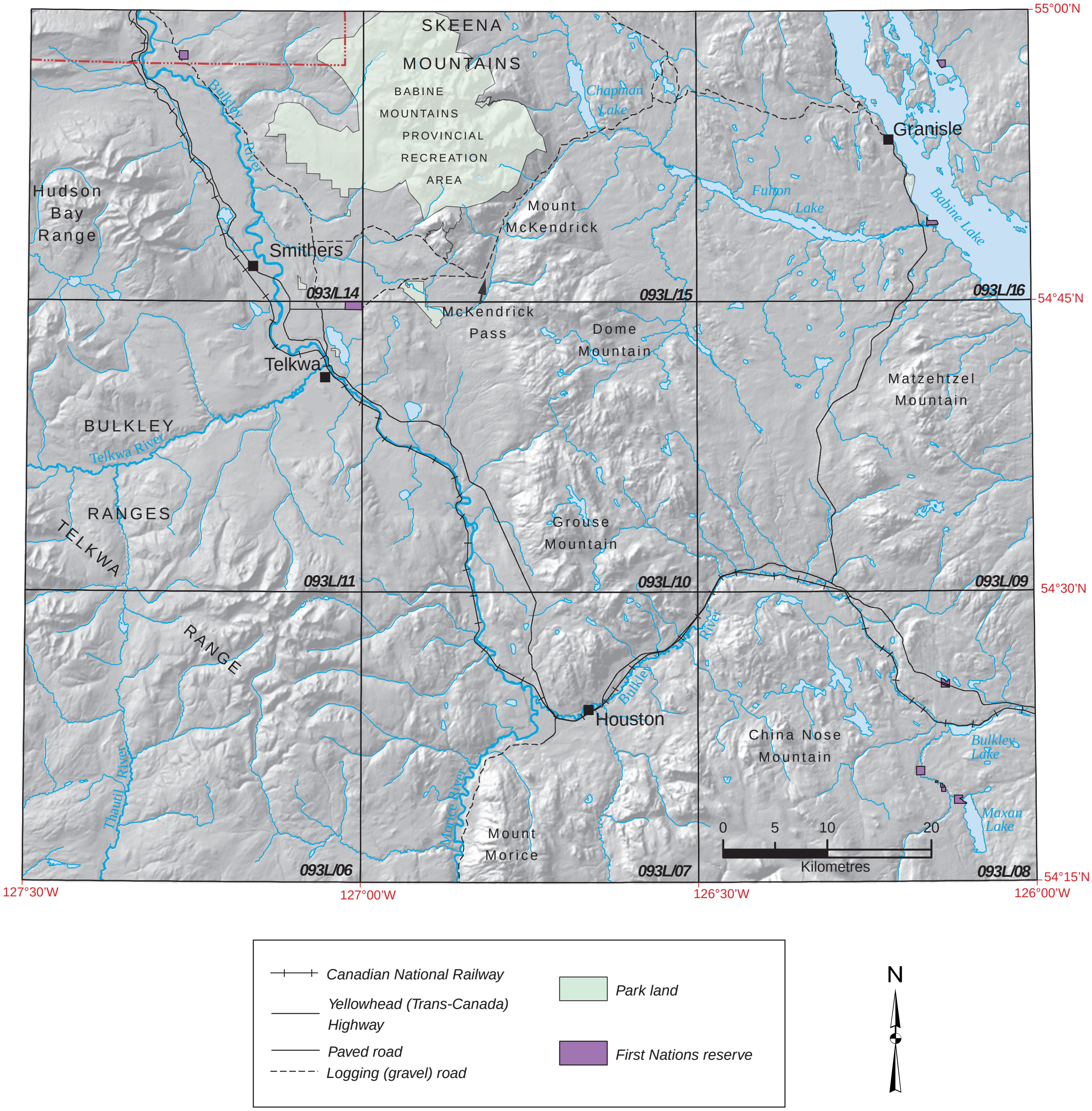


Figure 2. Overview of the Bulkley River valley project area in west-central BC. The grid of 1:50 000 scale NTS map areas is overlain on the map.

the town centre of the District of Houston in NTS map area 093L/07 northwest to the town of Smithers in NTS map area 093L/14. The project area can be accessed from the Yellowhead (Trans-Canada) Highway 16 along an extensive system of forest service roads branching out from provincial highways, municipal, and/or farming roads.

PHYSIOGRAPHY

The Bulkley River valley project area is characterized by broad U-shaped drift-filled valleys, bordered by glacially rounded mountains, with only a few jagged peaks emerging from the highest mountains. The southern two-thirds of the project area, including much of the Bulkley River and Babine Lake valleys, lie within the Nechako Plateau, a physiographic subdivision of the Interior Plateau (Holland, 1976). The Nechako Plateau is characterized by its low relief (average elevation of 1200 m asl), with gently rolling to undulating topography. The area is covered predominantly by a thick cover (> 1 m) of glacial till. Although bedrock outcrop is relatively uncommon, some exposures are present on the highest hills, along deeply incised stream channels, on the stoss (i.e., up-ice) end of crag-and-tail or drumlinoid features, and along the shores of lakes. Along the centre of the Bulkley River and Babine Lake valleys, ridged and flat-lying proglacial meltwater sediment (deposits of sand and gravel or silt and clay) and modern riverine sediments are present at the land surface.

The Bulkley River valley is bordered to the north and south by the Skeena and Hazelton mountains, respectively. The height of the Skeena Mountains average 1600 m asl north of the towncentre of the District of Houston and rise steeply to over 2100 m asl northwest of the Town of Smithers (Fig. 2). The Bulkley, Telkwa and Hudson Bay Ranges of the Hazelton Mountains lie south of the valley and reach elevations of over 2300 m asl. Glaciers and icefields are most common in the north-facing cirques. The Morice and Telkwa River valleys drain these mountains to the Bulkley River, which flows northwest to the Skeena River and on to the Pacific Ocean. Babine Lake drains south and then east and lies within the Fraser River watershed. A low divide formed by glacial sediments separates the Skeena River and Fraser River watersheds along the eastern boundary of the project area. In some places, glacial meltwater streams have cut narrow channels across the divide. These meltwater streams drained glacial lakes that formed in the Bulkley River and Fraser River drainages (Plouffe, 2000; Stumpf et al., 2004).

BEDROCK GEOLOGY

The Bulkley River valley project area lies entirely within the Stikine terrane of the morphogeological Intermontane Belt, just east of the Coast Belt (Gabrielse et al., 1991). The bedrock geology in the NTS 093L 1:250,000-scale map area was first described and mapped by Armstrong (1944), and later revised by Tipper and Richards (1976). Additional geological mapping and data compilation (e.g., MacIntyre et al. 1987; Massey et al., 2003; Struik et al., 2007) has been conducted to update information describing the geological units and tectonic setting. Recent bedrock geology mapping in Bulkley River valley and adjacent areas (supported by Geoscience BC) was focussed on compiling existing field data for Skeena Group and Bowser Basin rocks (MacIntyre, 2006; Evenchick et al., 2008).

A large part of the Bulkley River valley project area is underlain by Middle to Late Triassic, Early to Middle Jurassic volcanic, volcaniclastic and related marine sedimentary rocks of the Takla and Hazelton Groups (Figs. 3a and b; MacIntyre, 2006). Locally, these rocks are unconformably overlain by Late Jurassic to Early Cretaceous marine to nonmarine sedimentary rocks of the Bowser Lake and Skeena groups, which were deposited along the southeastern margin of the Bowser Basin (MacIntyre, 2006; Alldrick et al., 2007). Over the western half of the project area, Late Cretaceous to early Eocene volcanic and related pyroclastic and volcaniclastic rocks unconformably overlie rocks of the Stikine terrane and Bowser Basin (Figs. 3a and b; MacIntyre, 2006). From the town centre of the District of Houston to the southeast, the Stikine terrane is unconformably overlain by Early Eocene andesite and basalt flows with related pyroclastic rocks of the Endako Group (Fig. 3a and b). These stratified rocks are cut by intrusive rocks classified to four plutonic suites (Topley, Bulkley, Babine and Nanika) associated with major magmatic events that occurred during the Early Jurassic, Late Cretaceous, and Eocene. Most of the mineral deposits in the study area are related to the Late Cretaceous Bulkley and Eocene Babine and Nanika suites (Carter, 1981; MacIntyre, 2006).

MINERAL OCCURRENCES

The BCGS MINFILE database accessed at http://www.minfile.ca/ lists a total of 248 mineral occurrences in the project area (including petroleum and industrial minerals such as coal and limestone). The most economically important mineral deposit types associated with the Cretaceous- and Eocene-age volcanic intrusions are the following:

- epithermal and polymetallic veins – intrusions outcropping on Grouse and Dome Mountains (Fig. 4);
- porphyry Cu±Mo±Au deposits – Bell past producer (MINFILE 093M 001; BC Geological Survey, 2012), Granisle past producer (MINFILE 093L 146; BC Geological Survey, 2012) and Big Onion developed prospect (MINFILE 093L 124, BC Geological Survey, 2012), all shown on Fig. 4; and

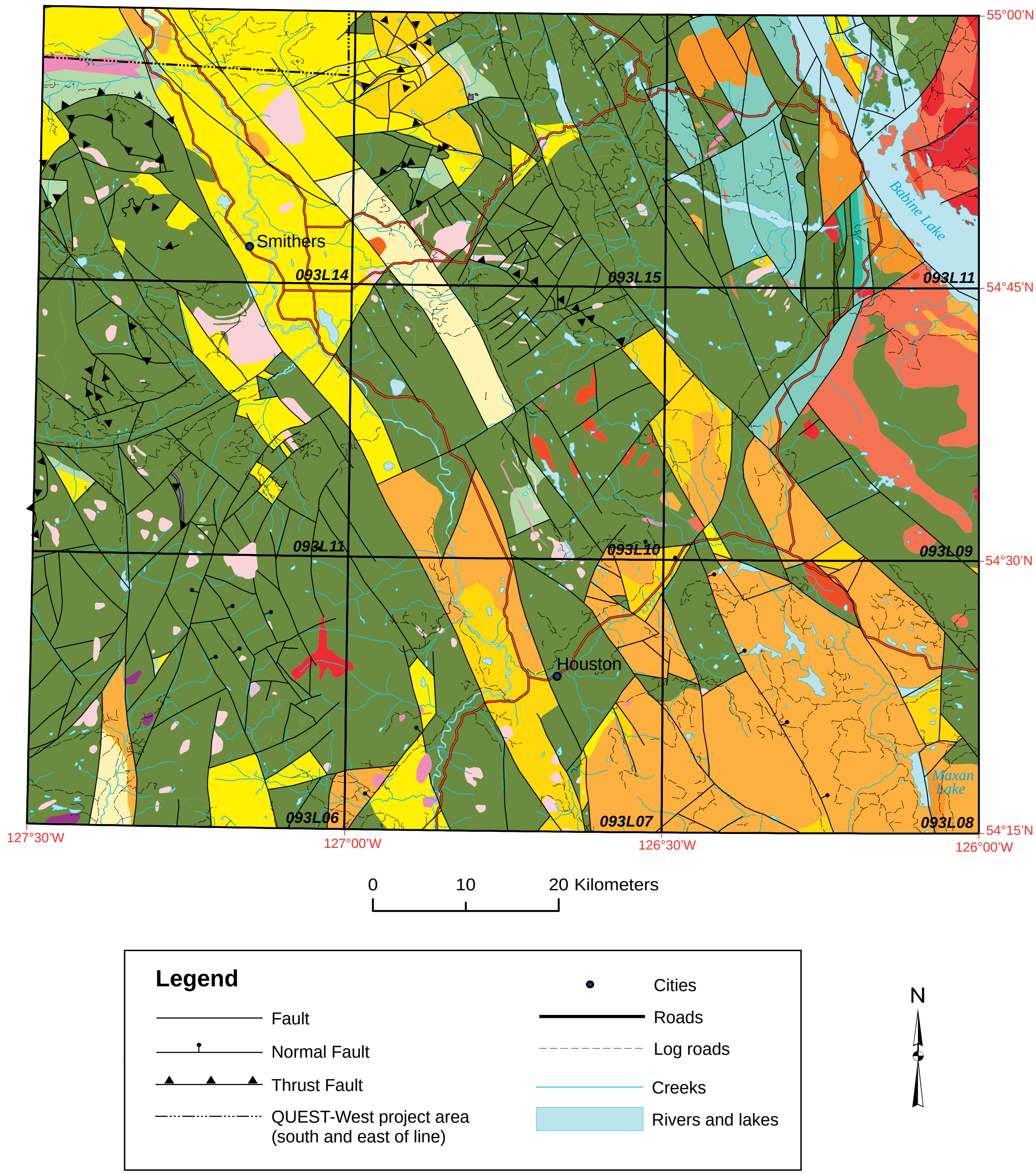


Figure 3. (A) Bedrock geology of the Bulkley River valley project area (from Geoscience BC, 2010).

SEDIMENTARY AND VOLCANIC ROCKS

CENEZOIC

EOCENE
Nechako Plateau Group - Endako Group (Eocene to Lower Miocene)

Basaltic volcanic rocks; Endako Formation - coarse volcaniclastic and pyroclastic volcanic rocks, andesitic volcanic rocks
Goosly Lake Formation - alkaline volcanic rocks; Buck Creek Formation - basaltic volcanic rocks

Nechako Plateau Group - Ootsa Lake Group (Eocene)

Newman Formation - Basal Conglomerate Member: comglomerate, coarse clastic sedimentary rocks; Mafic Flows Member: andesitic volcanic rocks; Porphyritic Flows Member: basaltic volcanic rocks; Breccia Member: coarse volcaniclastic and pyroclastic volcanic rocks; Lahar Member: coarse volcaniclastic and pyroclastic volcanic rocks

CENEZOIC to MESOZOIC

CRETACEOUS TO EOCENE

Unnamed coarse clastic sedimentary rocks

Unnamed rhyolite, felsic volcanic rocks

MESOZOIC

CRETACEOUS
Kasalka Group (Late Cretaceous)

Porphyritic andesite flows and related pyroclastics, lahars, debris flows, breccias and epiclastic beds, basal conglomerate; lesser dacite, rhyodacite, basaltic andesite, quartz porphyry

Skeena Group (Lower Cretaceous)

Rocky Ridge Formation - Subvolcanic Rhyolite Domes: alkaline volcanic rocks
Red Rose Formation - Sandstone, siltstone, argillite, chert-pebble conglomerate, mudstone, mainly fluvial origin
Kitsuns Creek Formation - feldspathic and volcanic sandstone, siltstone, shale, conglomerate, coal

MESOZOIC

CRETACEOUS to JURASSIC
Bowser Lake Group (Jurassic to Cretaceous)

Ashman Formation - argillite, greywacke, wacke, conglomerate turbidites; mudstone, siltstone, shale fine clastic sedimentary rocks
Trout Creek Formation - interbedded conglomerate, sandstone, siltstone, shale and coal; marine and non-marine

MESOZOIC

JURASSIC
Hazelton Group (Lower to Middle Jurassic)

Eagle Peak Formation - Volcaniclastic rocks; Nilkitkwa Formation - argillite, greywacke, wacke, conglomerate turbidites, undivided sedimentary rocks; Telkwa Formation - Felsic to Intermediate Volcanic Member andesitic volcanic rocks; Mafic Volcanic Member: basaltic volcanic rocks, calc-alkaline volcanic rocks, undivided volcanic rocks; Saddle Hill Formation - undivided volcanic rocks; Volcaniclastic-Sedimentary Member conglomerate, course clastic sedimentary rocks; Mafic Submarine Volcanic Member: basaltic volcanic rocks; Intermediate Volcanic Member: volcaniclasitc rocks, coarse volcaniclastic and pyroclastic volcanic rocks; Smithers Formation - marine sedimentary and volcanic rocks, undivided sedimentary rocks; Unnamed greenstone, greenschist, and metamorphic rocks

Figure 3. (B) Bedrock geology legend.

Triassic to Jurassic
Takla Group (Late Jurassic to Early Triassic)

Undivided volcanic rocks; Savage Mountain Formation - volcanic rocks; Moosevale Formation - argillite, greywacke, wacke, conglomerate turbidites; Dewar Formation - mudstone, siltstone, shale fine clastic sedimentary rocks; Unnamed conglomerate, coarse clastics sedimentary rocks

PALEOZOIC TO MESOZOIC

Deformed Asitka or Takla Groups (Early Permian to Middle Triassic)

Metasedimentary Rocks undivided sedimentary rocks; Metavolcanic Rocks greenstone, greenschist metamorphic rocks

PALEOZOIC

Asitka Group (Early Permian)

Grey bioclastic limestone; argillaceous recyrstallized limestone with chert nodules; slate, slaty siltstone, and chert; intruded by metagabbro; minor serpentinite and listwanite

INTRUSIVE VOLCANIC ROCKS

Unnamed (Eocene)

Rhyolite, quartz-feldspar porphyry, plugs, domes and dykes

Babine Plutonic Suite - Goosly Plutonic Suite - Nanika Putonic Suite (Eocene)

Biotite-Feldspar Porphyritic Phase: granodioritic intrusive rocks; Biotite-Quartz-Feldspar Porphyritic Phase: grandodioritic intrusive rock; Monzodioritic to gabbroic intrusive rocks; intrusive rocks, undivided

Unnamed (Cretaceous to Eocene)

Dioritic intusive rocks

Bulkley Plutonic Suite - McCauley Island Plutonic Suite (Late Cretaceous)

High-level quartz phyric, felsic intrusive rocks; Biotite-Quartz-Feldspar Porphyritic Phase: quartz monzonitic to monogranitic intrusive rocks; quartz dioritic intrusive rocks; Biotite-Feldspar Porphyritic Phase - granodioritic intrusive rocks; intrusive rocks, undivided; feldspar porphyritic intrusive rocks; dioritic intrusive rocks

McCauley Island Plutonic Suite - Spike Peak Intrusive Suite (Early Cretaceous)

Quartz monzonitic intrusive rocks; dioritic intrusive rocks; basaltic intrusive rocks; Quartz Monzonite Phase: granodioritic intrusive rocks; syenitic to monzonitic intrusive rocks; Tachek Creek Phase: granodioritic intrusive rocks

Unnamed (Late Jurassic)

Dioritic intrusive rocks

Topley Plutonic Suite (Early Jurassic)

Granodioritic intrusive rocks; Nose Bay Intrusive Breccia - coarse volcaniclastic and pyroclastic volcanic rocks

Topley Intrusive Suite (Late Triassic to Early Jurassic)

Megacrystic Porphyry Dykes: feldspar porphyritic intrusive rocks; Porphyritic Phase: granodioritic intrusive rocks; unnamed granodioritic intrusive rocks; intrusive rocks, undivided; Granodioritie to Monzonite Phase: granodioritic intrusive rocks

Topley Intrusive Suite (Late Triassic to Early Jurassic)

Tochcha Lake Stock - dioritic intrusive rocks

Figure 3. (B) Bedrock geology legend (continued).

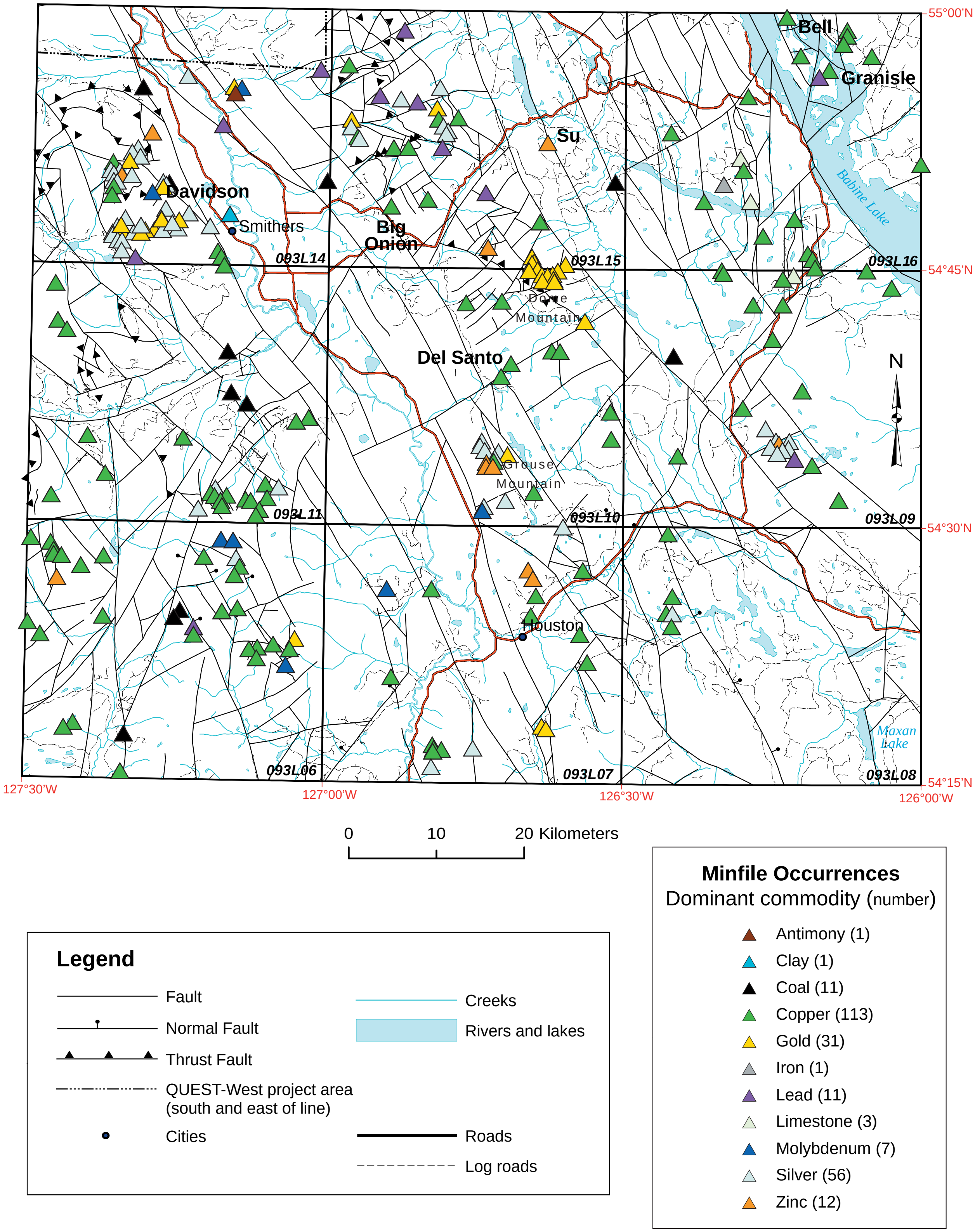


Figure 4. Mineral occurrences in the Bulkley River valley project area (NTS map areas 093L 06, 07, 08, 09,10, 11, 14, 15 and 16) obtained from the BCGS MINFILE database accessed at http://www.minfile.ca.

- porphyry Mo deposits – low F-type; Davidson developed prospect (MINFILE 093L 110; BC Geological Survey, 2012; Fig. 4).

In addition, Eskay Creek–type subvolcanic Cu-Ag-Au-(As-Sb) deposits (e.g., Del Santo prospect - MINFILE 093L 025; BC Geological Survey, 2012) (Fig. 4) have been recognized as potential target areas for further exploration. The most prospective rocks for discovery of this type of deposit include Middle Jurassic submarine volcanic rocks of the Hazelton Group (Massey et al., 1999) and mid-Cretaceous bimodal volcanic rocks of the Rocky Ridge Formation (MacIntyre and Villeneuve, 2001; Alldrick et al., 2007).

QUATERNARY GEOLOGY

Except during earlier mapping of the bedrock geology where notes were made about glacial landforms and features (e.g., Tipper and Richards, 1976; Tipper, 1994), mapping of glacial sediments in the study area was not conducted until the earlier 1980s by Clague (1984). Only the surficial materials and glacial landforms lying in the Bulkley River valley between the village of Telkwa and town of Smithers below 1220 m asl were mapped by Clague (1984).

Additional mapping was undertaken in other parts of the study area from 1995 to 1997 as part of the Nechako NATMAP project. Stumpf (2001) and Stumpf et al. (2004) described in detail the glacial sediments exposed in outcrops along the Bulkley, Morice, and Telkwa rivers. Levson et al. (1998), Stumpf et al. (2000) and Stumpf (2001) mapped the prominent glacial landforms and erosional features (e.g., striae, flutings, rat tails) found in the Bulkley River valley and on the adjacent uplands. The surficial geology of NTS map areas 093L/09 (Levson, 2002) and 093L/16 (Stumpf et al., 1996; Levson, 2002) were completed as part of geological studies conducted in the Babine Lake area. In the maps areas adjacent directly to the east and south of the project area, Plouffe (2000) and Ferbey (2010, 2011) mapped the surficial materials and discussed the Quaternary geology and stratigraphy.

Surficial Materials

In the Bulkley River valley project area, the surficial materials exposed along rivers and streams (Fig. 5) and roadcuts were studied to determine their physical characteristics. The most common geologic material encountered at the land surface in the project area was a massive, matrix-supported diamicton (interpreted as glacial till). The diamicton having a variable thickness forms hummocky, kettled, fluted, or relatively flat topography. The diamicton is typically over-consolidated, gray to dark brown in colour, and clayey silt to silty sand in texture, and unconformably overlies the bedrock. Typically, the diamicton contains vertical jointing and sub-horizontal fissility giving it a blocky structure. The diamicton contains clasts of all sizes from

Figure 5. Interstratified diamicton, sand and gravel, and silt and clay exposed along the southern bank of the Babine River, located 15 km northeast of the town centre of the District of Houston in the NTS map area 093L/09. The exposure is approximately 35 m high and 100 m wide.

pebbles to boulders, which vary in roundness from subangular to subrounded. In the Bulkley River valley the diamicton is generally exposed above 515 m asl. beyond the modern floodplain. Outside of the valleys, above approximately 1050 m asl, a discontinuous veneer or blanket of till is present on the bedrock surface. The diamicton encountered in the valley typically contains more clay than diamicton outside the valley. In valleys, the diamicton forms part of a thick valley-fill sequence. From geologic logs compiled for boreholes drilled to install water wells, as engineering structural tests, and for mineral exploration it appears that >50 m of glacial sediment overlies the bedrock in the deepest part of the Bulkley River valley (Stumpf, 2003). In the Babine Lake valley, the diamicton is subdivided into two facies, 1) sandy diamicton and 2) silty diamicton (e.g., Fig. 6A). The sandy loam diamicton is loose, typically oxidized, and contains a higher proportion of gravel and pebbles. This diamicton is interpreted as meltout or supraglacial till (cf. Dreimanis, 1989), or ice marginal debris flow deposits (Levson, 2002) that were deposited as ice in the Babine Lake valley melted (Stumpf, 2001). The silty diamicton is very dense, has strong vertical jointing, and gravel content below 20%. This diamicton is interpreted as subglacial basal till (cf. Dreimanis, 1989).

Deposits of glaciofluvial sand and gravel were encountered predominantly along the major river valleys and locally on the adjacent uplands. Glaciofluvial sediments form outwash plains, eskers, kames, terraces, and fans in valley bottoms and along edge of the valleys. The deposits consist mainly of poorly to well sorted, stratified, pebble and cobble gravels and sands of variable thickness (e.g., Fig 6B). Eskers are uncommon in the project area, but where present are composed mainly of stratified gravels and sands and with clasts of diamicton. The sand and gravel was deposited in front and along melting glaciers whose margins retreated up the main valleys and proglacial drainage extended down valley (Levson, 2002; Stumpf et al., 2004).

Glacial lakes formed in parts of the major river valleys and their tributary valleys when drainage was blocked by ice or sediment dams during deglaciation. Glaciolacustrine silt and clay are generally encountered in low-lying areas below an elevation of 750 m asl, typically near modern lakes and rivers (Levson, 2002; Stumpf et al., 2004). Steep slopes in the project area are commonly covered by colluvial deposits composed of a mixture of glacial sediment and eroded bedrock that have been reworked by gravitational processes. Modern alluvium composed of channel-fill sand and gravel and floodplain silt, fine sand, and organic material are confined to valleys containing the major rivers and streams. Organic deposits consisting of decayed plant material, fine sand, silt, and clay have formed in poorly drained, low-lying areas in the valleys and on the uplands.

Prominent Glacial Landforms

Throughout the project area, flutings, drumlins, crag-and-tails and roche mountonées, and smaller-scale features (e.g., glacial striae, rat-tails, grooves) present on the surface of bedrock

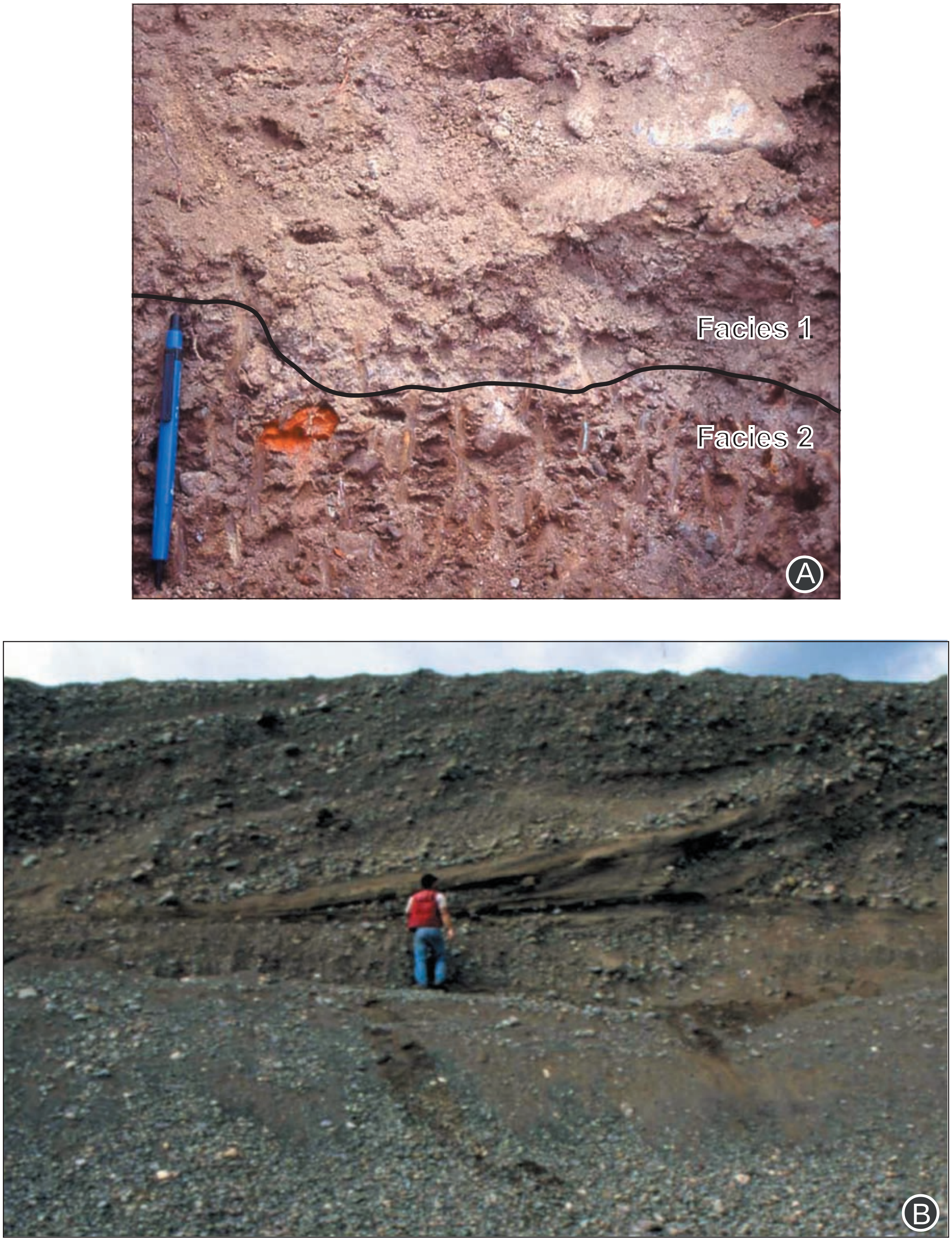


Figure 6. (A) Diamicton at sampling site 95-6594, located 44 km northeast of the town centre of the District of Houston in the NTS map area 093L/09. Two facies were identified; sandy diamicton (facies 1) overlying silty clay loam diamicton (facies 2). (B) Glaciofluvial sand and gravel composing an ice-contact deposit along the Babine Lake valley, 24 km northeast the town centre of the District of Houston in the NTS map area 093L/09. The exposure in the gravel pit is 10 m high.

with different lithologies clearly record former ice-flow directions of the Late Wisconsinan glaciation. The glacial landforms are present at different elevations from the bottom of valleys to the highest peaks on mountains (Fig. 7). The orientation of glacial striations, grooves, and rat-tails were measured on numerous bedrock outcrops in the project area (Fig. 8). These features on some outcrops record multiple ice-flow directions (e.g. Fig. 8B) that locally can be used to build a chronology of ice movements. Few moraines are mapped in the area; only moraines formed during recent (Holocene) advances of valley glaciers are preserved in high mountains. A series of moraine-type ridges were identified in the Bulkley River valley north and east of the Town of Telkwa in NTS map areas 093L/10, 11, and 14. However, these ridges are composed of silt and clay with deformed bedding, diamicton, or sand and gravel and were likely formed during the melting of stagnant ice or readvance of ice over saturated and soft sediment. A large meltwater channel is present east of Bulkley Lake in the NTS map area 093L/09 (Fig. 2) and contains the drainage divide between the Skeena and Fraser River systems. The channel was eroded by glacial meltwater during deglaciation (Stumpf, 2001).

Ice-Flow History

Stumpf et al. (2000), Stumpf (2001) and Levson (2002) provide a detailed discussion of the ice-flow history of the Bulkley River valley project area. These ice-flow histories were in part built from other studies of glacier flow in central BC (e.g., Clague, 1984; Plouffe, 1991; Tipper, 1994). The chronology of ice flows in the project area was compiled by measuring the orientation of streamlined landforms, such as drumlins, crag-and-tail ridges, and flutings from aerial photographs, and from the orientation, crosscutting patterns, and degree of preservation of striations, rat-tails and grooves on bedrock outcrops.

Three main phases of ice flow were recognized in the project area (Fig. 9). At the onset of Late Wisconsinan glaciation, cirques and valley glaciers expanded from accumulation centres in the Skeena and Hazelton Mountains and flowed westward along the Bulkley River valley into the Skeena River valley and to the south and east onto the Nechako Plateau (yellow arrows in Fig. 9). At this time, the direction of glacier flow was controlled primarily by higher topography bordering the valleys.

Upon further accumulation, expansion and thickening of the ice, the glaciers eventually formed a single (Cordilleran) ice sheet. At its maximum extent, the ice sheet reached a thickness over 2000 m, at which time the centres of accumulation had shifted to the east of the project area over the Nechako Plateau (Stumpf et al., 2000). This reconfiguration in the ice sheet caused a major reversal in glacier flow across the project area. At this time, the ice sheet was able to flow unobstructed above major topographic barriers in the Skeena and Hazelton Mountains. Subsequently, glacier flow was from east to west across the Bulkley River valley project area, away from ice centres located further inland, crossing the Coast Mountains to the Pacific Ocean

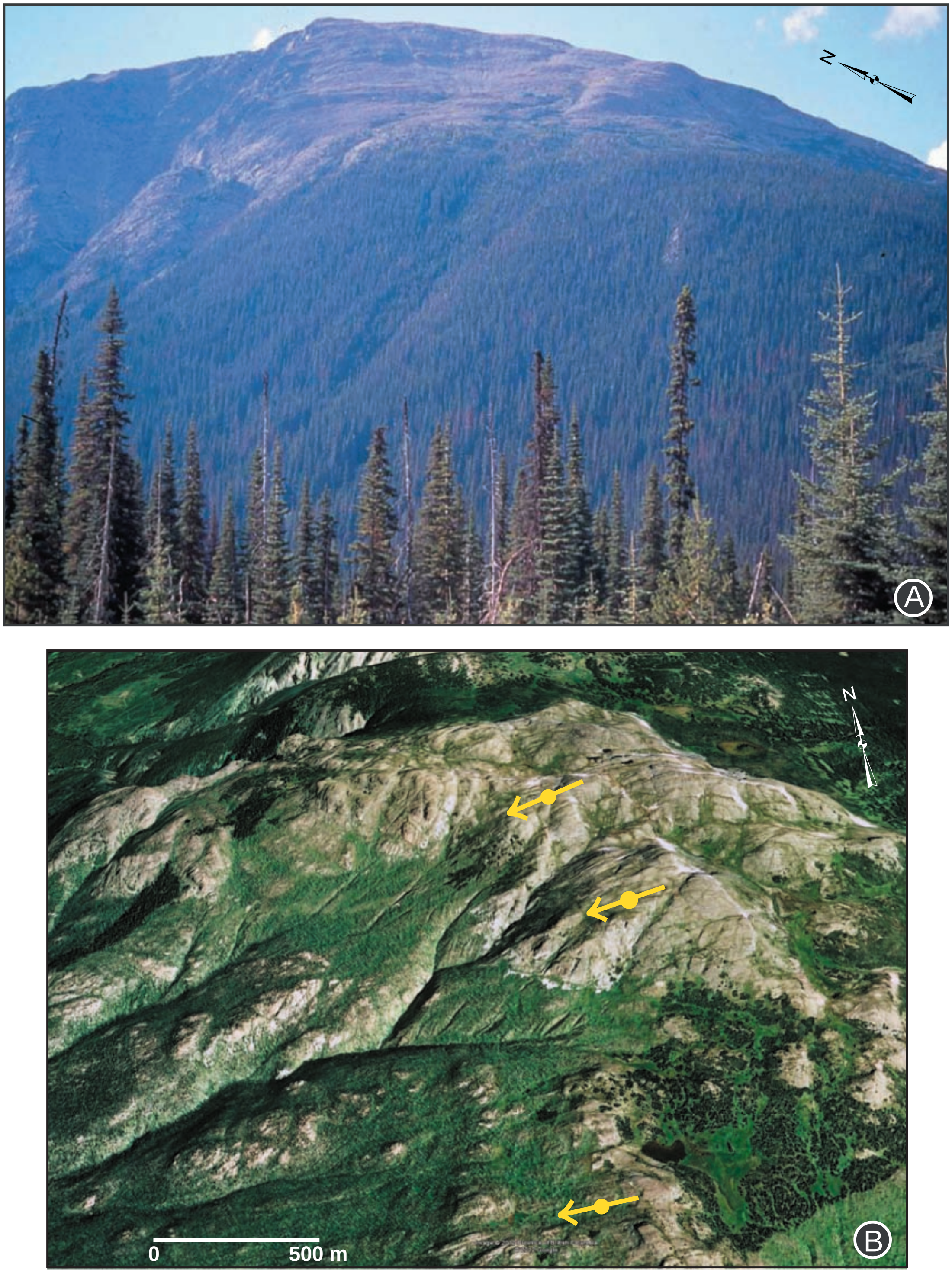


Figure 7. (A) Flutes and roche mountonées on northwest-facing slope of Mount McKendrick at elevations between 1486–1733 m asl. View is to the east. The ice-flow directions measured range from 225–246° (south-southwest to west-southwest). Mount McKendrick is located in the NTS map area 093L/15 (Fig. 2). (B) Oblique view of glacially fluted and rounded bedrock on Mount Morice. Land surface elevations range from 1200–1825 m asl. The dominant direction of ice flow is towards the west-southwest. Mount Morice is located in the NTS map area 093L/07 (Fig. 2). Image source: “Mt. Morice” 54°16'9.00"N and 126°47'4.00"W. Google Earth, source Province of British Columbia. Image taken June, 2003. Date accessed April 6, 2012.

Figure 8. Examples of striated bedrock. (A) Rat-tails on porphyritic andesite bedrock on Dome Mountain in NTS map area 093L/10 (Fig. 2). At this site, glaciers flow west-southwesterward parallel to the pencil. (B) Striations on Hazelton Group volcanic bedrock in McKendrick Pass, approximately 20 km northeast of the town of Telkwa in NTS map area 093L/15 (Fig. 2). Two distinct ice movements are shown. In this case, the first ice movement was towards the south-southwest (210° or towards the top of the photograph), and the second one was towards the south-southeast (146° or towards the lower right).

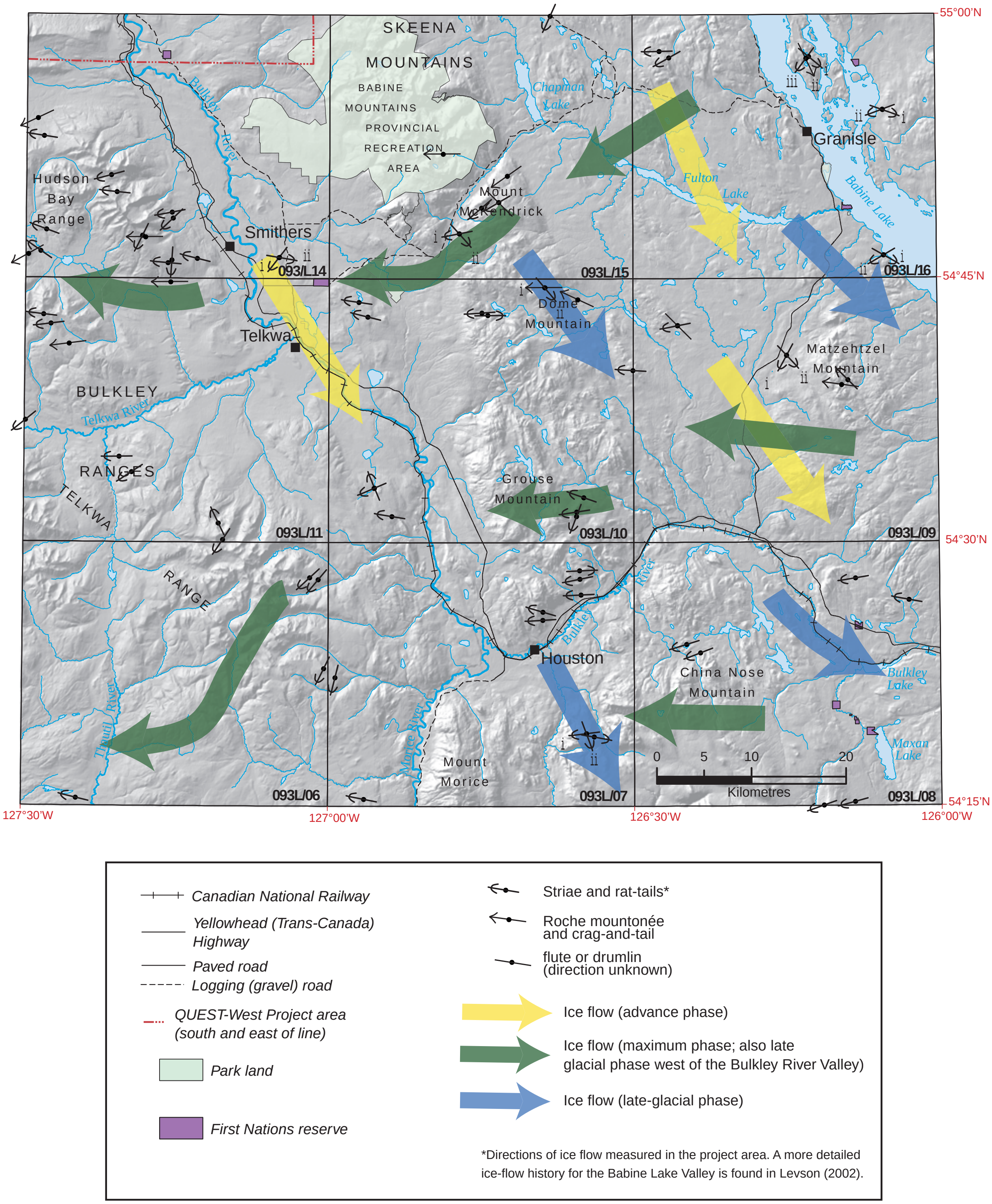


Figure 9. Ice-flow history of the Bulkley River valley project area reconstructed using orientations of glacial striations, drumions, flutings, roche moutoneés, rat-tails, and crag-and-tails (from Stumpf et al. 2000; Stumpf 2001; Levson, 2002).

(green arrows in Fig. 9). This reversal continued well into the glaciation until the surface of the ice sheet fell below elevation of the topographic barriers in the Skeena and Coast Mountains. At this time, the centres of growth shifted westward to the Skeena and Hazelton Mountains causing the pattern of glacier flow to shift back to the configuration of the early (advance) glacial phase (blue arrows in Fig. 9; Stumpf et al., 2000). These reversals are not only recognized by mapping ice-flow indicators, but also by the pattern of glacial transport determined from till geochemistry surveys and tracing erratics back to their bedrock sources (Stumpf et al., 2000; Ferbey and Levson, 2010; Ferbey et al., 2012).

GLACIAL SEDIMENT SAMPLING AND ANALYSIS

Field Methods

During the 1996, field season as part of till geochemistry and Quaternary geology studies in the Babine Lake area in support of the Nechako NATMAP project in central BC, till sampling and clast lithology analyses were completed in the Bulkley River valley project area to expand the collection of geochemical data in the region and possibly confirm the dominant direction of glacial transport inferred from the indicators of ice flow. A total of 146 till samples were collected for geochemical analyses (Fig. 10; Appendix 1). In addition, pebble-sized clasts were collected from till samples at an additional 19 sites for identification of their lithology.

Till sampling sites were selected to set the greatest density of samples along transects perpendicular to established directions of ice flow as in a similar manner as that outlined in Levson (2002). Samples of basal till (the preferred sampling medium for till geochemistry programs in central BC; see Levson, 2001) were collected from natural and man-made exposures, including roadcuts, river shore exposures, borrow pits and soil pits (e.g., Fig. 11). The average depth of sampling was approximately 1 m and till samples typically weighed between 3 and 5 kg. Field sites were marked with metal tags and flagging tape, both labelled with the unique site number (Fig. 10). The locations of sampling sites were plotted on a 1:50 000 scale NTS topographic maps with the aid of aerial photographs and a hand-held Global Positioning System (GPS) unit. Spatial coordinates measured with the GPS unit in Universe Transverse Mercator (UTM) coordinate system referenced to NAD 83 datum in zone 9 were recorded for each sampling site on field sheets (Appendix 1).

Site conditions and sedimentological data were collected at all sampling sites, and this information was archived in a relational database using Microsoft® Access® 2010 (Appendix 1). The database contains descriptions of sediment type, primary and secondary structures, matrix texture, presence of fissility and compactness, total percentage and modal size of clasts, rounding of clasts, presence of striated clasts, and sediment genesis and thickness. Further

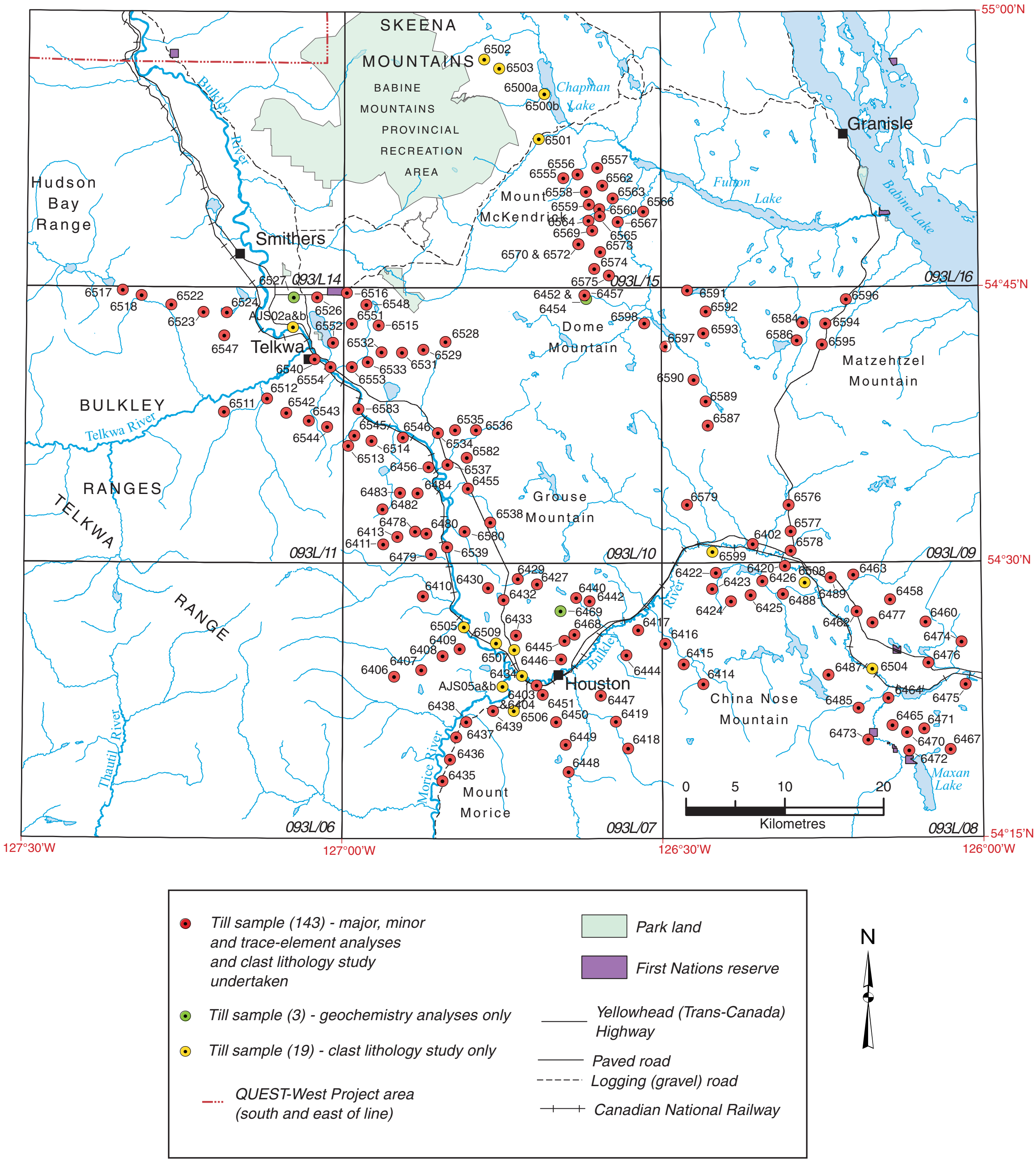


Figure 10. Location of till sampling sites in the project area. The till samples were collected for geochemical analyses and study of the clast lithologies.

Figure 11. Example of sampling site along forestry road in project area. Till samples were collected from the C soil horizon. The pick (shown for scale) is 65 cm long.

information was noted on soil horizons, local slope, bedrock striae, bedrock lithology, clast provenance and abundance of mineralized erratics.

Also, to determine the direction and distance of glacial transport from bedrock source units, the lithology of 50 to 100 clasts in the 25 to 100 mm size range were collected from till samples at 162 sites (Fig. 10). The lithology of the clasts were identified and grouped into broad categories to reflect the main lithologies of the bedrock sources. Distribution maps for each lithological category were also created, and most are presented in Appendix 2.

Laboratory Methods

Geochemical analyses were performed on the matrix of till sampled during this geochemical survey. Each 3–5 kg sample was air dried, split, and sieved to the silt-plus clay (<0.063 mm or -230 mesh) fraction by Rossbacher Laboratories Limited in Burnaby, BC. The pulps and unsieved split were subsequently returned to the BCGS sample preparation laboratory in Victoria, BC for archiving in case grain size or other follow-up analyses were requested. The silt plus clay-sized fraction from each sample was further divided into 10 and 30 gram portions. The subsample with the smaller mass was sent to Acme Analytical Laboratory (ACME), Vancouver, BC where samples were analyzed for inductively coupled plasma–emission spectrometry (ICP-ES) for 30 elements after an aqua-regia digestion. The heavier, 30 gram sample was submitted to Activation Laboratories Limited (ACTLABS) in Ancaster, ON for the analysis of 35 elements by instrumental neutron activation analysis (INA). Instrumental detection limits for these methods are provided in Tables 1 and 2. The same size fraction was analyzed for Hg by flameless cold vapour-atomic absorption (CAA) spectrometry. Total carbon was determined by Leco. Loss on ignition (LOI) on the silt plus clay-sized fraction was determined by weight difference after ignition at 1000°C.

For the ICP-ES method, a 0.5 gram sample is digested with 3 millilitres of 3-1-2 HCL-HNO_3-H_2O for one hour and diluted to 10 millilitres with water. This leach is partial for Mn, Fe, Sr, Ca, P, La, Cr, Mg, Ba, Ti, B, and W and limited for Na, K, and Al. The INA method was used because it is non-destructive, provides concentrations for a wide range of element, and has very low detection limits for most elements.

Due to possible contamination at ACTLABS during the processing of the samples (see Levson, 2002), 1 sample was rerun for the analyses of gold to complete the QA/QC. Analytical results for all 146 samples included in the regional data set are provided in Appendix 3 for ICP-ES data and Appendix 4 for INA data. Distribution maps for most elements analyzed are provided in Appendices 5 and 6

ELEMENT		DETECTION LIMIT	UNIT
Antimony	Sb	2	ppm
Aluminum	Al	0.01	wt. %
Arsenic	As	2	ppm
Barium	Ba	1	ppm
Bismuth	Bi	2	ppm
Boron	B	3	ppm
Cadmium	Cd	0.2	ppm
Calcium	Ca	0.00	wt. %
Chromium	Cr	1	ppm
Cobalt	Co	1	ppm
Copper	Cu	1	ppm
Gold	Au	2	ppm
Iron	Fe	0.01	wt. %
Lanthanum	La	1	ppm
Lead	Pb	3	ppm
Magnesium	Mg	0.01	wt. %
Manganese	Mn	2	ppm
Molybdenum	Mo	1	ppm
Nickel	Ni	1	ppm
Phosphorus	P	0.001	wt. %
Potassium	K	0.01	wt. %
Silver	Ag	0.3	ppm
Sodium	Na	0.01	wt. %
Strontium	Sr	1	ppm
Thorium	Th	2	ppm
Titanium	Ti	0.01	wt. %
Tungsten	W	2	ppm
Uranium	U	5	ppm
Vanadium	V	1	ppm
Zinc	Zn	0.1	ppm

Table 1. Elements analyzed by the ICP-ES method on the silt plus clay-sized fraction (<0.063 mm) of till matrix, and associated detection limits.

ELEMENT		DETECTION LIMIT	UNIT
Antimony	Sb	0.1	ppm
Arsenic	As	0.5	ppm
Barium	Ba	50	ppm
Bromine	Br	0.5	ppm
Calcium	Ca	1	wt. %
Cerium	Ce	3	ppm
Cesium	Cs	1	ppm
Chromium	Cr	5	ppm
Cobalt	Co	1	ppm
Europium	Eu	0.2	ppm
Gold	Au	2	ppb
Hafnium	Hf	1	ppm
Mercury	Hg	1	ppm
Iridium	Ir	5	ppb
Iron	Fe	0.01	wt. %
Lanthanum	La	0.5	ppm
Lutetium	Lu	0.05	ppm
Molybdenum	Mo	1	ppm
Neodymium	Nd	5	ppm
Nickel	Ni	20	ppm
Rubidium	Rb	15	ppm
Samarium	Sm	0.1	ppm
Scandium	Sc	0.1	ppm
Selenium	Se	3	ppm
Silver	Ag	5	ppm
Sodium	Na	0.01	wt. %
Strontium	Sr	0.05	ppm
Tantalum	Ta	0.5	ppm
Terbium	Tb	0.5	ppm
Thorium	Th	0.2	ppm
Tin	Sn	0.01	ppm
Tungsten	W	1	ppm
Uranium	U	0.5	ppm
Ytterbium	Yb	0.2	ppm
Zinc	Zn	50	ppm

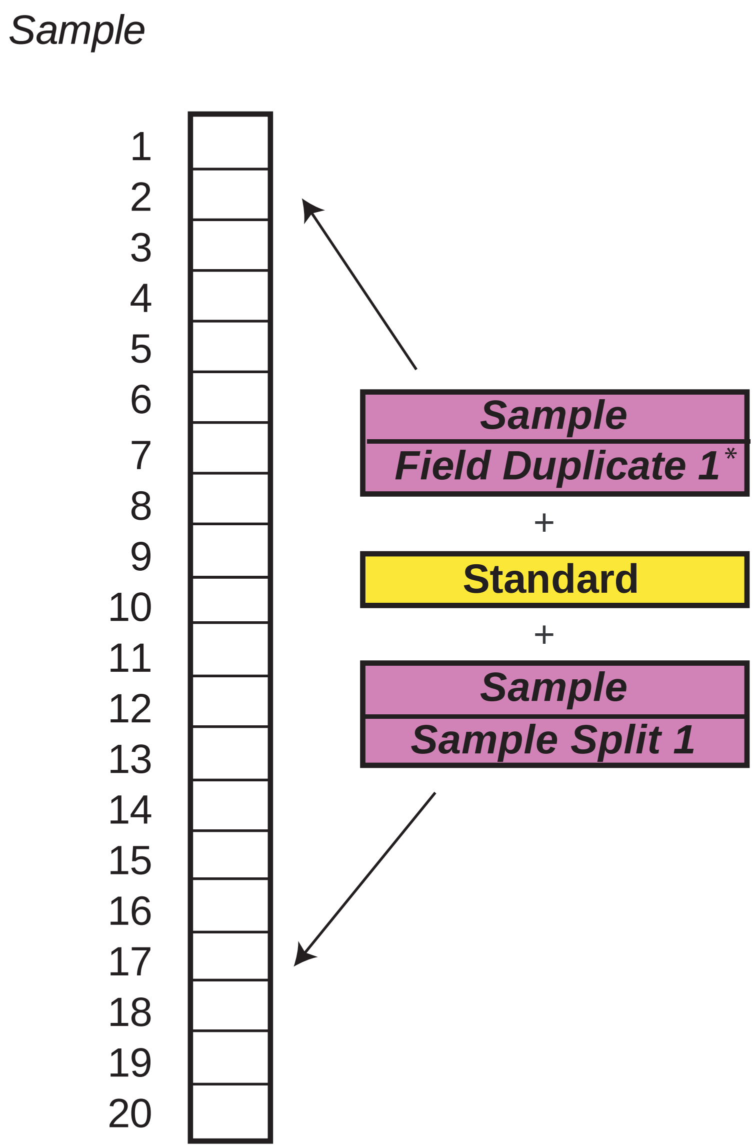
Table 2. Elements analyzed by the INA method on the silt plus clay-sized fraction (<0.063 mm) of till matrix, and associated detection limits.

Quality Assurance–Quality Control

To discriminate geochemical trends related to geological factors from those that result from spurious sampling or analytical errors, a number of quality assurance and quality control measures (QA/QC) were included in both the field and laboratory components of the project. These included the use of field duplicates, analytical or blind duplicates, and control standards. One each of the analytical duplicates and control standards were randomly inserted into each set of 18 routine field samples to make a block of 20 samples submitted for geochemical analysis (Fig. 12). Field duplicates were randomly inserted in 20 sample blocks in the last 100 samples. Field duplicates were taken from randomly selected field locations and subjected to identical laboratory preparation procedures. Analytical or blind duplicates consist of sample splits taken after laboratory preparation procedures, but prior to analysis. ACME also ran analytical duplicates to evaluate QA/QC. Control standards used in the QA/QC include certified reference samples from the Canada Centre for Mineral and Energy Technology (CANMET) and in-house BC Geological Survey geochemical reference materials comprising the –180 µm size fraction of a variety of bulk samples. Also, ACME Analytical Laboratories Limited inserted their own internal laboratory standards (C and C2) in the analysis to monitor matrix affects and internal drifts. Duplicate field and laboratory samples were included to measure sampling variability and analytical precision, respectively, whereas reference standards were used to measure the analytical accuracy.

For this project, 9 field duplicate samples were collected (i.e., nine duplicate pairs). In Appendices 7 and 8, FDUP1 identifies the first sample collected at a field duplicate site while FDUP2 is the second sample collected at the same sampling site. Ten analytical pairs and ten reference standards were also inserted into the sample sequence before analysis. Elemental concentrations for analytical duplicates analyzed using the ICP-ES and INA methods are provided in Appendices 9 and 10. Certified and reference values for ACME, CANMET, and BCGS standards used in this project are provided in Appendices 11 and 12.

The main elements of interest selected for quality control analyses were Ba, Ca, Cr, Co, Cu, Fe, Pb, Zn by ICP-ES after aqua regia digestion and Au, As, Ba, and Sb by INA,. Scatter plots of geochemical analyses from pairs of duplicate field and analytical samples were developed for these selected elements and shown in figures 13 and 14. In figures 15 and 16, scatterplots of trace element concentrations measured in analytical duplicates by the ICP-ES and INA methods, respectively, are presented. For the most part, analyses of the field and analytical duplicate samples suggests that there is good reproducibility (high precision; R^2>0.8). The main exceptions are Au (by INA; Figs. 14 and 16) and Pb (ICP-ES; Figs. 13 and 15). The concentrations of these elements in till from the project area generally show better reproducibility for analytical duplicates than for field duplicates (Figs. 13–16), as expected, due to the higher number of variables introduced in the field sampling process. In the case of Au,



* Field duplicates were only inserted in the last 100 samples (6500-6599)

Figure 12. Typical 20-sample block QA/QC scheme used for sampling and analysis in this project. For every 20 samples submitted for geochemical analyses, one field duplicate and split sample pair, and a CANMET or BCGS standard was included. The scheme is adapted from similar QA/QC schemes used by the BCGS and the GSC for regional geochemical surveys (e.g. Lett et al. 1995).

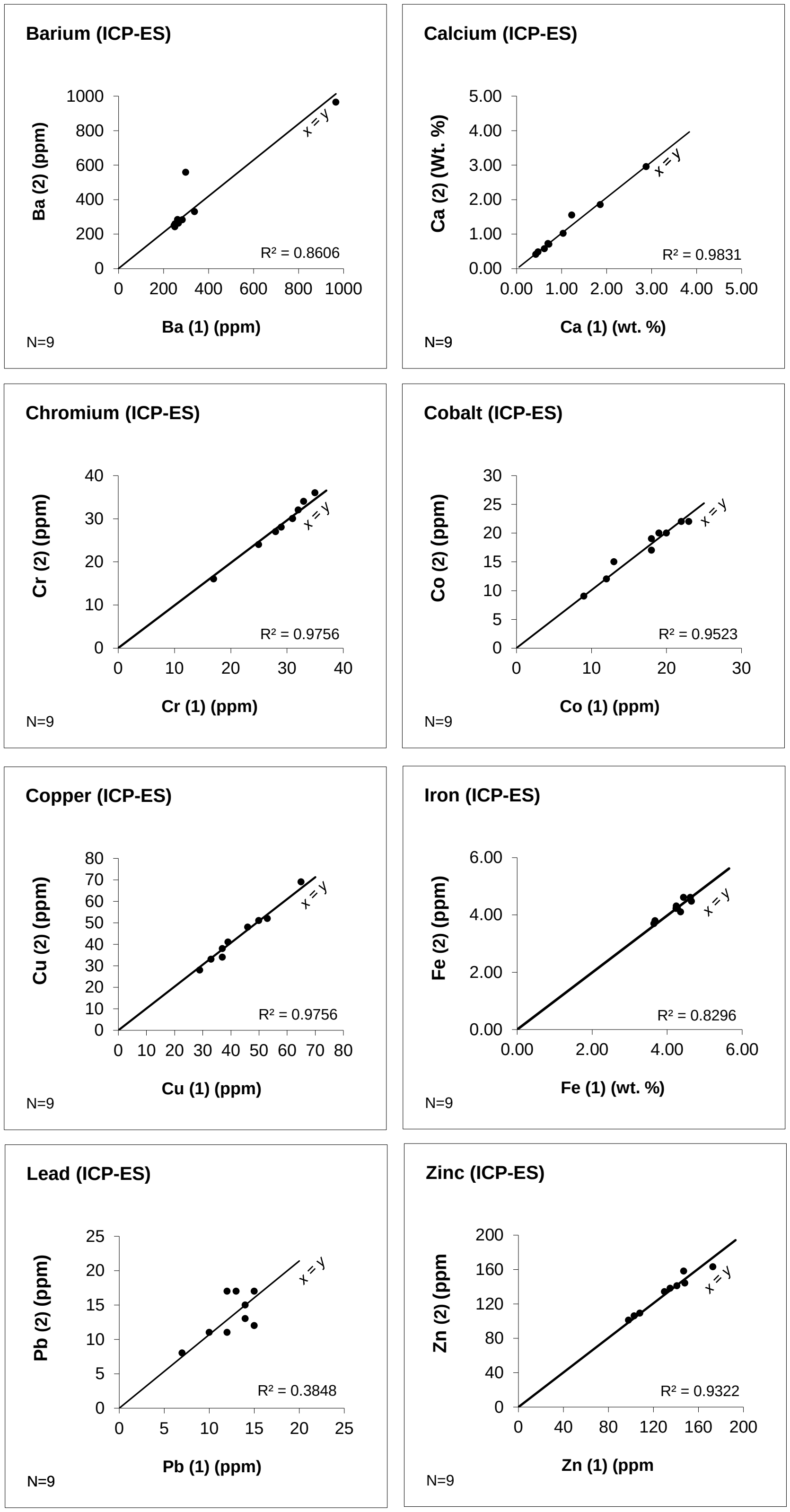


Figure 13. Field duplicate scatter plots for selected elements (barium, calcium, chromium, cobalt, copper, iron, lead, and zinc) in the <0.063 mm fraction of basal till samples analyzed by the ICP-ES method.

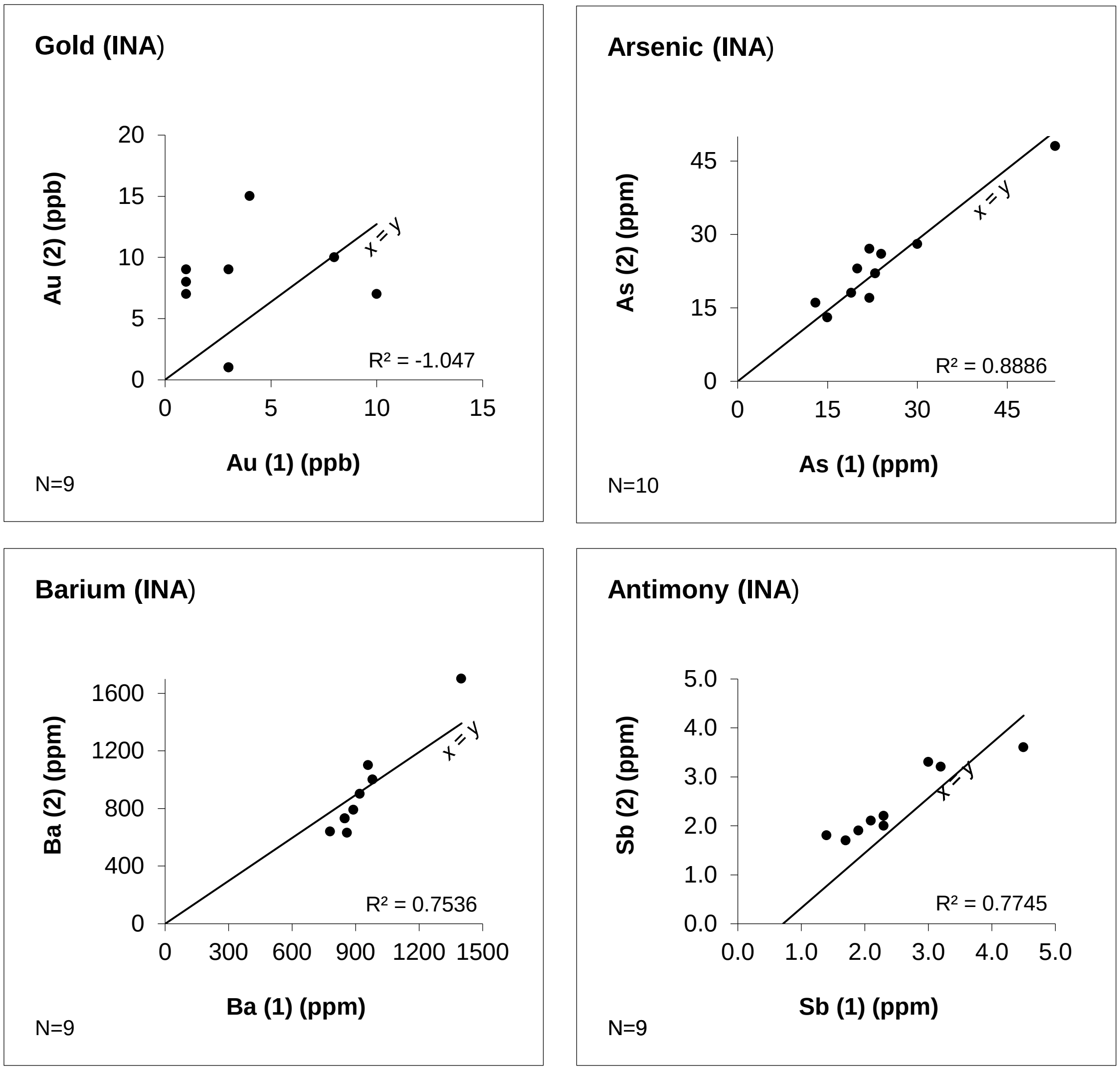


Figure 14. Field duplicate scatter plots for selected elements (gold, arsenic, barium, and antimony) in the <0.063 mm fraction of basal till samples analyzed by the INA method.

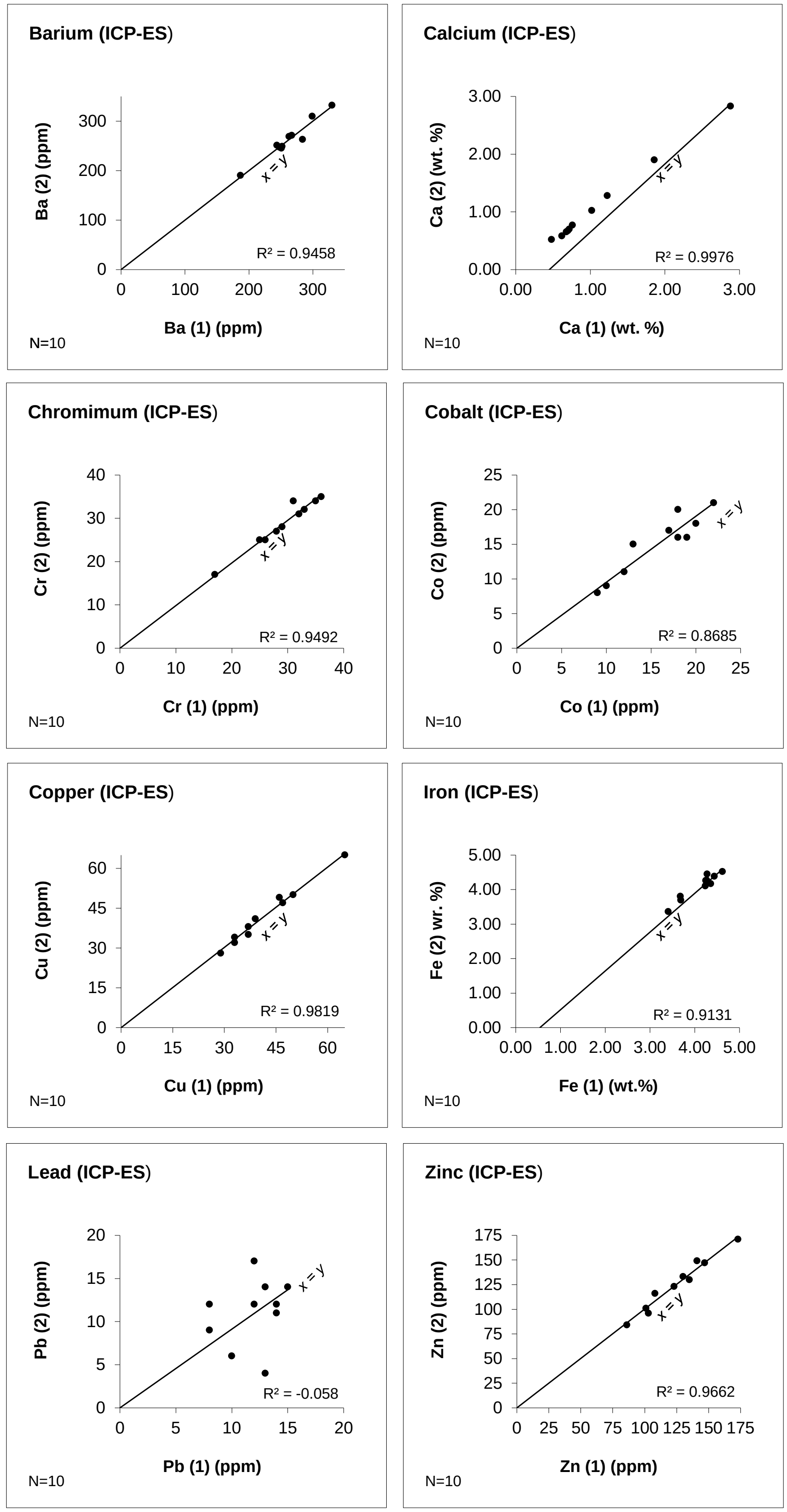


Figure 15. Analytical duplicate scatter plots for selected elements (barium, calcium, chromium, cobalt, copper, iron, lead, and zinc) in the <0.063 mm fraction of basal till samples analyzed by the ICP-ES method.

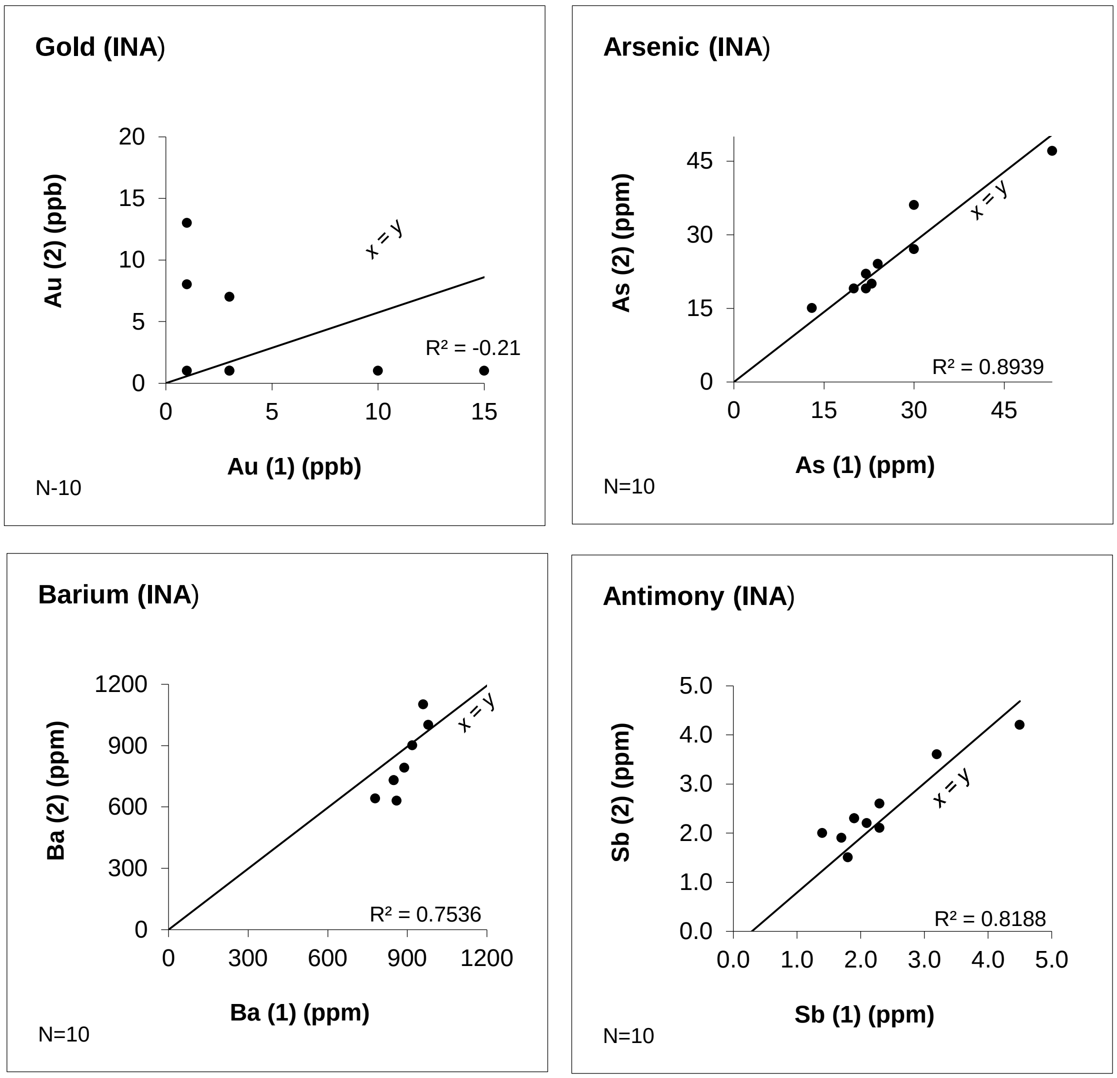


Figure 16. Analytical duplicate scatter plots for selected elements (gold, arsenic, barium, and antimony) in the <0.063 mm fraction of basal till samples analyzed by the INA method.

extremely poor reproducibility is attributed to the heterogeneous distribution of Au grains, the “nugget effect” (e.g., Day and Fletcher, 1986). The source of the poor precision in Pb is unknown.

Also, the data presented in Tables 3–5 shows that there is also good reproducibility in certified and reference standards and that the analytical methods used demonstrate an acceptable degree of accuracy and precision. As an evaluation of precision, the percent relative standard deviations (%RSD) were calculated. For the majority of elements the %RSD ranges between 1.56 and 21. In exploration geochemistry, %RSD values <20 % are considered applicable (Ferbey et al., 2009).

RESULTS AND INTERPRETATION

Till Geochemical Data

In the following section, an overview is provided on the regional distributions of elements analyzed from 146 till samples taking into account the bedrock geology and patterns of glacial transport, but is not a comprehensive discussion of all the elements for which analytical results were obtained. Maps of the geochemical composition in till are presented using proportional symbols for the economically significant elements discussed below. Additional maps of the other elements analyzed are provided in Appendices 5 and 6. Some maps are depicted with the bedrock geology units or traces of faults derived from Geoscience BC, 2010. The elemental concentrations are subdivided at ≤50th, >50th, 75th, 90th, 95th, and 98th percentile breaks. These breaks are commonly used in BC as an unbiased method to classify till geochemical data (e.g., Plouffe and Ballantyne, 1993; Levson, 2002; Lett et al., 2006; Ferbey, 2010).

Selected summary statistics of elemental concentrations for Cu, Mo, Pb, Zn, Ag, Au, As, Sb, Ni, Cr, and Co (N=146) are presented in Tables 6 and 7. Some elements presented in the report were analysed by using both the ICP-ES and INA methods. For simplicity, the discussions that follow refer to results for Cu, Mo, Pb, Zn, Ag, Ni, and Co from the ICP-ES method and Au, As, Sb, and Cr from the INA method.

For the summary statistics and geochemical maps, the second sample collected at a field sample site (i.e., FDUP20; see Appendices 7 and 8) were removed from the data set. The background concentration for the elements in the project area are defined as the median value and concentrations >95th percentile are considered elevated (cf. Ferbey, 2010). The term ‘elevated’ is used in the comparison of elemental concentrations to other till samples in the project area and does not directly imply economic significance (cf. Levson, 2002). When analyzing and interpreting the geochemical data it is important to consider that elemental

Detemination ACME Std. C	Ba (ppm)	Ca (wt. %)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (wt. %)	Pb (ppm)	Zn (ppm)
detection limit	1	0.01	1	1	1	0.01	3	0.1
expected	181	0.51	60	31	58	4.01	41	134
mean	193	0.51	63	36	57	3.86	40	144
maximum	199	0.51	67	38	61	4.07	46	148
minimum	187	0.51	59	33	53	3.64	34	140
standard deviation	8	0.00	6	4	6	0.30	8	6
%RSD	4	0.00	10	11	11	7.77	20	4
n	2	2	2	2	2	2	2	2

Detemination ACME Std. C2	Ba (ppm)	Ca (wt. %)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (wt. %)	Pb (ppm)	Zn (ppm)
detection limit	1	0.01	1	1	1	0.01	3	0.1
expected	204	0.55	67	37	61	3.95	40	141
mean	191	0.53	63	35	58	3.83	39	148
maximum	204	0.56	67	36	62	3.94	49	153
minimum	180	0.52	60	33	53	3.70	36	142
standard deviation	6	0.01	2	1	2	0.06	3	3
%RSD	3	1.89	3	3	3	1.56	8	2
n	20	20	20	20	20	20	20	20

Table 3. Summary statistics and percent relative standard deviation (%RSD) values for ACME standards C and C2.

Determination CANMET STSD-4	Ba (ppm)	Ca (wt. %)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (wt. %)	Pb (ppm)	Zn (ppm)
Detection Limit	1	0.01	1	1	1	0.01	3	0.1
expected "partial"			30		66	2.60	13	82
expected "total"	2000	n/a	93	13	65	4.10	16	107
mean	969	1.22	34	12	68	2.83	15	100
maximum	987	1.25	35	13	70	2.90	16	102
minimum	951	1.20	33	12	66	2.78	12	99
standard deviation	18	0.03	1	1	2	0.06	2	2
%RSD	2	2.46	3	8	3	2.00	13	2
n	3	3	3	3	3	3	3	3

Determination CANMET STSD-4	Au (ppb)	As (ppm)	Ba (ppm)	Sb (ppm)
Detection Limit	2	0.5	50	0.1
expected "partial"	4	15	2000	7.3
expected "total"				
mean	8	15	2167	7.2
maximum	9	16	2200	7.4
minimum	7	14	2100	7.1
standard deviation	1	1	58	0.2
%RSD	13	7	3	2.8
n	3	3	3	3

Table 4. Summary statistics and percent relative standard deviation (%RSD) values for CANMET standard STSD-4.

Determination of BCGS Standard 1	Ba (ppm)	Ca (wt. %)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (wt. %)	Pb (ppm)	Zn (ppm)	Au (ppb)	As (ppm)	Ba (ppm)	Sb (ppm)
detection limit	1	0.01	1	1	1	0.01	3	0.1	2	0.5	50	0.1
expected	58	1.01	23	10	196	5.34	7	54	85	10.9	553	1.1
mean	62	1.03	25	11	197	5.06	10	62	96	9.4	517	0.9
maximum	73	1.09	27	12	211	5.40	14	64	140	12.0	870	1.2
minimum	51	0.94	20	8	183	4.72	7	58	76	7.2	360	0.6
standard deviation	6	0.04	2	1	7	0.18	2	2	17	1.4	108	0.1
%RSD		3.88	8	9	4	3.56	20	3	18	14.9	21	8.3
n	13	13	13	13	13	13	13	13	21	21	21	21

Determination of BCGS Standard 2	Ba (ppm)	Ca (wt. %)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (wt. %)	Pb (ppm)	Zn (ppm)
detection limit	1	0.01	1	1	1	0.01	3	0.1
expected	53	0.83	21	9	177	4.84	7	55
mean	58	0.84	22	10	177	4.61	9	63
maximum	77	0.89	24	12	195	4.85	13	78
minimum	48	0.80	20	9	166	4.43	5	57
standard deviation	7	0.02	1	1	7	0.12	3	6
%RSD	12	2.38	5	10	4	2.60	33	10
n	13	13	13	13	13	13	13	13

Determination of BCGS Standard 3	Au (ppb)	As (ppm)	Ba (ppm)	Sb (ppm)
Detection Limit	2	0.5	50	0.1
Expected	50	8.6	528	0.9
mean	50	7.5	516	0.8
maximum	67	9.3	580	0.9
minimum	41	6.3	460	0.6
standard deviation	8	0.8	40	0.1
%RSD	16	10.7	8	12.5
n	14	14	14	14

Table 5. Summary statistics and percent relative standard deviation (%RSD) values for BCGS standards 1, 2, and 3.

	Cu (ppm) ICP-ES	Mo (ppm) ICP-ES	Pb (ppm) ICP-ES	Zn (ppm) ICP-ES	Ag (ppm) ICP-ES	Ni (ppm) ICP-ES	Co (ppm) ICP-ES
detection limit	1	1	3	0	0.3	1	1
maximum	159	19	56	547	1.8	72	24
minimium	16	<1	4	59	<0.3	12	6
mean	43	1	12	129	0.4	31	14
median	42	1	12	121	0.4	31	14
n	146	146	146	146	146	146	146

Table 6. Summary statistics for aqua regia ICP-ES determinations of Cu, Mo, Pb, Zn, Ag, Ni, and Co on the silt plus clay-sized fraction (<0.063 mm) of till samples.

	Au (ppb)	As (ppm)	Cr (ppm)	Sb (ppm)
detection limit	2	0.5	5	0.1
maximum	30	99.0	140	6.9
minimium	<2	8.2	53	1.0
mean	8	21.5	78	2.2
median	8	18.0	77	1.8
n	146	146	146	146

Table 7. Summary statistics for INA determinations of Au, As, Cr, and Sb on the silt plus clay-sized fraction (<0.063 mm) of till samples.

concentrations in till are typically one or more orders of magnitude lower than in their source bedrock. Therefore, the concentrations should be regarded as relative values rather than absolute concentrations in order to make meaningful interpretations of the till geochemistry.

Copper

Elevated concentrations of copper (>98th percentile) are present in till samples at three sites in the project area (Fig. 17). The highest Cu value in the project area is 159 ppm from sampling site 6542, located in the vicinity of intrusive rocks assigned to the Bulkey Plutonic Suite-McCauley Plutonic Suite. The other two anomalies are located over 1 km away from known mineralization at the Chris showing and past producers Topley Richfield, Silver Cup, and Golden Eagle (Fig. 17). These anomalies could be part of dispersal trains formed to the south and southwest of these mineral occurrences.

Molybdenum

Only 11 till samples had molybdenum concentrations above the detection limit of 1 ppm. The two highest concentrations for molybdenum (19 ppm and 9 ppm) were measured in till from sampling sites 6555 and 6563, respectively (Fig. 18), located to the south of polymetallic veins containing Ag-Pb-Zn+/-Au mineralization at the Su mineral showing (Fig. 18). These elevated concentrations are present in the same area as >98 percentile concentrations for multiple elements, including Zn, Ag, As, and Sb (discussed below).

Lead

Elevated concentrations of Pb were measured in only 3 till samples in the project area. These anomalies appear to be associated with subvolcanic mineralization at the Westgarde mineral showing, developed prospect and past producers at Dome Mountain, and possibly part of a dispersal train formed to the west (down-ice) of Grouse Mountain (Fig. 19). Also, samples that returned >90th percentile concentrations of Pb were collected at sites located to the south of the Su mineral showing and west of the Bulkley River valley.

Zinc

Elevated concentrations of Zn were measured in till sampled at or nearby five mineral occurrences in the project area; south of the Su showing, at Dome Mountain, in the vicinity of the Westgarde showing, at the Bob Creek past producer, and northwest of the Bill and Huber showings (Fig. 20). The highest concentrations of Zn, 547 and 490 ppm, were measured in till samples collected at sites 6544 and 6555, respectively (Appendix 3; Fig. 10). The elevated concentrations for Zn at sites near the Su and Bob Creek properties are coincidental with >98th percentile values measured for Ag, As, Sb, and Co.

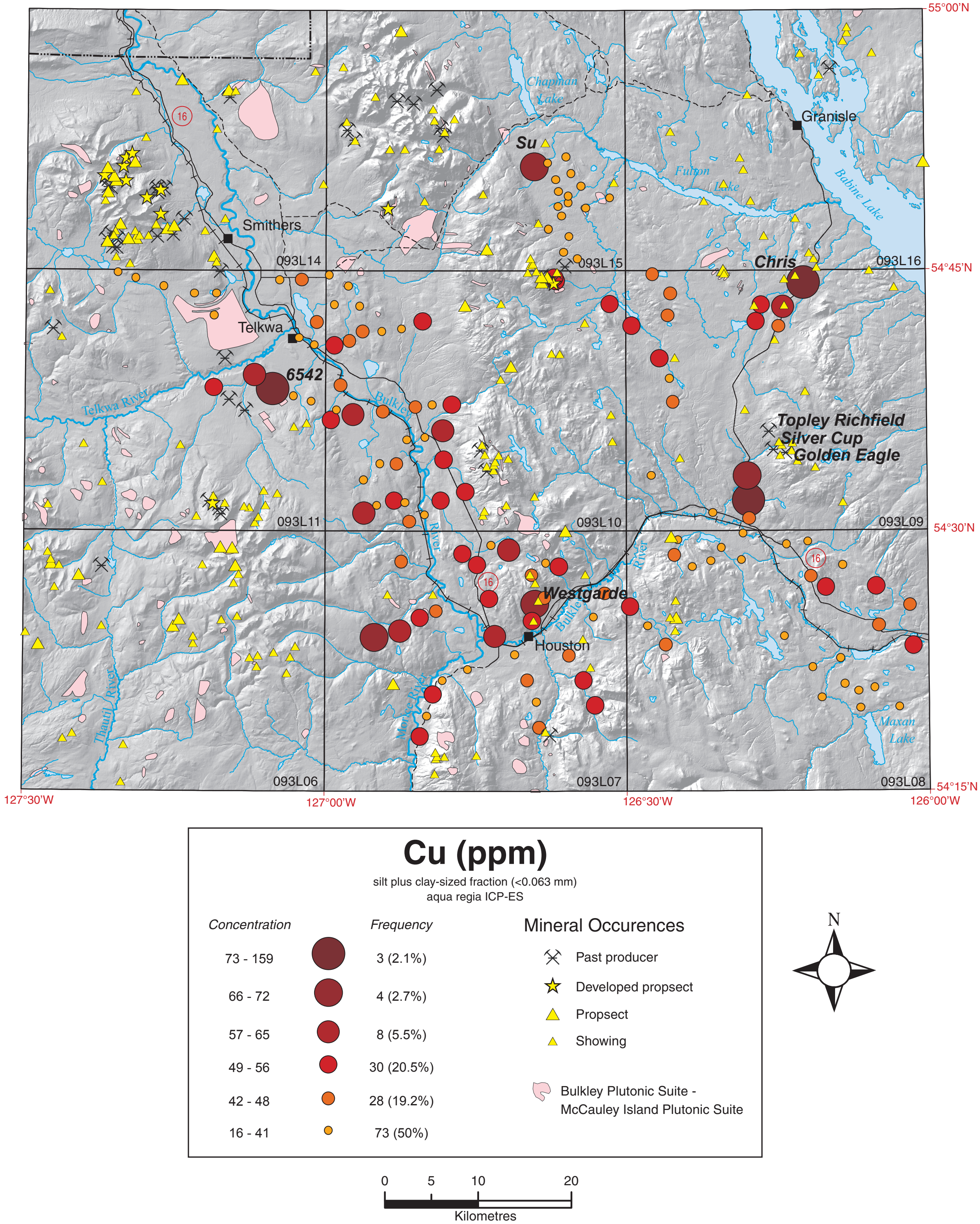


Figure 17. Copper concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

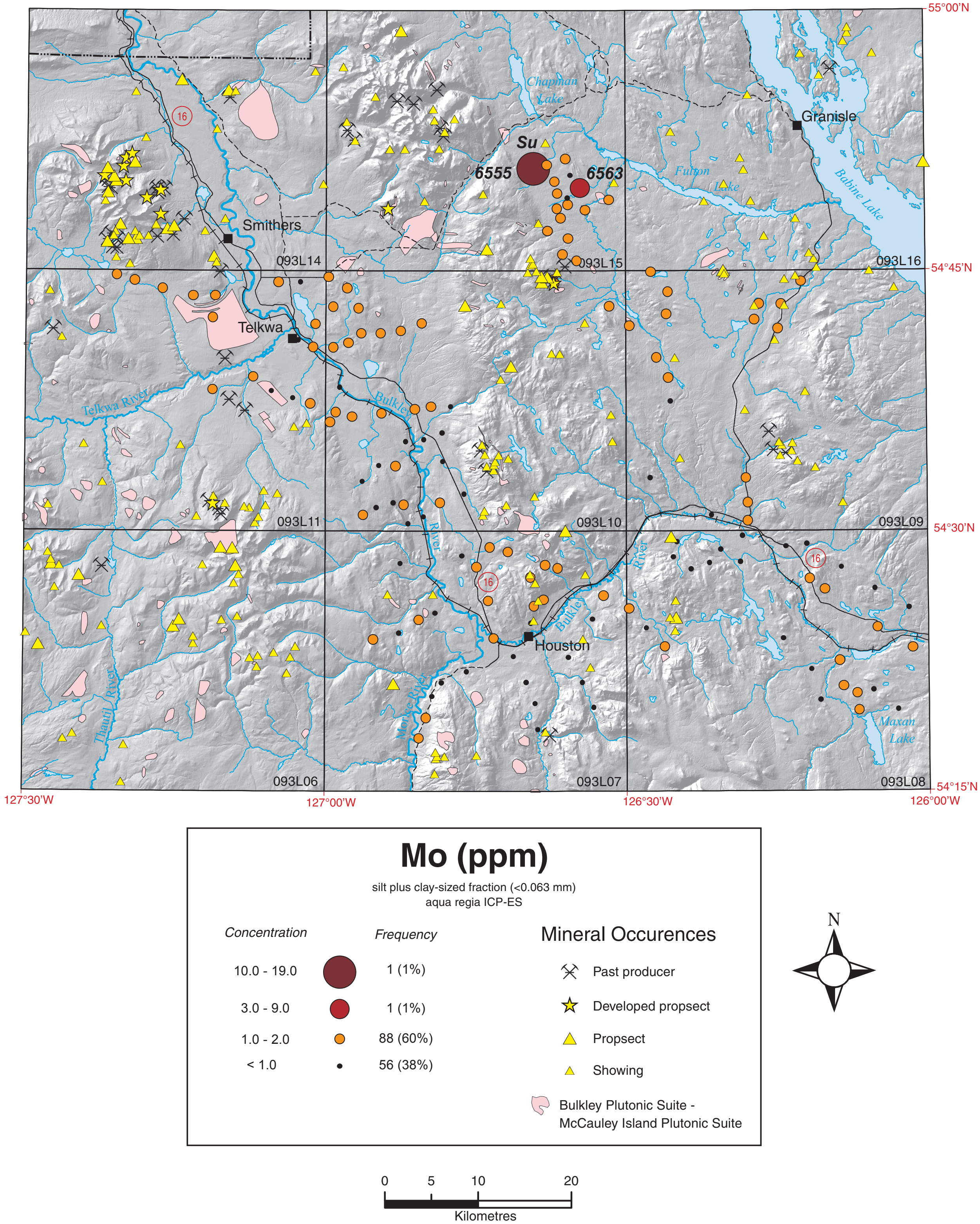


Figure 18. Molybdenum concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

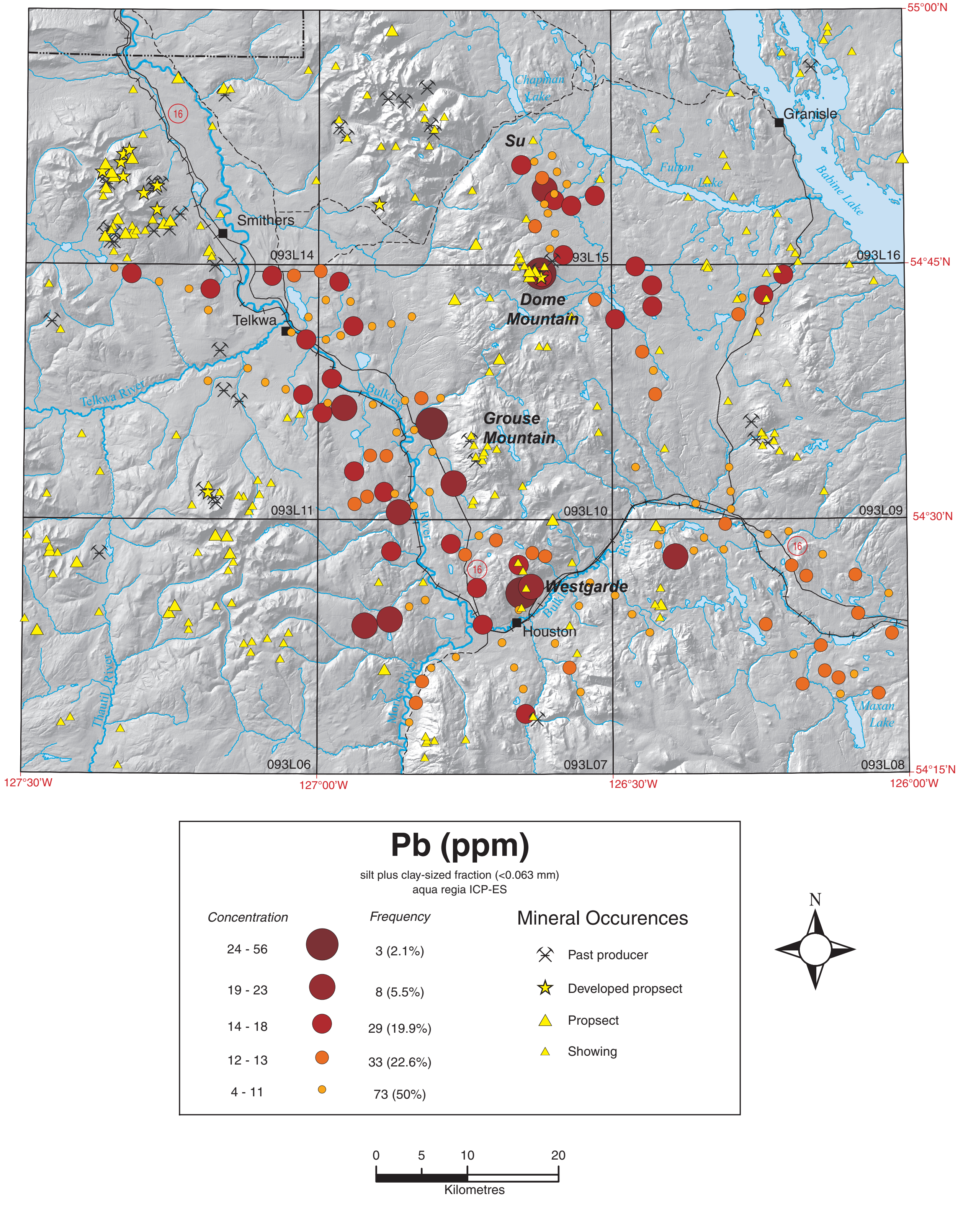


Figure 19. Lead concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

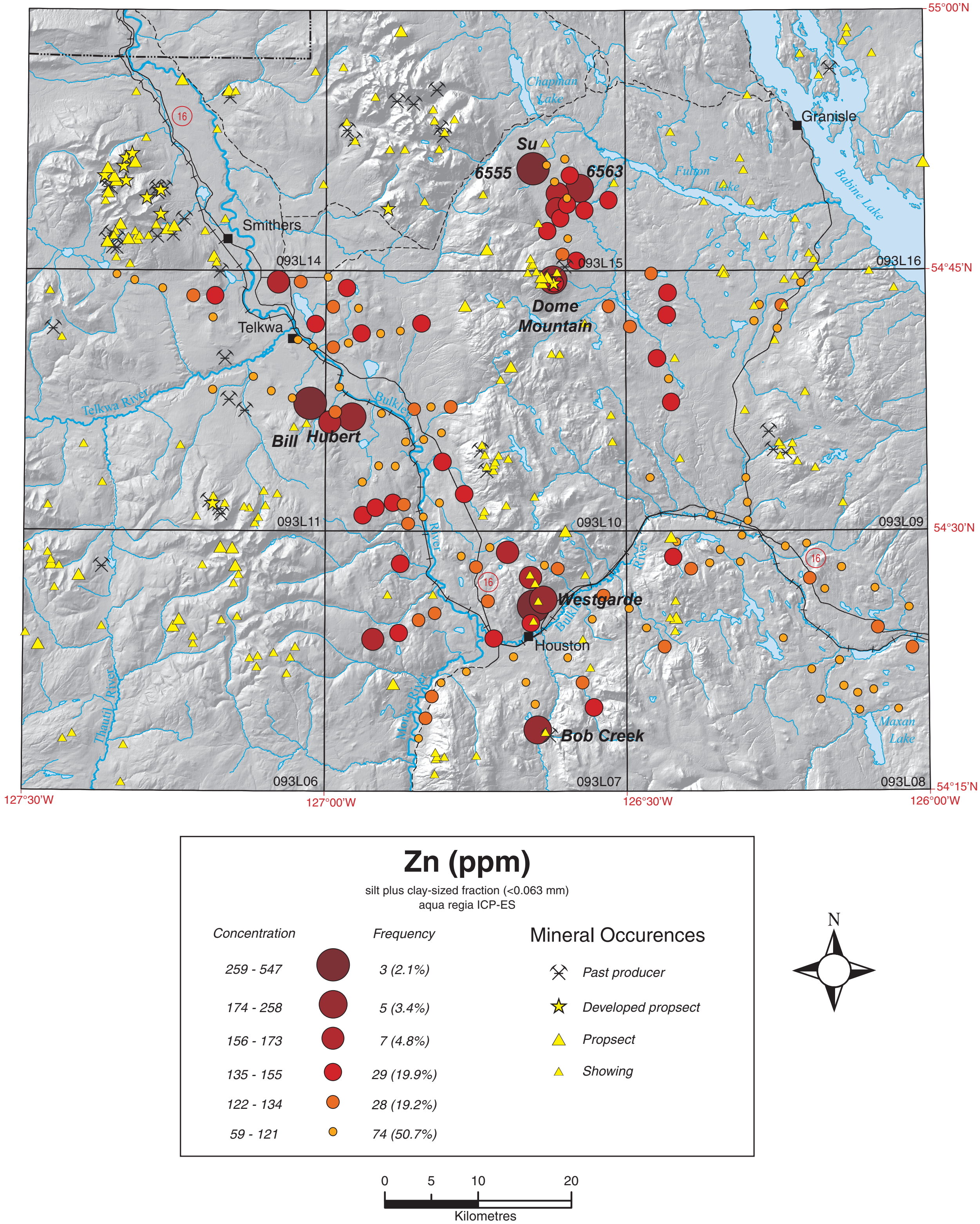


Figure 20. Zinc concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

Silver

Only 3 till samples had concentrations of Ag that were in the >98 percentile of the dataset (Fig. 21). These elevated Ag concentrations were measured at sampling sites located south of the Su showing, in the Bulkley River valley along the southern part of NTS map area 093L/010, and east of the Town of Telkwa. Over two-thirds of the samples analyzed had Ag concentrations below the detection limit.

Gold and potential pathfinders: arsenic and antimony

Coincidental elevated concentrations for Au, As, and Sb were measured in till samples collected at sites in the vicinity of Dome Mountain (Figs. 22-24). But the highest gold values (18-21 ppb) were measured in till sampled at other sites located along the Bulkley River valley (Fig. 22). The majority of sites where above background concentrations for arsenic and antimony (Table 7) were measured in till are located in areas south of the Su showing and at Bob Creek past producer (Figs. 23-24). There also appears to be a direct relationship between the above background concentrations for these elements and the location of mapped faults. For example, an elevated arsenic concentration (77 ppm) measured at sampling site 6542 located southwest of the Town of Telkwa (Fig. 23) may be associated with mineralization along a fault mapped nearby the site.

Other metals: nickel, chromium, and cobalt

The spatial distributions of elevated concentrations for Ni, Cr, and Co do not appear to be primarily associated with known mineralization. Although elevated concentrations for Ni and Co were measured at sampling sites south of the Su showing (Figs. 25 and 26), at Dome Mountain and Westgarde showing, and south of the APEX 9 prospect (Fig. 27), coincidental anomalies for Ni and Cr are present to the northeast of the Town of Telkwa (Figs. 25 and 27), far from known mineralization and mapped bedrock structures. Elevated concentrations of Cr measured at several sites west of the Bulkley River in the NTS map area 093L/10 (Fig. 27) are found in the same area where elevated concentrations of Au and Ag were measured (Figs. 21 and 22). The highest concentrations for Ni and Cr (72 ppm and 140 ppm, respectively; Tables 6 and 7) were measured at site sampling 6467 east of Maxan Lake in the NTS map area 093L/08 (Figs. 25 and 27), but this site is located approximately 7 km to the west of the nearest mineral showing.

Clast Lithology Data

The spatial distribution of clasts sampled from the till having specific lithologies confirms the directions of glacial transport determined from indicators of ice flow on the bedrock surface and dispersal of elements in the till. For example, clasts of greenstone, syenite or lapilli tuff, and extrusive volcanic rocks (Figs. 28–30) to the west and southwest of source bedrock units indicate transport during the maximum phase of glaciation (Fig. 9). The presence of greenstone pebbles southeast of bedrock sources (Fig. 28) additionally supports transport by glaciers along

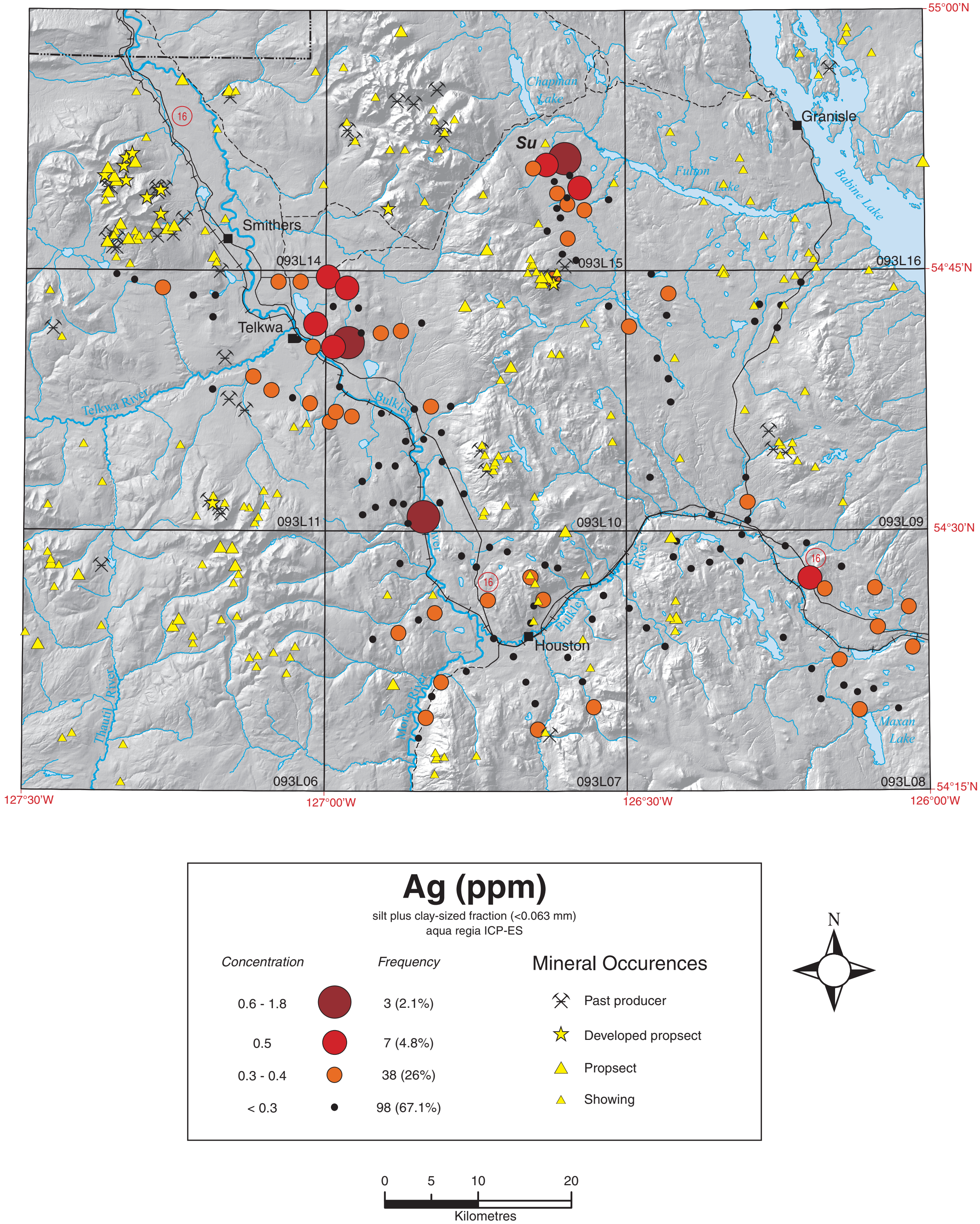


Figure 21. Silver concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

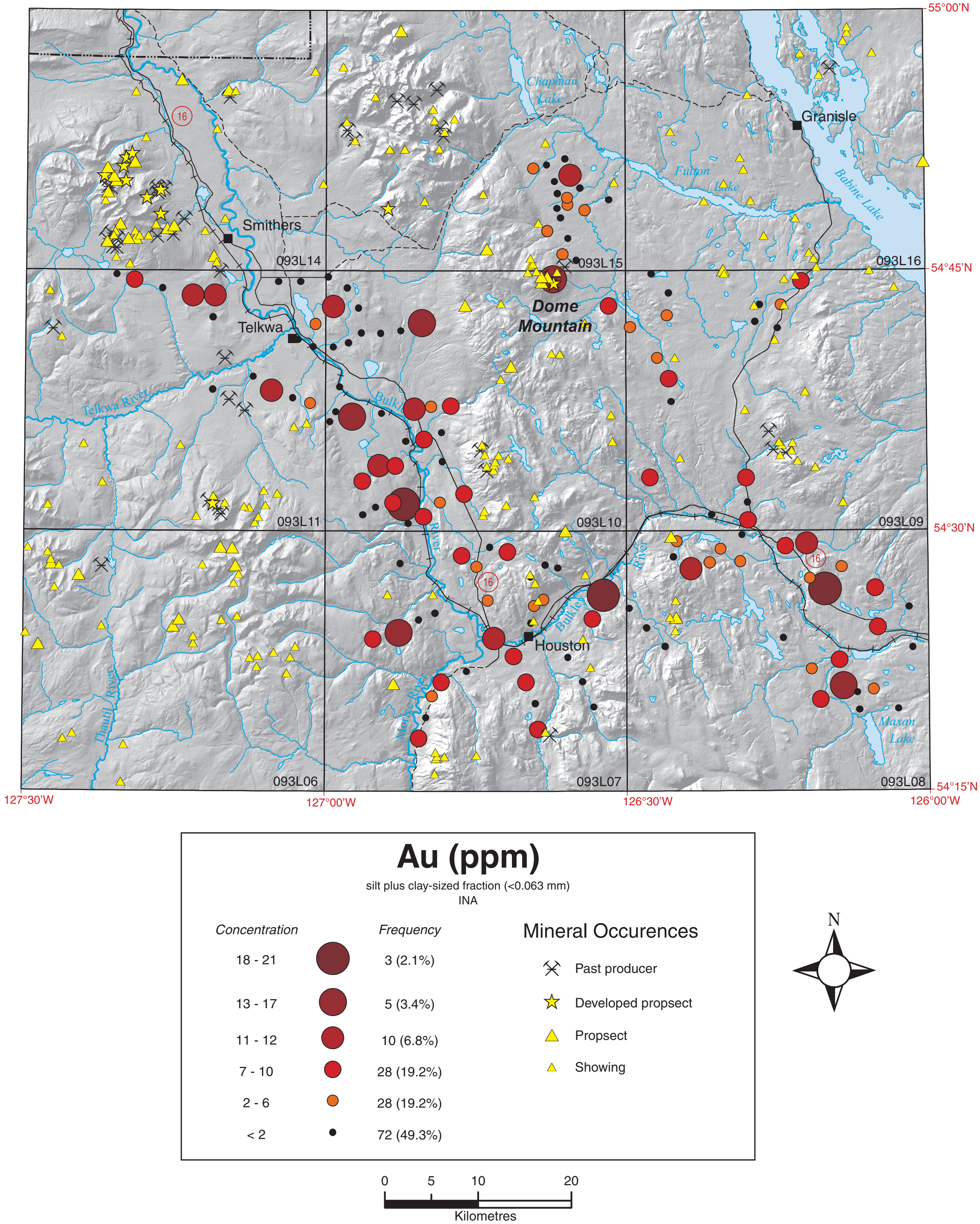


Figure 22. Gold concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

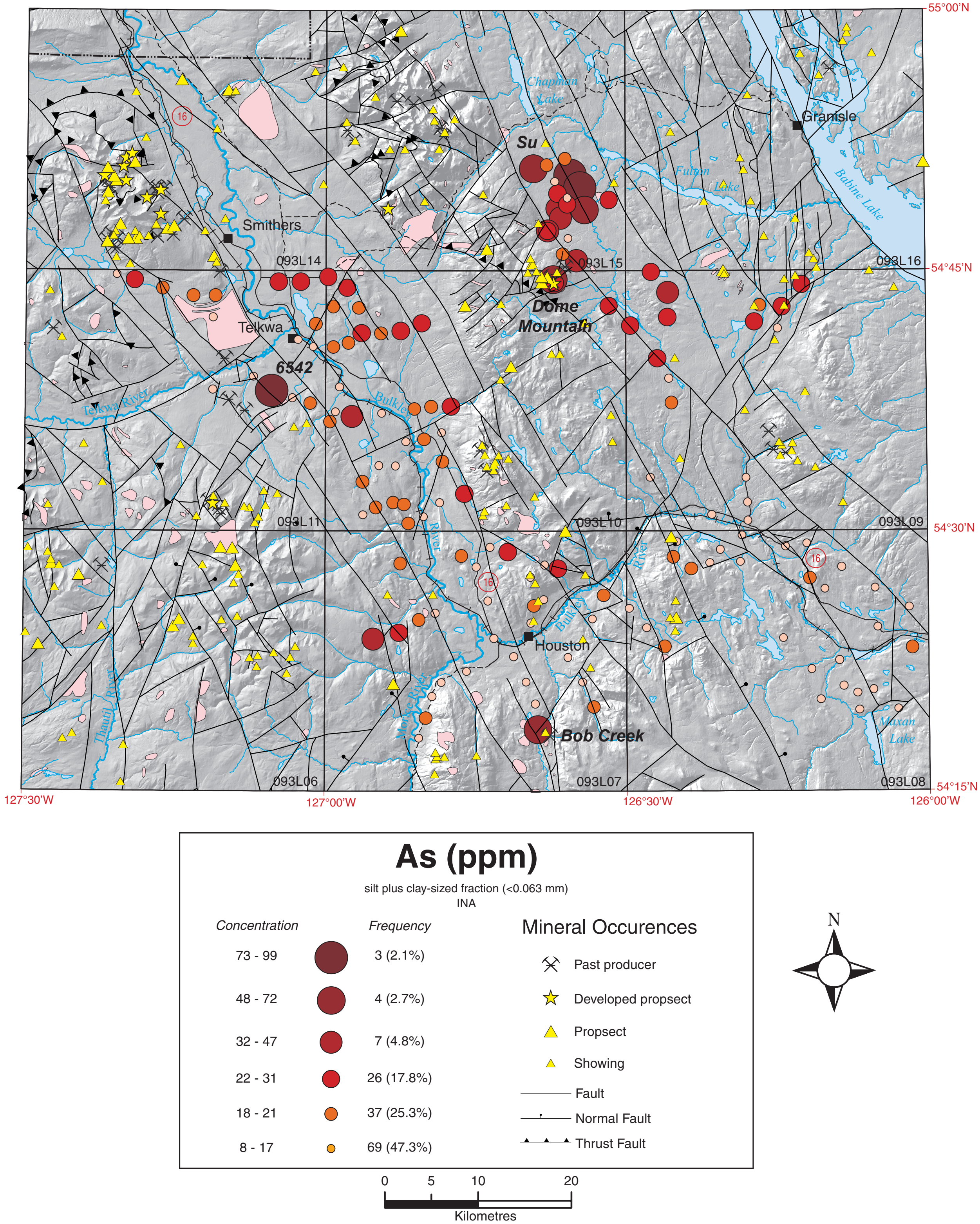


Figure 23. Arsenic concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

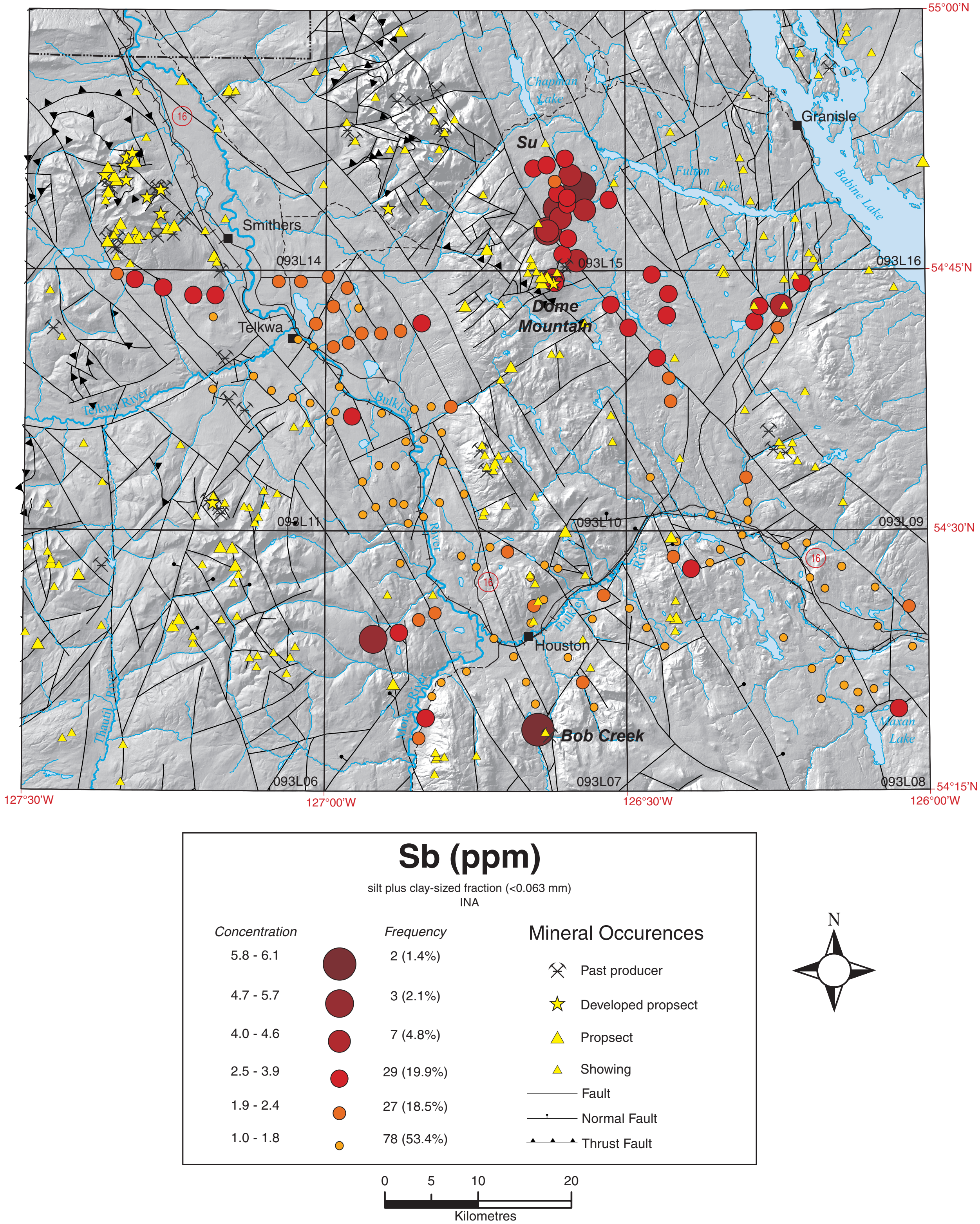


Figure 24. Antimony concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

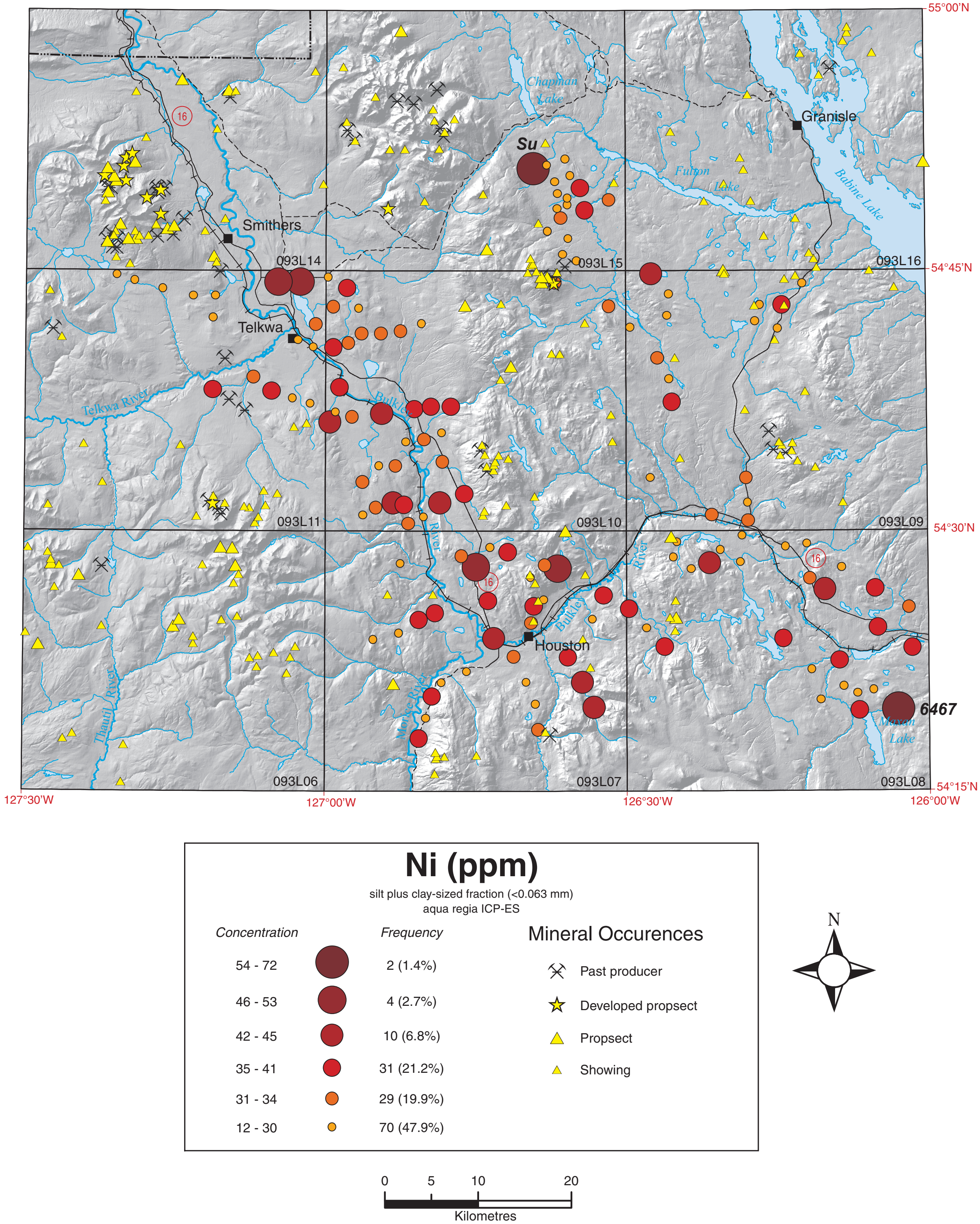


Figure 25. Nickel concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

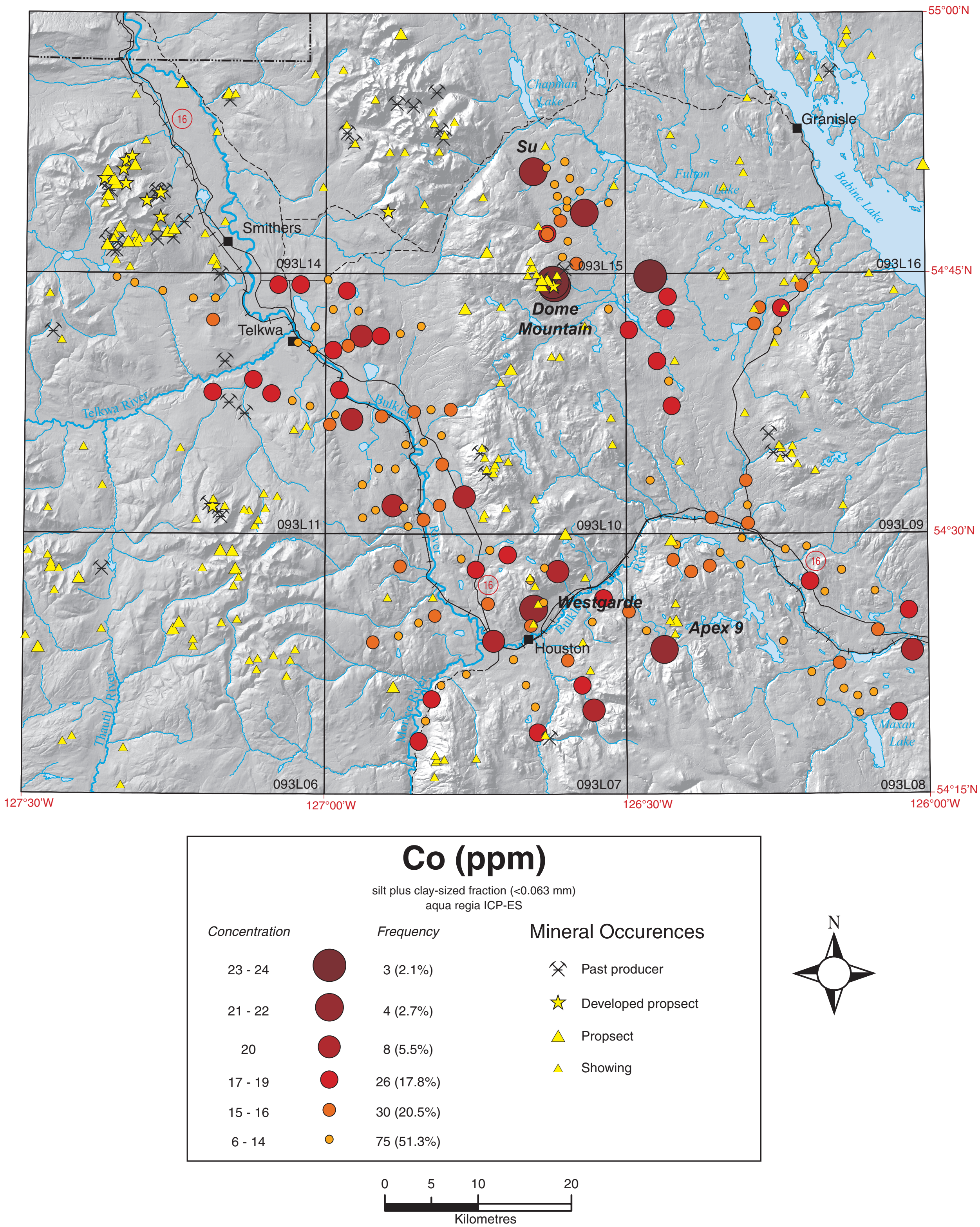


Figure 26. Cobalt concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

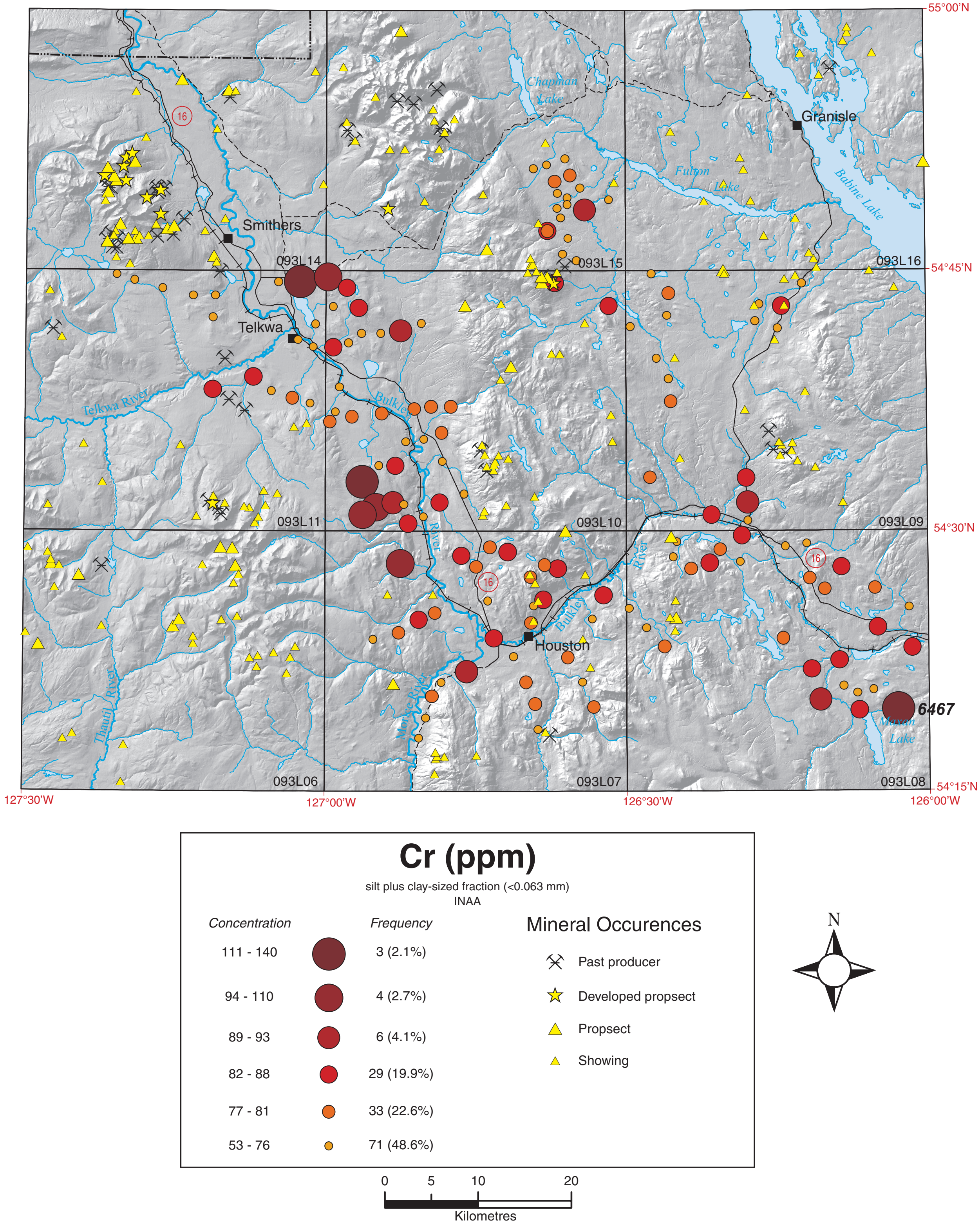


Figure 27. Chromium concentrations in the <0.063 mm fraction of basal till geochemical samples from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

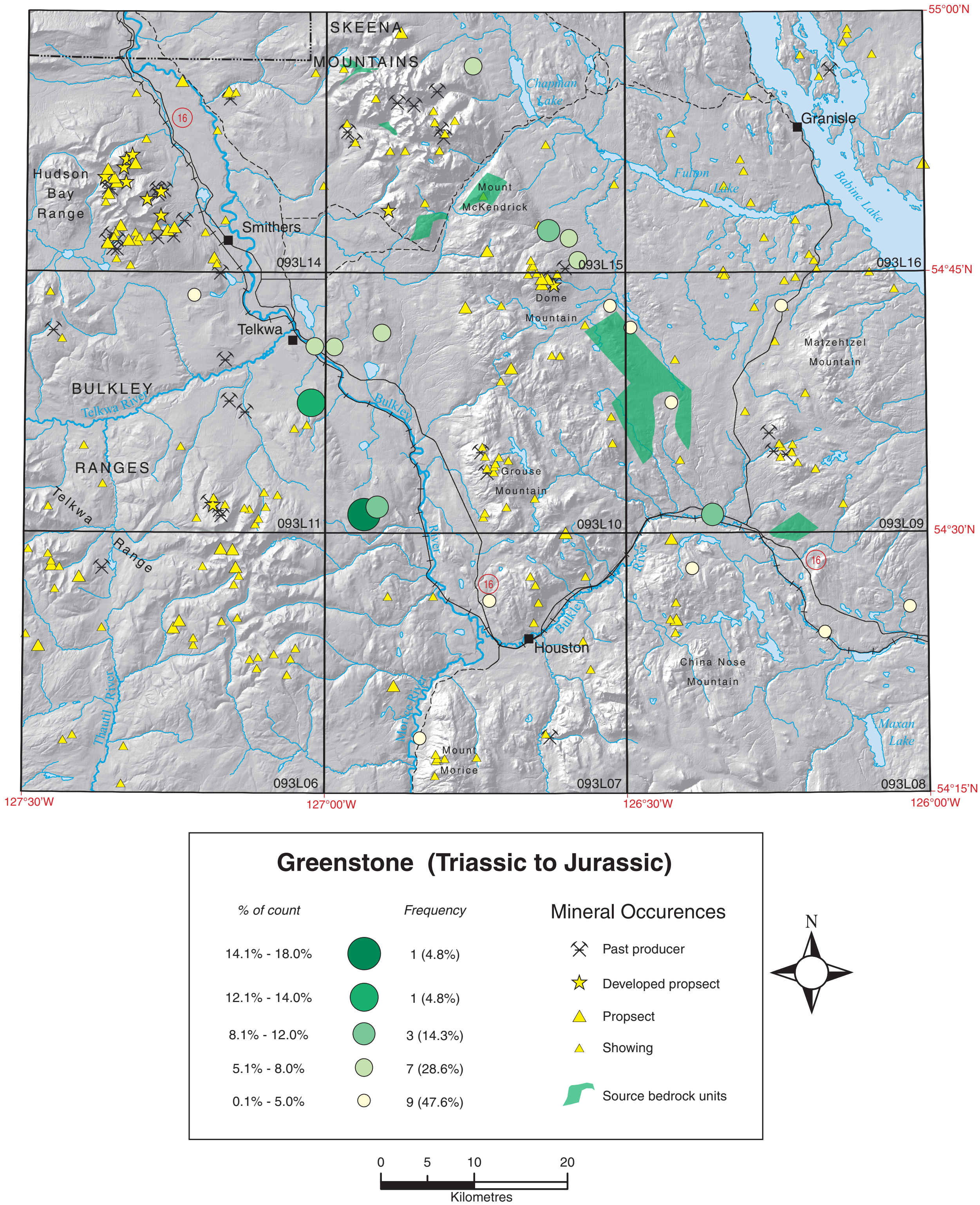


Figure 28. Percentage of greenstone clasts in till from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

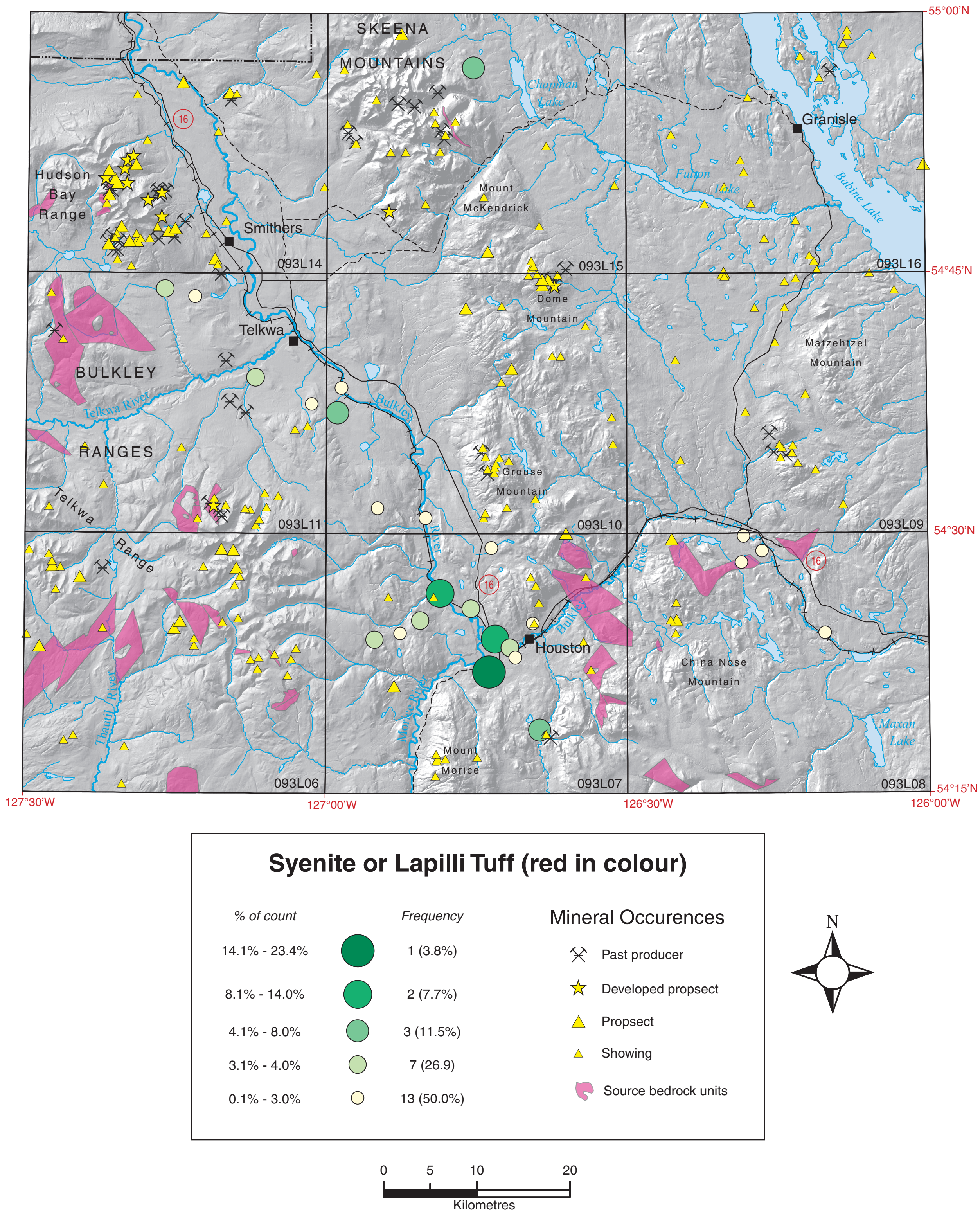


Figure 29. Percentage of syenite and red-coloured lapilli tuff clasts in till from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

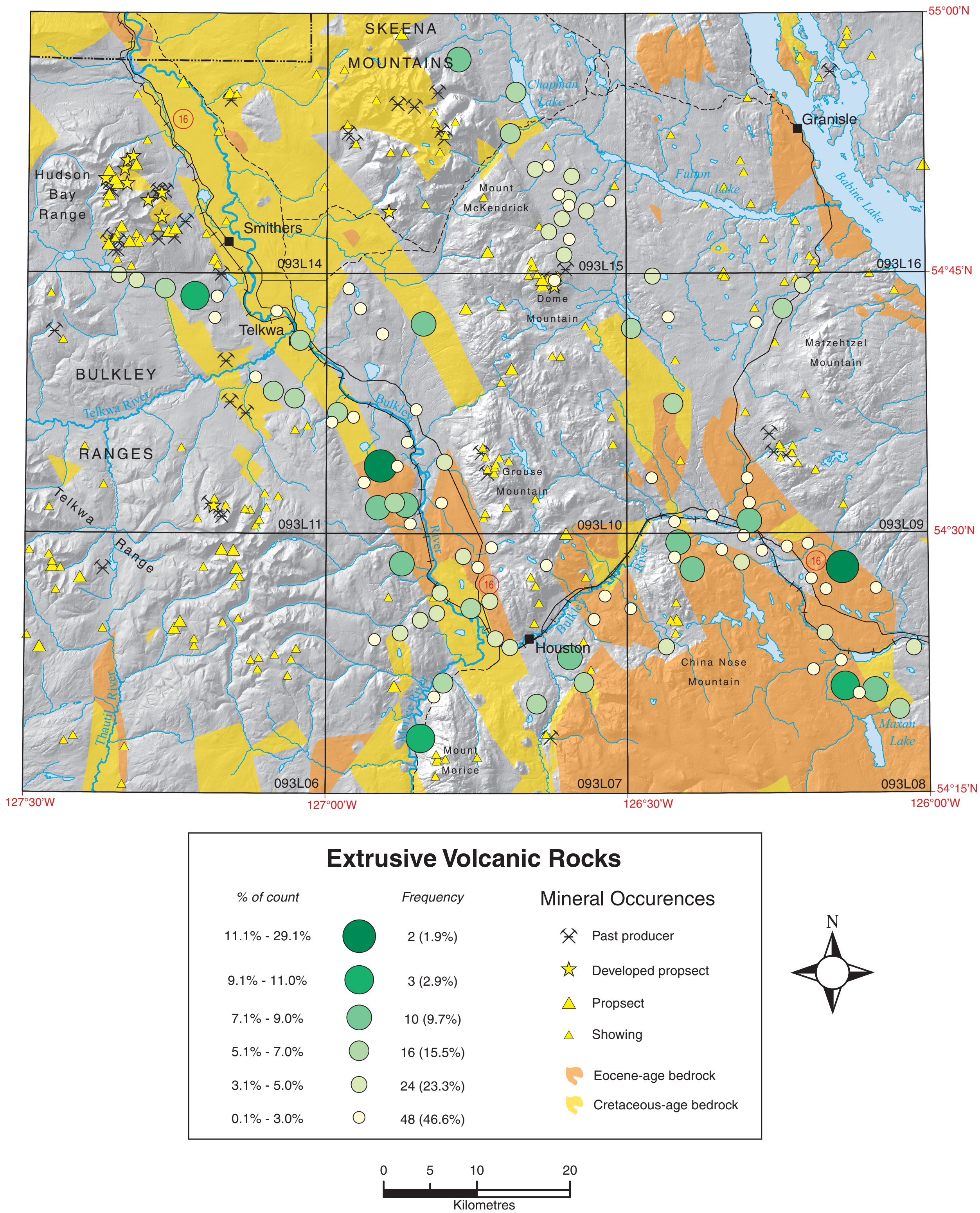


Figure 30. Percentage of extrusive volcanic clasts in till from the Bulkley River valley project area grouped by percentile classes, approximating the >98th, >95th, >90th, >70th, >50th and <50th percentiles.

the Babine Lake valley either during the advance or late-glacial phases of glaciation.

In some areas, the clast lithology information can also be used to infer the lithology of the underlying bedrock. For example, the highest percentages of extrusive volcanic rocks in till were recorded at sampling sites located on Eocene basaltic rocks and Cretaceous Kasalka Group andesitic flows and related rocks (Fig. 30). Clasts of extrusive volcanic rocks found in the Babine Lake valley to the east of Mount McKendrick and northwest of Matzehtzel Mountain likely were eroded from basaltic or pyroclastic volcanic rocks assigned to the Hazelton Group (Fig. 3); units that have not been differentiated on bedrock geology maps.

SUMMARY AND CONCLUSIONS

Results of this project demonstrate the applicability of till geochemistry and clast lithology studies to locate mineralization in this part of west-central BC, where a thick cover of glacial sediment masks the bedrock surface. In some parts of the project area, there is a direct relationship between the till composition and the underlying bedrock lithology. Elevated elemental concentrations in till were measured in the vicinity of known mineral occurrences. Furthermore, the directions of ice flow during different phases of the last (Wisconsin) glaciation are revealed by the spatial distribution of economically significant elements and clasts of distinctive lithology dispersed in till containing material eroded from their original bedrock source. During the maximum phase of glaciation, ice flowed to the west and southwest transporting its deposits long distances from their sources across confining topography that controlled the direction of ice movement during previous glacial events. In some areas, glacial dispersal was in the opposite direction of previous and later ice movements.

Elevated concentrations of Mo, Pb, Zn, Ag, and Ni in till were measured at sampling sites overlying and down-ice of known mineral deposits. The anomalies for these elements near the Su showing and Dome Mountain are coincidental with elevated concentrations measured for As, Sb, and Co. Elevated concentrations in till for some elements were also measured at sampling sites located in the Bulkley River valley north of the Town of Telkwa and east of Maxan Lake, and above the valley west of Grouse Mountain where no mineral occurrences have been reported. This information suggested that mineralized bedrock (not been previously mapped) may be present in the area below the cover of glacial sediment.

The clasts identified in till from the project area suggest glacial dispersal was up to 30 km down-ice of their bedrock source. For example greenstone and syenite clasts were found 20–30 km west (down-ice) of Late Cretaceous- and Eocene-age volcanic rocks. Also, the clasts in the till data can be used to map lithology of the underlying bedrock where the bedrock surface is masked by glacial sediment. In the project area, the number of clasts in the till of a specific lithology increases a short distance down-ice of contacts for bedrock having the same lithology.

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REFERENCES

Alldrick, D.J., MacIntyre, D.G. and Villeneuve, M.E. (2007): Geology, mineral deposits, and exploration potential of the Skeena Group (NTS 093E, L, M; 103I), central British Columbia; in Geological Fieldwork 2006, BC Ministry of Energy, Mines and Petroleum Resources, Paper 2007-1, p. 1–17, URL < http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Documents/02-Alldrick.pdf > [April, 2012].

Armstrong, J.E. (1944): Preliminary map, Smithers, British Columbia; Geological Survey of Canada, Paper 44-23, scale 1:126 720.

BC Geological Survey (2012): MINFILE BC mineral deposits database; BC Ministry of Energy, Mines and Petroleum Resources, URL <http://minfile.ca/> [March, 2012].

Carter, N.C. (1981): Porphyry copper and molybdenum deposits, west-central British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Bulletin 64, 150 p., URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/BulletinInformation/BulletinsAfter1940/Documents/Bulletin_064.pdf> [April, 2012].

Clague, J.J. (1984): Quaternary geology and geomorphology, Smithers-Terrace-Prince Rupert area, British Columbia; Geological Survey of Canada, Memoir 413, 71 p. (includes Map 1557A, 5 sheets at 1:100 000 scale), URL <ftp://ftp.nrcan.gc.ca/ess/publications/geopub/me_413.pdf> [March, 2012].

Day, S. and Fletcher, K. 1986. Particle size and abundance of gold in selected stream sediments, southern British Columbia, Canada. Journal of Geochemical Exploration, v. 26, p. 203–214.

Dreimanis, A. (1989): Tills: their genetic terminology and classification; in Genetic Classification of Glacigenic Deposits, Goldthwait, R.P. and Matsch, C.L., Editors, A.A. Balkema, Rotterdam, p.17–83.

Evenchick, C.A., Mustard, P.S., McMechan, M.E., Ritcey, D.H. and Smith, G.T. (2008): Geology, northeast Terrace and northwest Smithers, British Columbia; Geological Survey of Canada, Open File 5895, scale 1:125 000, URL <http://apps1.gdr.nrcan.gc.ca/mirage/full_result_e.php?id=226216> [April, 2010].

Ferbey, T. (2010): Till geochemistry of the Nadina River map area (093E/15), west-central British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Open File 2010-7, Geoscience BC, Report 2010-10, 56 p., URL < http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2010/Pages/2010-7.aspx> [March, 2012].

Ferbey, T. (2011): Till Geochemistry of the Colleymount map area (093L/01), west-central British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Open File 2011-6, Geoscience BC, Report 2011-9, 51 p. URL < http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2011/Pages/2011-6.aspx> [March, 2012].

Ferbey, T. and Levson, V.M. (2010): Evidence of westward glacial dispersal along a till geochemical transect of the Copper Star Cu±Mo±Au occurrence, west-central British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Open File 2010-04, 17 p., URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2010/Documents/2010-4/OF2010-4.pdf> [March, 2012].

Ferbey, T., Levson, V.M., and Lett, R.E. (2012): Till geochemical exploration targets, Babine Porphyry Copper Belt, central British Columbia. BC Ministry of Energy, Mines and Petroleum Resources, Open File 2009-04, Geoscience BC, Report 2009-10. 32 p., URL http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2009/Pages/2009-4.aspx [April, 2012].

Ferbey, T., Levson, V.M., and Lett, R.E. (2012): Till geochemistry of the Huckleberry Mine area, west-central British Columbia (NTS 093E/11). BC Ministry of Energy, Mines and Petroleum Resources, Open File 2012-02, 32 p., URL http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2012/Pages/2012-2.aspx [March, 2012].

Gabrielse, H., Monger, J.W.H., Wheeler, J.O. and Yorath, C.J. (1991): Tectonic framework - part A. Morphogeological belts, tectonic assemblages and terranes; in Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C. J. Yorath (ed.), Geological Survey of Canada, Geology of Canada, v. 4, p. 15–28.

Geoscience BC (2010): QUEST-West Project - Geology; Geoscience BC, Map 2010-12-1, scale 1:500 000, URL < http://www.geosciencebc.com/i/project_data/GBC_Report2010-12/map_2010_12_1_geology.pdf> [March, 2012].

Holland, S.S. (1976): Landforms of British Columbia: a physiographic outline (second edition); BC Ministry of Energy, Mines and Petroleum Resources, Bulletin 48, 138 p, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/BulletinInformation/BulletinsAfter1940/Documents/Bull48-txt.pdf> [April, 2012].

Lett, R.E. (1995): Analytical methods for drift samples; in P.T. Bobrowsky, S.J.N. Sibbick, J.M. Newell, and P.F. Matysek (eds.), Drift Exploration in the Canadian Cordillera, Province of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Paper 1995-2, p. 215-228. URL: http://www.em.gov.bc.ca/DL/GSBPubs/Paper/P1995-2/Paper1995-02-DriftExplorationintheCanadianCordillera_2.pdf [March, 2012].

Lett, R.E., Cook, S.J. and Levson, V.M. (2006): Till geochemistry of the Chilanko Forks, Chezacut, Clusko, and Toil Mountain map areas, British Columbia (NTS 93C/1, 8, 9, and 16); BC Ministry of Energy, Mines and Petroleum Resources, GeoFile 2006-1, 272 p. URL: http://www.empr.gov.bc.ca/MINING/GEOSCIENCE/PUBLICATIONSCATALOGUE/GEOFILES/Pages/2006-1.aspx [April, 2012]

Levson, V.M. (2001): Regional till geochemical surveys in the Canadian Cordillera: Sample media, methods and anomaly evaluation; in Drift Exploration in Glaciated Terrain, Geological Society of London, Special Publication Volume 185, p. 45-68.

Levson, V.M. (2002): Quaternary geology and till geochemistry of the Babine porphyry copper belt, British Columbia (NTS 93 L/9, 16; 93M/1, 2, 7, 8); BC Ministry of Energy, Mines and Petroleum Resources, Bulletin 110, 278 p, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/BulletinInformation/BulletinsAfter1940/Documents/00-cover.pdf> [April, 2012].

Levson, V.M., Stumpf, A.J. and Stuart, A.J. (1998): Quaternary geology and ice flow studies in the Smithers and Hazelton map areas (93 L and M): implications for exploration; in Geological Fieldwork 1997, D.V. Lefebure and W.J. McMillan (ed.), BC Ministry of Energy, Mines and Petroleum Resources, Paper 1998-1, p. 5.1–5.8, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Documents/1997/levson.pdf> [March, 2012].

Levson, V.M., Cook, S.J., Huntley, D.H., Stumpf, A.J., O'Brien, E.K. and Hobday, J. (1997): Preliminary till geochemistry - Old Fort Mountain Area (NTS 93 M/1); BC Geological Survey, Ministry of Energy, Mines, and Petroleum Resources, Open File 1997-18. URL < http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/1997/Pages/1997-18.aspx>, [April, 2012]

MacIntyre, D.G. (2006): Geology and mineral deposits of the Skeena arch, west-central British Columbia: a Geoscience BC digital data compilation project; in Geological Fieldwork 2005, BC Ministry of Energy, Mines and Petroleum Resources, Paper 2006-1, p. 303–312, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Documents/2005/Paper25.pdf> [April, 2012].

MacIntyre, D.G. and Villeneuve, M.E. (2001): Geochronology of mid-Cretaceous to Eocene magmatism, Babine porphyry copper district, central British Columbia; Canadian Journal of Earth Sciences, v. 38, p. 639–655, URL <http://article.pubs.nrc-cnrc.gc.ca/RPAS/rpv?hm=HInit&calyLang=eng&journal=cjes&volume=38&afpf=e00-107.pdf> [April, 2012].

MacIntyre, D.G., Brown, D., Desjardins, P. and Mallet, P. (1987): Babine project (93L/10, 15); in Geological Fieldwork 1986, BC Ministry of Energy, Mines and Petroleum Resources, Paper 1987-1, p. 201–222, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Documents/1986/201-222-macintyre.pdf> [April, 2012].

Massey, N.W.D., Alldrick, D.J. and Lefebure, D.V.L. (1999): Potential for subaqueous hot-spring (Eskay Creek) deposits in British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Open File 1999-14, 54 p. (includes 2 sheets at scale 1:2 000 000), URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/1999/Pages/1999-14.aspx> [April, 2012].

Massey, N.W.D., MacIntyre, D.G. and Desjardins, P.J. (2003): Digital geology map of British Columbia: tile NN9 north coast BC; BC Ministry of Energy, Mines and Petroleum Resources, GeoFile 2003-13, scale 1:250 000. URL < http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/GeoFiles/Pages/2003-13.aspx> [April, 2012].

Plouffe, A. (2000): Quaternary geology of the Fort Fraser and Manson River map areas, central British Columbia; Geological Survey of Canada, Bulletin 554, 62 p. (includes 4 sheets).

Plouffe, A. (1991): Preliminary study of the Quaternary geology of the northern interior of British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 91-1A, p. 7–13.

Plouffe, A. and Ballantyne, S.B. (1993): Regional till geochemistry, Manson River and Fort Fraser area, British Columbia (93K, 93N), silt plus clay and clay size fractions; Geological Survey of Canada, Open File 2593, 210 p.

Struik, L.C., MacIntyre, D.M. and Williams, S.P. (2007): Nechako NATMAP project: a digital suite of geoscience information for central British Columbia; Geological Survey of Canada, Open File 5623 and BC Ministry of Energy, Mines and Petroleum Resources, Open File 2007-10, CD-ROM, URL <http://geoscan.ess.nrcan.gc.ca/cgi-bin/starfinder/0?path=geoscan.fl&id=fastlink&pass=&search=R=224578&format=FLFULL> [April, 2012].

Stumpf, A.J. (2001): Late Quaternary ice flow, stratigraphy and history of the Babine Lake–Bulkley River region, central British Columbia, Canada; Ph.D. thesis, University of New Brunswick, 234 p, URL <http://www.collectionscanada.gc.ca/obj/s4/f2/dsk4/etd/NQ68165.PDF>, [March, 2012].

Stumpf, A.J. (2003): 3-D geologic mapping for mineral resource and groundwater exploration, Smithers, British Columbia, Canada; British Columbia and Yukon Chamber of Mines, 20th Cordilleran Exploration Round-up, Vancouver, BC, Abstracts (Poster).

Stumpf, A.J. (2012): Development of a database for geological field observations, west-central British Columbia (part of NTS 093L), in Geoscience BC Summary of Activities 2011, Geoscience BC, Report 2012-1, p. 53–58. URL < http://www.geosciencebc.com/i/pdf/SummaryofActivities2011/SoA2011_Stumpf.pdf>, [April, 2012]

Stumpf, A.J., Broster, B.E. and Levson, V.M. (2004): Glacial stratigraphy of the Bulkley River region: a depositional framework for the Late Pleistocene in central British Columbia; Géographie physique et Quaternaire, v. 58, no. 2–3, p. 271–228 (published in June 2006), URL <http://www.erudit.org/revue/gpq/2004/v58/n2-3/013139ar.pdf> [April, 2012].

Stumpf, A.J., Broster, B.E. and Levson, V.M. (2000): Multi-phase flow of the Late Wisconsinan Cordilleran Ice Sheet in western Canada; Geological Society of America Bulletin, v. 112, p. 1850–1863, URL <http://gsabulletin.gsapubs.org/content/112/12/1850.full.pdf+html> [March, 2012].

Stumpf, A.J., Huntley, D.H. and Levson, V.M. (1996): Surficial geology and Quaternary stratigraphy of the Fulton Lake area (93L/16), BC Ministry of Energy, Mines and Petroleum Resources, Open File 1996-10, 1:50,000 scale, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/1996/Documents/OF1996-10.pdf> [March, 2012].

Tipper, H.W. (1994): Preliminary interpretations of glacial and geomorphic features of Smithers map area (93L), British Columbia; Geological Survey of Canada, Open File 2837, 7 p., URL http://geoscan.ess.nrcan.gc.ca/cgi-bin/starfinder/0?path=geoscan.fl&id=fastlink&pass=&search=R=193997&format=FLFULL [March, 2012].

Tipper, H.W. and Richards, T.A. (1976): Geology of the Smithers map-area, British Columbia; Geological Survey of Canada, Open File 351, 2 sheets at scales 1:125 000 and 1:250 000, URL <http://geoscan.ess.nrcan.gc.ca/cgi-bin/starfinder/0?path=geoscan.fl&id=fastlink&pass=&search=R=129458&format=FLFULL> [April, 2012].