TILL GEOCHEMISTRY: A VIABLE TOOL FOR POLYMETALLIC MINERAL EXPLORATION IN BRITISH COLUMBIA'S SOUTHERN INTERIOR

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INTRODUCTION

The bedrock geology in the Kootenay, Slide Mountain and Quesnel terranes has high potential for new discoveries of polymetallic mineral deposits, but typically, such targets are mantled by unconsolidated sediments of varying complexity and thickness. In such an area, drift prospecting techniques must be used by relying on the recognition of subtle geochemical anomalies which are related to clastic dispersal of mineral grains and the provenance of the sampled media. The intent of the regional till geochemical surveys (Bobrowsky et al. 1997a; Bobrowsky et al. 1998; Paulen et al. 2000a, 2000b) that were conducted in the southern interior was to identify areas of potential mineralization. This regional dataset can also be used to outline the shape, extent and bedrock source of geochemical dispersal trains. The regional till geochemistry survey has led to several new MINFILE occurrances, such as the Rock Island Lake anomaly (MINFILE 092P185) in the eastern Bonaparte Plateau and the Cam-Gloria showing (MINFILE 082M266) in the Adams Plateau.

Regional till sampling by the British Columbia Survey has lead to the discovery of new auriferous (Cathro 1998; Lett et al. 1998; Cathro and Lefebure 2000; Logan 2000) and massive sulphide occurrences and has further defined several areas with high potential for polymetallic mineral deposits (Bourdon and Addie 2000). Bedrock mineralization was reflected by dispersal trains in lodgement till.

Typically, dispersal trains have characteristic geochemical dispersion consisting of specific pathfinder elements or heavy minerals. These trace element trains are primarily controlled by glacial (physical) transport, drift thickness, depositional environments and topography, the latter of which can also alter dispersal trains by hydromorphic distribution (Paulen 2001). Whole rock analysis of till defines areas locally up-ice that exhibit constrasting chemistry indicative of bedrock contacts and lithological changes. This is particularly important where lack of bedrock exposure inhibits observation of lithological and chemical changes of the subcrop.

This Geofile presents a compilation of till geochemical data from surveys in southern interior region that provides an insight into the effectiveness of applying till geochemistry to prospect for mineral deposits in this part of British Columbia. A small portion of this work was initially presented at the 19th International Geochemical Exploration Symposia (Paulen et al. 1999a) held in Vancouver in 1999.

OBJECTIVE

During the late 1970s and early 1980s, the British Columbia Geological Survey conducted several years of mapping the bedrock geology of the Adams Plateau region (Figure 1). The net result of this work included a detailed map (Schiarizza and Preto 1984) and report describing the bedrock structure and geology (Schiarizza and Preto 1987). The region was revisited by the Geological Survey in the late 1990s to conduct regional till geochemistry surveys to stimulate mineral exploration in the region. Over 1300 till samples were collected and analysed for trace element and whole rock (major oxides) geochemistry and released as open files (Bobrowsky et al. 1997a, 1998; Paulen et al. 2000a, b).

The objective of this study is to compare trace element and whole rock geochemistry of till samples collected within the Eagle Bay and Slide Mountain terranes to the underlying bedrock. It is possible to develop a geochemical dispersal map of the till based on bedrock

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geochemistry and model down-ice dispersal of geochemically distinctive rock units. Our purpose is to augment the current bedrock and geophysical data regarding possible buried rock lithologies and contacts, based on the surface till geochemical signature.This is especially important in areas of thick (>5m) drift cover and may outline regions where the surface till geochemistry indicates buried bedrock that has a high potential for hosting mineral deposits.

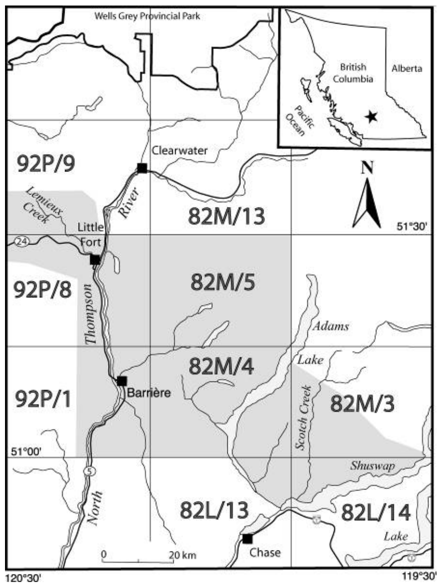

Figure 1. Location of the study area in south central British Columbia. Coverage from the Eagle Bay (1996-1998) till geochemistry surveys is indicated by the shaded region.

PREVIOUS WORK

Historically, mineral exploration soil surveys conducted in the region have outlined various anomalous sites with high potential for discovery of polymetallic mineral deposits. Previous geochemical studies published in mineral assessment reports provide an early indication as to the style of mineralization, configuration of the anomaly plumes and regional dispersal patterns one can expect in the area. Several examples are discussed by Bobrowsky et al. (1997b), Paulen et al. (1998a, 1999b), Lett et al. (1998, 1999), Lett (2001) and Paulen (2001). Till (Yeow, 1998; Lett and Jackaman 2000), hydrogeochemical (Sibbick et al. 1997) and stream sediment (Lett et al. 2000) dispersion studies have enhanced the exploration potential of the study area. A geochemical exploration model (GEM) for volcanogenic massive sulphide deposits and volcanogenic sulphide-barite deposits hosted in the Fennel Formation and Eagle Bay Assemblage was developed for the region (Lett 2002). Boulder tracing in the areas where high geochemical anomalies have been reported resulted in the discovery of additional mineralized bedrock occurrences and zones where mineralized bedrock is believed to occur under the glacial drift (Lett and Earle 2000).

BACKGROUND AND SETTING

Located in south-central British Columbia (Figure 1), the North Thompson – Adams Plateau area lies in the southwestern part of the Shuswap Highland and the northeastern part of the Thompson Plateau within the Interior Plateau (Holland, 1976; Mathews 1986). This region is characterized by moderate to high relief, and glacially and fluvially dissected topography (Figure 2). Elevations range from 360 to 2380 m above sea level. Most of the area is covered by unconsolidated sediments of mixed genesis and of variable thickness, but rarely exceeding a few tens of metres. Till (of various facies) dominates the landscape, followed in turn by colluvial, glaciofluvial, fluvial, glaciolacustrine sediments and organic sediments.

Figure 2. Adams Plateau dissected by Scotch Creek, north of Shuswap Lake.

REGIONAL BEDROCK GEOLOGY

The study area is within a belt of structurally complex low-grade metamorphic rocks which occur along the western margin of the Omineca Belt. This belt is flanked by high grade metamorphic rocks of the Shuswap Complex to the east and by rocks of the Intermontane Belt to the west (Figure 3). Early Paleozoic to Mississippian rocks of the Eagle Bay Assemblage (Kootenay Terrane) underlie a major part of the area. These consist of calcareous phyllite, calc-silicate schist and skarn or mafic metavolcanics overlain by felsic and locally intermediate metavolcanics and clastic metasediments (Schiarizza and Preto 1987). The eastern part of the Adams Plateau and west of Seymour Arm is underlain by the western margin of the Shuswap Metamorphic Complex (Silver Creek Formation, Mount Ida Group). These comprise strongly foliated and lineated assemblages of Cambrian-Ordovician paragneiss and schists intruded by Jurassic-Cretaceous dikes, sills and small irregular bodies of granitic rocks (Okulitch 1974). To the north, the Permian to Devonian rocks of the Fennell Formation comprises imbricated oceanic rocks of the Slide Mountain Terrane. These consist of bedded cherts, gabbro, diabase, pillowed basalt and volcanogenic metasediments (Schiarizza and Preto 1987). To the northeast and northwest, mid-Cretaceous granodiorite and quartz monzonite intrusions of the Baldy Batholith (Preto et al. 1980) and the late Triassic – early Jurassic monzo-granite and granodiorite Thuya River Batholith (Campbell and Tipper 1971) underlie the area, respectively. The very northwestern margin of the study area is underlain by Upper Triassic Nicola Group (Quesnel Terrane) andesites, tuffs, argillites, greywacke and limestone in generally faulted contact with the rocks of the Fennell Formation (Schiarizza and Israel 2001). Paleozoic Harper Ranch Group do occur locally. Eocene andesite and breccia occur sporatically along the western edge of the Thompson River valley and as isolated outliers.

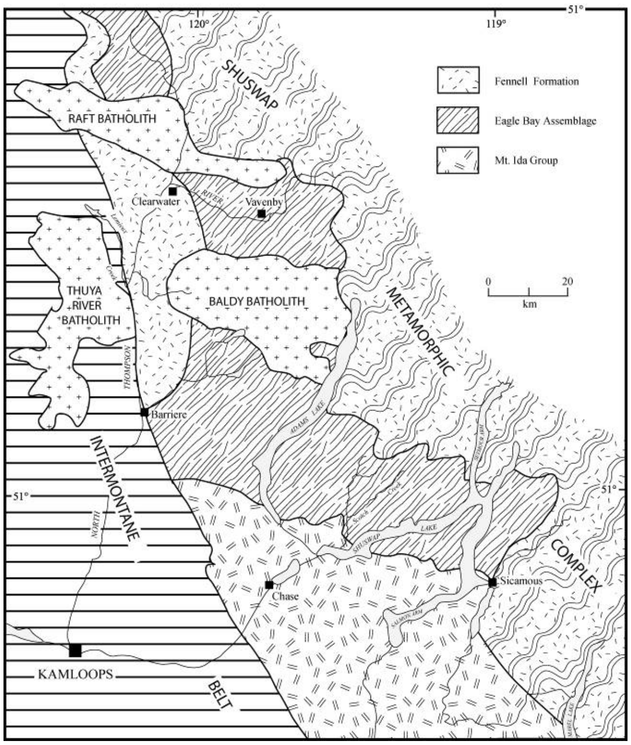

Figure 3. Geologic setting of the Adams Plateau - Clearwater - Vavenby area, modified after Schiarizza and Preto (1987) and Campbell and Tipper (1971). Not shown are Tertiary volcanic rocks and numerous small granitic plutons.

The Eagle Bay Assemblage consists of a complex succession of metasedimentary and metavolcanic rocks that are intruded by Late Devonian orthogneiss (Okulitch 1979, 1989; Schiarizza and Preto 1987) and Jurassic-Cretaceous granodiorite and quartz monzonite of the Raft and Baldy batholiths (Figure 4). Rocks of the Eagle Bay Assemblage are contained within four west directed thrust slices that collectively contain a succession of Cambrian (and possibly Late Proterozoic) quartzites, gritstone and quartz mica schists (Units EBH and EBQ), mafic metavolcanic rocks and Tshinakin limestone (EBG). These lithologies are overlain by undated phyllite, carbonate, and metavolcanics (Unit EBS), metamorphosed basalt, chert and quartzite (Unit EBM), and carbonaceous phyllite and limestone (Unit EBL). The upper part of the Eagle Bay Assemblage consists of felsic to intermediate metavolcanic and metasedimentary rocks (Units EBA and EBP; Schiarizza and Preto 1987).

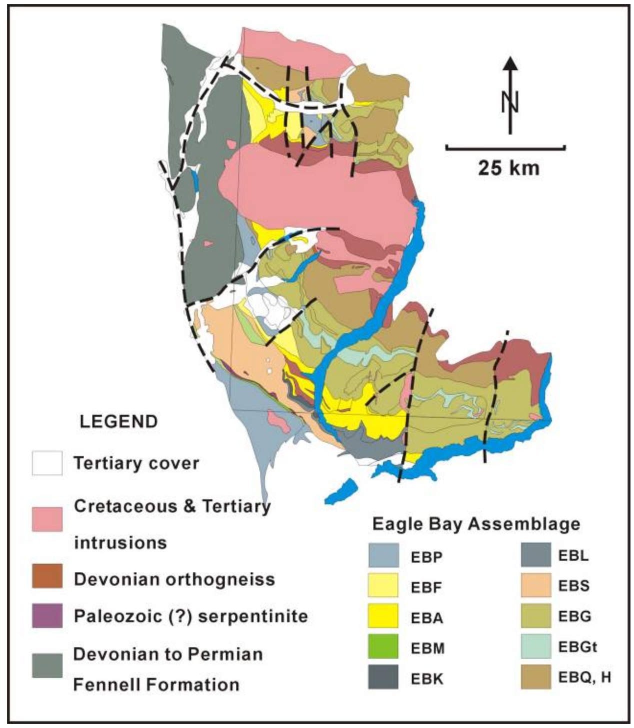

Figure 4. Lithologies of the Eagle Bay Formation from Seymour Arm of Shuswap Lake to the north Thompson River valley (see Figure 1), modified from Schiarizza and Preto (1987).

A major north-south fault paralleling the North Thompson River valley separates the Kootenay and Slide Mountain terranes from the younger Quesnel terrane. This fault is a single break until Lemieux Creek, where it separates into several splays collectively referred to as the Rock Island Lake fault system (See Figure 2a, Schiarizza and Israel 2001, p. 4). This extensive dextral strike-slip system signifies a major structural event which cut rocks as young as Eocene.

Polymetallic precious, sedimentary exhalative and Noranda/Kuroko type volcanogenic massive sulphide (VMS) base metal occurrences are hosted by Devono-Mississippian felsic to intermediate metavolcanic rocks of the Eagle Bay Assemblage (Schiarizza and Preto 1987). Massive sulphides are hosted in oceanic basalts of the Fennell Formation, skarn mineralization and silver-lead-zinc mineralization occur as numerous vein deposits within the Fennell Formation near the Cretaceous granitic intrusions (Schiarizza and Preto 1987). Plutonic-related gold-quartz vein deposits are hosted by the mid-Cretaceous Baldy Batholith (Logan 2000). Platinum mineralization within ultramafic rocks, copper-gold skarn occurrences, porphyry-style copper and numerous vein and shear-related gold showings are hosted in the Nicola Group (Schiarizza and Israel 2001).

REGIONAL TILL SAMPLING (1996-1998)

Over 1300 bulk sediment samples (1-5 kg) were collected for the till geochemistry study. Total till sample density averaged one sample per 2 km^2 for the three-year survey. This density of survey and sampling provides a very high level of reconnaissance information for the region (Figure 5). Most of the samples taken for geochemical analysis were collected from basal till (first order derivative, Shilts 1993). Although emphasis was placed on collecting basal till samples, ablation till, colluviated till and colluvium were also collected under certain circumstances. Natural exposures and hand excavation were used to obtain samples from undisturbed, unweathered C-horizon (parent material) deposits (Figure 6).

Sediment samples were dried, split and sieved to <63 µm (silt + clay fraction of the till matrix). The <63 µm fraction was analyzed by aqua regia digestion for 30 elements by inductively coupled plasma emission spectroscopy (ICP-ES) and for major oxides by Lithium metaborate ($LiBO_2$) fusion-ICP (11 oxides, loss on ignition and 7 minor elements). The to <63 µm material was also analyzed by instrumental neutron activation analysis (INAA) for 35 elements. Results of the analyses, including quality control, are presented in open file reports (Bobrowsky et al. 1997a, 1998; Paulen et al. 2000a, b).

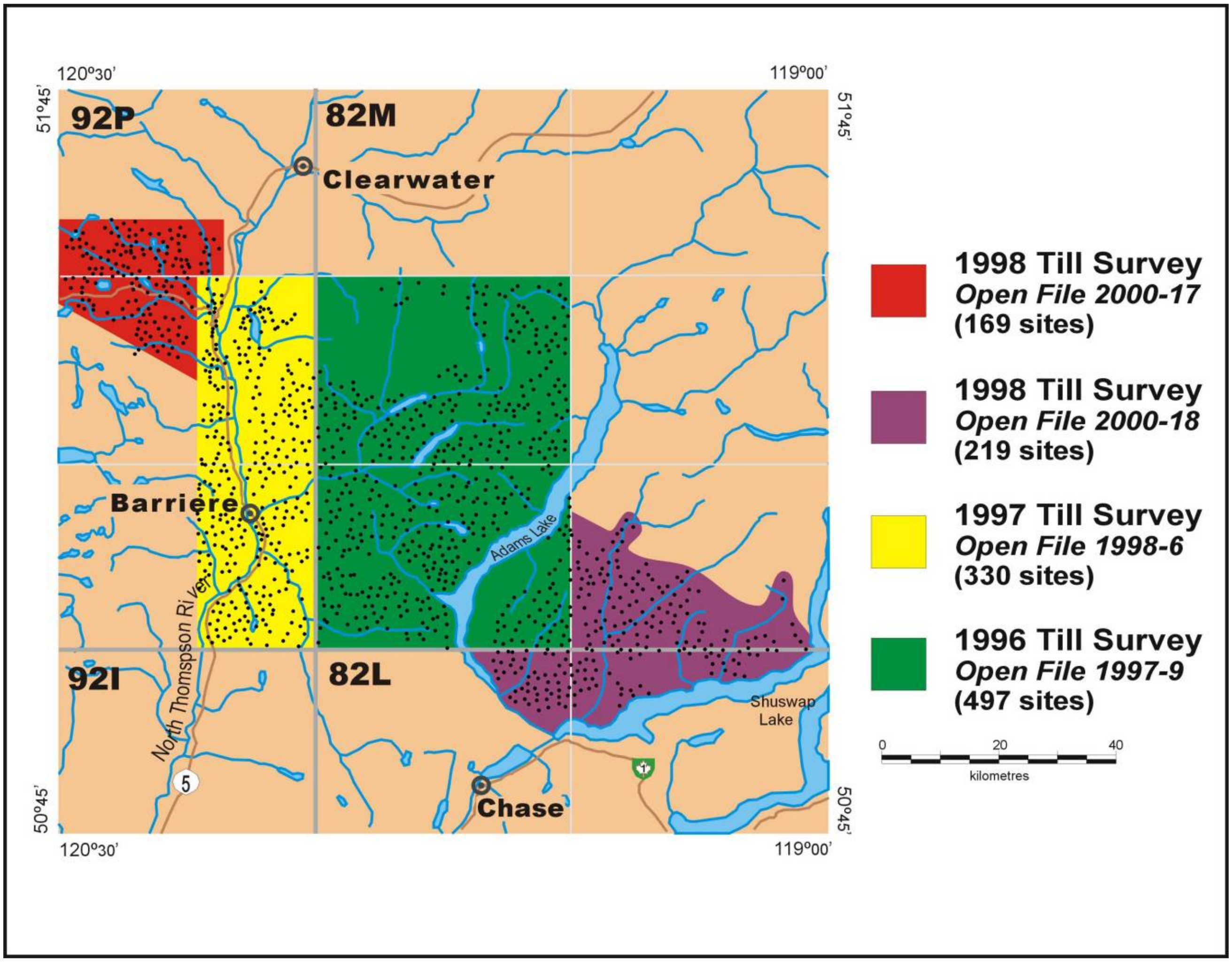

Figure 5. Sample location map of the 1996-1998 Eagle Bay till geochemistry survey.

To further aid interpretation of the till geochemistry, 221 rock samples that were collected during the British Columbia Geological Survey's original bedrock mapping programs (Preto 1979, 1981; Preto et al. 1980; Schiarizza 1981, 1982, 1986) were selected from each lithological map unit (Figure 4) and subjected to the same trace element and whole rock geochemical analyses that the till samples had undergone (Paulen et al. 2005). This bedrock geochemistry, combined with the overlying till geochemistry will provide a unique dataset to the region where geochemical exploration can be used to compare the tills to their erosional source, namely the bedrock which outcrops and/or subcrops up-ice. Spatial analysis of both datasets is now possible and this may shed some light on some of the unexplained elevated trace element and major oxide concentrations observed in the tills. By eliminating some of the inherent bedrock chemistry, the till data can potentially provide some indication of possible blind bedrock lithologies and/or mineralization that likely occurs under a blanket of glacial sediment (>5 m thick) and were unaccessible to the geologists who mapped the bedrock of this region.

Figure 6. Basal till exposed in a recent roadcut.

GLACIAL HISTORY

The present day landscape of south-central British Columbia is the result of two glacial cycles, one interglacial and intense early Holocene erosion and sedimentation (Fulton 1975; Fulton and Smith 1978; Clague 1989; Ryder et al. 1991; Clague and James 2002). However, usually only evidence from the last glacial event and various post-glacial processes are found. At the onset of the Lake Wisconsin Fraser Glaciation, ice build-up began in the Coast, Cariboo and Monashee Mountains. Valley glaciers formed piedmont lobes in the Interior Plateau, and eventually coalesced to form the Cordilleran Ice Sheet (Ryder et al. 1991). Ice sheet margins reached a maximum elevation between 2200 and 2400 m, burying the entire Interior Plateau beneath an ice cap by approximately 19 ka. At Fraser Glaciation maximum, regional ice flow was to the south-southeast on the Bonaparte and Adams plateaus (Tipper 1971; Fulton et al. 1986; Dixon-Warren et al. 1997; Leboe et al. 1997; Paulen et al. 1998b, c) with local deviations up to 45°. This deviation was particularly noted in the eastern part of the study area, where ice from the north and west coalesced with ice flowing from the Monashee Mountains to the east, and was subsequently directed into the Shuswap Basin.

Deglaciation of the Interior Plateau was rapid; the equilibrium line likely rose considerably, reducing the area of accumulation for the Cordilleran Ice Sheet, and the ice mass decayed by downwasting and complex frontal retreat. Post glacial radiocarbon dates between 11 300 and 9800 BP (Fulton 1971; Clague 1980, 1981) indicate that deglaciation of plateau areas began about 12 000 BP. As the Cordilleran Ice Sheet stagnated, late-glacial, ice-dammed lakes developed within the region: glacial Lake Thompson, glacial Lake Shuswap and glacial Lake Deadman (Fulton 1969; Johnsen and Brennand 2004). A 9740 – 10210 BP date from bog sediments near Armstrong (Dyck et al. 1965) provides a minimum age for all late-glacial lakes in the southern Interior (Fulton 1969).

Intense and vigorous erosion immediately followed deglaciation in the early Holocene. As sediment loads decreased, deposition was replaced by erosion, and water courses cut through valley fills, leaving glaciofluvial terraces abandoned high on valley sides. Following the complete deglaciation of the region, unstable and unvegetated slopes were highly susceptible to erosion. Intense mass wasting of surface deposits on oversteepened valley slopes resulted in the deposition of colluvial fans and aprons along valley bottoms. Most post-glacial deposition occurred within the first few hundred years of deglaciation (Fulton 1967). The modern drainage pattern was established prior to 8.9 ka (Dyck et al. 1965; Fulton 1969). Fluvial fan deposits, active talus slopes and present rivers and floodplains typify the modern sedimentation in the area.

The striation record in the study area is poor due to the paucity of unweathered outcrop exposure. However, there is an abundance of sculpted landforms on the plateaus that provide regional ice-flow information during the peak of glacial activity. In general, local paleo-ice flow parallels the regional south to southeast ice flow (Fulton et al. 1986). Detailed ice flow for the study area is as follows (Figure 7). In the northwestern area, regional ice-flow directions are to the southeast, with ice buildup and deglacial deviations to the south in the North Thompson River valley. In the centre of the study area, the ice flowed in a southerly direction across the Adams Plateau, except in areas of variable relief where topography deflected ice flow. In the easternmost region, the landforms and striae show a south-southwesterly flow direction as ice was diverted in the Shuswap Basin. The location of southeast and southwest ice convergence is unknown due to the poor striation record, but the coalescence likely occurred near the southeastern edge of the Adams Plateau, west of Scotch Creek; ice flow here was deflected southward, into the Shuswap Basin.

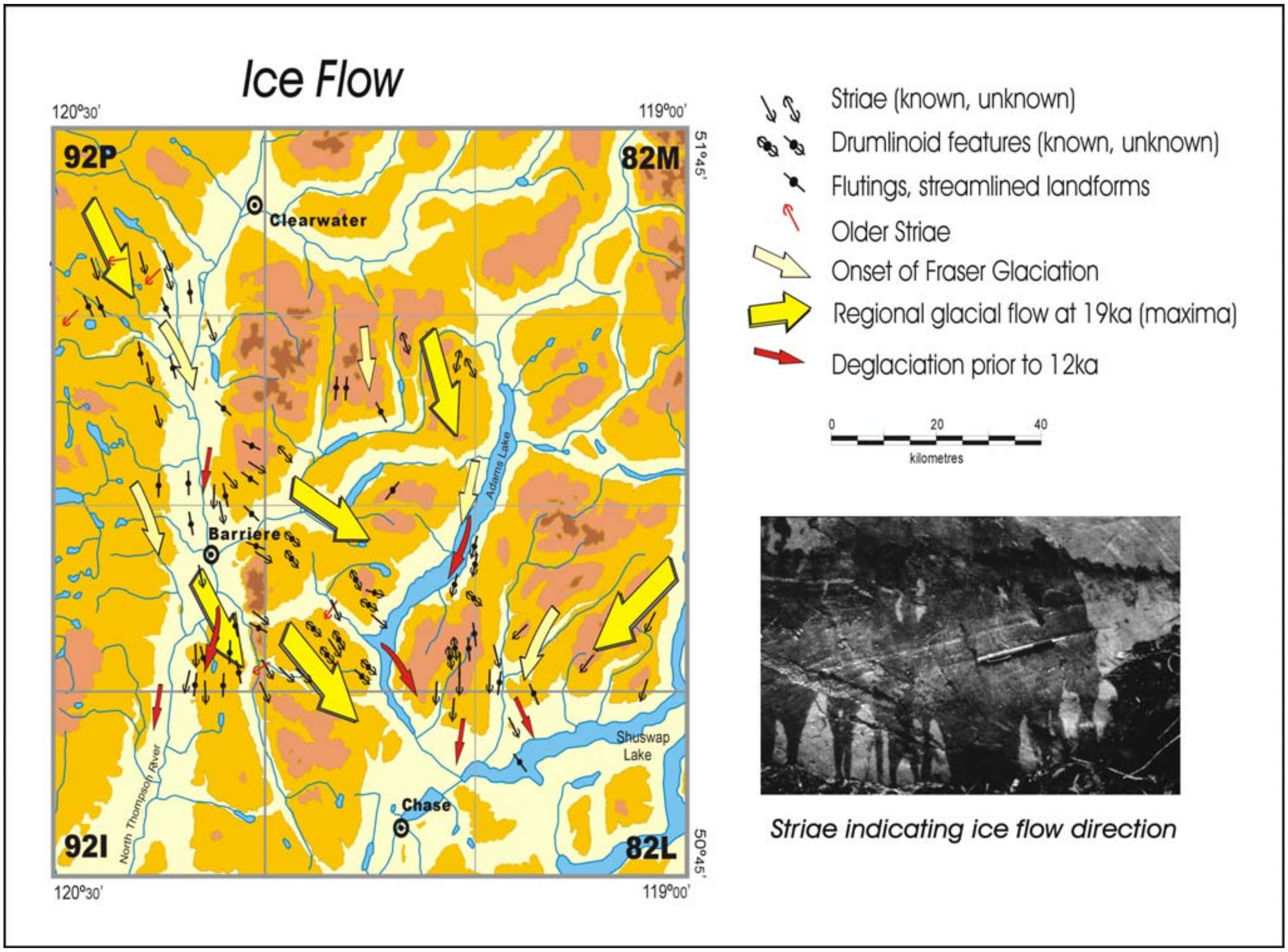

Figure 7. Ice-flow history and general pattern of flow for the study area during the Fraser Glaciation. Ice-flow indicators were measured from airphoto interpretation of streamlined landforms, ground based striation evidence (see inset photograph) and previous work by Tipper (1971) and Fulton et al. (1986).

RESULTS AND OBSERVATIONS

Eight till geochemistry plots from the combined dataset are shown here as examples to illustrate the pattern of element dispersion in the study area. This exercise could be repeated for many of the individual elements or multi-element associations by comparing the bedrock geochemistry (Paulen et al. 2005) to the till geochemistry (Bobrowsky et al. 1997a, 1998; Paulen et al. 2000a, b) dataset. Whole rock till geochemistry for Fe_2O_3, TiO_2, Cr_2O_3 and CaO are selected to show the expected down-ice pattern of dispersal from the volcanic, mafic and ultramafic and calcium-rich rocks of the area. Pathfinder elements Ni ($LiBO_2$ fusion-ICP), Au (INAA), As (INAA) and Cu (aqua regia ICP-ES data from 1996 combined ultrasonic nebulizer ICP-MS sata from 1997/98) are also selected as examples to highlight regions of high mineral potential for the Eagle Bay Project area. In each plot the symbol size reflects breaks at the 99, 98, 95 and 90 percentile concentration. Mineral deposits discussed here are referred to by their MINFILE names. The eight till geochemistry plots shown here are layered upon the regional bedrock terrane geology. This bedrock map was downloaded from British Columbia Ministry of Energy and Mines MapPlace facility at:

http://www.em.gov.bc.ca/Mining/Geolsurv/MapPlace/default.htm

The Fe_2O_3 plot (Figure 8) shows elevated values in the basal till adjacent to the southern end of Adams Lake. The higher Fe_2O_3 in the till probably reflects the down-ice dispersion of sulphide-bearing rocks derived from Lower Cambrian volcanic belt (EBG) and the Rea/Samatosum volcanic belt. The cluster of elevated values to the northwest reflect till derived from the volcanic rocks of the Nicola Group.

The Cr_2O_3 plot (Figure 9) shows elevated concentrations clustered in till at various locations. This likely indicates that the down-ice glacial dispersion (erosion) of bedrock rich in Cr_2O_3 can only be detected for a few kilometers. However, the regional till survey does indicate that the dispersion of Cr_2O_3 probably reflects the regional mafic and ultramafic rocks mapped in the Eagle Bay Assemblage (EBG). The dispersion of mafic rocks of the Fennell Formation and mafic rocks adjacent to the Thuya Batholith are also reflected in the till geochemistry.

TiO_2 is a good dispersal indicator derived from very mafic to ultramafic bedrock lithologies (Figure 10). Elevated TiO_2 values in the till samples likely reflect erosion and entrainment of the mafic metavolcanic rocks in the Lower Cambrian volcanic belt (EBG). There are also elevated values occurring in the tills overlying the Rea/Samatosum volcanic belt (EBM).

CaO reflects the calcium-rich rocks in the study area (Figure 11). The peak values seen in this plot are likely associated with the limestones of EBL and EBG (Tshinakin Limestone) rock units and calc-silicate schists of EBK. To the far northwest, elevated CaO values in the till may reflect dispersion of Permian limestone of the Harper Ranch Group or from limestones of the Nicola Group (central volcanic belt (uTrNsv unit) from Schriarizza and Israel 2001).

The Au plot shows that most of the elevated values in the till were derived from the prospective rocks in the Nehalliston and Bonaparte plateau areas (Figure 12). This region contains a large number of mineral occurrences contained within and adjacent to the belt of ultramafic - mafic - syenitic plutons that defines the western part of the central Nicola belt (see Figure 4, Schriarizza and Israel 2001, p. 21). Potential Au-bearing source rocks include the Au-quartz veins and the quartz-carbonate-altered fault zones associated with the Dum Lake Intrusive complex, skarn occurrences near Deer Lake and Au prospects north and east of Deer Lake. The till sample collected west of Honeymoon Bay, Adams Lake, that led to the discovery of the Cam-Gloria Au showing is also obvious in this plot. The high Au content in a single till sample adjacent to the Scotch Creek prospect reflects local disperson from a pyritic, ferruginous chert horizon.

The distribution of Ni in the till reflects short dispersion of this element down-ice, usually only a few hundred metres (Figure 13). Clusters of elevated Ni values are derived from the ultramafic rocks that rim the Thuya River Batholith. In the Agate Bay region of Adams Lake, a fan-shaped regional train in the till reflects Ni dispersion from the mafic metavolcanics (Unit EBG) that overlie the felsic volcanics (EBA) east of the past producing Rea and Samatosum mines. Erosion and entrainment of bedrock from Lower Cambrian volcanic belt (EBG) resulted in a Ni-rich till spread over a large area southeast of Adams Lake.

The large cluster of As-rich till samples derived from many of the mineral deposits in the Quesnel Terrane overshadows some of the other dispersion patterns shown by this element (Figure 14). A remarkably long linear ribbon dispersal train can be seen down-ice of the Samatosum deposit. Tetrahedrite in this deposit contains up to 3% As (Friesen 1990) and other associated elements, such as Sb, Zn and Ag have the same dispersal pattern (Bobrowsky et al. 1997a; Paulen 2001).

Lastly, the Cu plot highlights several areas of interest (Figure 15). In the northwest, the metalliferous skarns adjacent to the Deer Lake and Dum Lake bodies and porphyry-style Cu occurrences in the Friendly Lake complex provide a general enrichment of this metal over a large region. Individual dispersal trains are evident, but would be better defined with a property-scale sampling survey. Glacial erosion of the Agate Bay – Pine deposit produced a short dispersal train terminating in Adams Lake. High Cu values in the till occur south of the Chu Chua deposit east of the North Thompson River. Elevated Cu values in the till overlying the felsic volcanic rocks (EBA) immediately south of the Baldy Batholith. Broken Ridge and Harper Ranch deposits probably contribute to this extensive Cu anomaly.

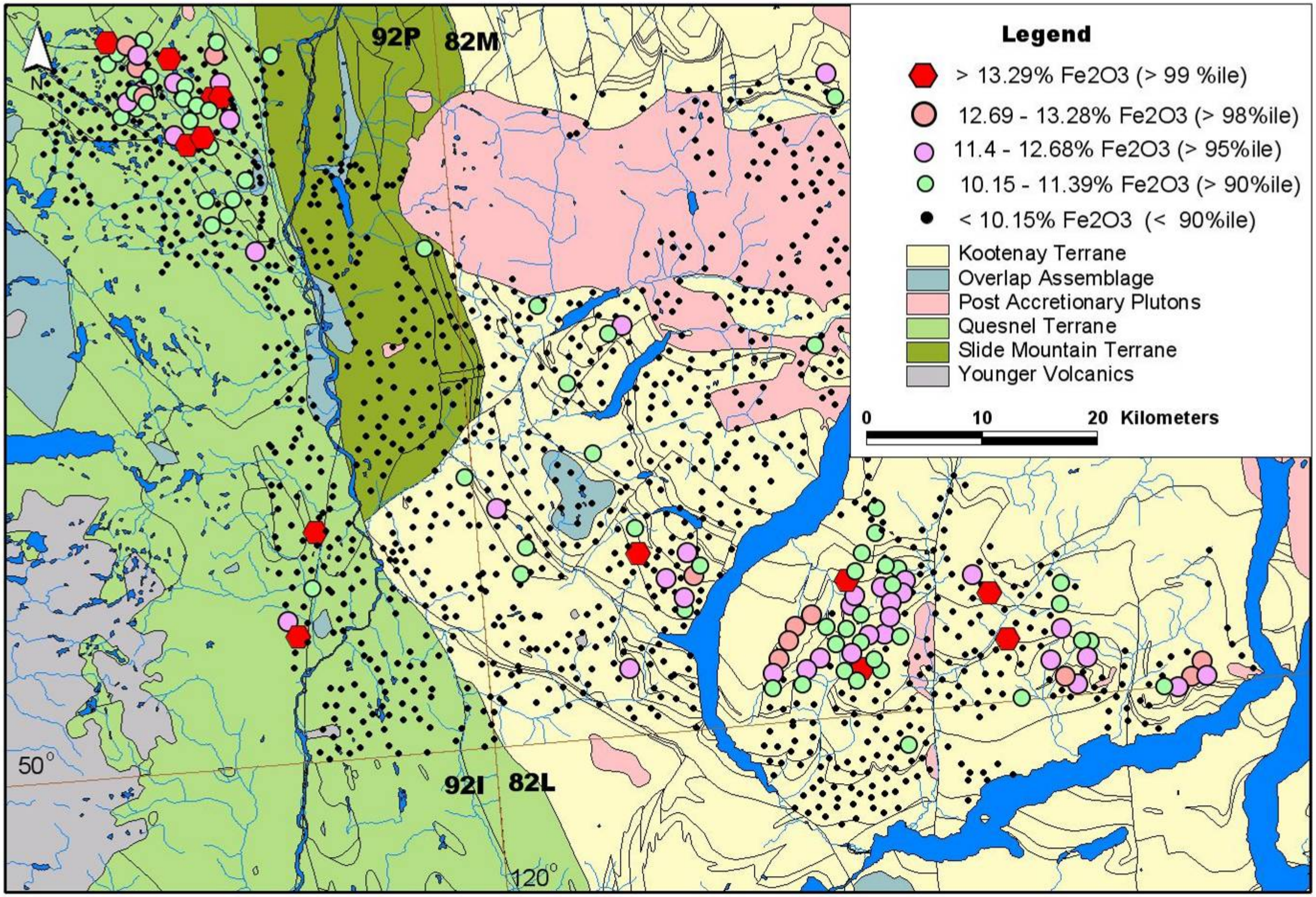

Figure 8. Fe_2O_3 for the 1996-1998 Eagle Bay Project area.

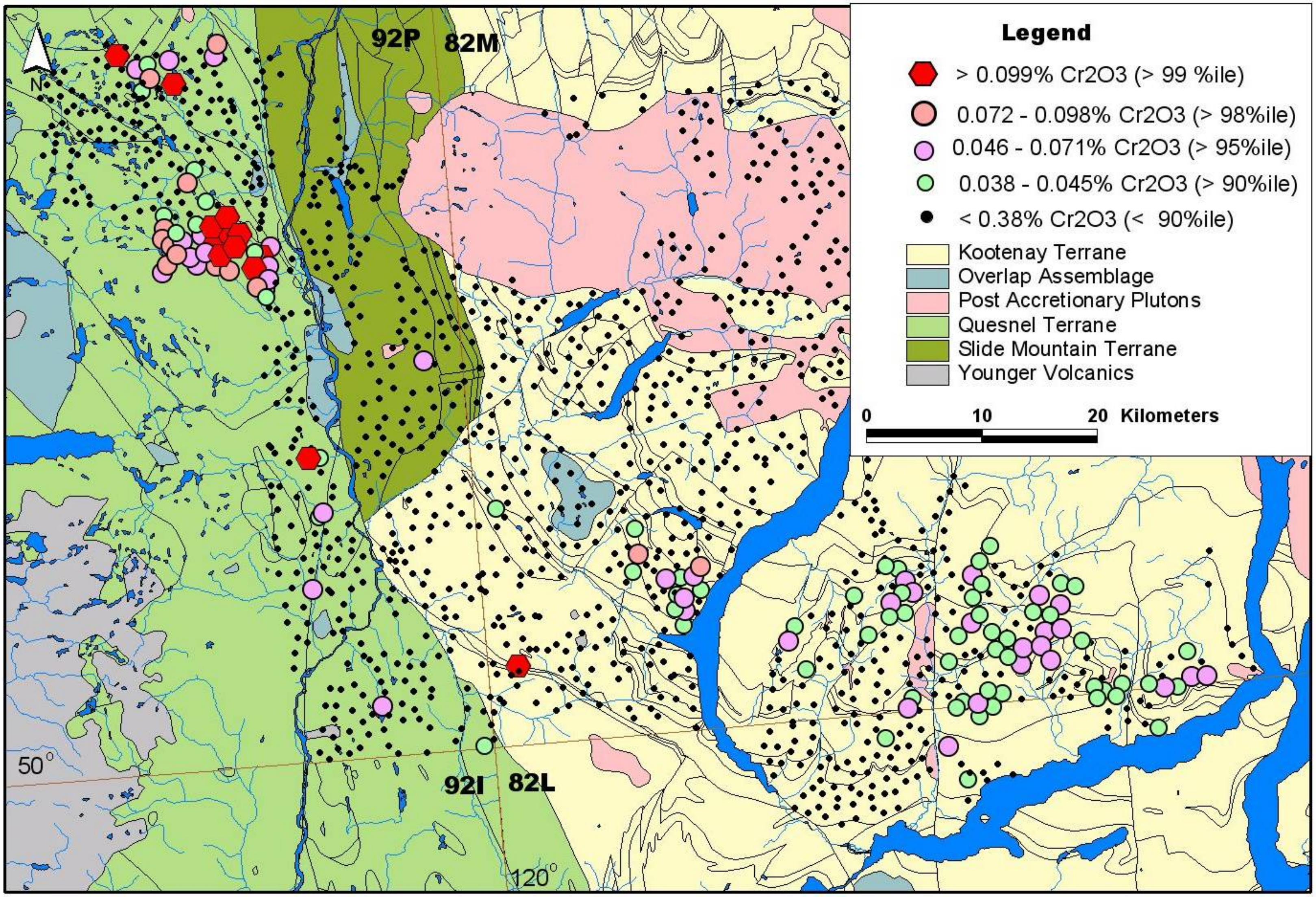

Figure 9. Cr_2O_3 for the 1996-1998 Eagle Bay Project area.

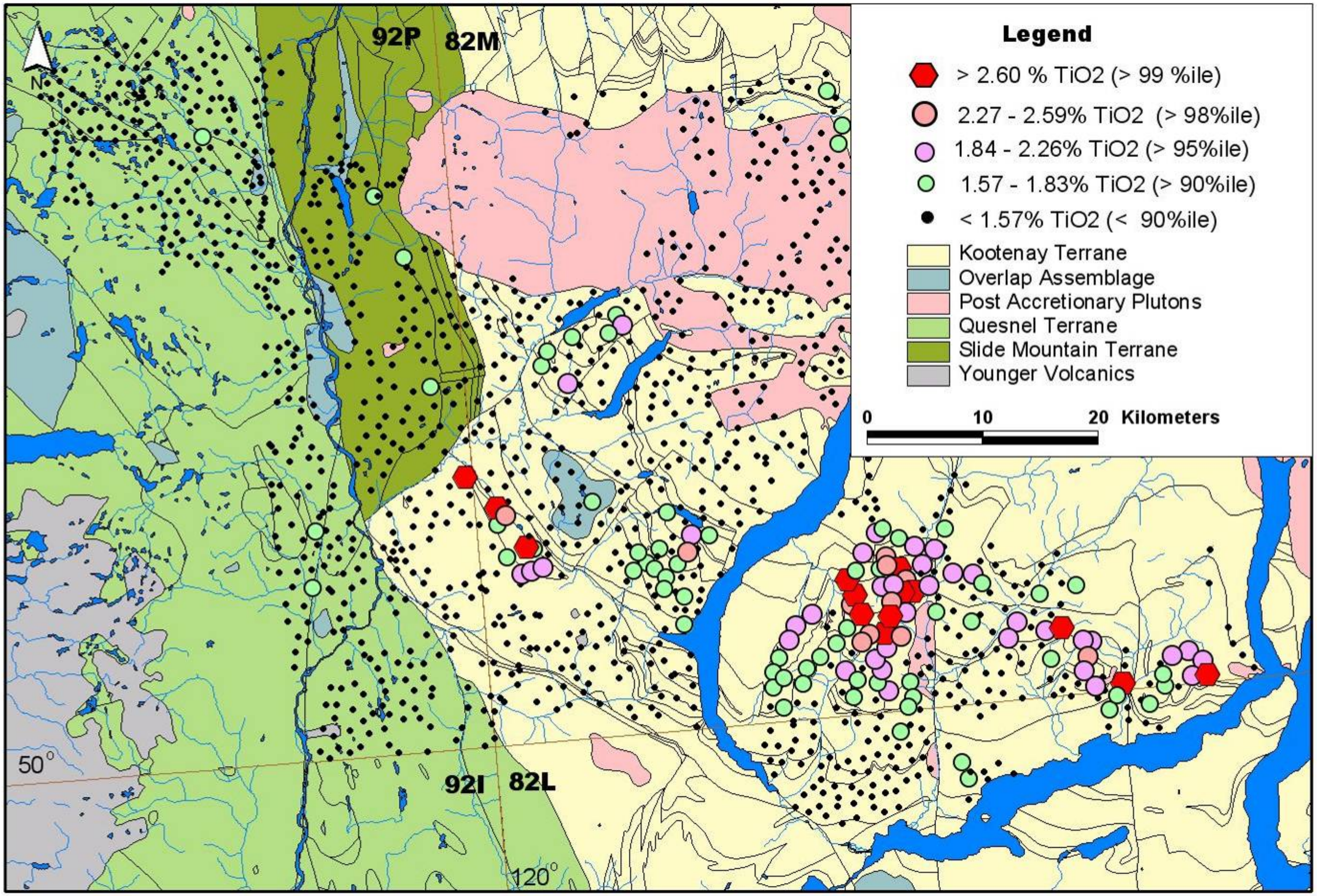

Figure 10. TiO_2 for the 1996-1998 Eagle Bay Project area.

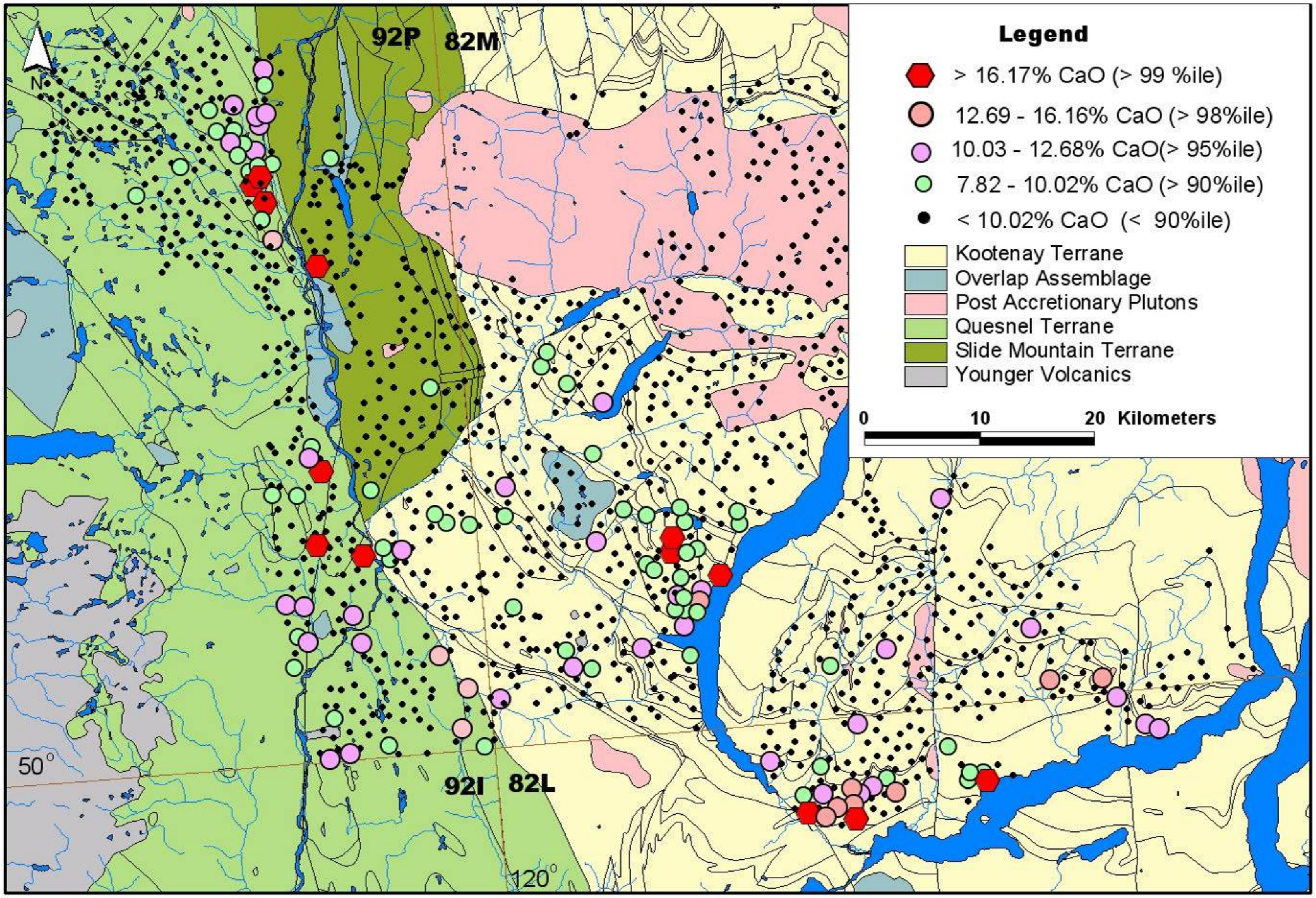

Figure 11. CaO for the 1996-1998 Eagle Bay Project area.

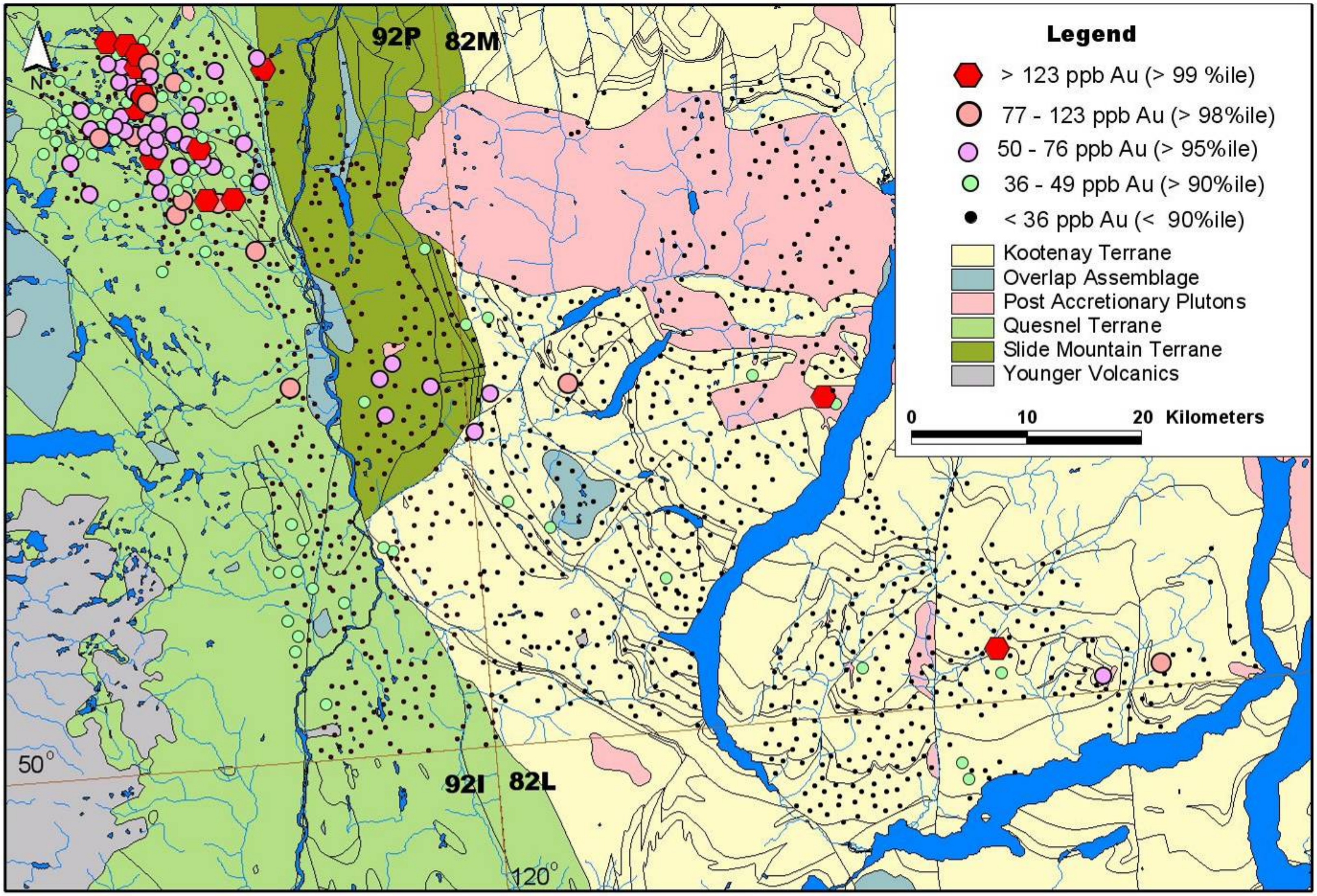

Figure 12. Au for the 1996-1998 Eagle Bay Project area.

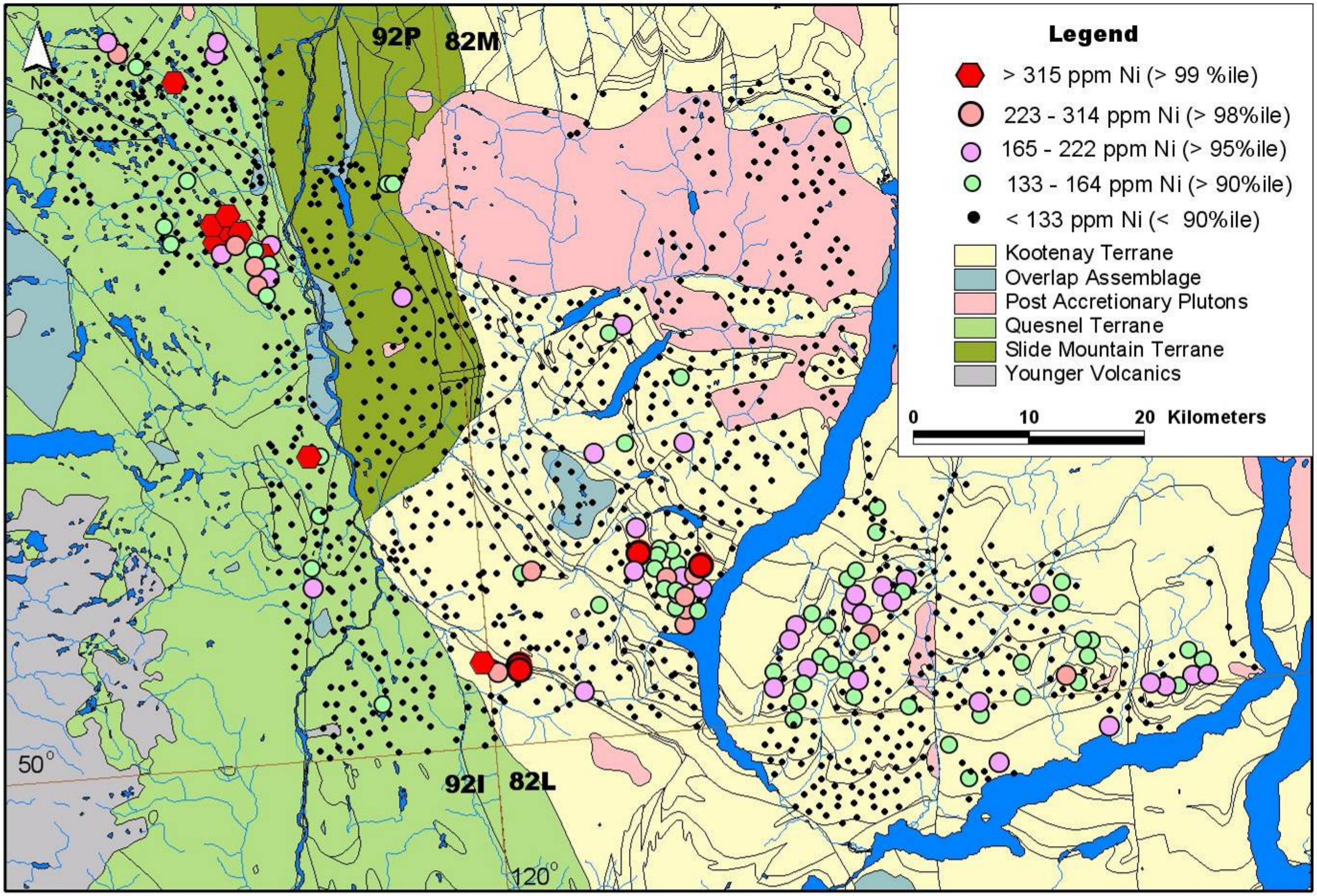

Figure 13. Ni for the 1996-1998 Eagle Bay Project area.

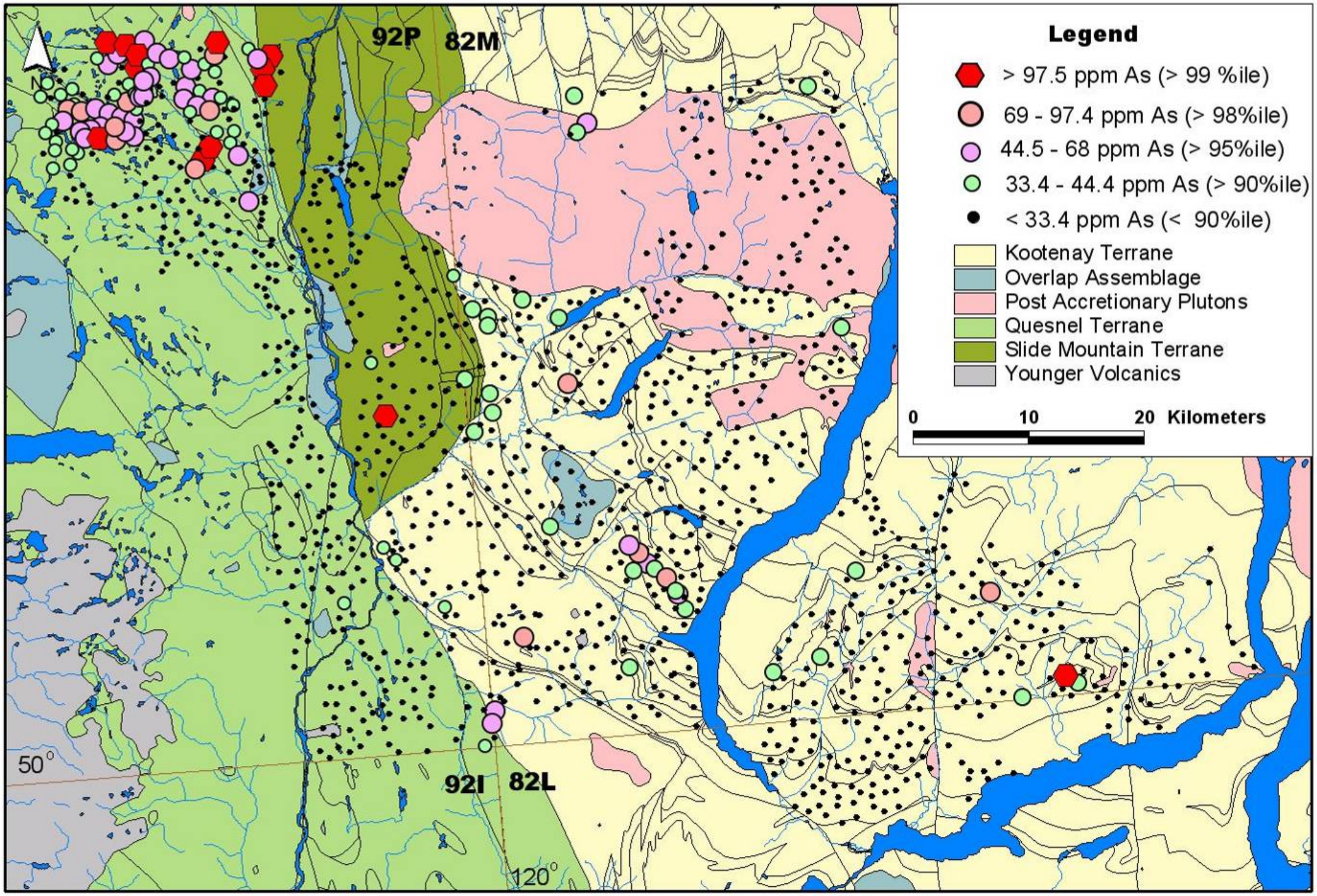

Figure 14. As for the 1996-1998 Eagle Bay Project area.

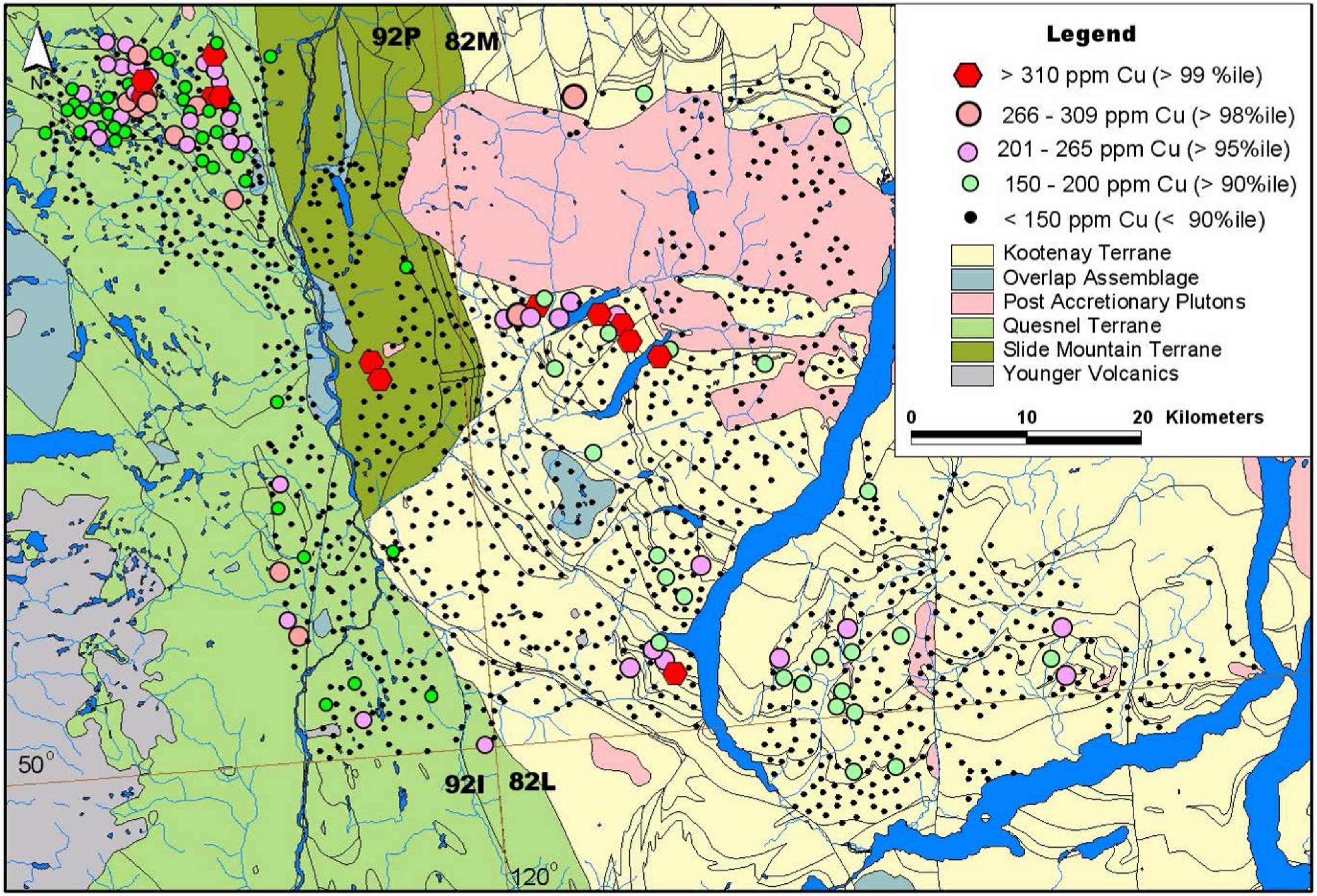

Figure 15. Cu for the 1996-1998 Eagle Bay Project area.

DISCUSSION

There is potential for additional discoveries of polymetallic mineral deposits in this region. Results from the Eagle Bay till sampling surveys have generated staking activity and led to the discovery of new mineral occurrences (Cathro 1998; Cathro and Lefebure 2000). The high number of gossanous outcrops in an area with moderate historical exploration, suggests that future work should expand along the mineralized belt of paragneiss in the northwestern part of 82M/3, east of Adams Lake. These showings follow a continuous mineralized trend roughly along strike with the Pet and Mosquito King occurrences in the southeastern corner of NTS 82M/4. Regional till surveys should extend into the northeastern part of NTS 82M/3 to follow up the recent results in the poorly understood, drift covered region. Renewed industry interest in the northwest (NTS 92P) and recent exploration programs should provide impetus for additional survey work in the highly mineralized, prospective rocks of the Nehalliston Plateau. Regional till sampling should extend northward and follow the Nicola Group volcanic terrane.

The thin drift-mantled upland plateaus and defined valley systems provide an excellent landscape for drift prospecting. The challenge is that regional ice flow directions are commonly parallel to the regional bedrock strike of the Eagle Bay Assemblage. It is futher expected that clastic dispersal patterns associated with any anomalous values detected from this reconnaissance survey will most likely parallel ice flow and be imprinted with minor fluctuations from hydromorphic downslope dispersal (cf. Paulen 2001). Reported geochemical anomalies from known mineral occurrences indicate that the dispersal plumes conform to classic down-ice shapes, usually proximal to the source bedrock. However, in areas of particularly thick drift, and at the edges of the plateau, dispersal trains can be several kilometres in length.

Identifying individual trains can be difficult if multiple mineralized sources are suspected. The presence of multiple mineral deposits can also supply metal-rich till over a large area, producing irregular and elevated background concentrations. Additional research on the distribution of elements with respect to the bedrock geology and multiple element associations is in progress for this area.

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