Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

Exploration and Geological Services Division, Yukon Region

BULLETIN 11

Quaternary geology and till geochemistry of the Anvil district (parts of 105K/2, 3, 5, 6 and 7), central Yukon Territory

Jeffrey D. Bond

with contributions from
Panya S. Lipovsky and Dylan B. MacGregor

Canada

YUKON GEOLOGY PROGRAM

Yukon
Economic Development

Exploration and Geological Services Division, Yukon Region

BULLETIN 11

Quaternary geology and till geochemistry of the Anvil district (parts of 105K/2, 3, 5, 6 and 7), central Yukon Territory

Jeffrey D. Bond

with contributions from
Panya S. Lipovsky and Dylan B. MacGregor

2001

Published under the authority of the Minister of Indian Affairs and Northern Development, Ottawa, 2001.
http://www.inac.gc.ca
Printed in Whitehorse, Yukon, 2001

QS-Y155-000-EE-A1 Catalogue No. R71-62/11-2001E ISBN 0-662-30016-5

This, and other Yukon Geology Program publications, may be obtained from:
Geoscience and Information Sales
c/o Whitehorse Mining Recorder
102-302 Main Street
Whitehorse, Yukon Y1A 2B5 Canada
phone (867) 667-3266, fax (867) 667-3267, geosales@inac.gc.ca
Visit the Yukon Geology Program web site at www.geology.gov.yk.ca

In referring to this publication, please use the following citation:
Bond, Jeffrey D., 2001. Quaternary geology and till geochemistry of the Anvil district (parts of 105K/2, 3, 5, 6 and 7), central Yukon Territory. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Bulletin 11, 39 p.

Production by K-L Services, Whitehorse, Yukon.

Cover: Ice contact glaciofluvial gravel above Anvil Creek. Since the last glaciation the modern stream has incised 250 m into the Quaternary drift and bedrock in this area. The proximity of this drainage to the Tintina Trench has made it susceptible to dramatic base-level changes.

Preface

This study summarizes a detailed surficial geological mapping and till geochemistry survey conducted over five 1:50 000-scale map sheets in the Anvil district of central Yukon. The study was part of a multidisciplinary study of this well-known zinc-lead camp, which includes the large Faro deposit. It was commissioned upon closure of the Faro mine in 1998, with the aim of capturing and synthesising current geological knowledge of the district in order to provide the best possible database for future exploration and assessment of mineral potential.

This report includes descriptions of the Quaternary history, surficial geology and till geochemistry, as well as detailed maps and a CD with the digital geochemical data. “Drift prospecting” is an exploration technique that has been used minimally in Yukon. This study clearly demonstrates it can be an effective tool for detection of massive sulphides buried beneath thick overburden. In future, till geochemistry may be used successfully in the Anvil District, but also elsewhere in prospective, overburden covered terrain in Yukon.

Fieldwork from 1998 to 1999 was funded by the Yukon Geology Program, a jointly managed program with the Department of Indian Affairs and Northern Development and the Yukon Government Department of Economic Development.

Grant Abbott
Chief Geologist and Regional Manager
Exploration and Geological Services Division
Indian and Northern Affairs Canada

Rod Hill
Manager, Mineral Resources Program
Department of Economic Development
Yukon Government

Préface

Cette étude présente les résultats de la cartographie géologique détaillée des dépôts meubles et de la géochimie du till couvrant cinq feuilles cartographiques à l’échelle 1/50 000, dans le district d’Anvil, au centre du Yukon. Elle s’inscrivait dans le cadre d’une étude multidisciplinaire d’un district zinco-plombifère bien connu qui comprend le vaste gisement de Faro. Cette étude a été commandée à la suite de la fermeture de la mine de Faro en 1998. Son but était de réunir et de synthétiser les connaissances géologiques actuelles sur le district d’Anvil afin de constituer la meilleure base de données possible pour les travaux d’exploration futurs et l’évaluation du potentiel minéral de la région.

Ce rapport comprend des descriptions de l’évolution du quaternaire, de la géologie des dépôts meubles et de la géochimie du till, de même que des cartes détaillées et un CD contenant des données géochimiques numériques. La prospection glacio-sédimentaire est une méthode d’exploration rarement utilisée au Yukon. Cette étude démontre qu’elle peut être un moyen efficace pour la détection d’amas de sulfures massifs ensevelies sous les morts terrains. La géochimie du till pourrait être employée utilement non seulement dans le district d’Anvil mais ailleurs au Yukon où les terrains prometteurs sont enfouis sont des dépôts meubles.

Les travaux de terrain effectués de 1998 à 1999 ont été financés par le Programme de géologie du Yukon, une initiative gérée conjointement par le ministère des Affaires indiennes et du Nord canadien et le ministère du Développement économique du Yukon.

Grant Abbott
Géologue en chef et gestionnaire régional
Division des services géologiques et d’exploration
Affaires indiennes et du Nord Canada

Rod Hill
Gestionnaire, Programme des ressources minérales
Ministère de l’Expansion économique
Gouvernement du Yukon

Contents

Figures

Maps and appendices (CD) in pocket

Open File 1999-5: Surficial geology map and till geochemistry of Swim Lakes (105K/2 NW), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-6: Surficial geology map and till geochemistry of Blind Creek (105K/7 SW), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-7: Surficial geology map and till geochemistry of Mt. Mye and Faro (105K/3 E and 6E), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-8: Surficial geology map of Mt. Mye and Faro (105K/3 W and 6 W), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-9: Surficial geology map and till geochemistry of Mt. Mye (105K/6 E), central Yukon (1:25,000 scale), by Panya Lipovsky and J.D. Bond

Open File 1999-10: Surficial geology map and till geochemistry of Mt. Mye (105K/6 W), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-16: Surficial geology map and till geochemistry of Rose Mountain (105K/5 NE), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-17: Surficial geology map of Rose Mountain (105K/5 SE), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-18: Surficial geology map and till geochemistry of Rose Mountain (105K/5 NW), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-19: Surficial geology map and till geochemistry of Swim Lakes (105K/2 NE), central Yukon (1:25,000 scale), by J.D. Bond

Open File 1999-20: Surficial geology map and till geochemistry of Blind Creek (105K/7 SE), central Yukon (1:25,000 scale), by J.D. Bond

Appendix 1. Faro case study till geochemistry

Appendix 2. Anvil regional till geochemsitry

Abstract

The integration of till geochemistry and glacial geology into Yukon mineral exploration has been largely underused. In the Anvil district, thick glacial deposits have consistently hampered exploration. From the time of the initial discovery made in Vangorda Creek, it took an additional 20 years before the Grum deposit was discovered only 2 km to the northwest. This work examines the utility of till geochemistry as a method to trace mineralized soil/till samples back to their source rocks in the Anvil district. The Anvil district was last glaciated during the McConnell glaciation, which had a significant impact on the local terrain. The relatively swift-flowing Cordilleran ice sheet deposited thick sequences of till in low-lying areas and eroded southeast-facing slopes and hill summits in the Swim basin and Vangorda plateau. This type of glacial history is conducive for till geochemical exploration. Evidence for a late glacial Cordilleran re-advance is discussed and has implications on prospecting in the district.

A 12-km^2 till grid was sampled northwest of the Faro deposit to map the glacial dispersion of mineralized sediment. The till geochemistry on the –230 mesh fraction (silt and clay) indicated a broad dispersion plume for lead, zinc and copper extending more than 5 km west of the Faro Pb/Zn deposit. A section of the dispersion train may have a palimpsest origin. The soil geochemistry on the –80 mesh fraction, from 1964 data, indicated a much narrower dispersion plume extending directly from the Faro deposit. The geochemical changes at depth in the till stratigraphy were examined at the Vangorda mine. Results showed that anomalous lead concentrations, unlike zinc concentrations, were found throughout the 20-m till column. Regional till sampling was carried out in three areas peripheral to the known massive sulphide deposits. Results from these sampling programs highlighted anomalies in lead, zinc and copper. Overall, the application of till geochemistry proved to be successful in the Anvil district. Applying similar techniques to drift-covered terrain elsewhere in the northern Cordillera would be beneficial.

Résumé

La géochimie du till et la géologie glaciaire ne sont pas suffisamment intégrées à l'exploration minérale au Yukon. Dans le district d'Anvil d'épais dépôts glaciaires ont constamment ralenti les travaux d'exploration. Il s'est passé 20 années entre le moment où on a fait une première découverte au ruisseau Vangorda et la découverte du gisement de Grum situé à 2 km seulement au nord-ouest. Le présent document examine l'utilité de la géochimie du till comme méthode permettant de tracer les roches mères des échantillons de sol et de till minéralisés prélevés dans le district d'Anvil. Ce district a été englacé au cours de la glaciation de McConnell, laquelle a eu un impact considérable sur le terrain local. La calotte glaciaire de la Cordillère à écoulement relativement rapide a déposé d'épaisses séquences de till dans des régions de faible relief et a érodé les pentes faisant face au sud-est ainsi que les sommets des collines dans le bassin de Swim et le plateau Vangorda. Ce type d'histoire glaciaire est propice à l'exploration géochimique du till. Les manifestations d'une réavancée glaciaire tardive de la Cordillère font l'objet d'une discussion dans le présent rapport; elles ont des incidences sur la prospection dans ce district.

Une maille du till de 12 km^2 a été échantillonnée au nord-ouest du gisement de Faro en vue de cartographier la dispersion glaciaire des sédiments minéralisés. La géochimie du till effectuée sur une maille d'une fraction de –230 (silt et argile) a révélé un vaste panache de dispersion pour le plomb, le zinc et le cuivre s'étendant sur plus de 5 km à l'ouest du gisement plomb-zinc de Faro. Une partie de la traînée de dispersion pourrait être d'origine résiduelle. La géochimie du sol exécutée sur une maille d'une fraction de –80 à l'aide de données recueillies en 1964, a révélé un panache de dispersion plus étroit s'étendant directement à partir du gisement de Faro. Les changements géochimiques en profondeur dans la stratigraphie du till ont fait l'objet d'un examen à la mine Vangorda. Les résultats ont montré que, contrairement aux concentrations de zinc, les concentrations anormales de plomb, se rencontraient tout au long de la colonne de till de 20 m. L’échantillonnage du till à l’échelle régionale a été fait dans trois régions situées à la périphérie de gisements de sulfure massif connus. Les résultats provenant de ces programmes d’échantillonnage mettent en évidence des anomalies de plomb, de zinc et de cuivre. Dans son ensemble, l’utilisation de la géochimie du till dans le district d’Anvil fut un succès. L’application de méthodes similaires à des terrains recouvert de dépôts détritiques ailleurs dans la Cordillère septentrionale serait avantageuse.

Introduction

Applying Quaternary geology and geochemistry to the exploration of buried mineral deposits is a well-established technique in parts of Scandinavia and eastern Canada. In northern and western Canada this technique, also referred to as drift prospecting, has increased in popularity in recent years. Exploration for diamonds in the Northwest Territories has used indicator minerals in till and glacial history as a means to trace dispersion trains back to the kimberlite pipe sources. In southern and central British Columbia, the provincial geological survey has been mapping surficial geology and conducting regional till geochemistry surveys to encourage mineral exploration in areas that previously received little attention due to thick overburden (Bobrowsky and Sibbick, 1996; Bobrowsky et al., 1997b, 1998; Kerr et al., 1992; Levson et al., 1997a,b). Drift prospecting in Yukon has been restricted to studies in the Tintina Trench, where epithermal-style gold mineralization was targeted (Plouffe, 1989; Plouffe and Jackson, 1992). No systematic studies have been completed that focus on the applicability of this technique in the northern Cordillera. Additionally, no regional till sampling, other than in the Tintina Trench, has been carried out to supplement existing geochemical databases in Yukon.

The Anvil district in central Yukon provides an opportunity to apply till geochemistry to both a case study and to regional exploration. Detailed examinations of the geochemistry in basal till down paleo-glacier flow from a known sedimentary-exhalative (SEDEX) deposit, as well as within till overlying a similar deposit, established background geochemical thresholds and physical dispersion models on a local scale. These local characteristics are useful for interpreting regional geochemical values and provide guidelines for conducting follow-up sampling on a more regional scale.

This bulletin presents results from data collected during the 1998 and 1999 field seasons. The 1998 field season focussed on case study examinations at the Faro and Swim SEDEX deposits. Regional sampling was also conducted in the Swim basin in 1998. During the 1999 field season, regional samples were collected in outlying drift-covered areas that had similar bedrock stratigraphy to areas of known mineralization in the Anvil district. This report includes results from each of the two field seasons and discusses the value and limitations of drift prospecting in the northern Cordillera.

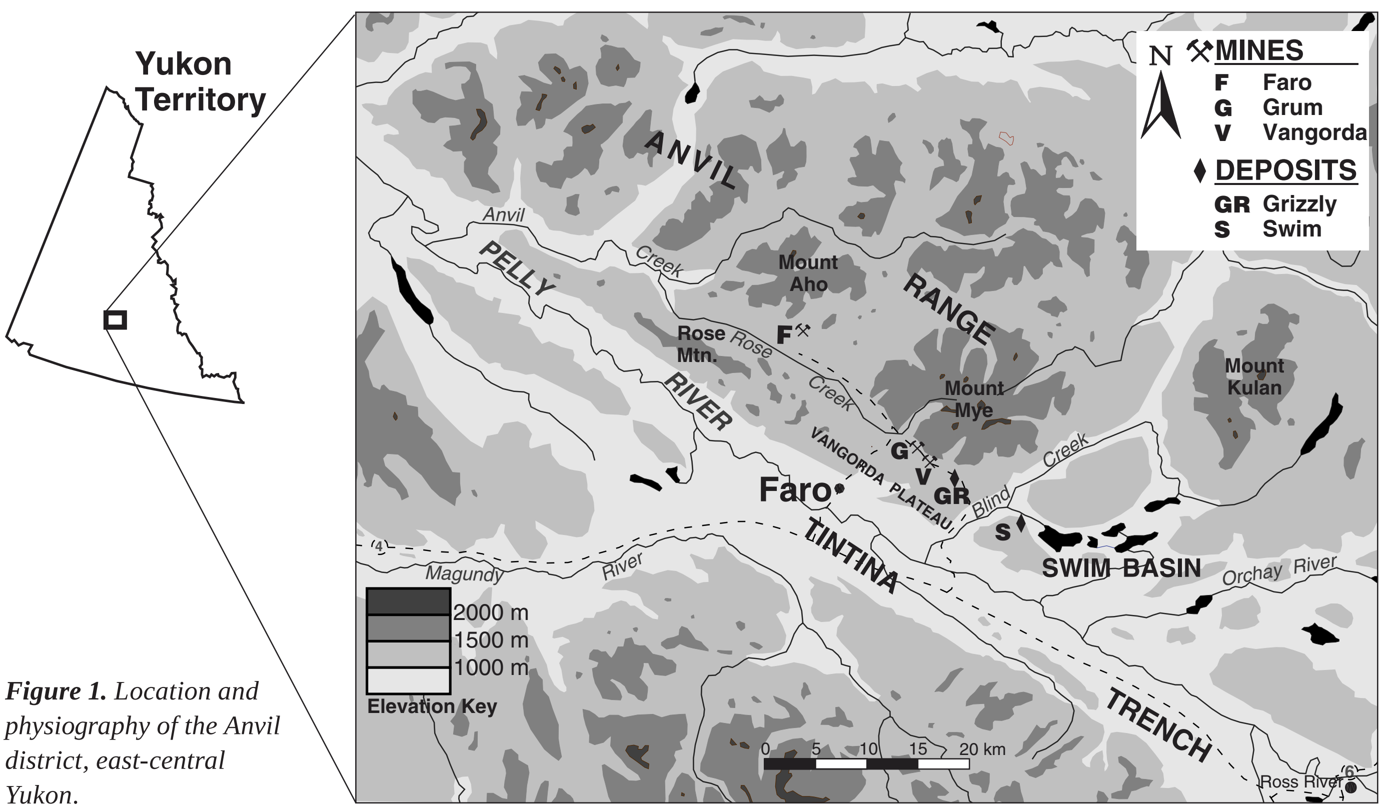


Figure 1. *Location and physiography of the Anvil district, east-central Yukon.*

Location and access

The Anvil district is located near the town of Faro in central Yukon (Figure 1), approximately 200 km northeast of Whitehorse. Access to the area is via the North Klondike highway to Carmacks and east on the Robert Campbell highway to Faro. Access to Faro is also obtained from the south via the Robert Campbell highway beginning at Watson Lake. Numerous mining roads and trails in the Anvil district provide access to the Vangorda plateau, Blind Creek valley and Swim basin. Trails accessible by all-terrain-vehicle extend north of Mount Mye, throughout the Swim basin, in Rose Creek valley and onto Mount Aho.

Physiography and hydrology

The Anvil district is located within the Yukon Plateau physiographic subdivision. The Yukon Plateau consists of a dissected plateau surface that comprises much of central Yukon. The Anvil district is bound by the Pelly Mountains and Tintina Fault to the southwest, and the Tay River to the north. The Anvil Range lies at the core of the district with summits rising above 1800 m (Figure 1). This study focussed on an area of the Anvil Range near Rose Mountain, Mount Aho, Mount Mye and Mount Kulan. Alpine valleys dissect the uplands and converge to form a system of interconnected valleys. Intermediate surfaces flank the uplands and form plateaus 150-450 m above the Tintina Trench. Two of these plateaus, in the study area, are Vangorda plateau and an unnamed, broad plateau/valley north of Mount Mye (Figure 1). The Swim basin, an area of relative low relief and poor drainage, lies at the southeastern edge of the study area.

Streams in the Anvil district are part of the Pelly River drainage. The main creeks in the study area are Blind Creek and Anvil Creek. Numerous unnamed tributaries to these creeks originate in the uplands of the Anvil Range. Restricted drainage in the Swim basin has occurred as a result of glacial erosion, which has created poorly drained glacial troughs in the landscape.

Geology

The Anvil district is part of the Selwyn Basin, a deep-water sedimentary basin that formed along the ancient North American continental margin during the late Proterozoic and early Paleozoic (Figure 2; Gabrielse, 1967). The Anvil district is located on the outboard edge of the basin and is dominated by successions of basin-

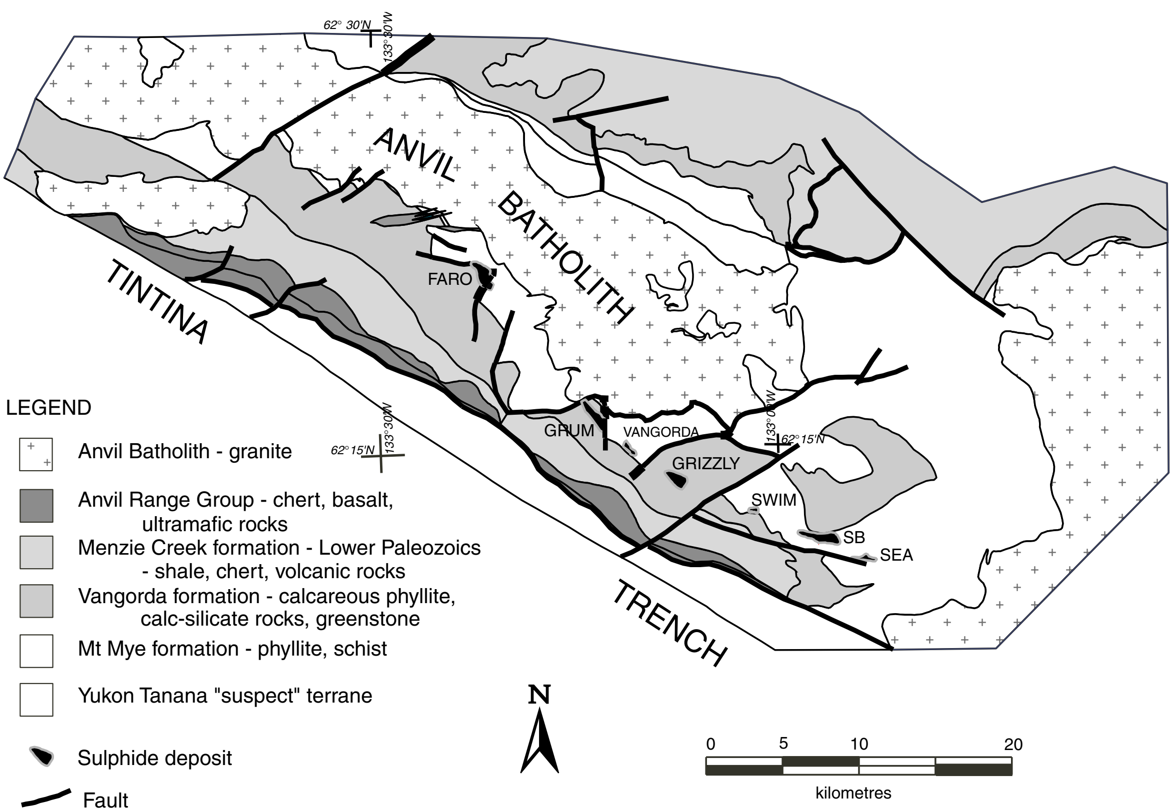


Figure 2. *Geology of the Anvil district (modified from Jennings and Jilson, 1986).*

filling sediments. The stratigraphic sequence comprising the Anvil district extends from latest Precambrian to Ordovician and can be divided into three formations: Mount Mye (oldest), Vangorda, and Menzie Creek (youngest; Jennings and Jilson, 1986). Mount Mye formation is a deep marine sequence dominated by non-calcareous phyllite and schist with lesser marble and calc-silicate lenses, carbonaceous schist, minor psammitic schist and metabasite. Vangorda formation is also a deep marine sequence, dominated by calcareous phyllite and schist with lesser marble and calc-silicate lenses, carbonaceous schist, minor psammitic schist and metabasite. Menzie Creek formation is a 1-km-thick sequence of metavolcanic rocks deposited during episodic extensional tectonism on the continental margin and is gradational with the Vangorda formation. The Anvil district Zn-Pb-Ag stratiform pyritic massive sulphide deposits occur within a 150-m interval in the pre-Ordovician strata at the contact between Mount Mye and Vangorda formations. Five ore deposits occur in the Anvil district along a southeast curvilinear trend: Faro, Grum, Vangorda, Grizzly, and Swim (Figure 1).

The mid-Cretaceous Anvil Range plutonic suite intruded the Selwyn Basin stratigraphy in response to collision of Yukon-Tanana suspect terrane with Ancient North America (Jennings and Jilson, 1986). Movement along the Tintina Fault began in the Late Cretaceous and continued into the early Tertiary (Pigage, 1990).

Soils, vegetation and permafrost

Soils

Soil development in the Anvil district reflects the physiographic diversity and the continental climate found in east-central Yukon. In alpine and sub-alpine zones, where frost action has a strong effect on surface sediment movement, soils are typically Regosols. In part, the lack of soil development at higher elevations, other than Ah or Ahb horizons, is due to the resistant nature of the rocky parent material. Dystric brunisols also occur locally above tree line in association with coarse, intrusive rocks and in areas of higher precipitation (Smith, 2001). Upland soils, below subalpine elevation, are typically Eutric brunisols on better-drained surface sediments, and Turbic cryosols on imperfectly drained parent material (Smith, 2001). In the Eutric brunisols, the depth of Bm soil development in basal tills rarely exceeds 30 cm depth below the surface. Soil development near valley bottoms form on a variety of glacial parent materials. Coarse-textured glaciofluvial and till deposits support Eutric brunisols, whereas poorly drained glaciolacustrine sediments are commonly underlain by permafrost and are classified as Turbic cryosols (Smith, 2001). On active alluvium, where little soil development occurs, Regosols are most common. Static and Turbic cryosols occur in backswamp areas of floodplains where imperfectly drained sediment is deposited.

Vegetation

The vegetation of the Anvil district ranges from boreal to alpine. Alpine vegetation communities consist of low ericaceous shrubs, prostrate willows and lichens (Smith, 2001). Near tree line, at 1500 m, subalpine fir, white spruce and shrub birch are extensive. The northern Cordilleran boreal forest in the study area consists of vegetation associations of white spruce, black spruce, lodgepole pine, trembling aspen, balsam poplar, paper birch, willow, shrub birch, ericaceous shrubs, grasses and feather moss. Site-specific associations vary according to slope, aspect, surficial sediments and fire history. On cooler, moister, north-facing slopes, black spruce, willow, shrub birch and feather moss are common. On warmer and better-drained sites, trembling aspen, white spruce, ericaceous shrubs and grasses are abundant. Recently burned areas contain lodgepole pine, trembling aspen and ericaceous shrubs. Near wetlands, willow, sedges and aquatic plants are common and often mix with black spruce, sedge tussocks and sphagnum moss in bogs fringing the low areas.

Permafrost

The Anvil district is located within the zone of discontinuous permafrost. Variations in permafrost distribution are controlled by surface sediments, soil moisture, slope aspect and snow depth (Burn, 1987). In the boreal forest zone, permafrost is located where soil moisture levels are higher, such as in till, colluviated till and glaciolacustrine deposits. Within areas mantled by till, permafrost is more common on north-facing slopes and in old growth forests; these sites typically receive reduced solar radiation. Patterned ground, palsas, thermokarst and frost boils are commonly associated with the glaciolacustrine deposits in the alpine valleys of Mount Mye. Thermokarst is also present on alluvial plains where streams are eroding fine-grained surficial deposits. Other evidence of permafrost activity occurs in the alpine and subalpine zones and includes frost shattering, stone stripes and solifluction.

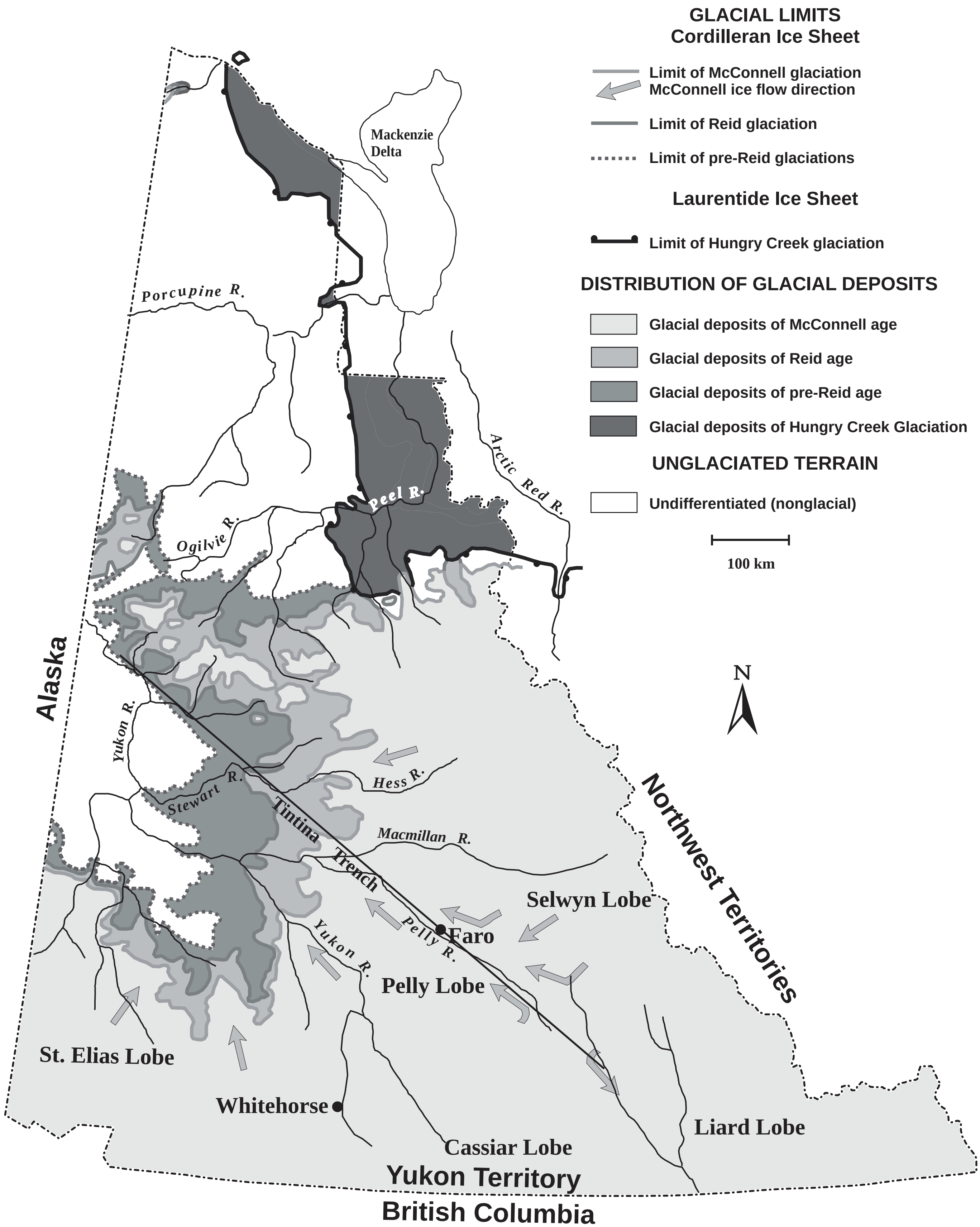


Figure 3. *Glacial limits, distribution of glacial deposits and McConnell ice flow patterns in the Yukon Territory (modified from Duk-Rodkin, 1999).*

Quaternary history

Yukon was last glaciated during the late Wisconsinan McConnell glaciation, approximately 25,000 to 15,000 years ago (25 – 15 Ka). The McConnell glaciation represents the most recent glaciation in a string of glacial/interglacial cycles that dates to the beginning of the Quaternary period, approximately 2.5 million years ago (2.5 Ma; Froese et al., 2000; Duk-Rodkin et al., 1996; Barendregt et al., 1995). The earliest glaciations (pre-Reid), at the onset of the Quaternary period or early Pleistocene, were the most extensive and are largely responsible for the current regional drainage configuration in Yukon. More recent glaciations such as the Reid (middle Pleistocene) and McConnell (late Pleistocene) have well-defined limits within the pre-Reid glacial limits (Figure 3; Bostock, 1966; Jackson, 1994; Bond, 1997). Evidence of older glaciations within the McConnell limit is restricted to isolated exposures along the Pelly River in the Tintina Trench and in the Kluane Range.

In southern Yukon, accumulation zones for the McConnell glaciation include the Selwyn, Pelly, Cassiar and St. Elias mountains (Figure 3). The Anvil district was glaciated by ice from the Selwyn and Pelly mountains, and by local glaciers that developed in the Anvil Range.

The Selwyn and Pelly lobes, in the vicinity of Ross River and Faro, advanced into the Tintina Trench and followed the topographic lineament northwest into central Yukon (Figure 3). Streamlined landforms developed proximal to the Tintina Trench as a result of rapid ice flow in the unobstructed lineament (Figure 4). Ice flow in the Swim basin, according to streamlined landforms, was largely from east to west, becoming more northwesterly upon intersecting the Vangorda plateau (Figure 5, in pocket). Till fabric data from exposures on the Vangorda plateau show some ice-flow variability, which likely reflects a directional change caused by Mount Mye alpine ice merging with the main Cordilleran ice sheet. Ice flow continued to the northwest into Rose Creek valley where it became valley confined. The upper limit of erratics mapped on Mount Mye (summit elevation 2061 m) is 1951 m, suggesting that nunataks may have been present in the Anvil Range during the height of the last glaciation.

McConnell deglaciation, according to Jackson (1987, 1994), occurred rapidly when the equilibrium line rose significantly above the 1830 m elevation. This resulted in a regional starvation of the ice sheet. A subsequent re-advance of the Cordilleran ice sheet has been documented in other areas of central Yukon and appears to be consistent with the glacial history of the Anvil district (Figure 5, in pocket; Plouffe, 1989; LeBarge et al., in prep.). It seems that local alpine glaciers had disappeared and did not reform when the Cordilleran ice sheet re-advanced. This is evident

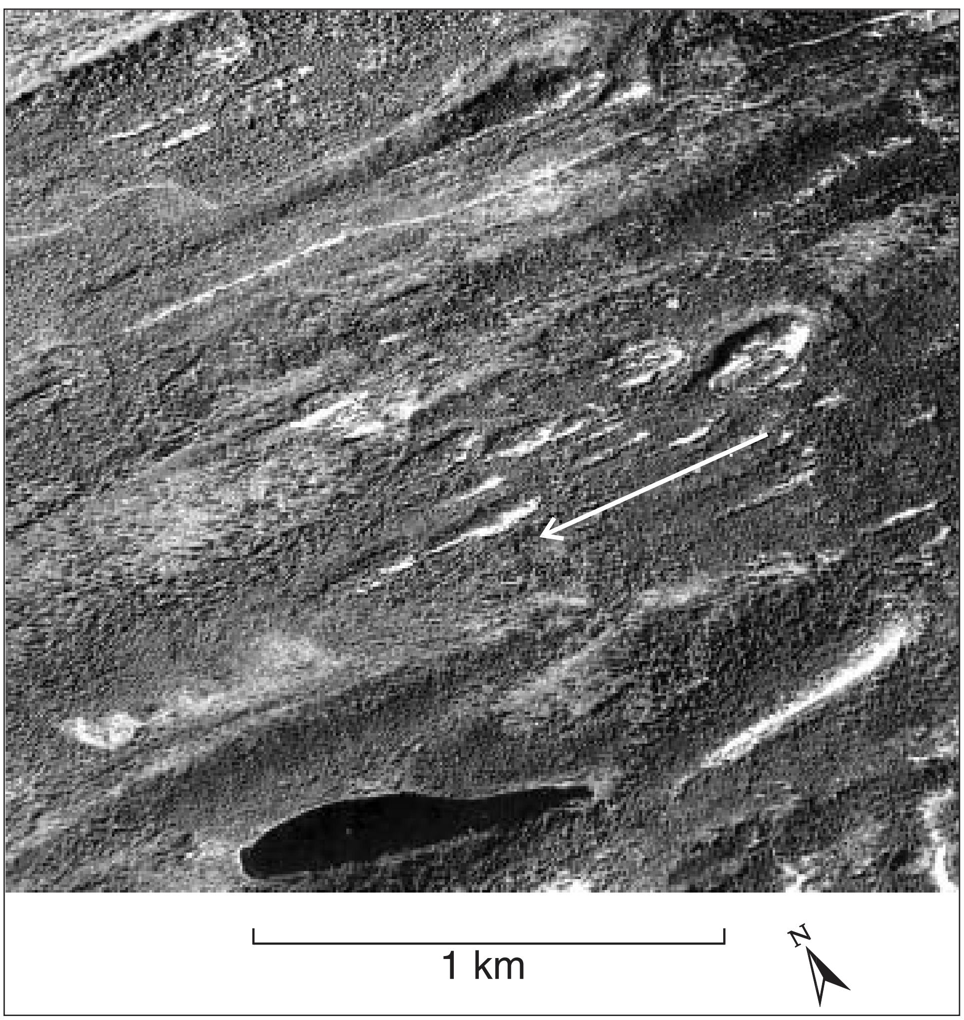


Figure 4. *Aerial photograph of streamlined landforms in the Swim basin. The ice-flow direction, indicated by the arrow, is to the west.*

from lateral moraines and meltwater channels of the Cordilleran ice sheet that extend to the back of local alpine valleys. Numerous glacial lakes formed in the alpine valleys as a result of the up-valley ice flow.

Outside of the Anvil uplands, two geochemically different tills were documented in natural exposures. The lower till contains clasts consistent with the local geology, whereas the upper re-advance till contains clasts of distal lithologies. These two till units will be discussed further in the section on implications of surficial geology, page 10.

Upon retreat of the ice sheet southeast of the Anvil district, a glacial lake formed in the Tintina Trench. This lake formed as a result of either a sediment dam in the trench or by isostatic depression. The glacial lake has been informally termed by the author glacial lake Pelly.

The onset of the McConnell glaciation occurred after 26,350 ± 280 B.P. (Jackson, 1991; TO-393) according to a radiocarbon date on a bone fragment of *Bison priscus* along the Ketza River. According to Ward (1989), deglaciation of the Pelly River was complete by 12,590 ± 540 B.P. (TO-931). On Vangorda plateau a radiocarbon date of 10,550 ± 40 B.P. (Beta – 128239) from this study was obtained from seeds at the base of a lacustrine unit that overlies outwash gravel and till. This date documents the timing of revegetation on Vangorda plateau.

Surficial geology

The surficial geology of the Anvil district is controlled by three physiographic divisions: Anvil Range, Vangorda plateau/Swim basin, and Tintina Trench (Figure 1).

Anvil Range is covered by colluvium with exposed rock and felsenmeer above 1770 m (5800 feet), and at lower elevations on north- and west-facing slopes where nivation processes are common (Figure 6; Bond 1999-6, 7, 9, 10, 16, 17, 18, 20, in pocket). Solifluction is common above tree line and is enhanced in moisture-rich soils on north- and west-facing slopes (Lipovsky and Bond 1999-9, in pocket). Meltwater channels were mapped to at least 1710 m (5600 feet) and erratics to 1950 m (6400 feet), but no significant glacial deposits were noted at these elevations (Figure 7). Glacial sediment cover becomes increasingly abundant below 1460 m (4800 feet; Figure 8).

Deltaic deposits and kame terraces are common near the mouths of alpine valleys in the region of Mount Mye and may be found as high as 1550 m (5100 feet) elevation. Near cirque headwalls, glaciofluvial deposits may be present in areas where glacial meltwater breached drainage divides during the late McConnell re-advance of Cordilleran ice (Figure 8). Glaciolacustrine blankets, deposited when Cordilleran ice dammed the mouths of alpine valleys, are common on the north side of Mount Mye (Lipovsky and Bond 1999-9, in pocket). Permafrost features, such as palsas and thermokarst lakes, are common where these glaciolacustrine deposits are found.

Till in the alpine valleys of Mount Mye is composed of sediments derived from local ice sources and the Cordilleran ice sheet. Till flanks the alpine valleys to an elevation of approximately 1550 m (5100 feet) and is commonly colluviated, draped by colluvium, or buried by talus. In valleys, separating the uplands in the Anvil Range, the till is thick and commonly underlies glaciofluvial deposits in areas of former meltwater drainage (Figure 9). Sporadic rock glaciers are present in the Anvil Range on north-facing slopes.

The Vangorda plateau and Swim basin are draped with till and minor outwash sediments (Bond 1999-5, 7, 8 and 19, in pocket). Glacial outwash deposits occupy low channels, which cut upland surfaces. Till veneers

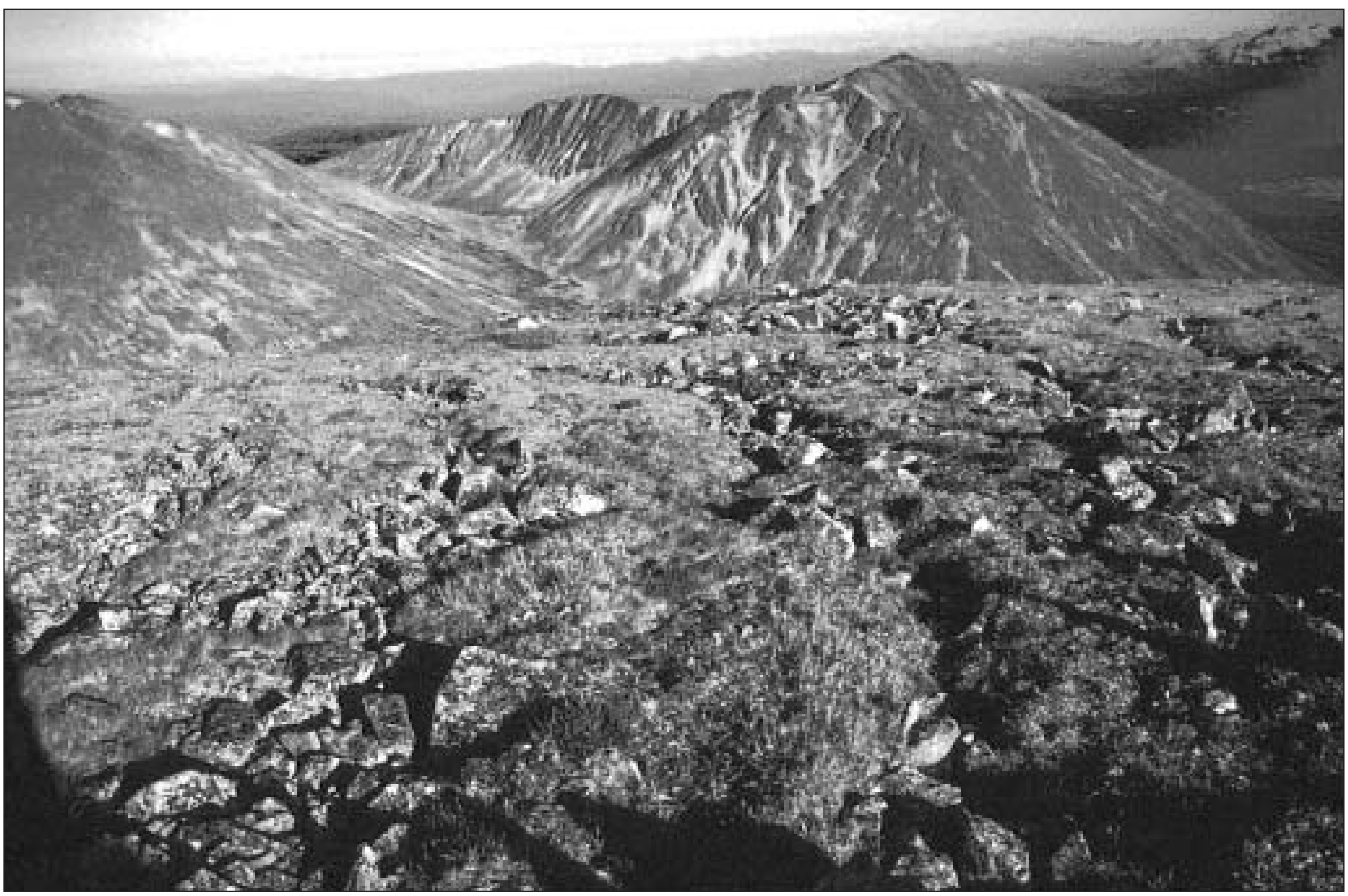


Figure 6. *Felsenmeer near the summit of Mount Mye in the Anvil Range. Note the stone stripes developed in the felsenmeer from frost reworking.*

__Figure 7.__ A meltwater channel formed by outwash emitted off the Selwyn ice lobe. The channel cuts across a plateau at 1680 m (5500 ft) on Mount Mye. Landforms such as this are common on the flanks of the Anvil Range between the elevations of 1310–1770 m (4300-5800 ft). The outwash channel is approximately 150 m across.

and colluviated till veneers are common on south- and southeast-facing slopes that were once exposed to glacial erosion by the northwesterly flowing ice sheet (Figure 5). Crag and tail landforms were also noted at the tops of southeast-facing slopes; these landforms were generated by subglacial erosion when the ice sheet intersected a resistant bedrock 'crag' leaving a pressure void in the down-ice direction. In the pressure void or 'tail', sedimentation occurs, and/or a ridge of bedrock is preserved (Figure 10). Crag and tail landforms are useful indicators of ice-flow direction. Organic deposits locally cover surficial deposits in poorly drained areas and on the east side of Blind-Cub Plateau (Bond 1999-5, in pocket). There is little alluvial accumulation in Swim basin due to poor drainage development. Where streams do occur, alluvium consists of fine-grained sediments derived from the reworking of till.

The Tintina Trench/Pelly River valley contains glaciolacustrine, glaciofluvial sediments, and till. Most deposits date from deglaciation and include thick sequences of glaciolacustrine silts deposited in glacial lake Pelly. Glacial lakes also developed in tributary valleys to the Tintina Trench when stagnating ice dammed local drainages. The hummocky terrain common in the Tintina Trench consists of a complex of glaciofluvial gravel and sand, melt-out till and debris-flow deposits composed of resedimented till (Figure 11 and Bond 1999-8, in pocket). Holocene erosion by the Pelly River resulted in the formation of benches of glaciolacustrine and till deposits marginal to the present-day floodplain.

Implications of surficial geology on exploration in the Anvil District

Thick glacial deposits across the Vangorda plateau and Swim basin have hampered exploration in the Anvil district. Relatively rapid ice flow through the area resulted in an increased sediment load carried by the glacier due

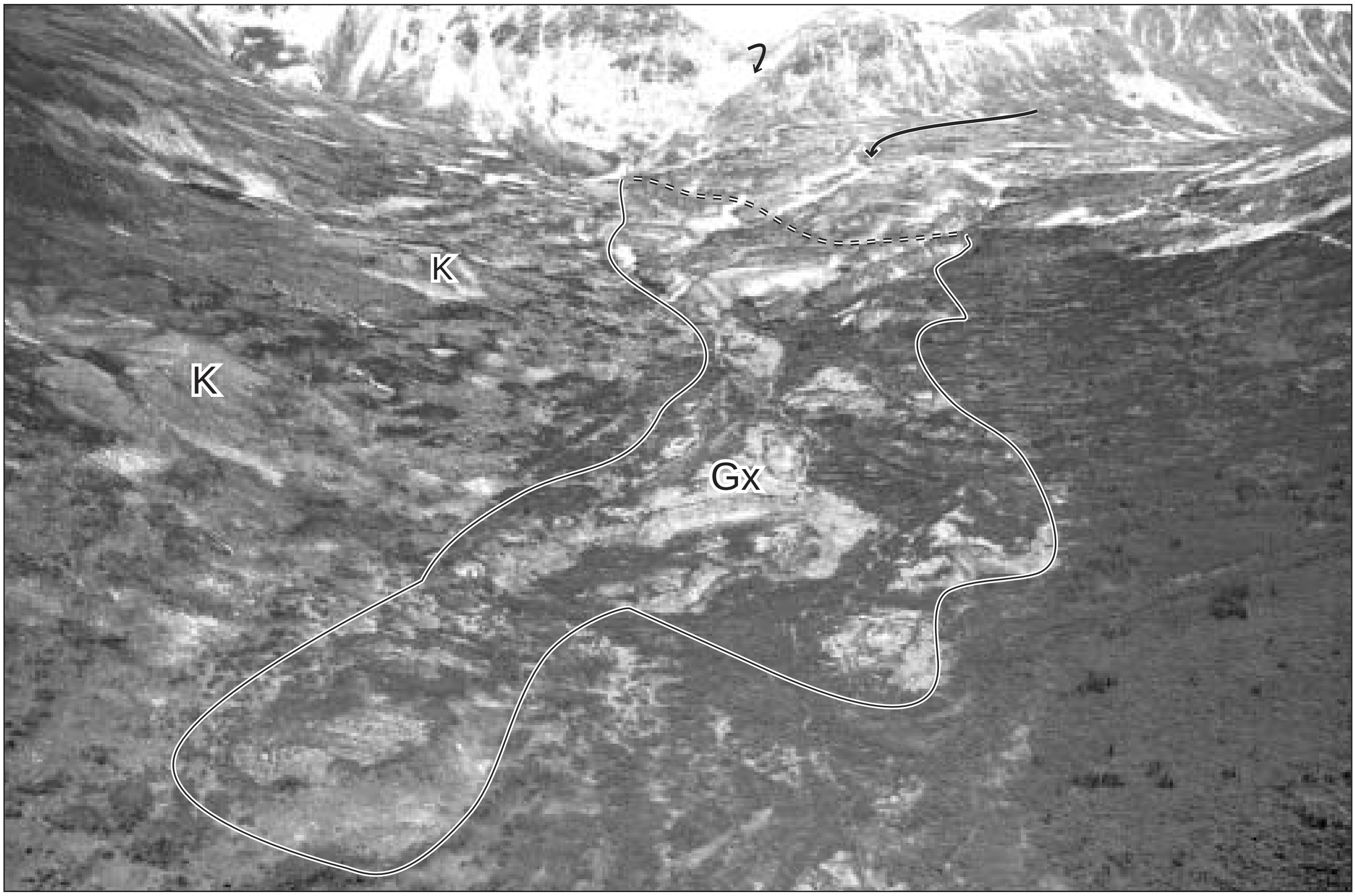


Figure 8. *Glaciofluvial deposits at the headwaters of an unnamed creek north of Mount Mye. The outwash (Gx) and the kame deposits (K) developed when meltwater from the Cordilleran re-advance breached cirque headwalls and arêtes on the south and east sides of the Mount Mye upland. See Figure 5 for location of meltwater channels.*

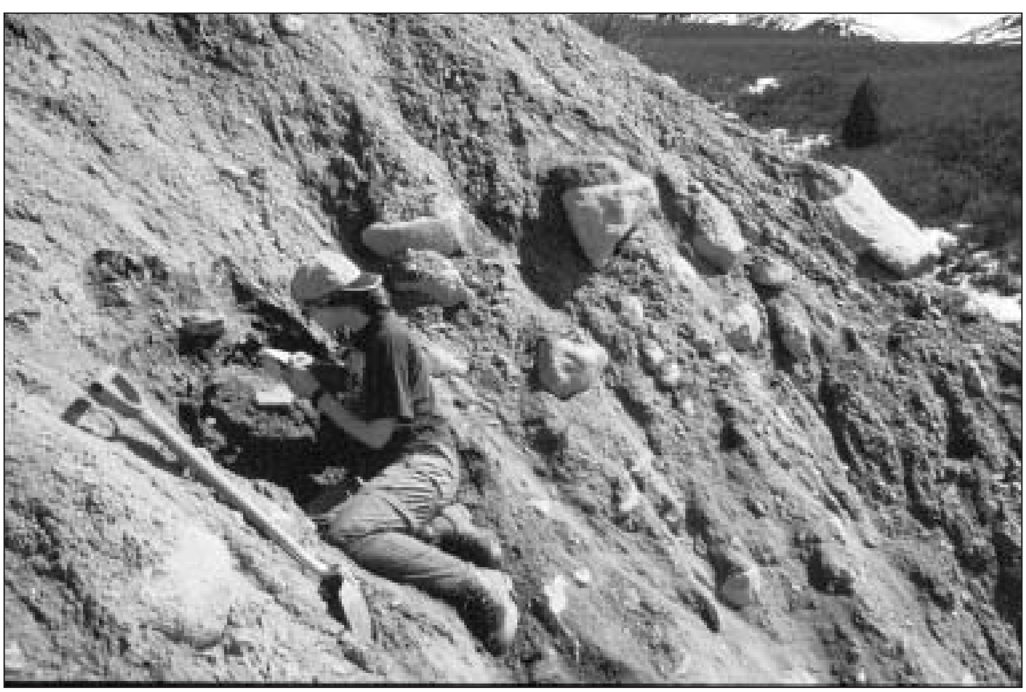
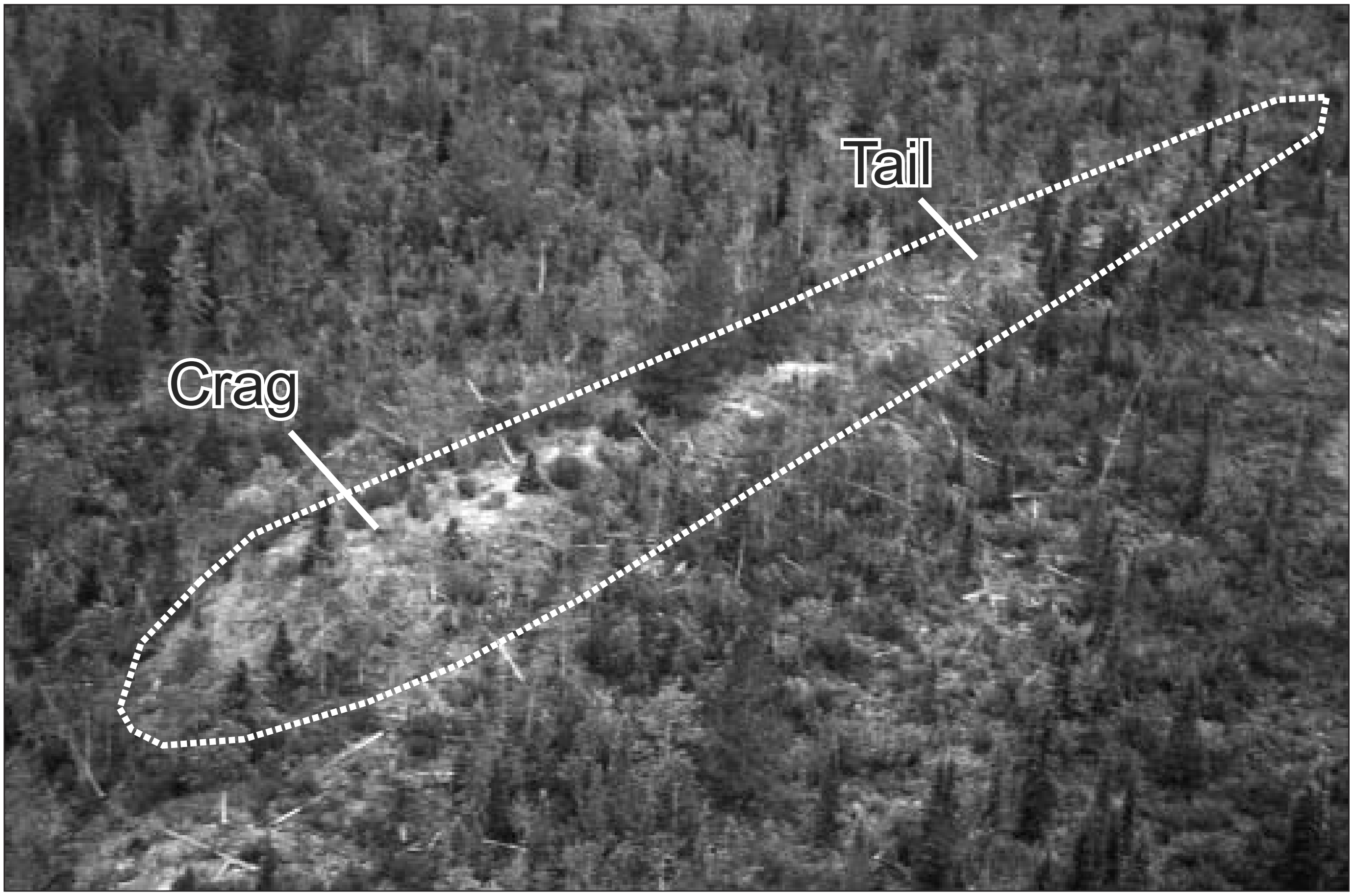


Figure 9. *Natural exposure of basal till in a inter-plateau valley, Anvil Range. Complex sequences of surficial geology dominate the valley bottoms of the Anvil Range. Basal till is often preserved at depth beneath outwash and/or meltout till in these settings.*



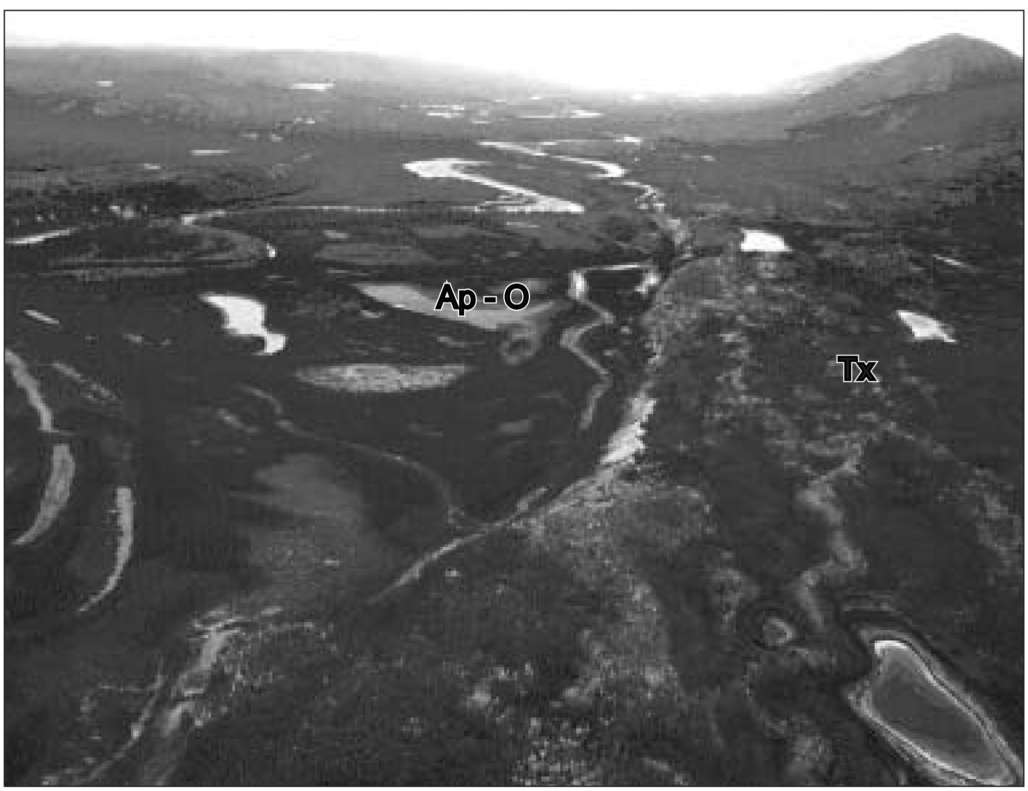


Figure 10. *(above) A crag-and-tail landform on the Vangorda plateau. Direction of ice flow was from the lower left to the upper right or to the west-northwest. This landform is approximately 175 m long.*

Figure 11. *Hummocky terrain (Tx) in the Tintina Trench near Faro. The Pelly River floodplain (Ap-O) is incised into the complex of glacial melt-out deposits and glacial lake sediments.*

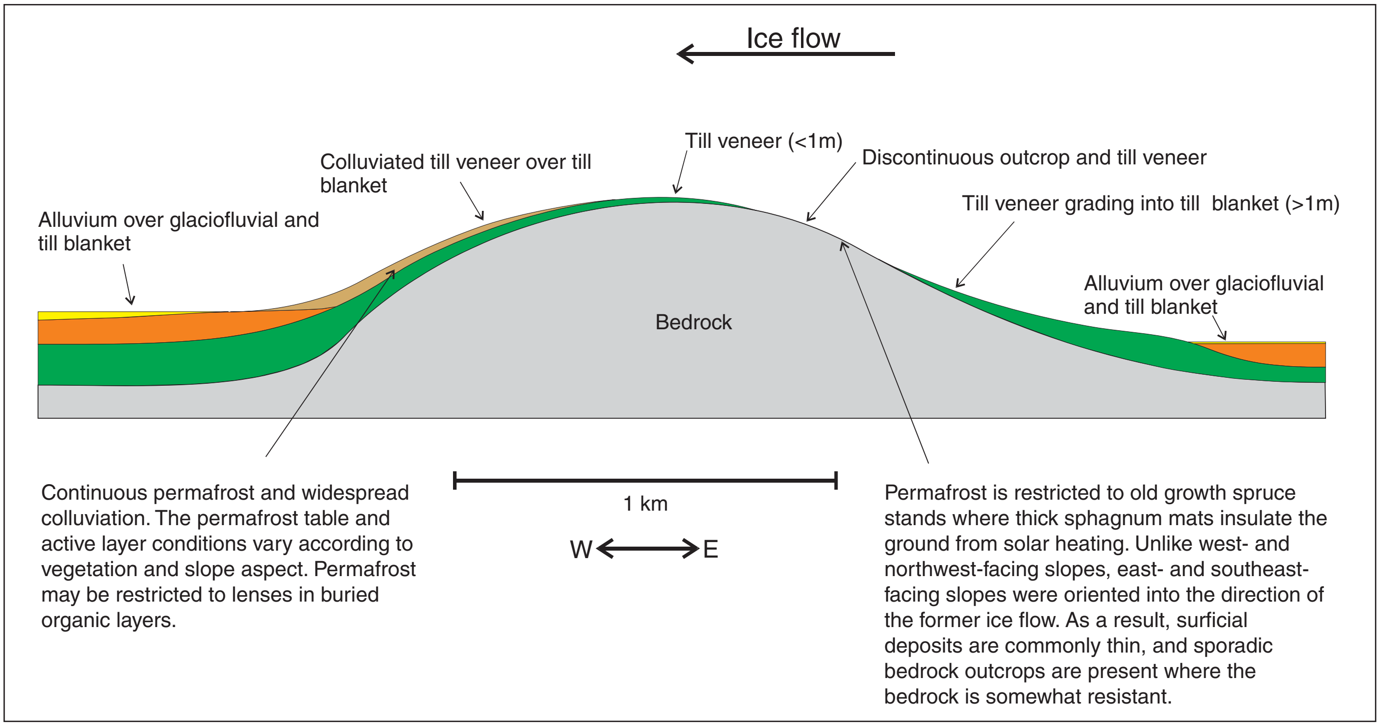


Figure 12. *Schematic diagram showing the generalized surficial geology in Swim basin relative to the dominant ice-flow direction.*

to its increased erosive power. As a result, thick packages of glacial sediments were deposited over the terrain where topography was low. Areas of thin drift (till veneers <1 m), or exposed bedrock, are found on or near the crest of southeast-facing slopes and on hill summits (Figure 12). Thick glacial deposits, in contrast, accumulated on the lee-side of hill slopes, in localized basins and on the lower flanks of southeast-facing slopes. Surface samples from an area of thick till generally reflect a distal bedrock source, as opposed to a sample obtained from a shallow till region, which will be representative of local bedrock sources. Consequently, the composition of a till sample should be evaluated according to its topographic setting relative to paleo-ice flow.

Geochemical variation between a glacial maximum till and a till deposited during a late glacial re-advance is of concern. Under glacial maximum conditions, local bedrock is incorporated into a till and subsequently deposited on bedrock further down-ice. During a re-advance, the

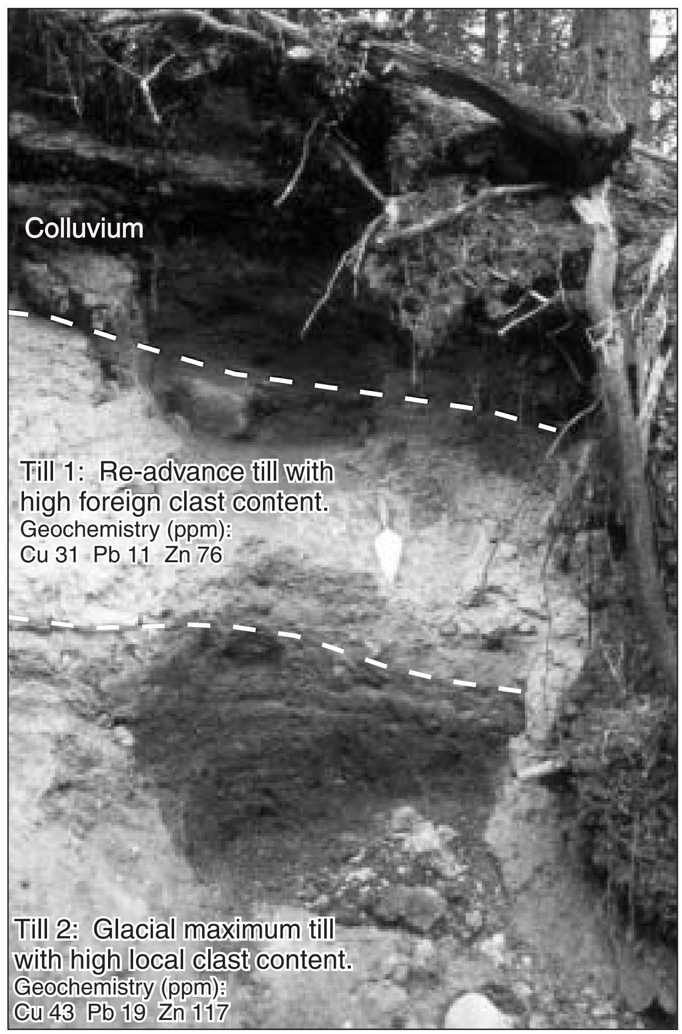


Figure 13. *Mudslide scarp exposure showing two tills in the Swim basin. Note the geochemical and colour differences that result from different lithologic sources.*

erosional energy of the ice is less due to a thinner ice mass and possibly less vigorous ice movement. Previously deposited till and local bedrock may not be re-entrained during a re-advance, and therefore the upper till will have a potentially different geochemical composition. The amount of re-entrainment of debris and bedrock will vary according to the topographic setting, whereby hillsides facing up flow will undergo more erosion as opposed to lee-side settings. In the Anvil district, because of poor exposure of surface sediment, it is unclear how much glacial maximum till was reworked during the re-advance phase. Exposures in mudflow scarps, however, and along the open-pit walls, did reveal a geochemical differentiation in near surface tills. In the Swim basin, two tills were documented in a mudflow scarp west of Swim Lake. A sample from each till was taken to examine the geochemistry. Results showed higher values for copper, lead and zinc in the lower till than the upper till (Figure 13). The colour of the lower till is greyer and contains more graphitic phyllite clasts, which is associated with the Vangorda formation. The upper till is a buff colour and contains more granitic clasts, which are believed to originate from bedrock at least 15 km away. Both tills are cohesive and are interpreted as basal lodgement tills. The lower and upper tills are interpreted as deposits of the glacial maximum and late glacial re-advance, respectively.

It should be recognized that a re-advance till may mask or dilute a sediment anomaly. Therefore, weak geochemical anomalies in areas underlain by re-advance till could be significant.

A re-advance by the Cordilleran ice sheet could also have implications in alpine valleys. Due to the absence of local alpine glaciers at the time of the re-advance, alpine valleys were inundated by Cordilleran ice, allowing for the deposition of regional sediment at the surface (Figure 5). This will affect the surface soil geochemistry and should be accounted for when interpreting dispersion trends in alpine valleys. Post-glacial processes, such as colluviation, may further rework local and regional till along the margins of the alpine valleys.

Till geochemistry

Background

The application of till geochemistry or boulder tracing to prospecting in glaciated terrain has long been recognized. In Finland, as early as 1740, it had been noted that erratics could be traced to their bedrock source and may have applications to the location of ore deposits (Shilts, 1976). It was not until the early twentieth century, however, that drift prospecting became recognized as a valuable method in the exploration industry. Canadian drift exploration studies have largely focussed on the Canadian Shield, and only more recently, in central British Columbia, Vancouver Island, and southern British Columbia by the British Columbia Geological Survey (Bobrowsky and Sibbick, 1996; Bobrowsky et al., 1997b, 1998; Kerr et al., 1992; Levson et al., 1997a, b). In Yukon, thesis research by Plouffe (1989) on the Grew Creek deposit aimed to characterize the till geochemistry down-ice-flow of an epithermal gold deposit. This work included a reconnaissance-scale sampling program in the Tintina Trench by the Geological Survey of Canada (Plouffe and Jackson, 1992). Jackson (1994) also characterized till near the Tintina Trench to distinguish background values between rocks of North American affinity and Yukon-Tanana Terrane.

While previous till geochemistry studies in Yukon have addressed reconnaissance scale (1:100 000 – 1:250 000) and property scale (< 1:10 000), no work has focussed on a regional scale of exploration (1:50 000). The sample density of regional scale programs is approximately 1 sample per 5 km^2, versus 1 sample per 20-50 km^2 for reconnaissance work. A regional sampling density is sufficient to intersect dispersal trains that are in the order of 10 km^2 in size. This scale of program would provide good coverage for areas that otherwise have limited geochemical data and extensive overburden cover.

The utility of till geochemistry in the northern Cordillera and concerns related to the presence of

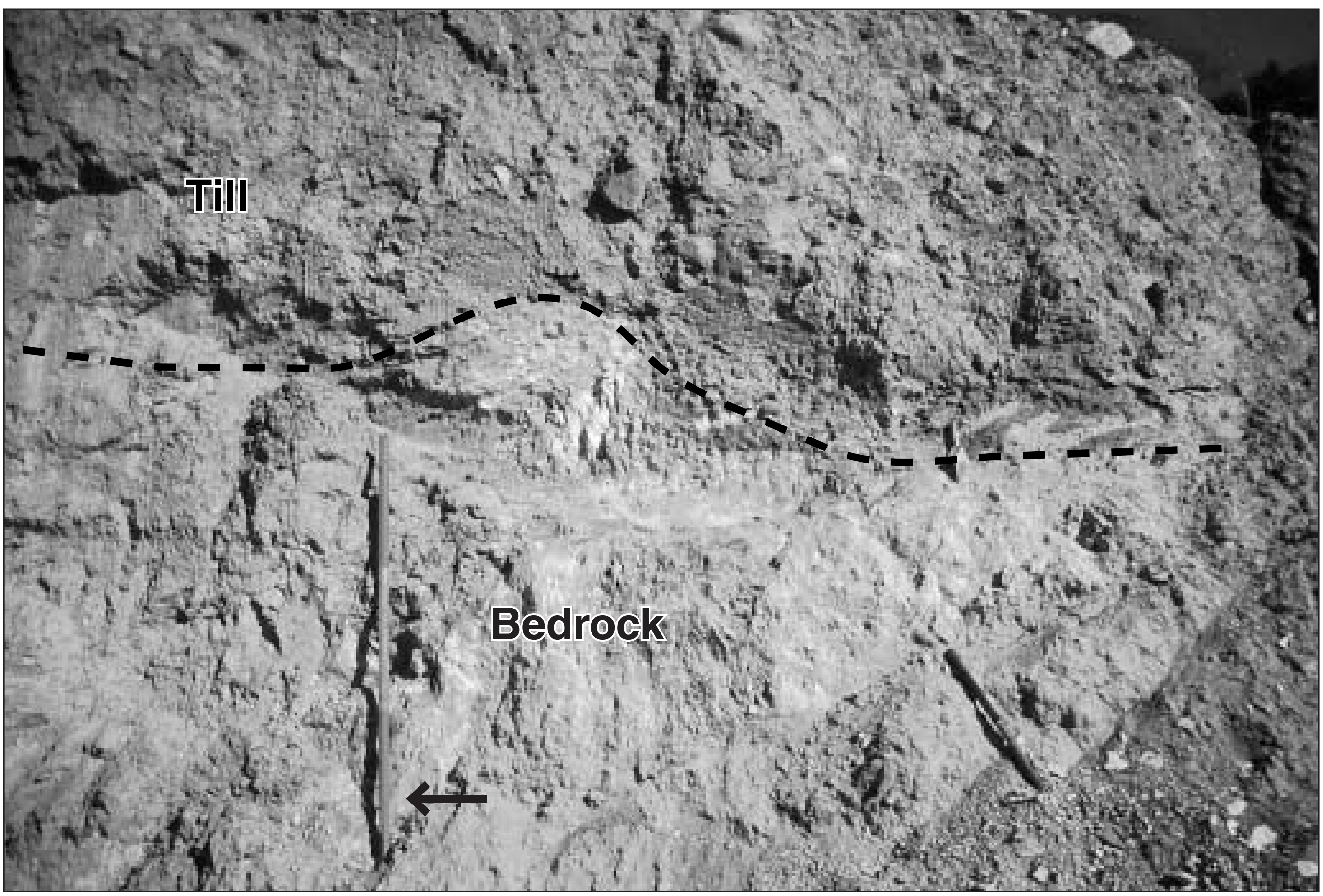


Figure 14. *Basal till exposed in the Grum mine open-pit. Staff (arrow) is 1.5 m long.*

permafrost, which might increase colluviation due to active layer movement and greatly hinder sampling, will be addressed in the following section.

Sample medium

In conducting till geochemistry, basal till is the most effective sample medium for several reasons (Levson, 1999):

- Basal till is a first derivative of bedrock and is deposited directly down-ice of its source, which allows anomalies to be traced in a more or less linear direction to their point of origin. This cannot be said for dispersion in ablation till, and glaciofluvial and glaciolacustrine deposits.
- Dispersion trains in basal till are typically large and more readily detected in regional surveys.
- The strong topographic control on ice flow in the Cordillera has resulted in linear, commonly valley-parallel transport of debris. As a result, locating a source for basal till anomalies is comparatively easy relative to regions with a more complex ice-flow history. In the Anvil district, opposing ice-flow directions were identified between the glacial maximum and a late glacial re-advance, which presents some local complexities when interpreting anomalies in this region.

Basal till typically consists of pebbles and cobbles with minor boulders in a matrix of sand, silt and clay (Figure 14). It is compact, matrix supported, and exhibits a blocky texture when dry. Clasts are mainly pebbles, and depending on the clast lithology, may be striated and faceted. Most clasts are classified as subrounded to rounded. Basal till is deposited at the base of a glacier by either meltout or lodgement mechanisms. Either process deposits sediment derived from relatively local bedrock sources. In general, basal meltout till contains more sorted sediment lenses than lodgement till.

Figure 15. *Sample taken in a compact basal till on the Faro grid. The White River ash is visible at the surface next to the shovel. Soil development at locations such as this is limited to the upper 25 cm. Pit depth is 65 cm.*

Anvil Range Surficial Geology Data Entry Form

Sample #: JB99-001 **Date (m,d):** 06/12/99 **UTM EAST:** 589990

Collector: Jeff Bond and Panya Lipovsky **NTS:** 105K/6 **UTM NORTH:** 6921953

Type
- [x] Routine Sample
- [ ] Field Duplicate
- [ ] Control Standard

Map Unit: Tb

Sample Medium: meltout till

Exposure: [ ] roadcut [ ] drill [ ] other [ ] streamcut [x] pit [ ] Mine cut

Topo Position: Plateau surface in valley bottom (till plain)

Aspect: 0

Elevation: 4500 **Slope (deg):** 0

Drainage: [ ] Poor [x] Moderate [ ] Well

Depth (cm): 56

Vegetation: [ ] White Spruce [ ] Grassland [ ] Black Spruce [ ] Alpine [ ] Aspen [x] Dwarf Birch [x] Willow [ ] Birch [ ] Pine [ ] Subalp. Fi

Soil (cm)
- Disturbed:
- Detrital: 0-6
- A-horizon:
- B-Horizon: 6-17
- Ash:
- CaCO3:
- Permafrost:

Fissility: [ ] none [x] weak [ ] mod [ ] high

Density: [ ] low [x] mod [ ] high

Oxidation: [ ] none [x] mil [x] mod. [ ] high

Jointing: [x] none [ ] weakly [ ] mod. [ ] well

Soil and Sedimentary Notes: Upper 33 cm - clay silt till; 33cm -56 cm fluvial sand

MATRIX
- percent: 75%
- color: 2.5Y 4/4 olive brown
- texture: sandy silt

CLASTS: [x] Pebble [ ] Cobble [ ] Gravel [x] Boulder; Max (cm): 52

Shape: [x] Angular [ ] Rounded [ ] Subangular [ ] Well rounded [x] Subrounded

Striated: [ ] No [ ] 1-10% commo [ ] <1% rar [ ] >10% abundant

Fabric or Striae Direction: 0

Bedrock: 3g Mt. Mye Non-calcareous phyllite

Lithology - local	%	Round	Striae
	0		
	0		
	0		
	0		
	0		

Lithology - boulders	%	Round	Striae
	0		
	0		
	0		
	0		
	0		

Description of Mineralized Clasts

Photos:

Anvil Range Surficial Geology Data Entry Form

Figure 16. *Sample field form used in the till geochemical sampling program.*

Recognizing basal tills from other diamicts involves understanding the textural and structural characteristics of each deposit. Without a clear understanding of the sedimentology it can be difficult to differentiate colluvial and debris-flow deposits, and ablation tills from basal tills. This emphasizes the need for a good understanding of surficial geology prior to conducting extensive till sampling programs. Typically, basal till is much more compacted compared with other diamicts.

Ablation till is another type of deposit that is common in the study area. Ablation till is deposited from a stagnating glacier and consists of sediment carried within or on top of the glacier. The texture of ablation till is commonly more coarse, loosely consolidated, and contains larger clasts. Landforms associated with an ablation till are typically hummocky or have a mottled texture on air photographs. Because ablation till is composed of sediment transported within or on top of the glacier, it generally reflects more distal sources than basal till. Consequently, ablation till should be avoided for the purposes of till geochemistry studies.

Deposits that have been resedimented under slope processes have crude bedding or flow structures parallel to the slope unlike intact basal till. In the Anvil district, ongoing colluviation of the active layer is widespread on slopes containing permafrost. Due to the rolling terrain in the regional sampling areas, there is a high frequency of colluviation related to permafrost conditions. Colluviated basal tills were sampled to obtain an adequate sampling distribution. A colluviated till will not be as compact as a basal till and may contain stringers of organic material.

In the northern Cordillera, permafrost enhances slope processes. Permafrost is found in the Anvil district on north-facing slopes, in poorly drained valley bottoms, and under thick humus cover common in old growth spruce forests. Where permafrost is present on slopes, the soils

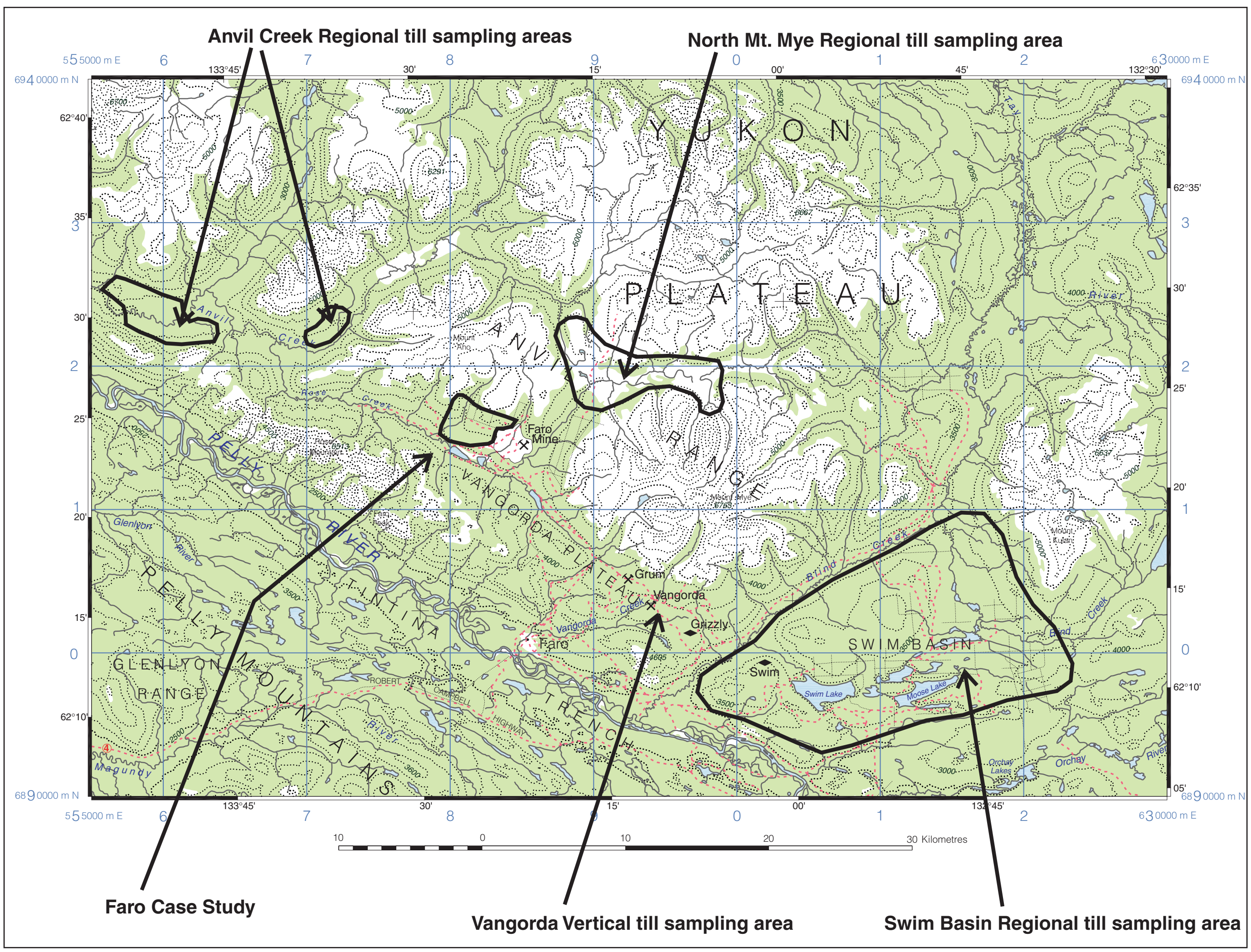


Figure 17. *Location of till sampling programs conducted in the Anvil district.*

are often cryoturbated and displaced downslope. The extent and quantity of displacement depends on the depth and moisture content of the active layer. Where the active layer is deep enough to penetrate the parent material, reworked lenses of the mineral soil are evident. No intact soil properties are preserved at these sites due to the mechanical reworking. A typical soil profile will consist of stringers of ash and parent material mixed with abundant organic material.

Till that has been remobilized or cryoturbated is commonly recognizable as a diamict. Stringers of basal till, were sampled as part of this study, in particular in the area of the Faro case study, where permafrost was widespread under old-growth forests. In most places, the diamict stringers had a similar texture to the intact basal till, which was sampled at higher elevations on the Faro grid, in more open and drier areas. Surface alluvial deposits were observed where water, derived from active layer melting, deposited a mixture of silt, fine sand and organic material. The alluvium is distinguished by low density and a consistent fine texture.

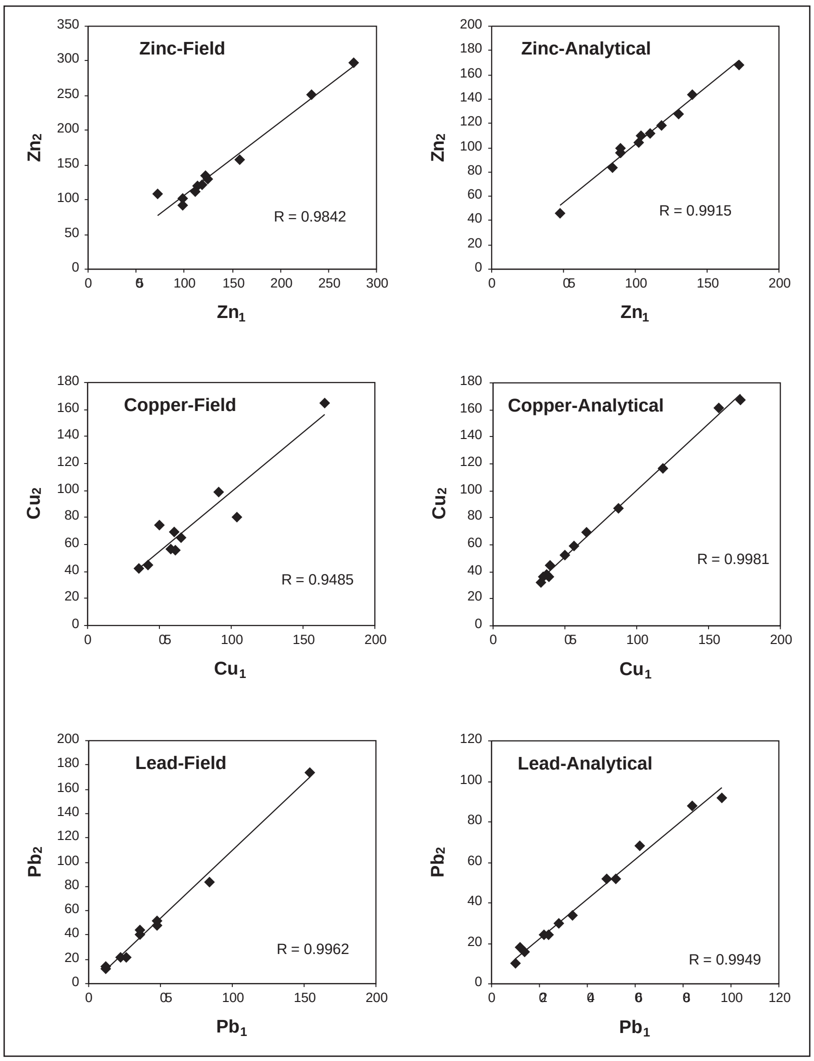


Figure 18. *Bivariate scatter plots for field and analytical duplicates showing zinc, copper and lead in parts per million. The r-values (>0.90) indicate a good correlation between the duplicate pairs with no major discrepancies for the field and analytical methods.*

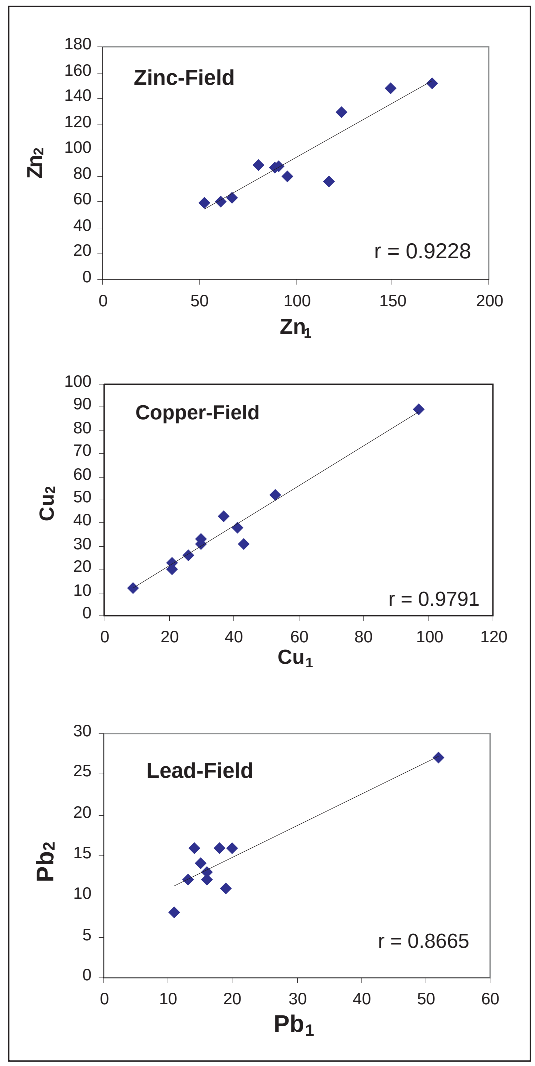


Figure 19. *Bivariate scatter plots for field duplicates showing zinc, copper and lead in ppm's. The r-values (>0.90) indicate a good correlation between the duplicate pairs. Lead duplicates showed poorer reproducibility which suggests lead is locally less predictable and anomalies should be approached with caution.*

Methodology

Surficial geological mapping was completed at 1:25 000 scale and provided baseline information for a glacial history interpretation of the Anvil district. The field component of this study focussed on till sampling, recording soil characteristics, ground-truthing the surficial geology, measurement of till fabrics and vegetation sampling. Till samples were collected in order to produce a regional geochemical database. This database was supplemented by a case study at the Faro mine and by documenting stratigraphic geochemical changes in till exposed on the open-pit walls (Figure 14).

Till samples were obtained by hand digging with a pick and shovel to a depth averaging 60-100 cm, or sufficiently deep enough to penetrate post-glacial soil development and any possible air-born contamination from nearby mining activity (Figure 15). Natural exposures were observed along terraces in the valley bottoms and at the head-scarps of mudslides. These exposures, although rare, are preferred sample sites because they provide more stratigraphic and sedimentologic data.

At each sample site a data sheet was completed covering all the site and soil characteristics. Features such as surficial geology, topographic position, vegetation, drainage, soil characteristics and sample texture were noted. Where the bedrock geology was known, it was recorded as well. Pebble counts were not completed during the study. A sample field form is shown in Figure 16.

Samples averaging 5-10 kg were bagged, and later split and sieved to separate the silt/clay fraction (–230 mesh). According to Shilts (1984), analysis of the –230 mesh fraction is advantageous for examining sulphide concentrations in till. Post-glacial weathering of sulphide minerals occurs readily and simultaneously causes metal enrichment in the clay-sized fraction. Clay minerals act as scavengers by retaining the metal fraction; thus the samples with a larger percentage of clay would give higher metal values, especially where mineralization occurs locally (Nikkarinen et al., 1983).

In 1998, the till was sieved in Whitehorse to extract the silt and clay fraction. These samples were submitted to Chemex Labs in Vancouver, B.C. for the standard 32-element ICP-AES and a fire assay for gold. In 1999, Acme Analytical Laboratories conducted both the sieving and analytical work. Analytical procedures were consistent with the previous work conducted in 1998.

The principal till geochemical case study was completed in 1998, northwest of the Faro deposit, in Rose Creek valley (Figure 17). In total, 140 samples were gathered from a 3 km by 4 km grid (Faro grid). Samples were spaced every 200 m and the spacing between lines progressed from 200 m to 500 m over 13 lines total (Bond, 1999-10, in pocket). Results from the case study were contoured and used to characterize the dispersal train associated with the former outcropping sulphide deposit.

Till was also sampled from exposures in the Faro, Grum, and Vangorda open-pits (Figure 17). At the Vangorda open-pit, a 20-m exposure of till was sampled at 1-m intervals to evaluate geochemical changes with depth.

Regional till sampling was carried out during the 1998 and 1999 field seasons to assess the potential for an undiscovered buried massive sulphide deposit and to better quantify the background geochemical values for the district. The area covered included the southeastern end of the Swim basin, north of Mount Mye and the Anvil Creek valley (Figure 17). A small geochemical grid was sampled west of the Swim deposit (Bond, 1999-7, in pocket). In total, 360 till samples from the 1998 and 1999 field seasons were collected from the Anvil district.

Quality control was maintained by submitting field and analytical duplicates to check the field sampling and analytical techniques. A field and analytical duplicate was submitted in every set of 20 samples taken in 1998. Analytical duplicates were omitted from the 1999 submissions because the sieving was conducted at the analytical lab. Field duplicates were taken in the 1999 sample set. CANMET control standards were submitted in every 30 samples taken in 1998 and in-house control standards were submitted in every 30 samples taken in 1999. An overview of the quality control is presented in Figures 18 and 19. Bivariate scatter plots were used to display the field and analytical duplicates. R-values indicate the degree of correlation between the assays for either the field or analytical components. R-values greater than 0.90 indicate an acceptable level of correlation.

Lead showed poorer reproducibility than zinc in the regional till samples from 1999. This is likely due to a more erratic distribution in soils at regional scales. Lead anomalies from regional sampling programs should be verified by analysing sample splits. Where property-scale sampling is being carried out (closer spacing), this may not be necessary.

Faro deposit case study

The study of till geochemistry is based on detecting a dispersal train from a buried ore deposit. The advantage of applying a drift prospecting methodology includes the possibility of detecting concealed bedrock mineralization and the increased probability of identifying a surface geochemical anomaly on the order of hundreds of times larger than the bedrock source. Conducting a case study 'down-ice' of a known deposit enables modelling of glacial transport, which can be used as a guide for interpreting regional data from surrounding areas. The objectives of the Faro deposit case study are: to describe the morphology of a dispersal train from an Anvil-type massive sulphide deposit, to characterize the geochemical signature (i.e., quantify anomalies), and to map in detail the surficial geology and soil conditions.

The Faro deposit case study was modelled after similar studies by the British Columbia Geological Survey in southern and central B.C. (Levson and Giles, 1994a,b; Levson et al., 1994; Giles and Kerr, 1993; Bobrowsky et al., 1995, 1997a,b, 1998). A 12 km^2 grid, composed of 140 sample locations, was surveyed and sampled northwest of the Faro deposits (Figures 17 and 20). Assay results for lead, zinc and copper were contoured, and are presented in Figure 21 (see also Appendix 1, on CD in pocket). The 1998 contoured geochemical maps are also compared with a similar geochemical data set obtained from 1964 soil geochemistry (Figure 22). The presumed difference in the data sets is in the sampling and analytical procedures. The industry norm in 1964 was to collect B-horizon soils and assay the –80 mesh, whereas the technique employed in this study, as outlined earlier, focussed sampling below the B-horizon and assays on the –230 mesh fraction. The densely spaced soil geochemistry obtained from the 1964 data set was interpolated to the 1998 sample locations.

Results

Contoured results for lead, zinc and copper are presented on the following pages for the 1998 and 1964 data.

Figure 20. *View of the area sampled during the till geochemistry case study. The Faro mine is visible on the right side of the photograph. View is to the north and ice flow was from right to left.*

Lead-1998

The 1998 geochemical contours for lead data clearly show an increase towards the Faro deposit (Figure 21a). The westward-oriented dispersal train is sub-parallel to ice flow, which was topographically controlled by Rose Creek valley. The train extends from high ground near the deposit to lower ground in Rose Creek valley. This reflects the progressive transport of subglacial debris into the valley bottom. However, in the vicinity of line 3 (L3) anomalous till values were mapped at higher elevations than the ore bodies.

Lead-1964

Lead contours from the 1964 data show a narrow elongated anomalous zone west of the Faro deposits (Figure 22a). Similarly, but more pronounced than the 1998 data, the anomalous zone extends over 4 km down Rose Creek valley. In contrast to the 1998 data, the lead values from the top of L3 are not anomalous.

Zinc-1998

The 1998 contoured geochemistry for zinc, like lead (1998), indicates a broad dispersal train to the west extending beyond the sample grid (Figure 21b). Contours show an extension of values that follow the topographic contours into Next Creek. Anomalies at the southwest end of lines 3 to 7 are likely attributed to glacial transport from the lower Faro deposit. An anomaly at the top of line 3 indicates proximal till enrichment 152 m (500 feet) above the source area.

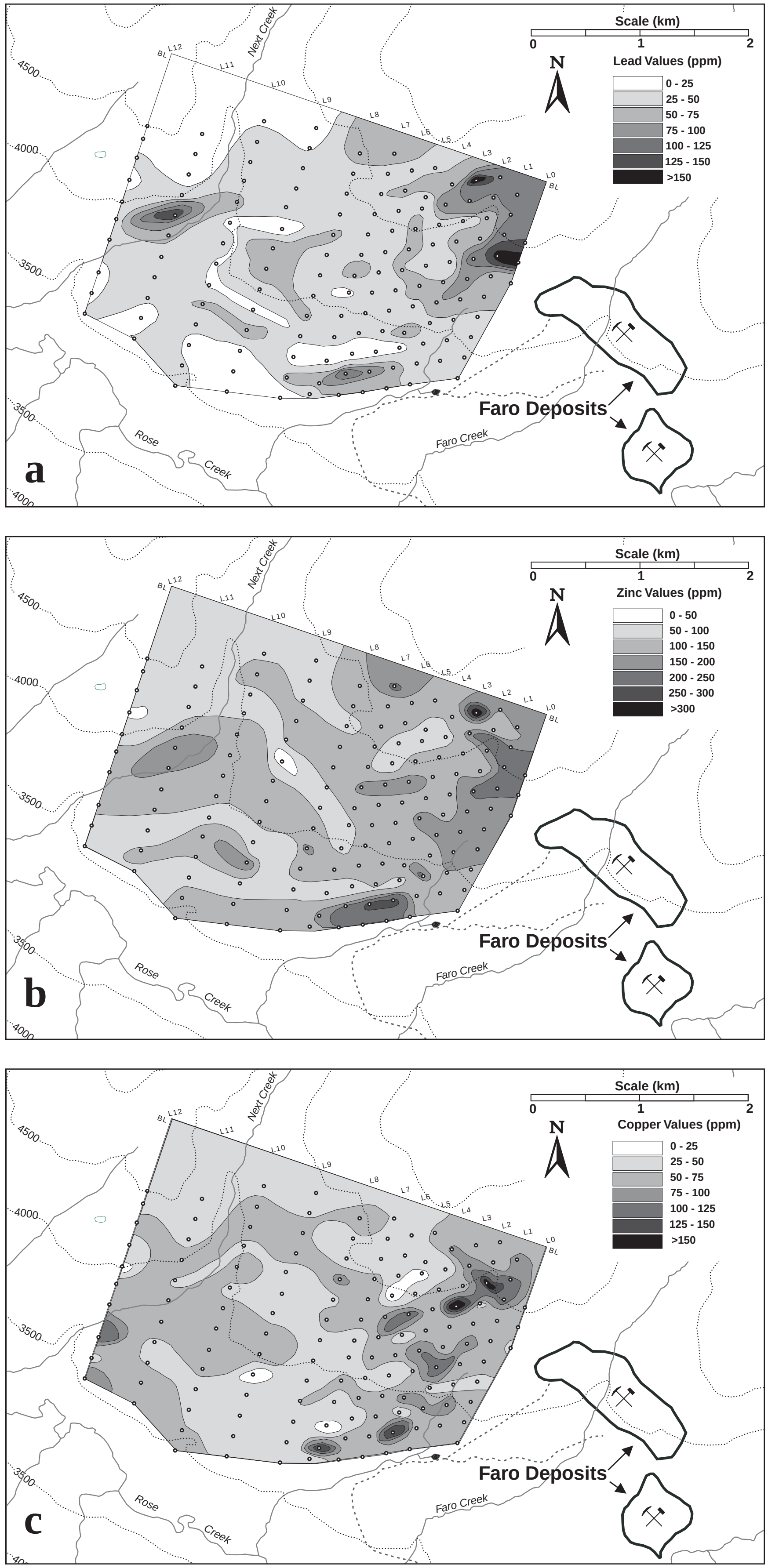


Figure 21. Contoured till geochemical values near the Faro ore deposits (1998 data). Elevation is in feet above sea level. (a) Lead: note the higher concentrations above the elevation of the upper Faro deposit. (b) Zinc: note the broad ameboid-shaped dispersal train from the Faro deposits. The contours also conform to Next Creek valley. (c) Copper: note the broad dispersal train to the northwest with a strong gradient of values decreasing down-ice flow.

Zinc-1964

The 1964 contoured geochemistry for zinc shows a well-defined dispersal train almost 1.5 km wide by at least 4 km long with a narrow secondary anomalous ribbon near the top of the grid (Figure 22b). The progressive down-slope trend of the train is well pronounced with a distinct anomalous core to the main dispersal body.

Copper-1998

The 1998 contoured geochemistry for copper shows a clear dispersal train with the highest values occurring in the first 1.5 km west of the upper ore deposit (Figure 21c). Ribbon-shaped plumes continue down-valley beyond the grid and appear to conform with Next Creek valley. The highest copper values in till were obtained from the top end of lines 1-3.

Copper-1964

The 1964 contoured geochemistry for copper shows a 600-m-wide ribbon-shaped dispersal train from the Faro deposits (Figure 22c). A second ribbon-shaped anomalous zone is visible near the end of the grid in Next Creek valley.

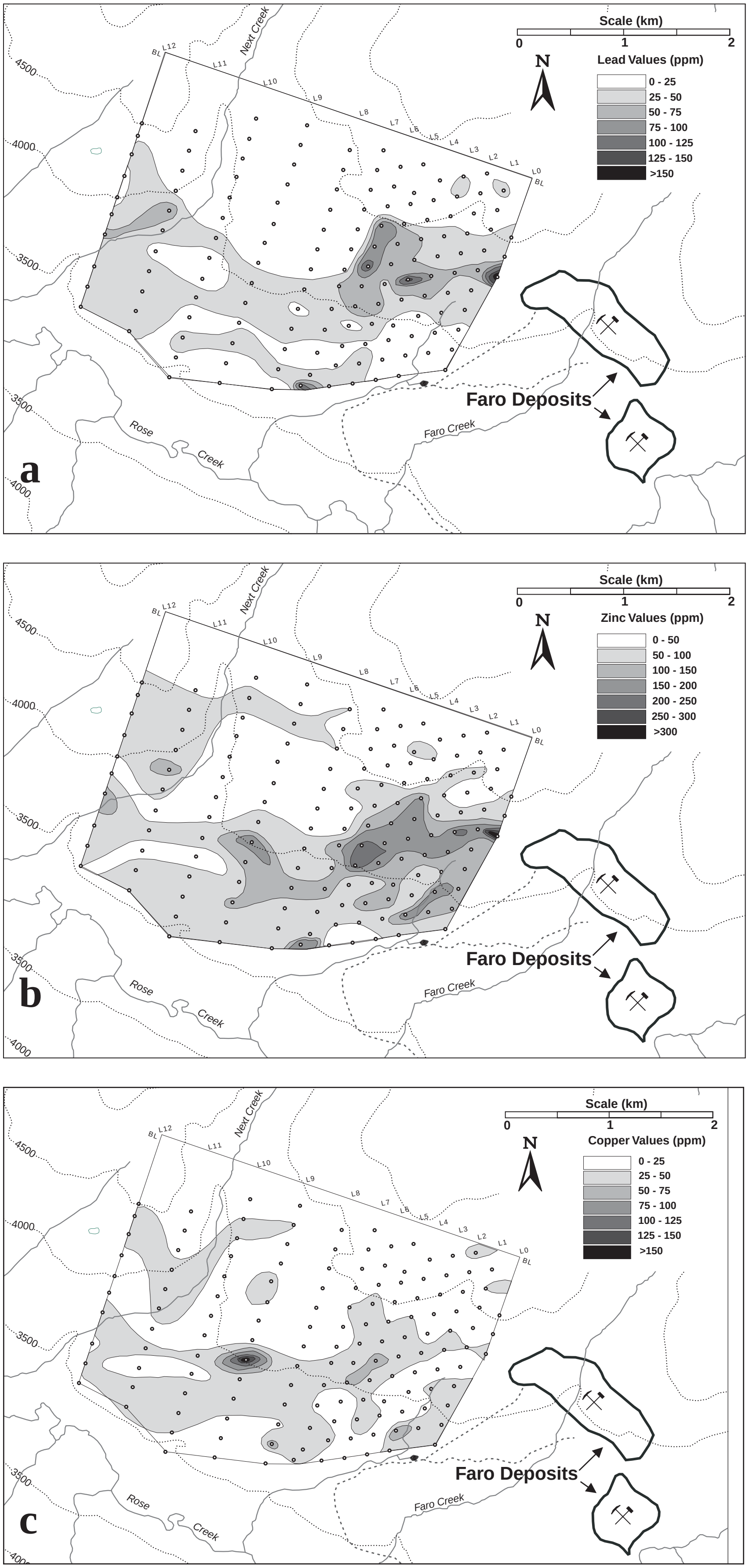


Figure 22. *Contoured soil geochemical values near the Faro ore deposits (1964 data). Elevation is in feet above sea level. (a) Lead: note the well-defined dispersal train from the upper Faro deposit to the west. (b) Zinc: note the well-defined dispersal train from the upper Faro deposit and a second ribbon at a slightly higher elevation. (c) Copper: the dispersal train is well defined, however lacks a decreasing concentration gradient away from the Faro deposits.*

Faro till geochemistry case study: discussion

The Faro till geochemistry case study outlined distinct dispersal trains for each of lead, zinc and copper. The primary dispersal train can be traced directly to the upper Faro deposit and in some instances to an anomalous area above the main ore bodies. For copper (1964 and 1998 data) and zinc (1964 data), a secondary dispersal train is visible at the top of the grid between lines 8 and 12 that appears to be directed towards an anomalous area above the main ore bodies. This can be explained as either a dispersal train from concealed bedrock mineralization or as a palimpsest dispersal train. Palimpsest dispersal trains are residual trains that are produced from multiple ice-flow directions, in which an earlier dispersal train is incompletely re-entrained by later glacial movement (Parent et al., 1996). A neighbouring, but topographically isolated, till anomaly could thus indicate an early dispersion (ice-flow direction) related to a differing ice-flow direction. The anomalies on the Faro grid could have formed when converging glaciers in Rose Creek valley forced ice to flow subparallel to the contours. This northwest-trending plume was then re-dispersed or elongated by a change in flow direction to the west. Evidence for a bedrock source that might otherwise explain this dispersal train is currently unknown in this area (L.C. Pigage, pers. comm., 1998).

The 1998 geochemical contours show a broad dispersal train from the source area, whereas the 1964 geochemical contours show a narrow and more confined dispersal train. The utility of glacial dispersion and till geochemistry is apparent from either of the two data sets. Typically, soil sampling is used as a method to trace anomalies at the property scale. Results from this study suggest it has wider applications to regional- and intermediate-scale massive sulphide exploration in drift-covered terrain. In contrast, the 1964 contoured data emphasizes the utility of this technique as a method in property-scale exploration for massive sulphides sub-cropping in drift covered terrain. In the case of the Faro deposit, the dispersal trains for lead and zinc in the 1964 data set point directly back to the source rocks.

To compare the two data sets, the Pb and Zn values from the 1998 and 1964 Faro grid lines are compared to a background value and a 95th percentile threshold derived from regional samples collected in the Swim basin during the 1998 and 1964 field seasons. The background threshold is equal to the median value and the 95th percentile is considered to be a higher-end anomalous threshold. Swim basin is considered to be the most representative area to calculate a regional threshold because of its similar geology, physiography and glacial history to the Vangorda plateau. It should be noted that the threshold values calculated for these data sets are based solely on relative significance, and what may be considered a highly anomalous value from this data may not be true for other areas in Yukon. From the 1998 Faro grid line data, 94 percent of the zinc and 100 percent of the lead values fell above the background levels of 76 and 14 ppm, respectively. When plotted relative to the regional 1998 95th percentile, 6.5 percent of the zinc values and 66 percent of the lead values were above the upper thresholds of 203 and 32 ppm, respectively. From the 1964 data, 51 percent of the zinc values and 70 percent of the lead values fell above background levels of 62 and 13 ppm, respectively. When the 1964 Faro grid line values were plotted relative to the regional 1964 95th percentile, 16 percent of the zinc values and 53 percent of the lead values were above the thresholds of 128 and 23 ppm, respectively.

From these results, a comparison of the significance of the geochemical dispersal trains mapped from the 1998 and 1964 data can be drawn. The percentage values indicate that the sample and analytical techniques employed during the 1998 study returned significantly more values above background levels. For the 1998 data, 30 percent more lead values and 43 percent more zinc values are above background in comparison to the 1964 data. The comparison of values above the 95th percentile differed less between the two data sets. For lead, 13 percent more values in the 1998 data lie above the 95th percentile, and for zinc, 10 percent more values in the 1964 data lie above the 95th percentile. In short, these results show that both methods recognized values above the 95th percentile. Significantly more lead values than zinc values for both data sets appear above the 95th percentile. This suggests that lead anomalies that fall above the 95th percentile, from soil or till samples, may be a more reliable indicator of a nearby sulphide deposit. When considering regional exploration, the method used during the 1998 study is more effective to identify subtle lead and zinc anomalies than the method used in 1964.

Glacial sedimentation into Next Creek basin has important implications in the interpretation of stream sediment geochemical surveys. The dispersal trains from 1998 data appear to extend into Next Creek valley. Glacial transport of mineralized debris to Next Creek valley could influence the stream sediment geochemistry, at least for lead, zinc and copper. This provides a good example of how, when in glaciated terrain, glacial transport must be considered in the interpretation of alluvium geochemistry.

Limitations

The limitations of till geochemistry relates to sample collection and processing. Determining a sample medium may often require exposing up to 1 m of the soil profile, which can be time consuming. Sediment identification is especially important, for instance, in valley systems where colluviation has amassed organic beds and resedimented till together in a near surface deposit. Sampling a lens of resedimented till is certainly more applicable to a till sampling study than would be an organic-rich alluvium. This deposit structure may not be readily identified from a soil auger or B-horizon sample. In short, a comparison of drift geochemical data requires homogeneity in the sample medium to best qualify the data set. Furthermore, the –230 mesh fraction in a Cordilleran basal till is not necessarily an abundant size fraction, which means that a large sample must be obtained to insure sufficient amount for procedures such as gold fire assays. It is also beneficial to collect 50 to 100 pebbles to identify lithologies that can be used to model glacial transport and interpret geochemical anomalies.

Permafrost may provide the greatest hindrance for the application of this technique in the north. Permafrost limits the depth to which a sample can be taken and causes a mixing of the soil through cryoturbation processes. At certain sample locations, cryoturbation had essentially overturned and buried the upper part of the soil column. White River ash, normally within 10 cm of the surface, was found in some areas at depths of 100 cm. Therefore, it is especially important in permafrost areas to be able to recognize a cryoturbated till in order to maintain overall sampling quality.

Vertical till geochemistry

Twenty till samples were collected at the Vangorda mine from a section exposed on the edge of the open-pit (Figure 23). The samples were collected vertically every metre up a 20-m exposure. The objective was to observe the geochemical changes at depth in the vicinity of a known massive sulphide deposit. The results for lead and zinc are shown in Figure 24.

The concentration of zinc increases rapidly near the bedrock contact. In total, 6 of 20 samples fell above the 90th percentile of the regional data set. This reflects the proximity of the till to its source material, which is the Vangorda deposit. Further up section, the zinc concentrations decrease to levels only slightly above background and remain consistent to the top of the section.

The concentration of lead is different compared to the concentration of zinc. The lead values were consistently higher relative to the regional data set, whereby 18 of the 20 samples fell above the 90th percentile. Samples taken within 3 m of bedrock returned values within the 99th percentile of the regional data set.

The differences between zinc and lead concentrations within the vertical exposure at Vangorda are consistent with the geochemical behaviour of lead and zinc mapped west of the Faro mine in the case study. The results from the Faro case study showed that significantly more lead values than zinc values, from both the 1964 and 1998 data sets, appear above the 95th percentile. This pattern likely has to do with the relative abundance of zinc within both the Vangorda and Mount Mye geologic units. A higher overall abundance of a mobile element regionally will increase the anomaly threshold for that element. The pattern of zinc within the section is, however, important. The clear increase in concentration towards the bottom of the section emphasizes the proximity of the till to the massive sulphide deposit. The behaviour of lead is most likely a factor of the overall availability of lead within the regional geology. Unlike zinc, lead is not widespread in the Anvil geology. So when in close proximity of a massive sulphide deposit,

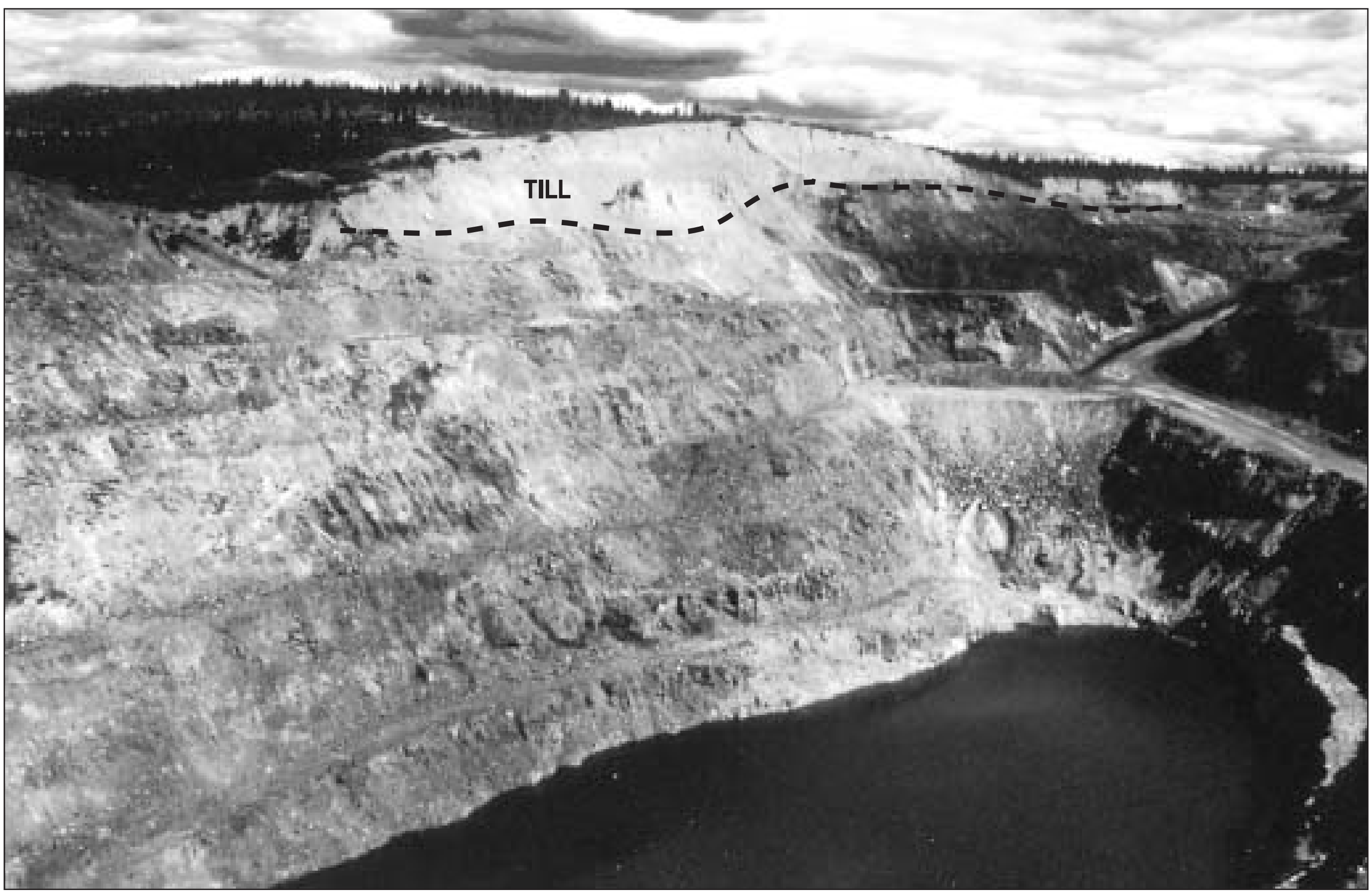


***Figure 23.** Till section exposed at the Vangorda mine. Till samples were collected every metre up the 20-m exposure in order to map the vertical geochemical changes.*

the presence of lead will become very obvious in the till geochemistry, even with 20 m of overburden. In other words, a false lead anomaly is less likely than a false zinc anomaly.

Data such as this would be useful when conducting an auger-drilling program in a covered area. In close proximity to a massive sulphide deposit, the lead values over the entire thickness of the overburden are likely to be consistently high and possibly above the 90th percentile of the regional data. This may not hold true where the overburden is greater than 20 m and may also be affected by more complex stratigraphy. For example, if a unit of outwash gravel separated two tills, then it would be expected that the upper till would not have a similar geochemistry as the lower till. Where a homogeneous till package is intersected, however, this model could be used to identify buried massive sulphides.

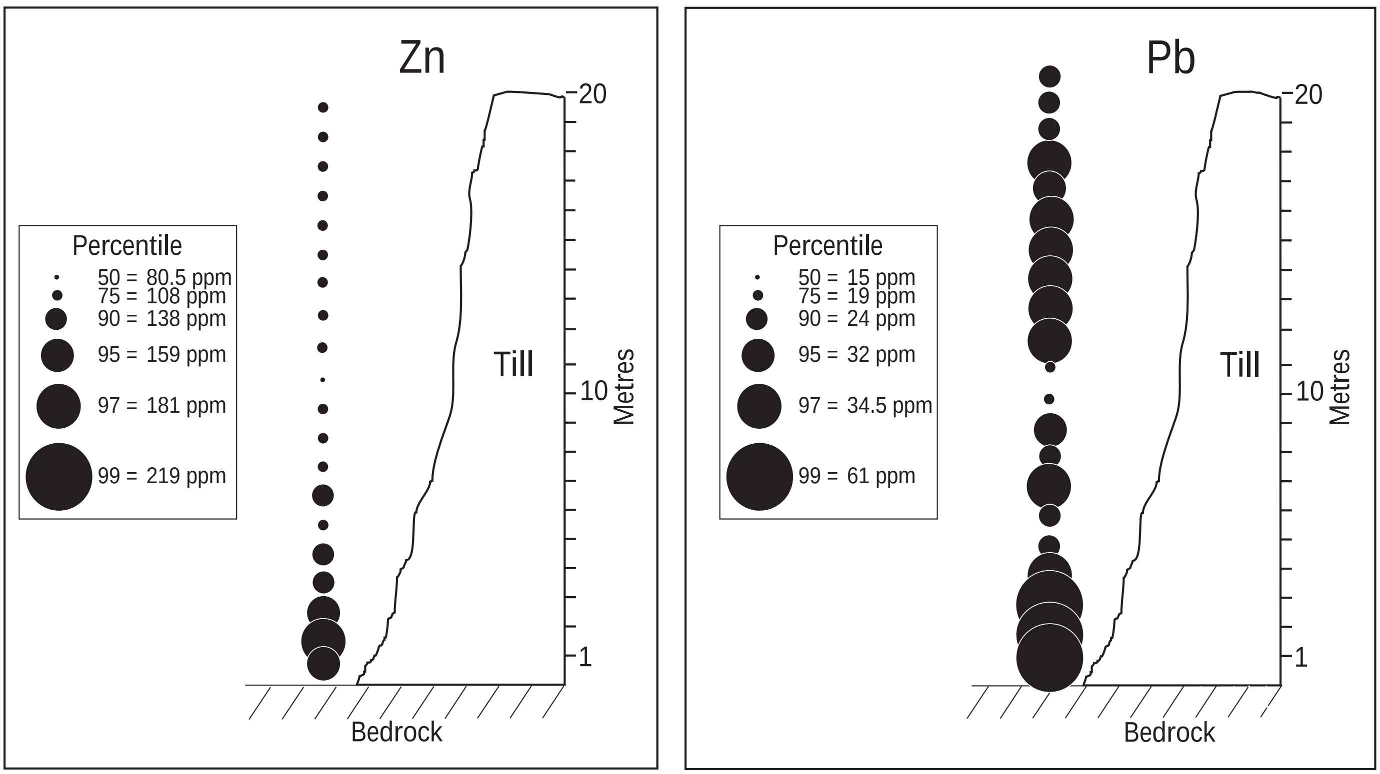


Figure 24. *Vertical till geochemistry at the Vangorda mine open-pit. The data is presented relative to the percentile ranges.*

Anvil regional till geochemistry

The regional till geochemistry sampling program focussed on three separate areas within the Anvil district. Each sampling area was chosen based on the lack of exposure of prospective Anvil geology due to till cover. The three areas included the Swim basin, North Mount Mye, and Anvil Creek. A total of 123 till samples were collected in Swim basin, the largest of the 3 areas (Figure 17). A total of 20 samples were taken north of Mount Mye on the north side of the Anvil Batholith, and 12 samples were taken in Anvil Creek along a continuation of Anvil stratigraphy west of the Faro deposits (Figure 17).

Data interpretation, Swim Basin

Swim basin lies to the southeast of Vangorda plateau and Blind Creek (Figure 17). The basin is underlain by rocks of the Mount Mye and Vangorda formations and also includes Menzie Creek formation, Earn Group and Yukon-Tanana Terrane immediately northeast of Tintina Trench (Figure 2). The Orchay pluton intrudes the stratigraphy along the southeastern margin of the basin.

The till geochemistry is presented in percentiles of the regional data set (Figure 25). Background is set by the statistical median (50^{th} percentile) and the anomalous values above background are subdivided into five intervals of significance. Geochemical values above the 90^{th} percentile are considered anomalous relative to the regional data set. The actual values for lead, zinc and copper at each sample location are presented on the surficial geology maps. The full suite of geochemical values for 32 elements plus gold can be found digitally in Appendix 2 (CD in envelope).

Lead

Elevated lead values in the Swim basin were identified near Swim Lake, west of Cub Lake, west of the Swim deposit and west of the Grizzly deposit on Vangorda plateau (Figure 25a). Elevated lead in till near Swim Lake is attributed to the SB deposit that underlies Swim Lake. The SB is a base-metal-deficient sulphide occurrence, similar to the Sea deposit that lies 4 km to the southeast. Despite the poor base-metal concentrations in the SB and Sea deposits, they still register anomalous values in the till. The elevated lead values at two locations west of Cub Lake can not be explained according to existing geological knowledge. A potential source for these anomalies, according to the dominant ice-flow direction, would be in the vicinity of Cub Lake. Anomalous lead and zinc values west of the Swim and Grizzly deposits are attributable to the proximity to the ore bodies. While the Grizzly deposit is not exposed at surface, vein exposures west of the deposit may account for elevated lead levels in this area.

Zinc

Elevated zinc values in the Swim basin include anomalies west of Swim Lake, Moose Lake, in upper Blind Creek, and near the Swim Lake road marginal to the Pelly River (Figure 25b). At Swim Lake, anomalies may be attributed to the proximity to the SB deposit and nearby outcrops of graphitic phyllite. Samples collected west of Moose Lake have zinc values of 208 ppm and 622 ppm, which most likely reflect the sub-cropping Sea deposit at depth. An isolated zinc anomaly of 149 ppm in upper Blind Creek is probably elevated from sub-cropping graphitic phyllites located to the north. South-flowing ice through this area during glacial maximum would account for this value. Anomalous zinc concentrations in resedimented till and alluvium near the Swim Lakes road and Pelly River valley are likely attributable to the high background of the underlying Road River Group.

Copper

In Swim basin, copper values are generally higher in the southern compared to the northern part of the basin (Figure 25c). Samples collected west of Swim Lake, or down-ice of the SB deposit and over the Sea deposit, are enriched in copper from these known showings. East of the Sea deposit, there are values in the vicinity of Moose and Cub lakes that reach 350 ppm. These anomalies can not be explained based on the existing knowledge of the geology in the southeastern part of Swim basin.

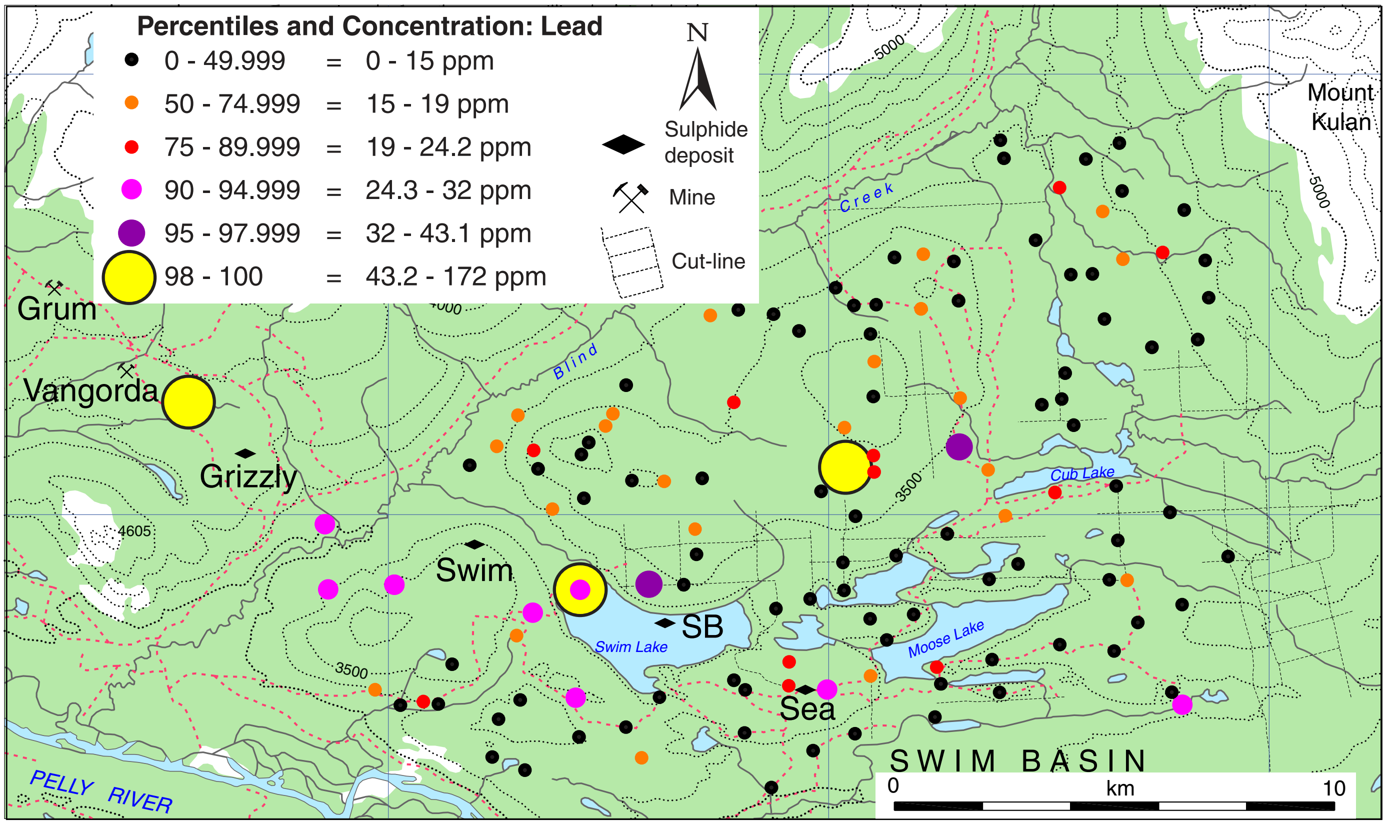


Figure 25a. *Lead concentrations from till samples collected in Swim basin.*

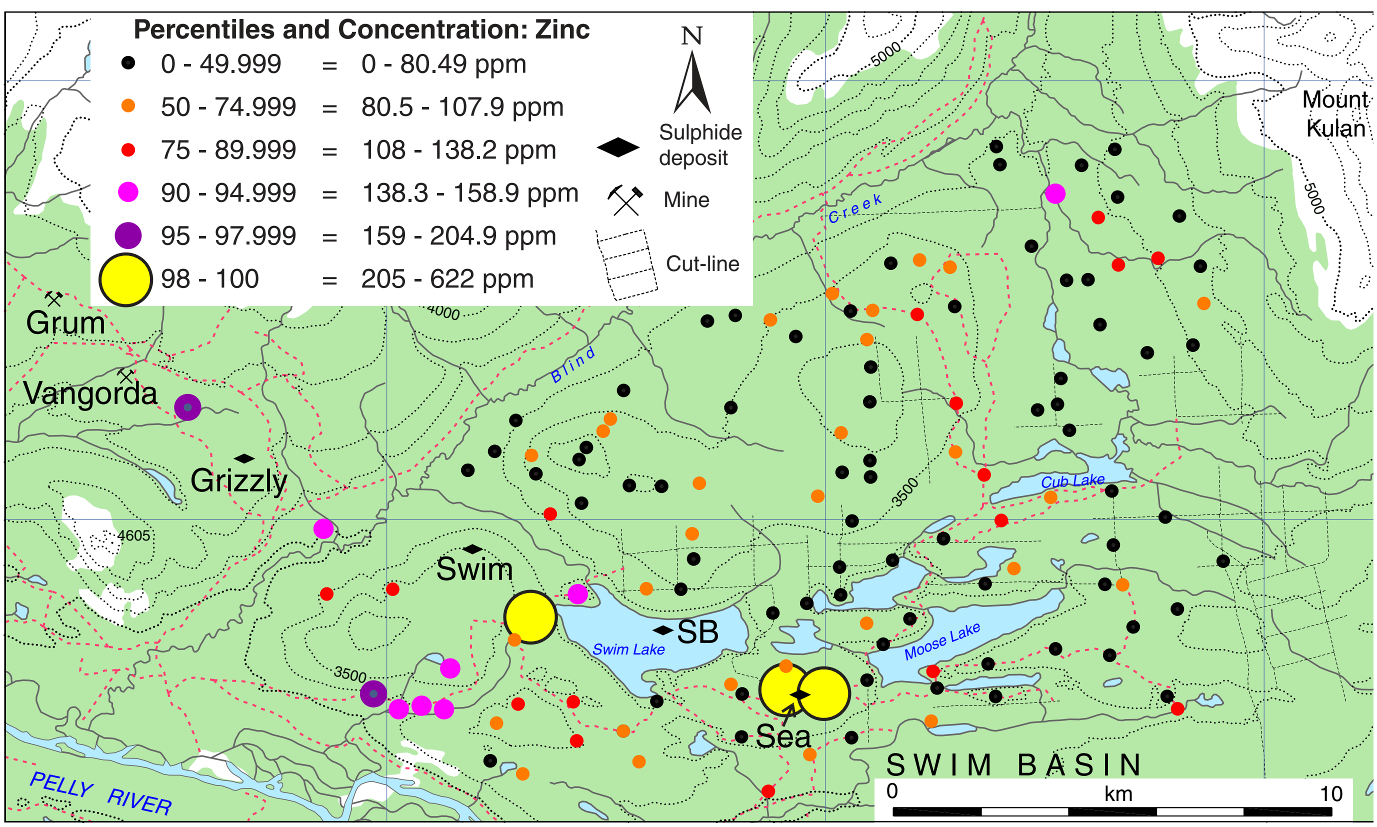


Figure 25b. *Zinc concentrations from till samples collected in Swim basin.*

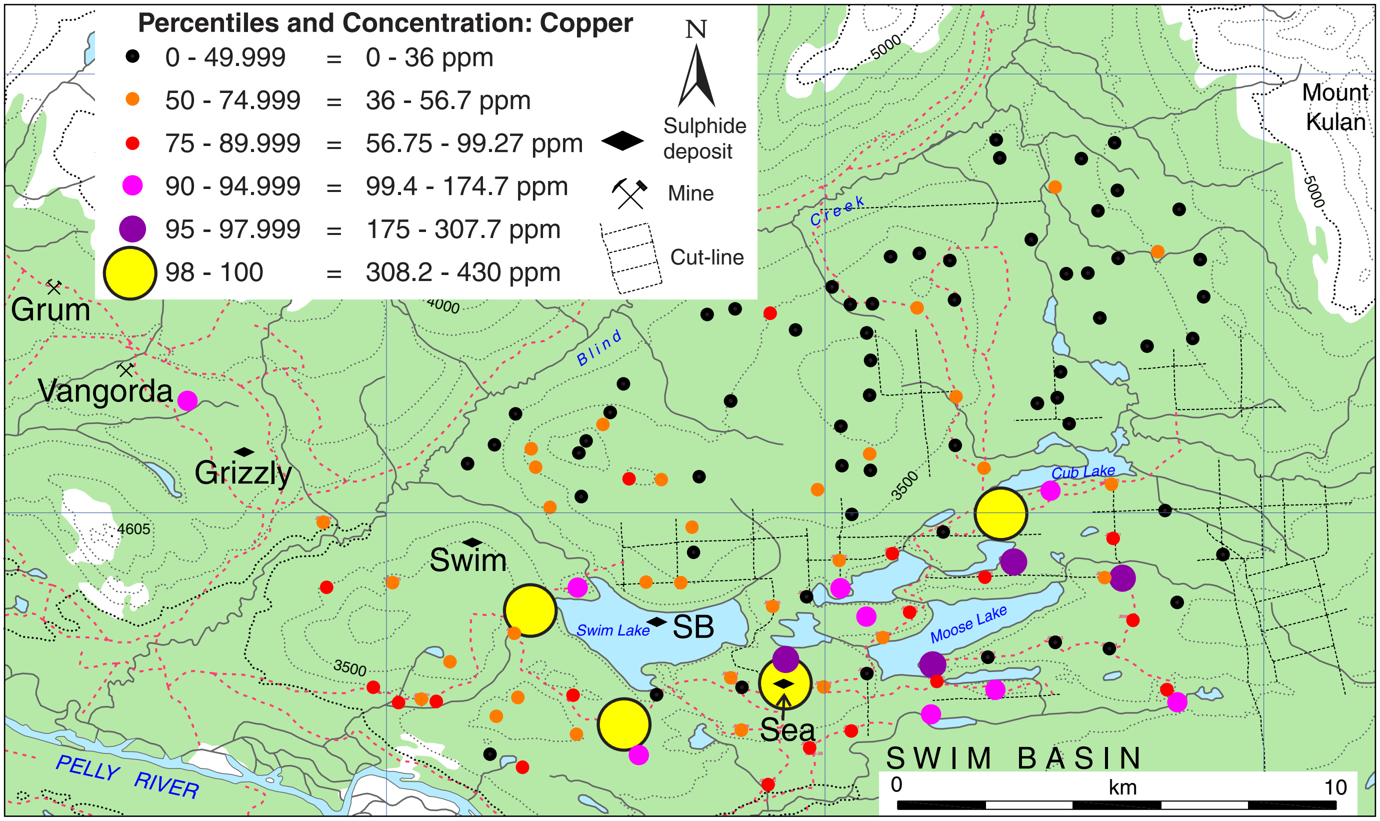


Figure 25c. *Copper concentrations from till samples collected in Swim basin.*

Data interpretation, north of Mount Mye

The Anvil Batholith forms the core of the Mount Mye upland and intrudes the Anvil stratigraphy, separating mirrored Anvil geology on either side of the massif (Figure 2). An alpine valley, informally named North Rose Creek valley, on the north side of the upland, separates Mount Mye from adjacent unnamed uplands to the north (Figure 17). Mount Mye and Vangorda formations underlie the valley bottom and outcrop on the north side of the valley. A thick blanket of variable glacial sediment drapes the valley bottom. The late glacial re-advance in the Anvil district terminated in North Rose Creek. Temporary glacial lakes formed against the waning ice sheet and deposited glaciolacustrine and glaciofluvial blankets, in addition to terminal moraines blocking the mouths of tributary alpine valleys. Areas unglaciated by the re-advance have a remnant glacial maximum till at surface, which is commonly overlain by outwash near the centre of the valley. Post-glacial downcutting has incised into the glacial fill, exposing the stratigraphy of the surficial deposits.

Lead

Lead values in till are shown in Figure 26a. Sample JB99-04 returned a lead concentration of 44 ppm, which was in the upper 98th percentile of the data set for the entire regional sampling program in 1998 and 1999. The sample was collected from the head-scarp exposure of a small landslide. The exposed till was approximately 5 m below the surface. A sample at this depth probably originated from glacial deposition during the glacial maximum and not the Pelly re-advance. Ice-flow in this area during the glacial maximum is inferred to have been from north to south, which is opposite the ice-flow during the Pelly re-advance. A source for the anomaly would lie to the north of the sample site. Additional anomalous lead values are present to the east, in upper North Rose Creek valley. Three samples returned values ranging between 25 and 27 ppm. While these are not especially high, compared to values derived down-ice of the Faro deposit, they do lie within the 90th and 95th percentile range of the regional data set. The underlying bedrock consists of the Anvil Batholith, but the geochemistry of the till is most certainly influenced by metasedimentary rocks further to the east. At both JB99-17 and JB99-18, pockets of iron-oxidized sediment and oxidized clasts were noted in the till. Similar oxidation in the Swim basin was only noted down-ice or west of the SB deposit that underlies Swim Lake. Sample JB99-18 was collected at depth from a till exposure in a terrace adjacent to North Rose Creek. The terrace is approximately 25 m above creek level and the sample was collected *ca*. 15 m below the surface of the terrace. This sample likely consists of sediment deposited by ice flowing to the west during glacial maximum. A potential source would underlie the valley fill to the east.

Zinc

Zinc concentrations are also elevated at two of the previously mentioned sites (JB99-04 and JB99-18) north of Mount Mye (Figure 26b). Both samples anomalous in zinc were collected at depth in natural exposures. JB99-04 contained 157 ppm and JB99-18 contained 218 ppm. Down-ice of the Faro deposit, values above 150 ppm in till were found within 2 km of the bedrock source. Proposed sources for samples JB99-04 and JB99-18 would underlie the valley fill to the east.

Copper

Elevated copper values in till north of Mount Mye also coincided with till samples JB99-04 and JB99-18, collected at depth from natural exposures (Figure 26c). Overall, copper concentrations are low compared with the regional data set in this area.

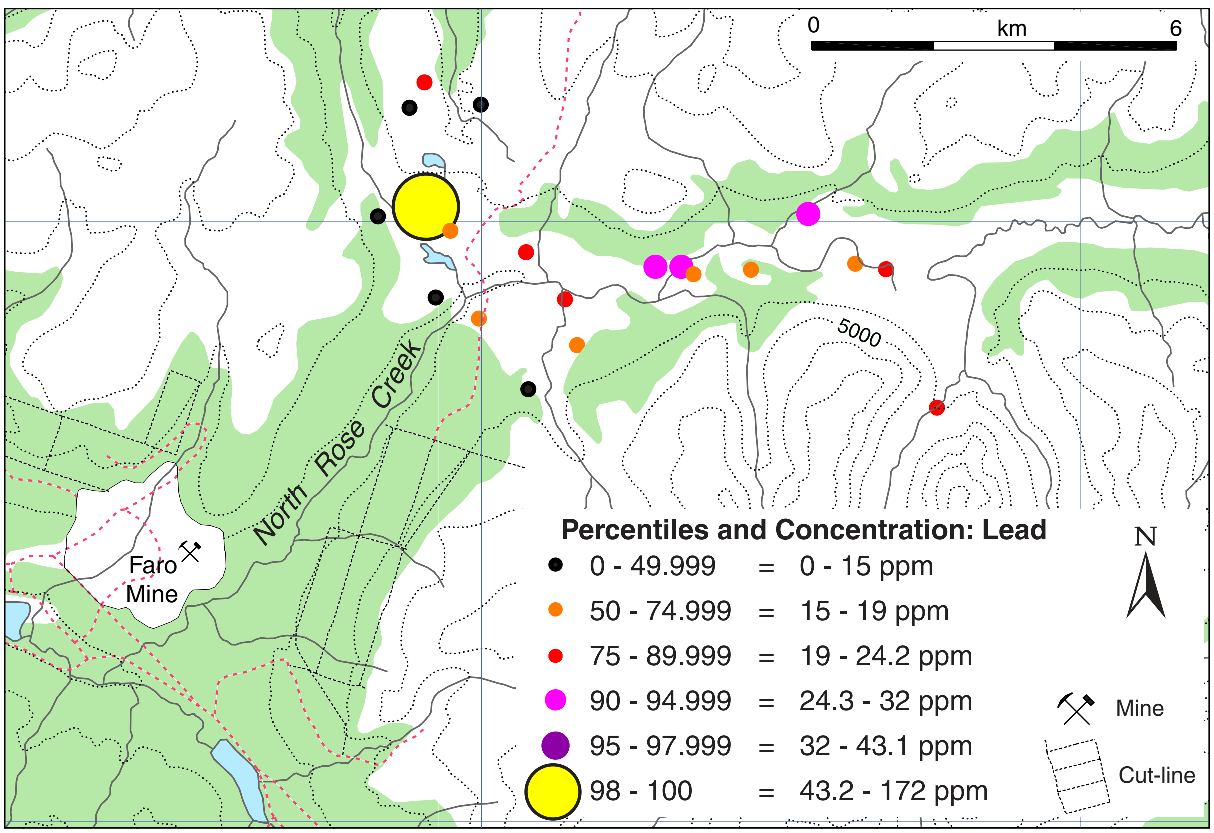


Figure 26a. *Lead concentrations from till samples collected north of Mount Mye.*

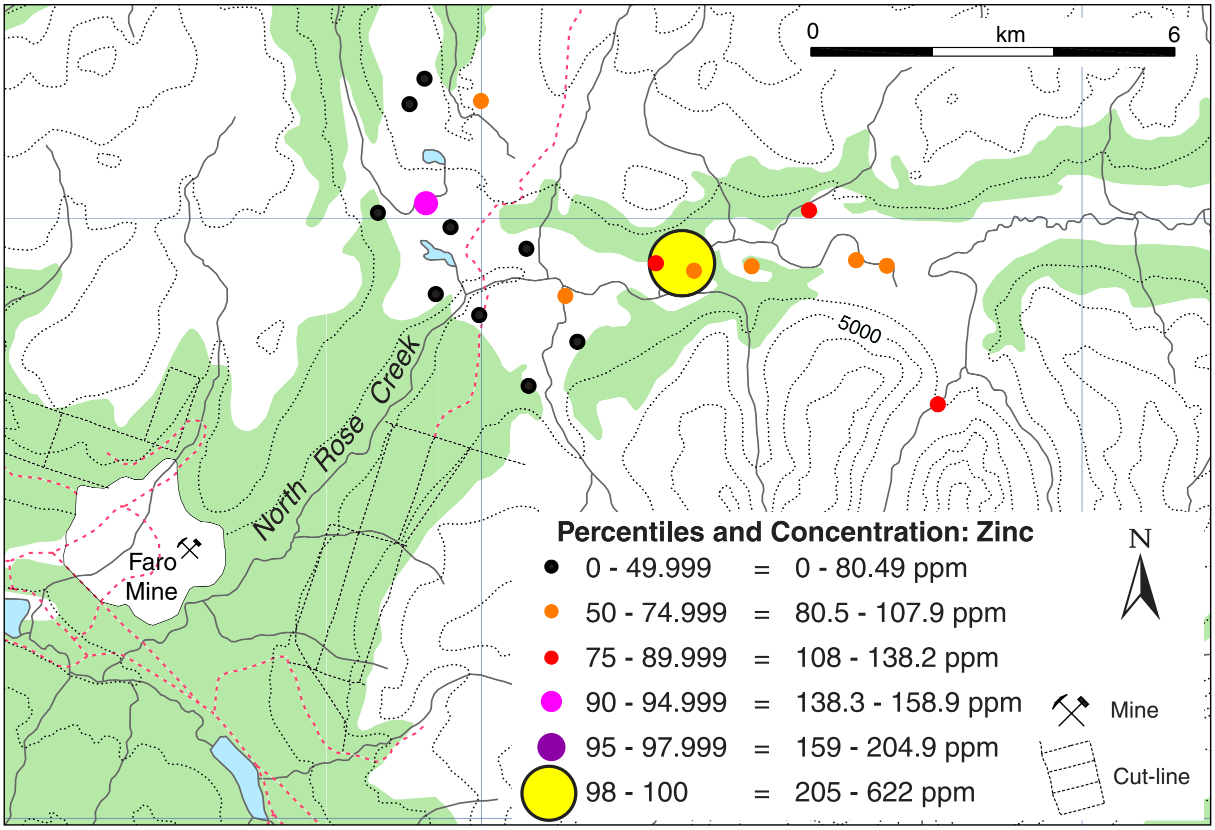


Figure 26b. *Zinc concentrations from till samples collected north of Mount Mye.*

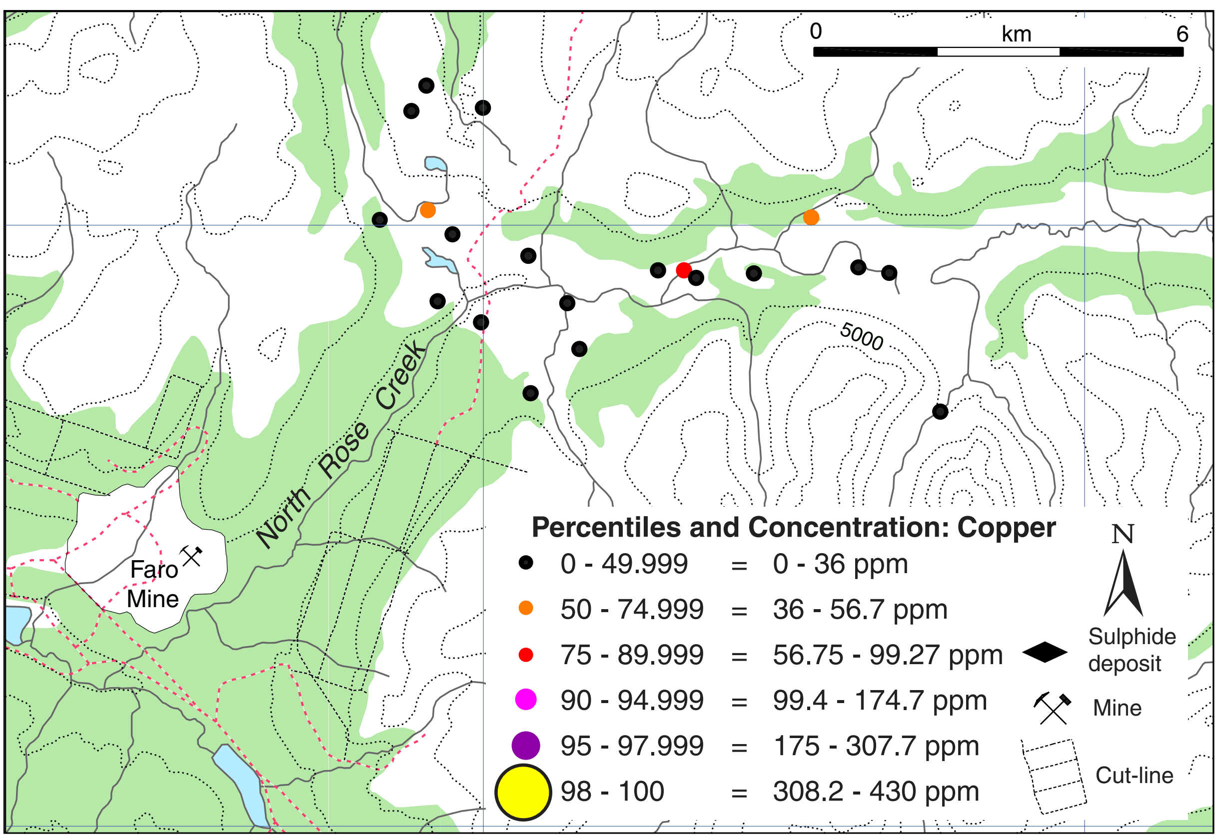


Figure 26c. *Copper concentrations from till samples collected north of Mount Mye.*

Data interpretation, Anvil Creek

Anvil Creek is 15 km northwest of the Faro mine (Figure 17). Prospective Anvil stratigraphy underlies the valley, except where the drainage cuts the Anvil Batholith. Metasedimentary rocks occur on the north side of the batholith. The depth of Quaternary fill in Anvil Creek is very substantial, and likely due to the proximity of the valley to the Tintina Trench. Near the batholith, the Quaternary stratigraphy consists of glacial outwash overlain by till. Further down the valley, glacial lake sediments intermixed with outwash are common. At higher elevations in the valley, basal till commonly caps the Quaternary sequence. Twelve samples were collected within the Anvil Creek drainage (Figure 27a). Four samples were collected near the edge of the batholith, at the upper end of the drainage (eastern part of map), and eight were collected further downstream. At each of the sample sites, it is unlikely that bedrock directly underlies the till exposed at surface. The till at surface likely represents debris that has been transported numerous kilometres and may contain some local material derived from the valley sides. In the upper part of Anvil Creek, about 2 m of till overlies at least 50 m of glacial outwash. The samples taken lower in the drainage overlie mixed Quaternary sequences in excess of 800 m in thickness.

Lead

Two samples from Anvil Creek valley yielded elevated lead levels compared to background concentrations (Figure 27a). JB99-100 and JB99-111 returned values of 27 and 26 ppm, respectively. These values are considered moderate anomalies and likely have sources up-ice, to the east and northeast.

Zinc

Two zinc anomalies were identified in upper Anvil Creek valley (Figure 27b). JB99-111 and JB99-112 have zinc concentrations of 171 and 172 ppm, respectively. A source for these anomalies likely lies further up-valley, on the north side of the Anvil Batholith. Prospective Anvil stratigraphy underlies these samples, but the contact with the batholith is nearby and, as mentioned above, high metal values in till are likely related to a source in the up-ice region as opposed to directly underneath the sample site.

Copper

No significant copper values were found in the Anvil Creek till samples (Figure 27c).

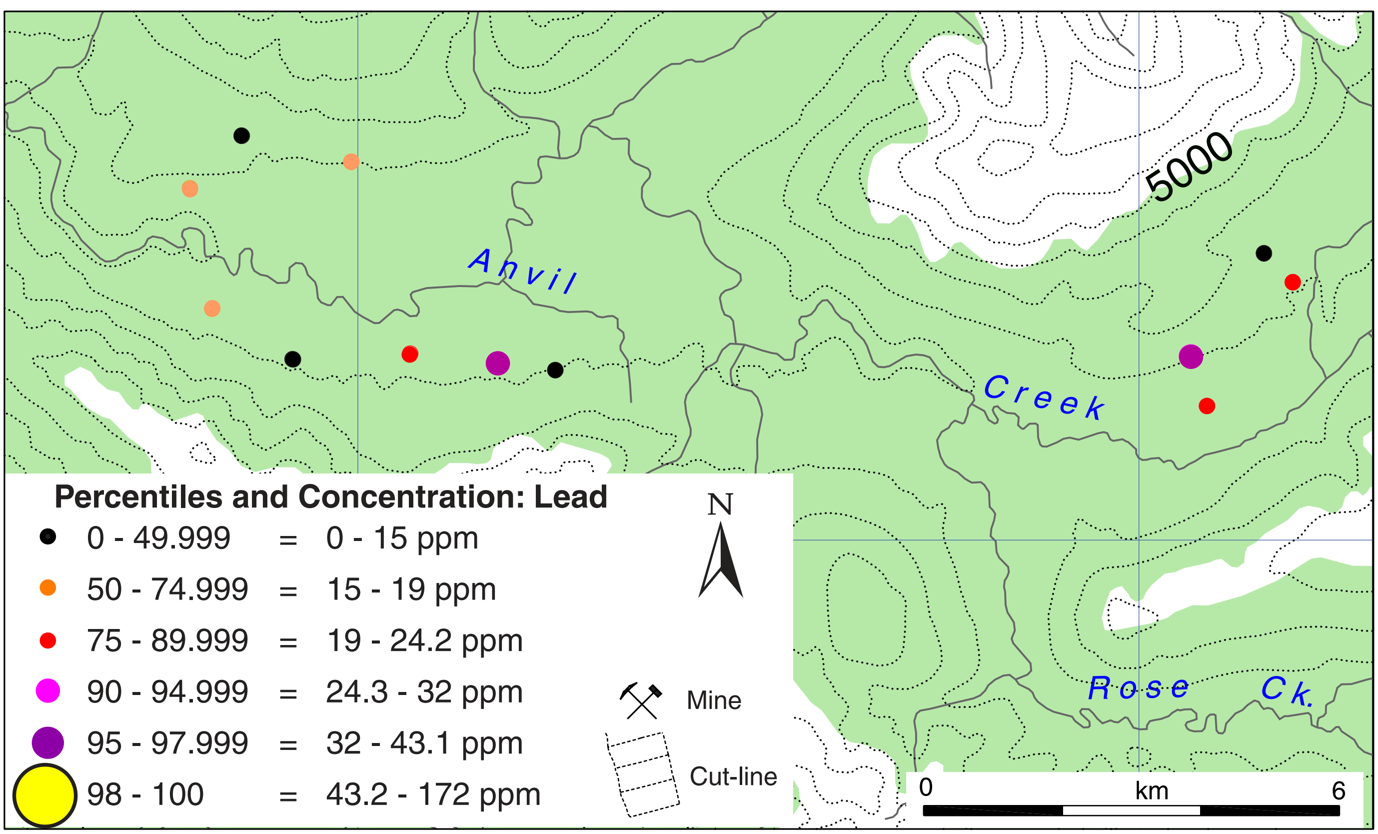


Figure 27a. *Lead concentrations from till samples collected near Anvil Creek.*

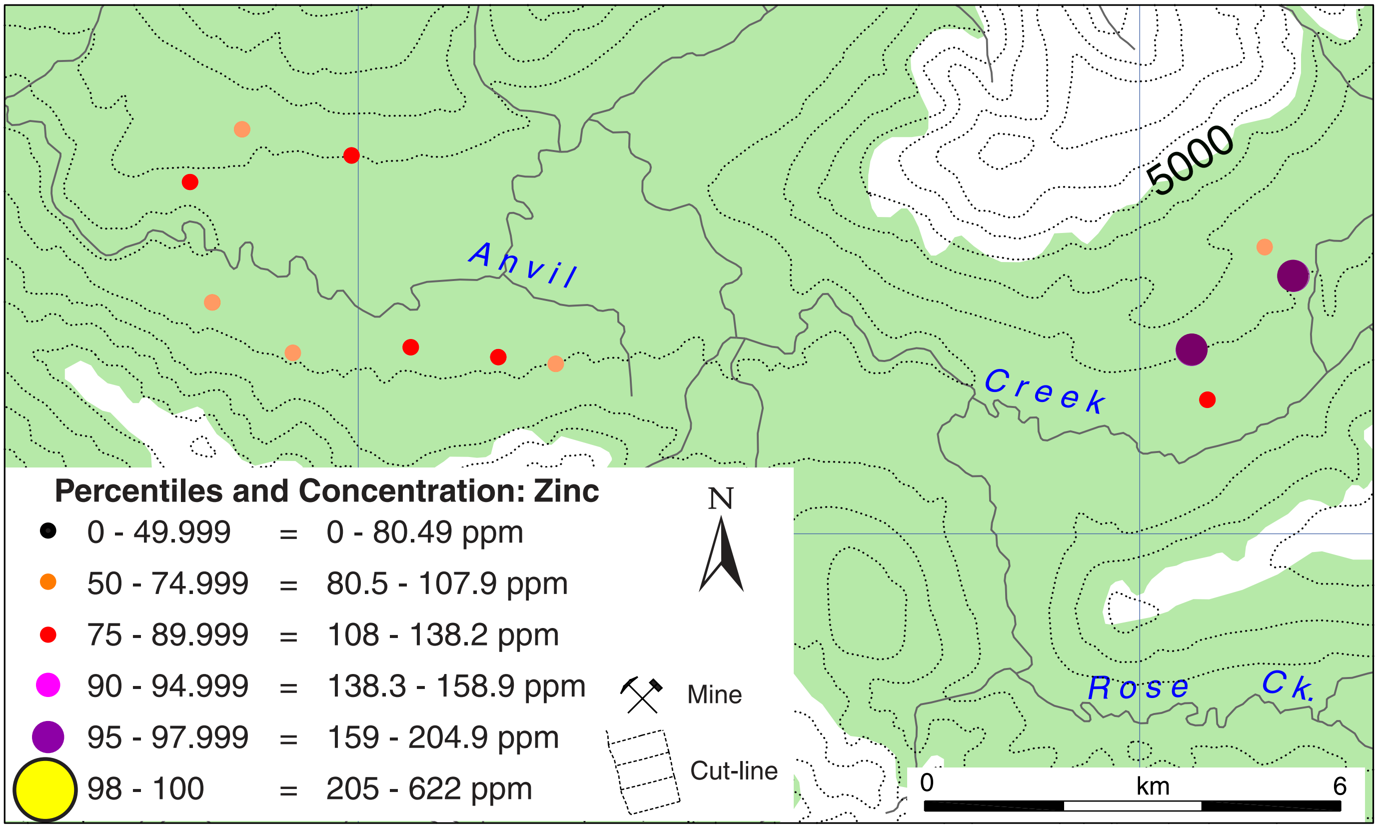


Figure 27b. *Zinc concentrations from till samples collected near Anvil Creek.*

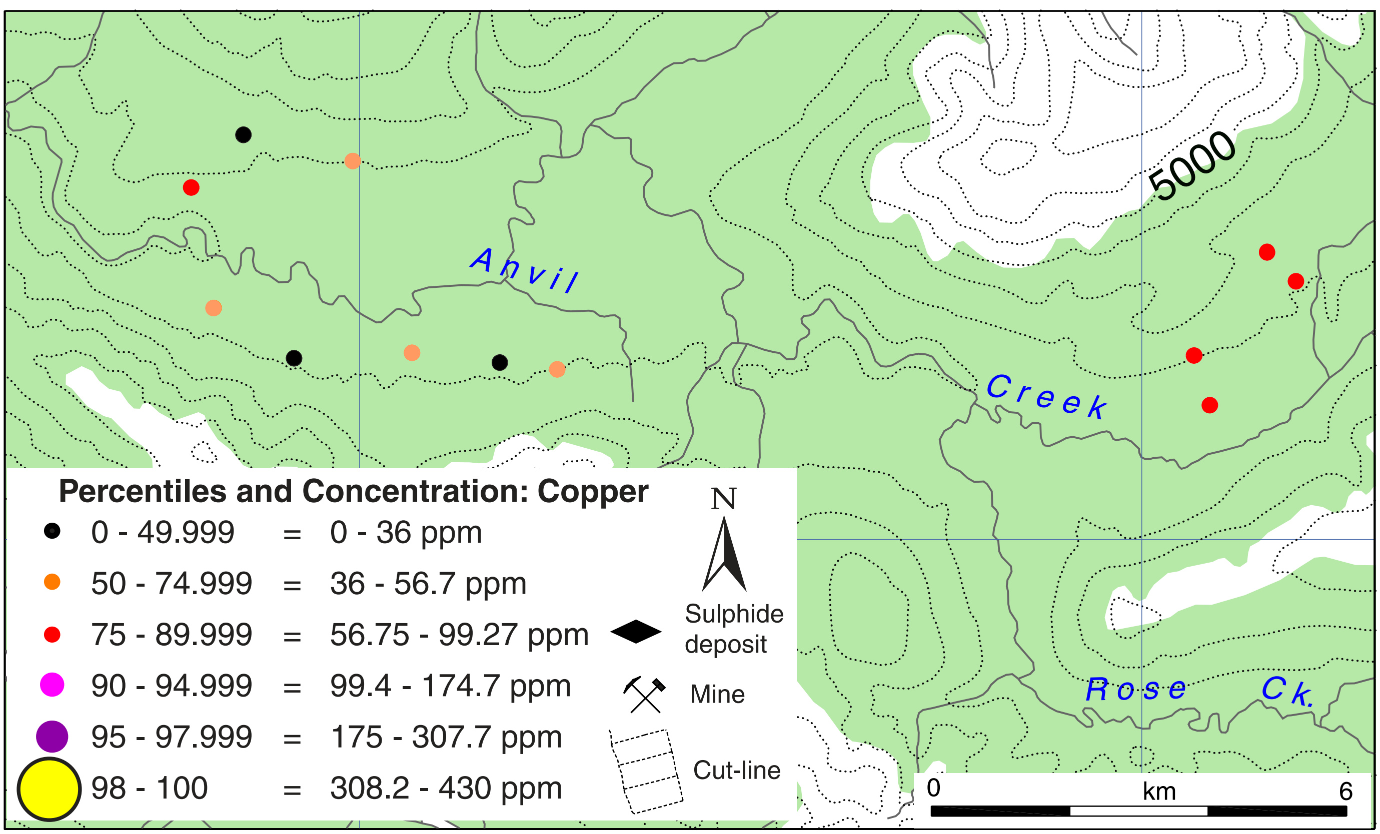


Figure 27c. *Copper concentrations from till samples collected near Anvil Creek.*

Summary

The Anvil district lies within the limit of the McConnell glaciation and is overlain by sediments originating from this glacial period. At the onset of the McConnell glaciation, alpine glaciers developed in the Anvil Range and the Selwyn and Pelly mountains. Valley glaciers were funnelled into the Tintina Trench, and as ice thickness built up, lobes of ice flowed northwest towards central Yukon. Isolated nunataks were present above 1950 m elevation. Ice flow through the district was controlled by topography, except in areas of low relief. The relatively rapid ice flow through areas adjacent to the Tintina Trench resulted in extensive glacial erosion. Till deposits on the Vangorda plateau and in the Swim basin range in thickness from < 1 m to 200 m.

A late glacial re-advance of the Cordilleran ice sheet invaded the already deglaciated alpine valleys of the Anvil Range. Ice-flow directions between Cordilleran glacial maximum and the subsequent re-advance are opposing in some areas of the Anvil Range. Geochemical variations between the Cordilleran glacial maximum till and till deposited during the re-advance were documented in the Swim basin. The 're-advance' till appears to have a more diluted geochemical signature under certain topographic settings than does the till from the glacial maximum. Ice-marginal lakes developed as the Cordilleran ice stagnated at the end of the re-advance. Glacial lake Pelly formed in the Tintina Trench and revegetation of the Vangorda plateau had begun by 10,550 +/- 40 BP based on a lake sediment C^{14} date.

The Faro deposit case study demonstrated that basal till geochemistry is an effective tool for detecting buried massive sulphide deposits in the northern Canadian Cordillera. Results of the 1998 till geochemistry case study, west of the Faro deposit, show a broad dispersal train of lead, zinc and copper extending greater than 5 km to the west. Anomalous metal values in till proximal to the Faro deposit, but at a higher elevation, may indicate a local anomalous bedrock source, or a paleo-dispersal train that preceded glacial maximum ice-flow. The dispersal train also shows a movement of metals into a tributary valley oriented transverse to glacial ice flow. This suggests the ice behaved much like a fluid rather than a rigid mass confined to Rose Creek valley, and exemplifies the influence of glacial transport on stream sediment composition.

The sampling and analytical techniques employed during the Faro case study returned significantly more values above background when compared to results from a 1964 data set. In addition, more lead values than zinc values for both the 1964 and 1998 data sets from Faro were above the 95^{th} percentile. This suggests that lead anomalies that fall above the 95^{th} percentile, from soil or till samples, will be a more reliable indicator of a nearby sulphide deposit.

When considering regional exploration for subtle geochemical anomalies, the method used during this study was a more effective identifier of above-background values for both lead and zinc. This is consistent with findings by Shilts (1984) that show how weathering readily breaks down sulphide minerals and releases metals that are subsequently scavenged by the clay fraction. The geochemical signature of a weathered till is thus most strongly expressed in the clay fraction. The –80 mesh fraction seems best utilized in the mapping of dispersion trains at the property scale.

Analyses of the till geochemistry vertically in an exposure over the Vangorda massive sulphide deposit showed that the lead concentration is a better indicator of the nearby deposit than zinc. This pattern likely reflects the greater abundance of zinc compared to lead within the regional bedrock. Zinc is more mobile than lead and therefore becomes dispersed more readily, requiring higher relative concentrations to register anomalies.

Regional till sampling in the Swim basin identified two lead anomalies west of Cub Lake, a zinc anomaly in upper Blind Creek, and copper anomalies in the vicinity of Moose and Cub lakes.

Regional till sampling north of Mount Mye identified an anomalous lead value, in the 98^{th} percentile of the regional data set, from a natural exposure. Higher geochemical values were obtained from samples collected at depth from natural exposures in this area. Two anomalous zinc values collected from samples taken in stream cuts were identified along upper Rose Creek.

Minor anomalies were identified from regional till samples collected in the Anvil Creek valley.

Limitations of till geochemical sampling in the northern Cordillera centre on sample collection and processing. Determining a sample medium may often require exposing up to 1 m of the soil profile, which can be time consuming. In addition, sediment identification is especially valuable as till geochemistry requires homogeneity in the sample medium to best qualify the data set. The necessary identification skills will require training, or the presence of a Quaternary geologist. Permafrost may provide the greatest hindrance for the application of this technique in the north. Permafrost limits the depth to which a sample can be taken and causes a mixing of the soil through cryoturbation processes. Where permafrost is pervasive, numerous pits were dug in order to find areas where the active layer was thick enough to permit access to a basal till, or a colluviated basal till. In the Anvil district, permafrost is most common where thick moss cover has accumulated on north-facing slopes and under mature forest cover.

Acknowledgements

This project was financed and coordinated by Exploration and Geological Services Division of Indian and Northern Affairs Canada, and Economic Development, Yukon Government. Gratitude is owed to Panya Lipovsky for excellent field assistance, drafting the surficial geology maps, completing much of the statistical analyses of the 1998 data, and for reformatting the database structure of Appendix 2. Dylan MacGregor provided excellent field assistance during the 1998 season. Vic Levson, Peter Bobrowsky, Stephen Cook and Ray Lett of the B.C. Geological Survey provided initial guidance for the till geochemistry component. A special thanks goes to Lee Pigage for advice on the bedrock geology of the Anvil district. Much thanks goes to Leyla Weston, Alain Plouffe, and Diane Emond for editing this document. Access to Anvil Range Mining Corporation files was made easier through consultation with Gregg Jilson. A sincere thanks goes to the people of Faro, Yukon and especially the remaining workers at the mine for their guidance and support.

References

Barendregt, R.W., Duk-Rodkin, A., Bond, J. and Jackson, L.E. Jr., 1995. Mid to late Cenozoic record of glaciations in the northern Canadian Cordillera. Poster presented at INQUA, Berlin, Germany.

Bobrowsky, P.T., Best, M., Dunn, C.E., Huntley, D.H., Lowe, C., Roberts, M., Seeman, D.A. and Sibbick, S.J.N., 1995. Integrated drift exploration studies on northern Vancouver Island (92L). *In:* Geological Fieldwork, 1994, B. Grant and J.M. Newell (eds.), B.C. Ministry of Energy, Mines, and Petroleum Resources, Paper 1995-1, p. 23-33.

Bobrowsky, P.T. and Sibbick, S.J., 1996. Till geochemistry of northern Vancouver Island area (NTS 92L/5, 6W, 11W, 12), British Columbia Ministry of Employment and Investment, Open File 1996-7, 201 p.

Bobrowsky, P.T., Leboe, E.R., Dixon-Warren, A. and Ledwon, A., 1997a. Eagle Bay project: Till geochemistry of the Adams Plateau (82 M/4) and North Barriere Lake (82 M/5) map areas. *In:* Geologic Fieldwork 1996, D.V. Lefebure, W.J. McMillan and G. McAuthor (eds.), B.C. Ministry of Employment and Investment, Paper 1997-1, p. 413-421.

Bobrowsky, P.T., Leboe, E.R., Dixon-Warren, A., Ledwon, A., MacDougall, D. and Sibbick, S.J., 1997b. Till Geochemistry of the Adams Plateau-North Barriere Lake Area (82 M/4 and 5). British Columbia Ministry of Employment and Investment, Open File 1997-9, 1:50 000 scale.

Bobrowsky, P.T., Paulen, R., Little, E., Prebble, A., Ledwon, A. *and* Lett, R., 1998. Till geochemistry of the Louis Creek-Chu Chua Creek area (NTS 92P/1E and 92P/8E). B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1998-6, 1:50 000 scale.

Bond, J.D., 1997. Late Cenozoic History of McQuesten Map Area, Yukon Territory, with Applications to Placer Gold Research. Unpublished M.Sc. Thesis, University of Alberta, 161 p.

Bostock, H.S., 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada, Paper 65-56, 18 p.

Burn, C.R., 1987. Notes on features visible from the highway between Stewart Crossing and Mayo. In: Guidebook to Quaternary Research in Yukon, S.R. Morison, and C.A.S. Smith (eds.), XII INQUA Congress, Ottawa, Canada, National Research Council of Canada, Ottawa, 40 p.

Duk-Rodkin, A., 1999. Glacial limits map of Yukon. Geological Survey of Canada, Open File 3694, 1:1 000 000 scale.

Duk-Rodkin, A., Barendregt, R.W., Tornacai, C. and Philips, F.M., 1996. Late Tertiary to late Quaternary record in the Mackenzie Mountains, Northwest Territories, Canada: Stratigraphy, paleosols, paleomagnetism, and chlorine-36. Canadian Journal of Earth Sciences, vol. 33, p. 875-895.

Froese, D.G., Barendregt, R.W., Enkin, R.J. and Baker, J., 2000. Paleomagnetic evidence for multiple Late Pliocene – Early Pleistocene glaciations in the Klondike area, Yukon Territory. Canadian Journal of Earth Sciences, vol. 17, p. 863-877.

Gabrielse, H., 1967. Tectonic evolution of the northern Canadian Cordillera. Canadian Journal of Earth Sciences, vol. 4, p. 271-298.

Giles, T.R. and Kerr, D.E., 1993. Surficial geology in the Chilanko Forks and Chezacut areas (93C/1, 8). In: Geologic Fieldwork 1992, B. Grant and J.M. Newell, (eds.), British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1993-1, p. 483-490.

Jackson, L.*E. J*r., 1987. Terrain inventory and Quaternary history of Nahanni map area, Yukon Territory and Northwest Territories. Geological Survey of Canada, Paper 86-18, 20 p.

Jackson, L.E. Jr., 1991. Pleistocene mammals, stratigraphy, and sedimentology at the Ketza River site, Yukon Territory. Geographie Physique et Quaternaire, vol. 49, p. 69-77.

Jackson, L.E. Jr., 1994. Terrain inventory and Quaternary history of Pelly River area, Yukon Territory. Geological Survey of Canada, Memoir 437, 41 p.

Jennings, D.S. and Jilson, G.A., 1986. Geology and sulphide deposits of Anvil Range, Yukon. In: Mineral deposits of Northern *Cor*dillera, J.A. Morin (ed.), Canadian Institute of Mining and Me[ta]llurgy, Special Volume 37, p. 319-361.

Kerr, D.K., Sibbick, S.J. and Jackaman, W., 1992. Till geochemistry of the Quatsino map area (92L/12). British Columbia Ministry of Energy, Mines, and Petroleum Resources, Open File 1992-21, 15 p.

LeBarge, W.P., Hein, F.J. and Bond, J.D. (eds), in prep. Placer gold deposits of Mayo, central Yukon, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada.

Levson, V.M., 1999. Till geochemistry and sampling techniques in the Canadian Cordillera. In: Drift Exploration in Glaciated Terrain, Short Course Notes, 19th International Geochemical Exploration Symposium, p. 95-116.

Levson, V.M. and Giles, T.R., 1994a. Surficial geology and Quaternary stratigraphy of the Fawnie Creek area (NTS 93 F/3). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1994-9, 1:50 000 scale.

Levson, V.M. and Giles, T.R., 1994b. Glacial dispersion patterns of mineralized bedrock with examples from the Nechako Plateau, central British Columbia. B.C. Ministry of Energy, Mines, and Petroleum Resources, Dri*ft E*xploration in Glaciated and Mountainous Terrain, Short Course Notes, Cordilleran Roundup, Vancouver, B.C., 13 p.

Levson, V.M., Giles, T.R., Cook, S.J. and Jackaman, W., 1994. Till geochemistry of the Fawnie Creek map area (NTS 93 F/3). British Columbia Ministry Energy, Mines and Petroleum Resources, Open File 1994-18, 1:50 000 scale.

Levson, V.M., Meldrum, D.G., Cook, S.J., Stumpf, A.J., O'Brien, E.K., Churchill, C., Broster, B.E. and Coneys, A.M., 1997a. Till geochemical studies in the Babine porphyry belt: Regional surveys and deposit-*sc*ale studies (NTS 93L/16, M/1, M/8). In: Geological Fieldwork 1996, D.V. Lefebure, W.J. McMillan and J.G. McArthur, (eds.), British Columbia Geological Survey, Paper 1997-1, p. 457-466.

Levson, V.M., Cook, S.J., Hobday, J., Huntley, D.H., O'Brien, E.K., Stumf, A.J. and Weary G., 1997b. Till geochemistry of the Old Fort Mountain area, central British Columbia (NTS 93 M/1). British Columbia Geological Survey, Op*en F*ile 1997-10a, 58 p.

Nikkarinen, M., Kallio, E., Lestinen, p. and Ayras, M., 1983. Mode of occurrence of copper and zinc in till over mineralized bedrock (abstract). In: X IGES-III SMGP, Finland 1983, Abstracts, A. Bjorklund and T. Kolijonen (eds.). Geological Survey of Finland, Espoo Finland, p. 54-55.

Parent, M., Paradis, S.J. and Doiron, A., 1996. Palimpsest glacial dispersal trains and their significance for drift prospecting. Journal of Geochemical Exploration, vol. 56, p. 123-140.

Pigage, L.C., 1990. Field guide to the Anvil Pb-Zn-Ag district, Yukon Territory, Canada. In: Mineral Deposits of the *Nort*hern Canadian Cordillera, Yukon-Northeastern B.C., 8th IAGOD Symposium Field Trip Guide Book, J.G. Abbott and R.J.W. Turner (eds.), Geological Survey of Canada, Open File 2129, p. 283-308.

Plouffe, A., 1989. Drift prospecting and till geochemistry in Tintina Trench, southeastern Yukon. M.Sc. thesis, Department of Earth Sciences, Carleton University, 81 p.

Plouffe, A. and Jackso*n*, *L*.E., Jr., 1992. Drift prospecting for gold in Tintina Trench, southeastern Yukon. Yukon Geology, Volume 3, T.J. Bremner (ed.), p. 196-213.

Shilts, W.W., 1976. Glacial till and mineral exploration. In: Glacial Till, R.F. Legget (ed.), Royal Society of Canada, Special Publication 12, p. 205-223.

Shilts, W.W., 1984. Till geochemistry in Finland and Canada. Journal of Geochemical Exploration, vol. 21, p. 95-117.

Smith, C.A.S., 2001. Ecoregions of the Yukon. In prep.

Ward, B.C., 1989. Quarternary stratigraphy along Pelly River in Glenlyon and Carmacks map areas, Yukon Territory. In: Current Research, Part E, Geological Survey of Canada, Paper 89-1E, p. 257-264.

Exploration and Geological Services Division

Bulletin 1 The Whitehorse Copper Belt: Mining Exploration and Geology 1967 - 1980 (105D)
D. Tenney

Bulletin 2 Geology and Genesis of the Mount Skukum Epithermal Gold-Silver Deposits, Southwestern Yukon Territory (105D)
B.W.D. McDonald

Bulletin 3 Shape and Composition of Lode and Placer Gold from the Klondike District, Yukon, Canada (115O, parts of 116B)
J.B. Knight, J.K. Mortensen and S.R. Morison

Bulletin 4 Sedimentology of Placer Gravels near Mt. Nansen, Central Yukon Territory (115I)
W.P. LeBarge

Bulletin 5 Natural Land Reclamation for Mineral Exploration Properties and Placer Mines in Yukon
C. Mougeot

Bulletin 6 Geology of the McQuesten River region, Northern McQuesten and Mayo Map Areas, Yukon Territory (115P/14-16, 105M/13-14)
Donald C. Murphy

Bulletin 7 Geology of the Mayo Map Area, Yukon Territory (105M)
Charlie Roots

Bulletin 8 A Transect Across Northern Stikinia: Geology of the Northern Whitehorse Map Area, Southern Yukon Territory (105D/13-16)
Craig J.R. Hart

Bulletin 9 Geology of the Upper Hart River Area, Eastern Ogilvie Mountains, Yukon Territory (116A/10, 11)
Grant Abbott

Bulletin 10 Geology and mineral occurrences of the Slats Creek, Fairchild Lake and "Dolores Creek" areas, Wernecke Mountains (106D/16, 106C/13, 106C/14), Yukon Territory
Derek J. Thorkelson

Bulletin 11 *Quaternary geology and till geochemistry of the Anvil district (parts of 105K/2, 3, 5, 6 and 7), central Yukon Territory*
Jeffrey D. Bond

Copies available from: Geoscience Information and Sales, Exploration and Geological Services Division, Indian and Northern Affairs Canada, 102-300 Main St., Whitehorse, Yukon, YIA 2B5
Phone 867 667-3266, Fax 867 667-3267, geosales@inac.gc.ca
Visit our Web Site: www.geology.gov.yk.ca