Geochemical Techniques for Detection of Blind Porphyry Copper-Gold Mineralization under Basalt Cover, Woodjam Prospect, South-Central British Columbia (NTS 093A/03, /06)

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Introduction

This paper outlines activities conducted under the Geoscience BC project entitled: "Seeing through Chilcotin basalts: the geochemical signal of what is hidden underneath (092P, 093A, C)". Field components of the study were undertaken in conjunction with another Geoscience BC project in the same area entitled: "Evaluation of plant exudates to assist in mineral exploration and the development of simple and cost effective field procedures and analytical methods" (see Heberlein et al., 2013).

Large areas prospective for porphyry and epithermal-style mineralization in central British Columbia are covered by either glaciofluvial sediments or young basalt units, most importantly of the Miocene to Pleistocene Chilcotin Group (Figure 1). Other recently completed Geoscience BC-funded projects have demonstrated that geochemical methods can assist in seeing through exotic cover (e.g., Cook and Dunn, 2007; Dunn et al., 2007; Barnett and Williams, 2009; Heberlein, 2010; Heberlein and Samson, 2010; Heberlein and Dunn, 2011). In areas where basaltic lavas cover the bedrock, application of exploration-geochemistry techniques has received relatively little attention in investigating the underlying bedrock, in part due to a lack in BC of basalt-covered sites with well-known mineralization, where deep-penetrating geochemical methods could be tested. The present study is aimed at establishing a geochemical strategy to see through the basalt cover, using a variety of analytical techniques on different sample media. Porphyry mineralization at the Woodjam prospect (Figure 1), the study site chosen for this project, occurs in close proximity to basalt cover and may also be present underneath.

Chilcotin Basalt

The Chilcotin Group comprises mostly olivine-phyric basalt as coherent lavas, lesser tuffs and sedimentary units including sandstone, siltstone, shale and conglomerate (Bevier, 1983; Dohaney, 2009). Basalt units, considered to be part of the Chilcotin Group, include Late Oligocene and Miocene, and locally as young as Pleistocene, lavas (Bevier, 1983). These units are not hydrothermally altered and weather to brown and dark grey colours. They typically
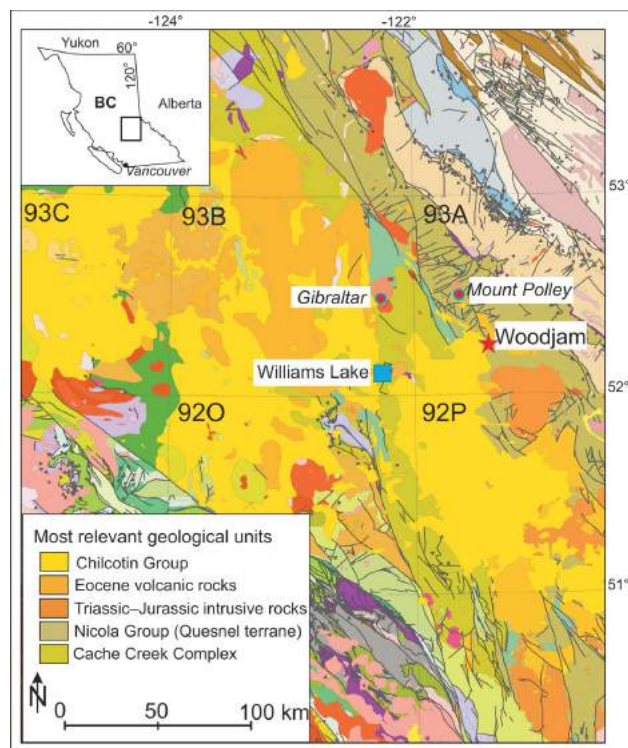

Figure 1. Regional geology of central British Columbia and location of the Woodjam study area as well as the nearby major porphyry deposits of Gibraltar and Mount Polley (after Massey et al., 2005); see inset for location within British Columbia.

consist of highly vesiculated coherent lavas, featuring variable degrees of columnar jointing. Chemically, they cover a broad range of compositions, from alkali olivine-basalt and basaltic andesite to less common hawaiite, mugearite and trachyandesite (Dohaney, 2009). Traditionally, Chilcotin basalt units have been mapped as extensive plateaus (e.g., Massey et al., 2005; Figure 1) and are best exposed in the incised valleys of present-day rivers. Recent work (Andrews and Russell, 2008; Dohaney, 2009) has established that most of the basalt lavas actually followed low-lying topography and, in many places where the Chilcotin Group is mapped, the basalt cover may be thin or absent, making exploration in those areas potentially viable. Their presence in the subsurface is commonly indicated by angular boulders and colluvial debris. Chilcotin Group rocks are also widely covered by Quaternary glacial sediments.

Geochemically the Chilcotin Group basalt units are distinctive from the underlying Triassic Nicola Group basalt flows and basalt-derived volcaniclastic sediments. In contrast to the Nicola Group (Vaca, 2012), these units have higher Ti, Ta, Nb, Th, U and light rare earth element contents, do not have a clear-cut arc signature, and plot in the tholeiitic and within-plate fields (Figure 2; Dohaney, 2009). The Nicola Group and along-strike equivalent Takla Group commonly host porphyry Cu-Au mineralization, including the Woodjam prospect (Figures 1, 3) where the field sampling for this study was carried out, whereas the Chilcotin Group basalt units are not known to be mineralized.

Benefits to the Mining Industry

This study is designed to test whether a geochemical signal of mineralization under basalt cover can be detected in the near-surface environment. It also aims to provide the mineral-exploration community with a better understanding of different sampling media that can be used for geochemical exploration in regions with basalt cover. The study provides comparisons of element concentrations in soils and plants (spruce) subjected to various total-analysis and selective-leach methods, and assesses the relative capabilities of each medium for recording the secondary geochemical-dispersion patterns of the geology, including blind mineral deposits under cover. It also examines the trace-element composition of coatings and materials within vesicles in the basalt units; a selection of results is reported herein.

Project Area

Test sites selected for this study lie within Gold Fields Canada Exploration and Consolidated Woodjam Copper Corp.'s Woodjam property, which is located in the Cariboo Mining District of central BC. (NTS map areas 093A/03, /06; Figure 3). The property, which consists of 178 mineral claims totalling 58 470 ha, lies about 50 km to the northeast of Williams Lake. Horsefly, the nearest settlement and lo-

gistical base for the fieldwork, is within the property boundary and is accessible by a paved road from Williams Lake.

The two test sites, known as Deerhorn and Three Firs (formerly known as Megalloy; Figure 3), lie 8 and 12 km respectively to the southeast and south of Horsefly; both are readily accessible via a network of well-maintained logging roads. Within those areas, one east-oriented and one east-northeast-oriented sample traverse pass from glaciofluvial sediment-covered areas into glaciofluvial sediment- and/or basalt-covered areas. In both transects, mineralization is known to underlie the unconsolidated sediments near the transition to basalt-covered areas. At the time of writing, no mineralized zone directly underlying basalt cover had been defined by drilling, although one (MAG-12-04) of three angled drillholes (Figure 3; Consolidated Woodjam Copper Corp., 2012a) at Three Firs passes through about 60 m of glaciofluvial material and about 30 m of basalt into mineralized bedrock. The top of the bedrock, which is fragmental and clay rich, contains Fe and Mn oxides just below the basalt; this can be interpreted as a paleoregolith but it may also be interpreted as fault gouge.

Surficial Environment

The project area lies at the boundary between the Fraser Plateau and Quesnel Highland physiographic regions of central BC (Holland, 1964). The terrain in the study areas has characteristics of both regions. The Deerhorn test site lies at a fairly sharp transition between relatively flat, rolling topography typical of the Fraser Plateau on the western side of the mineralized zone, and low hills of the Quesnel Highland to the east (Figure 3). Elevations across the Deerhorn sample traverses, which cross the transition, vary from 900 m at the west to 1030 m at the highest point, close to the eastern end. A number of small lakes and ponds are dotted throughout the area; the largest of these is Mica lake, which lies on the southwestern side of the mineralized zone. Lakes are linked by small streams and boggy depressions, which form part of a dendritic drainage pattern connecting with the Horsefly River about 5 km to the northeast of Deerhorn. Three Firs lies in a similar physiographic setting to Deerhorn (Figure 3). More than half of the Three Firs sample traverse crosses relatively flat terrain typical of the Fraser Plateau, where elevations range from 975 to 1000 m asl. At these lower elevations, a number of swamps and small creeks define a northwest-flowing dendritic drainage pattern, which merges with Woodjam Creek some 8 km to the northwest. The terrain gradually rises eastward into the rounded hills of the Quesnel Highland, where the maximum elevation at the eastern end of the line is 1140 m.

Quaternary glacial deposits cover the mineralization at both study areas. To the east of Deerhorn, surficial deposits consist of an intermittent till veneer, which mantles the hill-
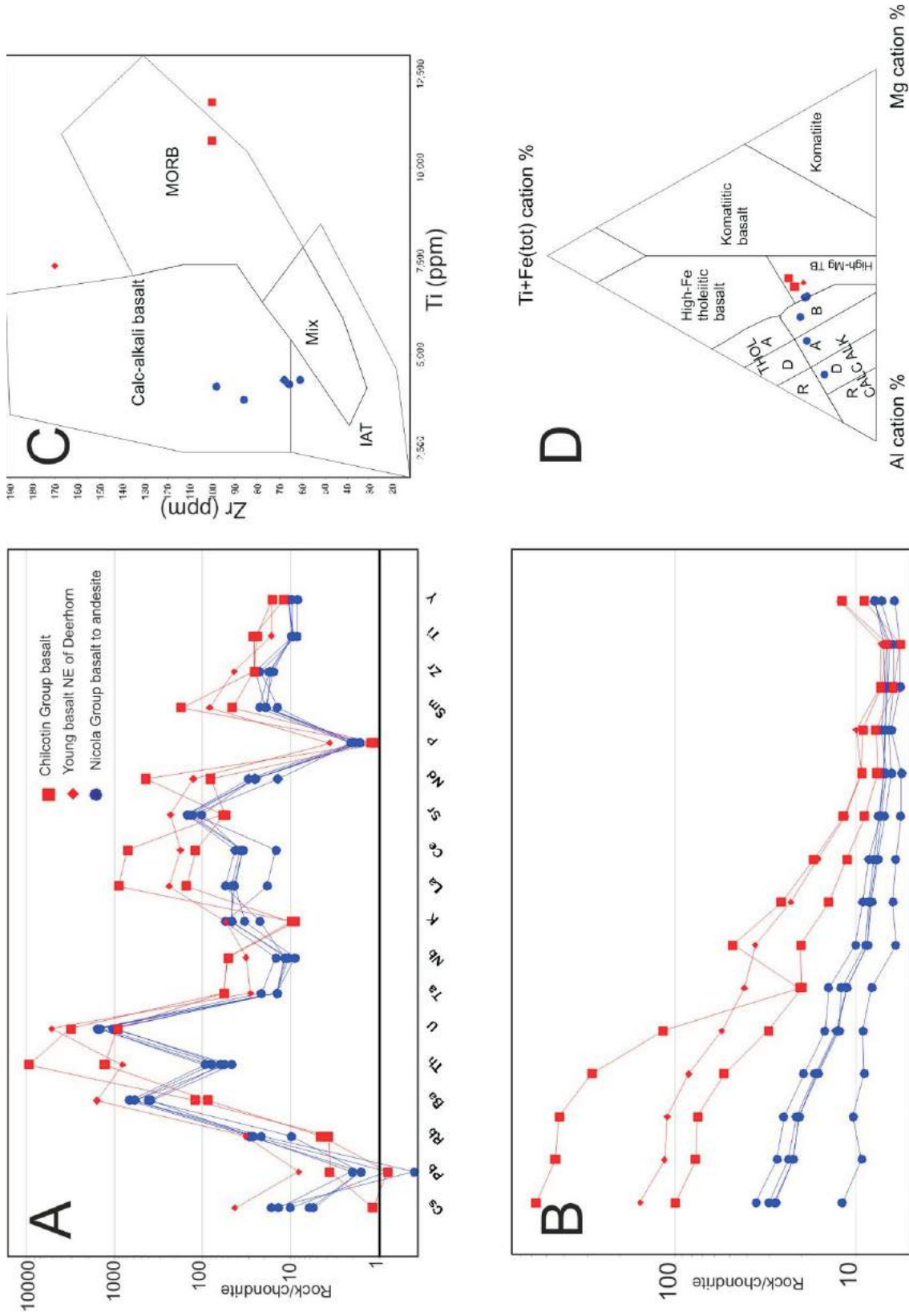
Figure 2. Whole-rock geochemistry of basalt to basaltic andesite in the Woodjam area, south-central British Columbia. Blue symbols indicate Triassic Nicola Group and red squares, Late Oligocene to Pliocene Chilcotin Group basalt sampled in the western part of the Woodjam property. Red diamonds indicate one sample taken northeast of the Deerhorn study area. The Nicola Group samples have an arc signature, whereas the Chilcotin and Deerhorn basalt units have a within-plate to tholeiitic signature: **a)** and **b)** chondrite-normalized spider diagrams (chondrite values from Sun and McDonough, 1989); **c)** basalt classification diagram; **d)** Jensen cation plot (Pearce et al., 1973; Jensen 1976) for basalt classification (diagrams modified from Rollinson, 1993; data for Nicola Group basalt units from Vaca, 2012).

sides and becomes thicker in topographic depressions. The maximum thickness of the till is unknown but the presence of outcrops on the northern flank of the hillside east of Deerhorn suggests that it is likely to be no more than a few metres thick at that location. Glacial landforms, such as drumlinoid features, are present in this area and east of the sample traverse. Their long axes indicate a west-northwesterly ice-flow direction. Cover thickens rapidly westward onto the lowlands and drilling at Deerhorn has shown that the bedrock surface is buried beneath up to 60 m of till and glaciofluvial sediments (Skinner, 2010; Del Real et al., 2013). Surficial deposits on the eastern shore of Mica lake and southern limit of the projected mineralized zone (Figure 3) consist of well-sorted sand and gravel of probable glaciofluvial origin; the distribution of these deposits is unknown. A hill consisting of basaltic rocks assigned to the
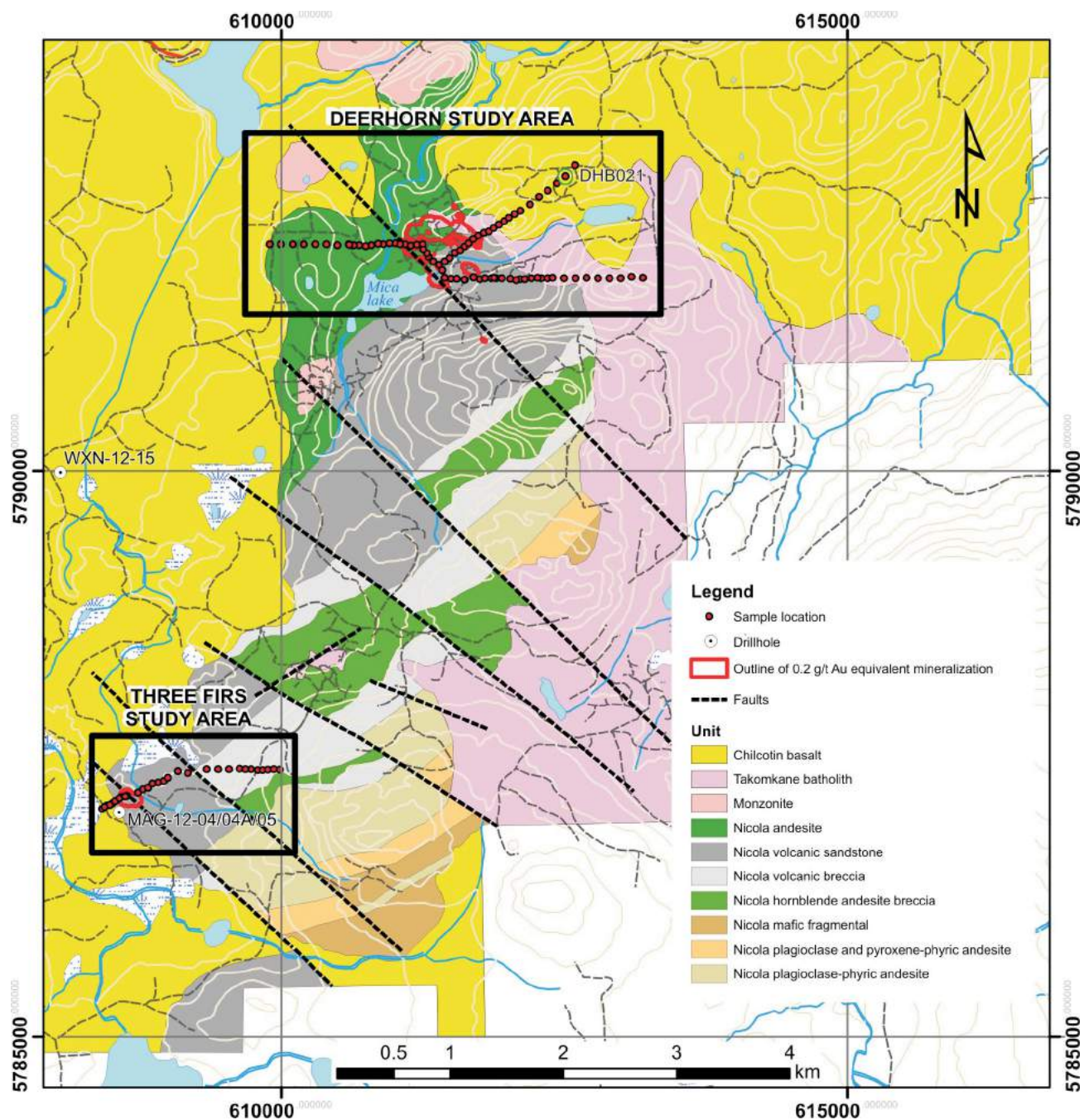

Figure 3. Bedrock geology of the Woodjam South prospect, south-central British Columbia. (modified from Del Real et al., 2013; J. Blackwell, pers. comm., 2012). Map is in UTM NAD 83 projection, Zone 10. Red outlines denote surface projection of the +0.2 g/t Au equivalent mineralization; black dots show soil-sample locations. Specific drillhole and sample locations mentioned in the text are indicated. Abbreviations: IAT, island-arc tholeiite; MORB, mid-ocean ridge basalt. Place name with the generic in lower case is unofficial.

Chilcotin Group lies to the east-northeast of the mineralized zone (Figure 3). Samples collected along the east-, northeast-oriented traverse largely come from this basalt-covered area. The depth to bedrock below the basalt flows and potential presence of mineralization below this basalt is unknown.

At Three Firs, the cover environment contains a Tertiary basalt unit beneath the glacial deposits in the western part of the sample traverse. Drilling has indicated that the basalt may cover a part of the mineralized zone. The basalt consists of a fresh, black, highly vesicular flow unit up to 20 m thick. Nicola Group rocks at its lower contact are fragmented and intensely clay-altered over several metres in what is either a gouge-filled fault zone or a paleoregolith. The extent of basalt cover is unknown, although its distribution is most likely restricted to paleovalleys rather than forming a continuous cap over the mineralized area. This would be typical of other occurrences of Chilcotin Group flows in the region (Dohaney, 2009). Surficial deposits at Three Firs consist predominantly of glacial till, which forms a blanket 40–100 m thick. There is no outcrop in the vicinity of the mineralization. Till cover appears to thin gradually eastward and outcrops of a distinctive 'turkey-track' feldspar porphyritic andesite become widespread in the east-central part of the sample traverse. On the hillside, at the eastern end of the traverse, till cover is present as a thin veneer of no more than a metre or two thick.

Regional Geological Setting

The Woodjam prospect lies in the southern part of the highly prospective Quesnel terrane: a Late Triassic to Early Jurassic magmatic arc complex, which extends for most of the length of the Canadian Cordillera. It is flanked to the east by assemblages of Proterozoic and Paleozoic carbonate and siliciclastic rocks of ancestral North American affinity, but is separated from them by a sliver of oceanic basalt and chert of the Slide Mountain terrane (Schiarizza et al., 2009). Oceanic rocks of the Late Paleozoic to Early Mesozoic Cache Creek terrane bound the Quesnel terrane to the west. The southern part of the Quesnel terrane hosts a number of important Cu-Au porphyry deposits; nearby examples include Gibraltar and Mount Polley.

In the Woodjam area, the Quesnel terrane is represented by Middle to Upper Triassic volcano-sedimentary rocks of the Nicola Group (Figures 1, 3). Locally, this consists of a shallow northwest-dipping sequence of volcanic and volcanic-derived sedimentary rocks, which include augite-phyric basalt flows and polymictic breccias containing latite, trachyte and equivalent volcanic clasts (Gold Fields Canada Exploration, unpublished data, 2012). Sandstone and conglomerate are intercalated with the volcanic units. A suite of more or less coeval intrusions of alkaline to calc-kaline affinity intrudes the volcanic and sedimentary sequence. These intrusions include the Early Jurassic Takomkane batholith, located to the south and east of the project area, and a number of smaller syenite, monzonite, quartz monzonite and monzodiorite stocks and dikes within the Woodjam property itself, many of which are associated with Cu-Au mineralization.

The Woodjam South property contains several centres of Early Jurassic porphyry-style Cu-Mo-Au mineralization (Schiarizza, 2009; Sherlock et al., 2012; Mineral Deposit Research Unit, unpublished data, 2011). Style of mineralization, hostrocks and metal association vary from one mineralized centre to another; these include the Southeast, Takom, Megabuck, Deerhorn and Three Firs zones (Figure 3; Del Real et al., 2013). The Southeast zone is at the most advanced stage of exploration and is currently undergoing advanced exploration drilling. Copper-molybdenum mineralization is hosted in intrusive rocks, which form part of the Takomkane batholith. Deerhorn is the next most advanced prospect and is currently at the advanced exploration drilling stage. It is characterized by Cu-Au mineralization hosted in Nicola Group volcanic rocks and a series of small porphyry stocks and dikes (see below). The remaining prospects are all at the exploratory drilling stage. Three Firs represents a new discovery that was made early in 2012 (Consolidated Woodjam Copper Corp., 2012a); it is currently in the initial drill-testing stage. Nicola Group rocks in much of the western part of the Woodjam South property area and an area to the east of Deerhorn are covered by younger Cenozoic basalt flows belonging to the Chilcotin Group. This younger volcanic- and sedimentary-rock cover masks prospective areas of the underlying Nicola Group.

Geology of Test Areas

Deerhorn

Deerhorn is a blind zone of porphyry Cu-Au–style mineralization, which was discovered by drilling a large chargeability anomaly in 2007 (Skinner, 2010). The mineralization, defined by the red +0.2 g/t Au equivalent outline in Figure 3, is the surface projection of a pipe-like body containing a higher-grade shoot, which plunges at a moderate angle to the southeast (Gold Fields Canada Exploration, unpublished data, 2012). Its dimensions are approximately 350 m in strike, 100 m in width and 200 m in depth (Consolidated Woodjam Copper Corp., 2012b). Higher-grade mineralization is enclosed within a much more extensive lower-grade envelope defined by quartz and magnetite stockwork and veinlets, and disseminated chalcopyrite mineralization. Low-grade mineralization is coincident with an arcuate chargeability anomaly, which extends northwest of the Deerhorn drill site and continues south and west to the Megabuck East and Megabuck prospects.

Geological mapping and reconstruction of the bedrock geology from drilling by Gold Fields Canada Exploration

(Figure 3; J. Blackwell, pers. comm., 2012) indicate that the mineralization is hosted in a southwest-striking, northwest-dipping package of Nicola Group andesite and volcanic-derived sandstone. Higher-grade mineralization is associated with a number of northwest-striking dike-like monzonite bodies, which cross the contact between volcanic-derived sandstone in the southeast and andesite in the northwest of the mineralized zone. The intrusion and volcano-sedimentary units are offset by sets of west-northwest- and northeast-striking faults (Gold Fields Canada Exploration, unpublished data, 2012). Mineralization subcrops beneath a variable cover of Quaternary glacial and glaciofluvial deposits, which consist of a till blanket up to 40 m thick over the mineralization and a sequence of overlying glaciofluvial sand and gravel exposed in road-cuts near the southeastern shore of Mica lake; the extent of these deposits is unknown. To the northeast of the mineralized area, coherent basalt flows, presumably of the Chilcotin Group, are present. The thickness of these basalts is unknown but they appear to be directly underlying the soil profile in at least part of the area.

Three Firs (Megalloy)

Bedrock geology of the Three Firs study area is not well understood. Mineralization was only discovered at this prospect during the spring of 2012 and, at the time of sampling for this study, only three holes had encountered significant Cu-Au mineralization (Consolidated Woodjam Copper Corporation, 2012a). What makes this study area appealing from a deep-penetrating–geochemistry standpoint is the presence of a basalt unit, inferred to be part of the Chilcotin Group, which overlies at least part of the mineralized zone. The extent of the basalt is unknown and difficult to resolve from the interpretation of ground and airborne magnetic data (Gold Fields Canada Exploration, unpublished data, 2012). Drilling shows that it consists of one or several coherent flows and forms a cap at least 30 m thick overlying the altered and mineralized Nicola Group rocks. The known distribution of basalt and the surface projections of the mineralized drill intersections are illustrated in Figure 3 (Gold Fields Canada Exploration, unpublished data, 2012) and indicated for reference in the geochemical plots below. Overlying the basalt are Quaternary glacial sediments; where observed in drill road exposures, these appear to consist of a boulder till containing abundant large rounded clasts (up to 1 m in diameter) of distinctive 'turkey-track' andesite porphyry that is known to outcrop near the eastern end of the sample traverse and immediately to the southeast. The size and composition of the boulders indicate that the till is locally derived and possibly forms only a thin veneer across the survey area.

Field Procedures

Soils

At each sample station, at least one hole was dug to a depth of about 50 cm to collect a few grams of the upper Ae horizon (eluviated greyish zone immediately below the organic-rich Ah horizon) for pH and conductivity measurements, the upper B horizon (Bf or Bm horizon) and the interval of 10–25 cm beneath the base of organic matter for Mobile Metal Ion™ (MMI) analysis. The locations of the sample stations are shown on Figure 3 and the sample types on Figure 4.

Basalt

In addition to whole-rock analyses for three Chilcotin Group basalt samples, eight samples of vesicle infill have been separated (Figure 5). These are both from Chilcotin basalt-proximal and apparently overlying sulphide mineralization at the Three Firs zone, and from drillcore (WNX12-15) from an inferred background area located some 2 km to the north of known mineralization (Figure 3).
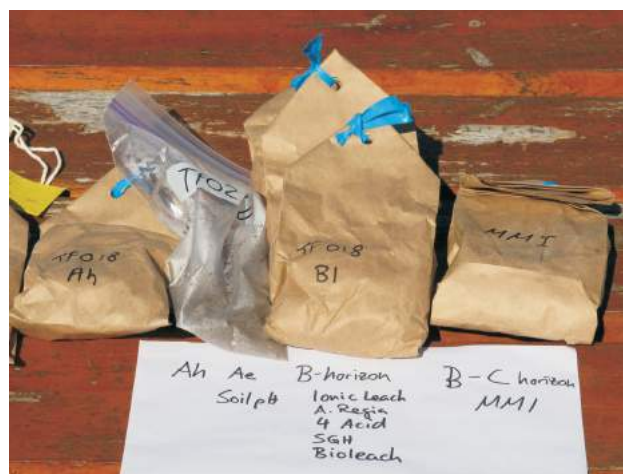

Figure 4. Suite of samples collected at each sample station for this study (not shown are spruce twigs and bark), Woodjam prospect, south-central British Columbia. The samples were collected together with those reported in Heberlein et al. (2013).

Figure 5. Example of vesicular Chilcotin basalt, with beige-brown clay (vermiculite) infill and white calcite infill, from drillhole MAG-12-04 (at 70.9 m) in the Three Firs zone, Woodjam prospect, south-central British Columbia. These two types of infill have been separated and analyzed by inductively coupled plasma–mass spectrometry (ICP-MS) following an aqua-regia digestion to test for a geochemical signature from underlying mineralization.

The vesicle infill consists of clay (poorly crystalline vermiculite) and carbonate (magnesian calcite). Infill was extracted from the crushed rock using hardened-steel tools or, in the case of carbonate infill, hand-picked from the crushed rock. More than 0.5 g of material was collected and analyzed at ALS Limited (Vancouver) using their ME-MS41L package, which consists of inductively coupled plasma–mass spectrometry (ICP-MS) following aqua-regia digestion. The intention of this analytical work is to test the potential for clay- and carbonate-vesicle infill to record a geochemical signal from underlying mineralization; the results are shown in Figure 6.

Analytical Methods

Samples from a range of soil horizons crossing the two zones of mineralization at Woodjam (Deerhorn and Three Firs) were submitted for comparative analysis by several commercially-available total, partial and selective extraction analytical methods. Table 1 provides a summary of the various analytical methods employed, which include:

- **Four-acid near-total digestion/ICP-MS (4 acid):** the sample is digested with perchloric, nitric, hydrofluoric and hydrochloric acids, which dissolve the silicate portion, including most of the resistate minerals.

- **Aqua-regia digestion/ICP-MS (AR):** partial leach (acid-leachable component, especially sulphides, amorphous oxides, carbonates and organic matter).

- **Ionic Leach (IL):** a proprietary sodium-cyanide leach buffered to pH 8.5 using the chelating agents ammonium chloride, citric acid and ethylenediaminetetra-acetic acid (EDTA). These dissolve weakly-bound ions attached to particle surfaces.

- **Mobile Metal Ion™ (MMI):** a proprietary method requiring no sample preparation or drying. Elements in a 50 g sample are extracted in weak solutions of organic and inorganic compounds (details not specified). MMI solutions contain strong ligands, which detach and hold in solution the metal ions that are loosely bound to soil particles.

- **Enzyme Leach (EL):** a proprietary method to selectively remove amorphous manganese-oxide coatings on soil particles, and thereby release trace elements into solution that are associated with these coatings.

- **Bioleach (BL):** a proprietary technology designed to digest remnant bacteria, which help to identify the metals associated with soil gas hydrocarbon anomalies.

- **Soil Gas Hydrocarbons (SGH)[SM]:** a proprietary organic-based geochemical method, which detects 162 organic compounds in the C5 to C17 carbon-number range. These compounds provide a signature directly related to bacteriological interaction with a mineral deposit at depth. Interpretation is undertaken by Activation Laboratories Ltd. (Ancaster, Ontario).

- **Organo-Sulphur Geochemistry (OSG):** a proprietary method similar to SGH in its rationale, in that it involves the selective extraction of 105 organo-sulphur–based compounds in the C7–C17 carbon series. It involves a very weak leach, almost aqueous, which isolates the compounds by high-resolution capillary-column gas chromatography.

- **pH and electrical conductivity (EC):** measured on Ae-horizon or top of B-horizon soil samples collected from immediately beneath the organic-rich Ah layer. This zone is optimal for stable H-ion signatures and assists in delineating carbonate remobilization caused by changes in pH at the edges of electrochemical cells over buried sulphide mineralization.

Field Measurements

Soil pH and Electrical Conductivity Measurements

Samples for soil pH and electrical conductivity (EC) measurements were collected from both study areas. Where possible, material was collected from the top centimetre of the leached Ae horizon (in podzol profiles) and from the top of the B horizon, where the Ae horizon was either absent or poorly developed (e.g., in brunisol profiles). At sample sites with poor drainage, where organic material comprises the upper part of the profile, no sample was collected. Samples were placed in heavy-duty double-seal Ziploc® plastic bags.

Conductivity measurements were made on a 1:1 slurry of soil in demineralized water using a VWR® conductivity meter. Soil pH readings were taken on the same slurry using a double-junction pHTestr® 30 handheld pH meter manufactured by Oakton® Instruments. The instrument was calibrated daily using standard pH-buffer solutions at pH 4.00, 7.00 and 10.00. Two pH measurements were taken on each sample: the first one 20 seconds after immersion of the electrode into the slurry and the second, 20 seconds after adding one drop of 10% hydrochloric acid and stirring. The acidified pH (pHa) is an indication of the buffer capacity of the soils and the closer the pHa values are to the original pH, the greater the buffering capacity. Readings were recorded into an Excel® spreadsheet and converted to H^+ concentrations and inverse-difference hydrogen (IDH) measurements for interpretation. The IDH measurement is the inverse of the difference between acidified and non-acidified H^+ concentrations in the soil and is a measure of the buffering capacity of carbonate remobilized around reduced chimneys (Hamilton, 1998). The results are presented in Figures 7–9.

Quality Control

Quality control measures employed for this study included the collection of field duplicate samples for each sample
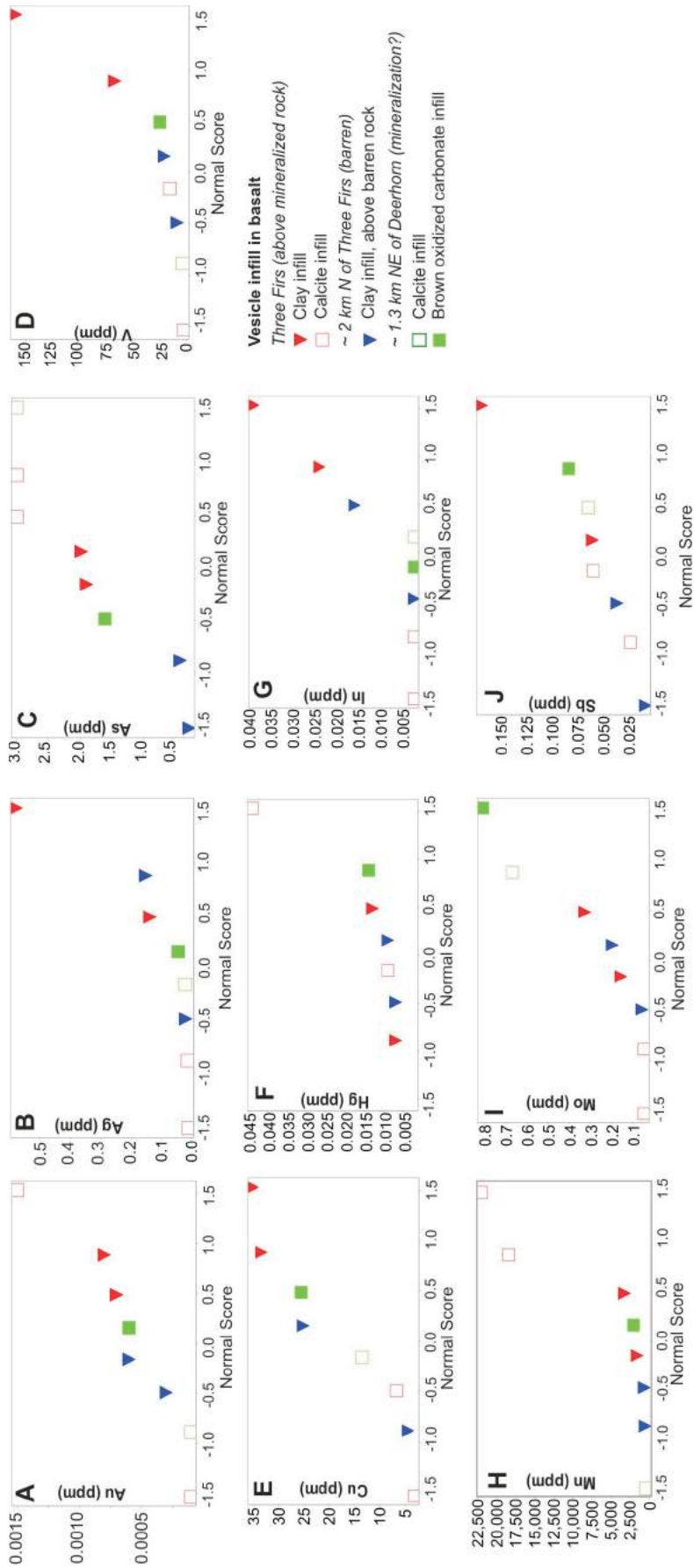
Figure 6 Chemistry (aqua regia) of vesicle infill in Chilcotin basalt, Woodjam prospect, south-central British Columbia. The x-axis on the probability plots shows the normal score in units of standard deviation for: **a)** Au; **b)** Ag; **c)** As; **d)** V; **e)** Cu; **f)** Hg; **g)** In; **h)** Mn; **i)** Mo; **j)** Sb. Analytical values are given in parts per million (ppm).

Table 1. Sample media and analytical methods employed. In addition to those listed, Ah horizon and spruce bark and twigs were collected (see Heberlein et al., 2013) at the Woodjam prospect, south-central British Columbia.

Sample medium	Analytical package	Laboratory	No. of samples	Description
B horizon (upper)	ME-MS41	ALS[1]	70	Standard aqua-regia leach (AR)
B horizon (upper)	ME-MS41L	ALS	70	Ultratrace aqua-regia digestion (high sensitivity)
B horizon (upper)	ME-MS61	ALS	70	4 acid strong leach (near-total digestion)
B horizon (upper)	Au-ST43L/aqua regia	ALS	70	Supertrace level gold (0.01 ppb)
B horizon (upper)	Ionic Leach	ALS	70	Sodium-cyanide leach buffered to pH 8.5
B horizon (upper)	Enzyme Leach	Actlabs[2]	70	Proprietary weak leach (amorphous oxide coatings)
B horizon (upper)	SGH-GC-MS	Actlabs	50	Proprietary weak leach-organic compounds
B horizon (upper)	OSG-HR-GC	Actlabs	50	Proprietary weak leach-sulphur compounds
B horizon (upper)	Bioleach	Actlabs	70	Proprietary weak leach-remnant from bacteria
B horizon (10-25 cm depth)	MMI	SGS[3]	27	Proprietary weak leach (loosely bound surface coatings)
Vesicle infill	ME-MS41L	ALS	8	Ultratrace AR digestion (high sensitivity)
Basalt whole rock	CCP-PKG01	ALS	3	Lithium-borate fusion and complete characterization

[1] ALS Chemex (Vancouver)

[2] Activation Laboratories Ltd. (Ancaster, Ontario)

[3] SGS Minerals Services (Lakefield, Ontario)

type; a total of 9 field duplicates were collected for each sample at randomly selected sample sites. At each site, material was collected using exactly the same procedures as that used for the original sample and from within 5 m of the original sample's location. In this report, analytical values for field duplicates are plotted for B-horizon soil samples and IDH measurements (Figure 9). Although some local-scale variability in soil pH and conductivity as well as As in B-horizon soil is apparent, the difference between original and duplicate sites is less than the overall variability in the apparent background of the sampled profile. The exception is one sample location (DHB021) in the Deerhorn northeast-oriented sample line, where As values in the original B-horizon sample are double to triple those of the duplicate sample, irrespective of the digestion method used. Conductivity and pH values are similar between the original and duplicate sites. Because the elevated As values were obtained on two different aliquots sent to two different laboratories (ALS Limited, Vancouver, and Activation Laboratories Ltd., Ancaster, Ontario), the discrepancy between the original and duplicate samples is interpreted as the result of local-scale variability in the soil rather than sampling or analytical error.

Results

A selection of preliminary analytical results is presented below. A complete description of the results will be presented in a final report to Geoscience BC in early 2013.

Vesicle Infill in Basalt

Some pathfinder elements, including As, Sb, In and V are present in concentrations 5–8 times higher in clay-filled amygdules (vermiculite) near mineralization compared to similar amygdules in basalt over unmineralized Nicola Group (Figure 6). Gold, Ag, Mn and Cu values are also elevated in vesicular clay over mineralization. Based on two

samples from Three Firs, the calcite amygdules appear to have higher As, Mn and Hg values than the clay amygdules over the mineralization. Unfortunately, carbonate-filled amygdules were not present at the background basalt location to the north of the mineralized zone. Carbonate amygdules sampled from basalt found near the eastern end of the northeastern transect at Deerhorn (DHB021, Figure 3) contain elevated Cu and Mo and As values (Figure 6). Soil samples at this locality are also anomalous for As (see below).

Soil pH and Conductivity

Soil H^+ and conductivity results are shown in Figures 7 and 8. Although there is considerable scatter in the data, some general patterns are apparent. Hydrogen-ion concentrations are highest over mineralization at Deerhorn and at the western margin of projected mineralization at Three Firs. The acidified H^+ (H^+a) values are higher near the margins than directly above the mineralized zones at both localities, although high H^+a values do also occur distal to mineralization (Figures 7, 8). At Deerhorn, H^+ and H^+a concentrations are generally lower over basalt than in areas where only glacial sediments cover the bedrock (Figure 7). Electrical conductivity at Three Firs is highest at the margins of the mineralized zone but relatively low directly above it. At Deerhorn this pattern is less obvious and elevated EC values occur at the margins of mineralized zones as well as distally. In general, the IDH data mimic the conductivity data quite well. At Three Firs, the highest IDH values occur at the western end of the line, where the presence of carbonate reacting with HCl acid was recorded in the B-horizon soil sample. It is noteworthy that at site DHB021 (Figure 3) at Deerhorn, there are coincident high EC and IDH values over basalt. This sample site also coincides with apparently elevated Cu, Mo and As in carbonate vesicle infill (Figure 6).
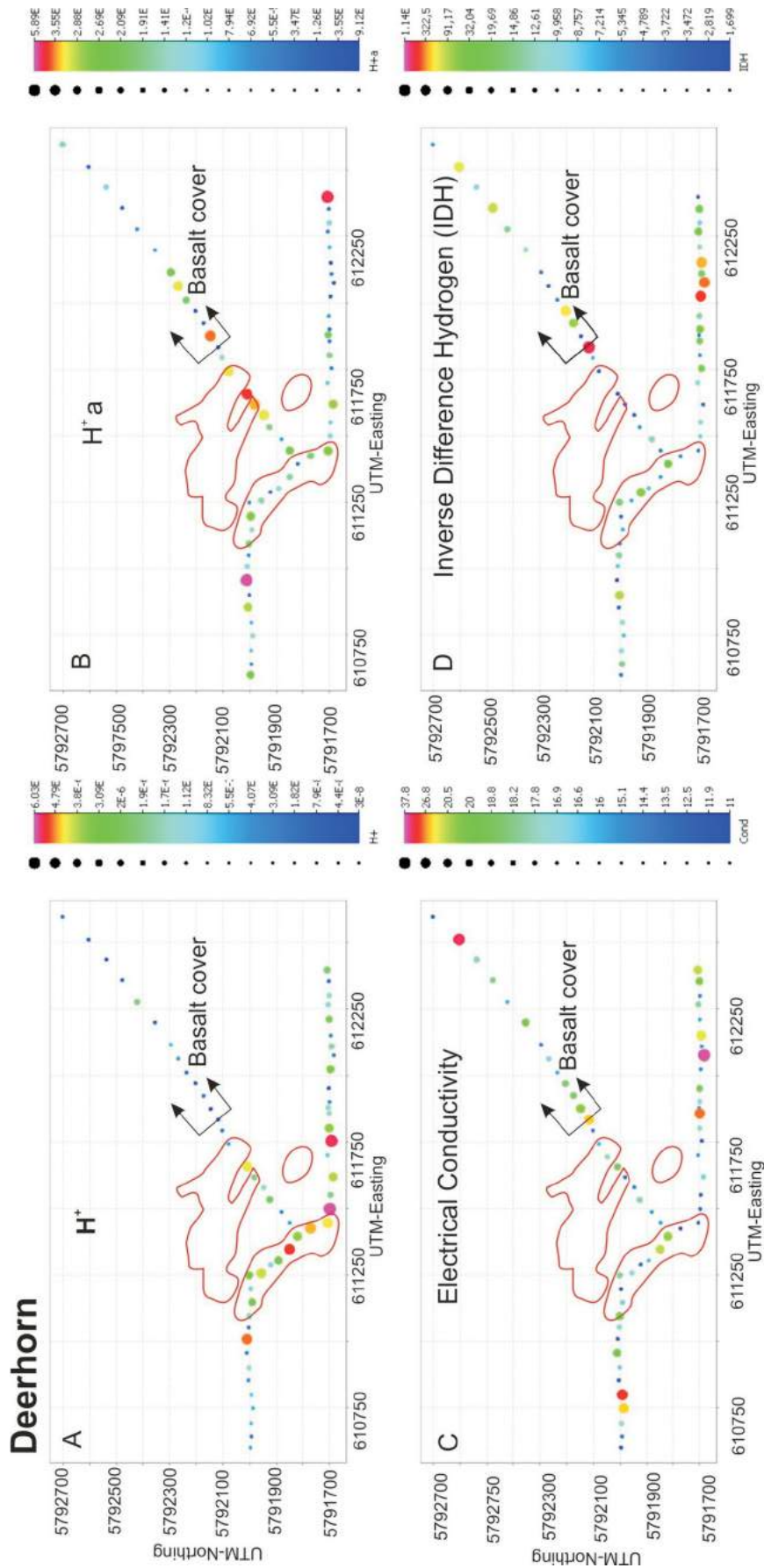
Figure 7. Soil pH and conductivity data for the Deerhorn survey area, Woodjam prospect, south-central British Columbia. Areas under basalt cover and surface projection of the mineralization, defined by the 0.2 g/t Au equivalent contours, are represented by graphs showing **a)** H^+, concentration of hydrogen ions (~inverse of pH); **b)** H^+a, concentration of hydrogen ions after addition of 1 drop of 10% HCl acid; **c)** electrical conductivity; **d)** inverse hydrogen difference, $1/(H^+a - H^+)$.
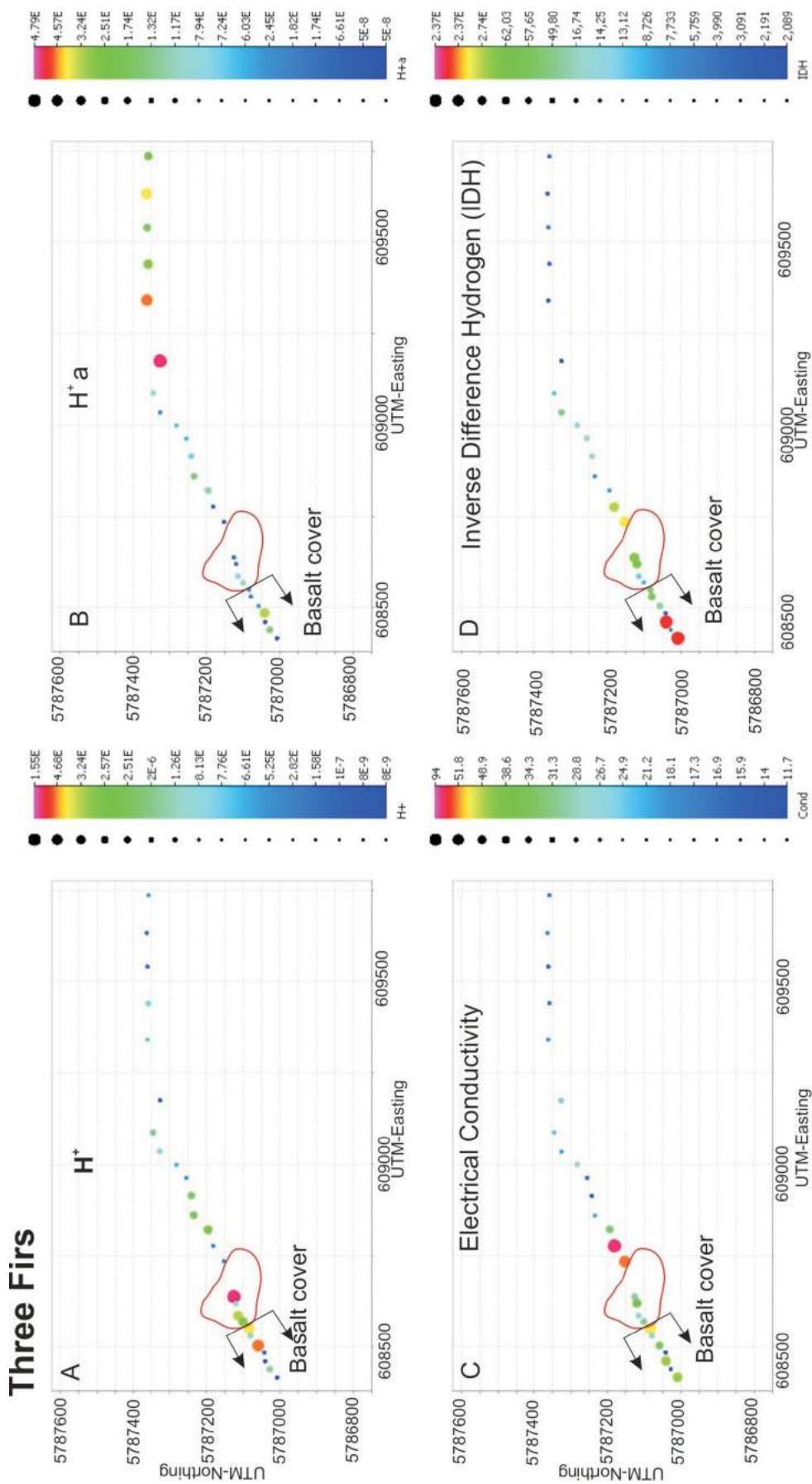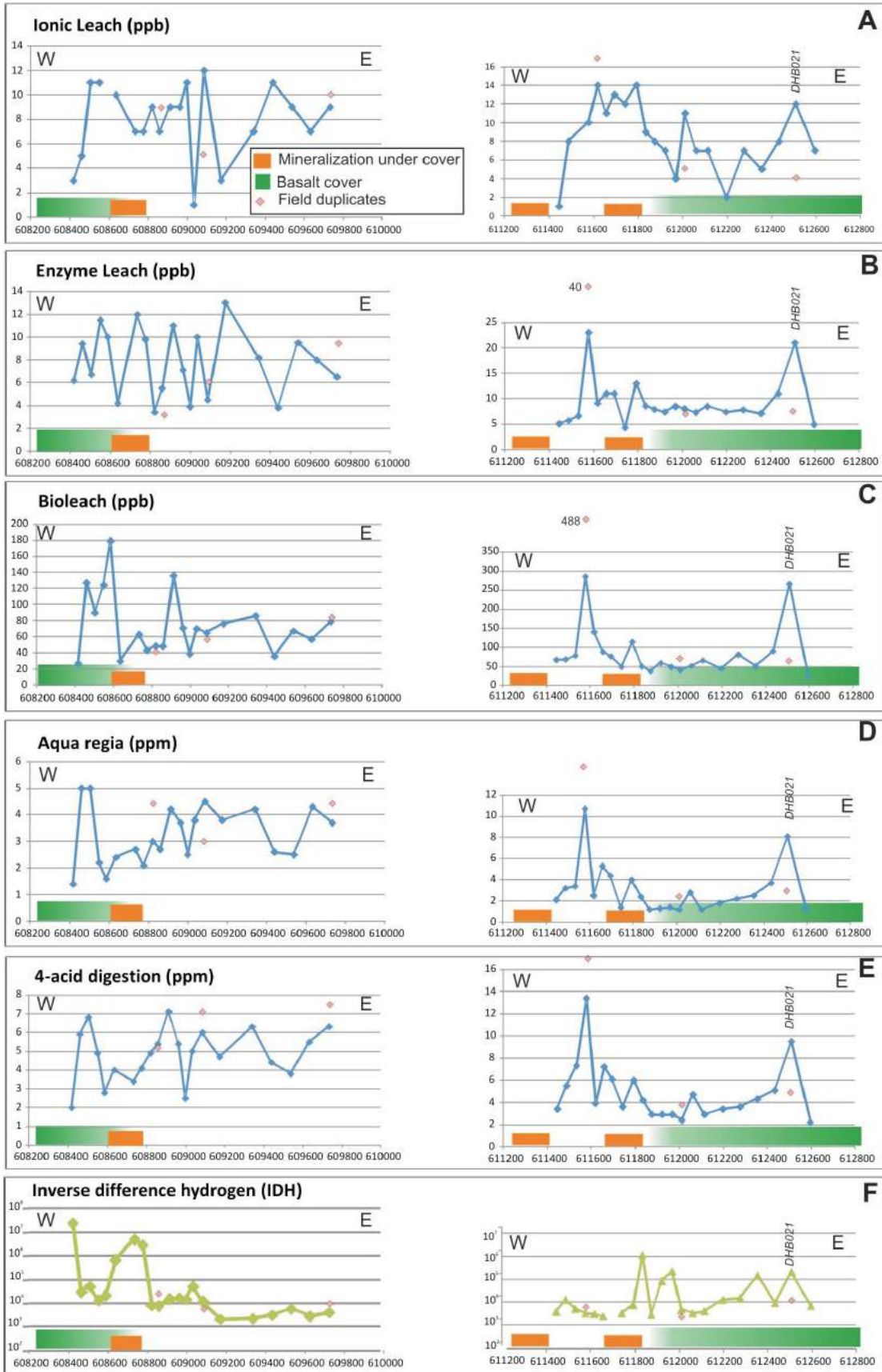
Figure 8. Soil pH and conductivity data for the Three Firs survey area, Woodjam prospect, south-central British Columbia. Areas under basalt cover and surface projection of the mineralization, defined by the 0.2 g/t Au equivalent contours, are represented by graphs showing **a)** H^+, concentration of hydrogen ions (~inverse of pH); **b)** H^+a, concentration of hydrogen ions after addition of 1 drop of 10% HCl acid; **c)** electrical conductivity; **d)** inverse hydrogen difference, $1/(H^+a - H^+)$.

Three Firs As in B-horizon soils

Deerhorn As in B-horizon soils (NE line)

Legend:
- Mineralization under cover (orange)
- Basalt cover (green)
- Field duplicates (pink diamond)

Panel A: Ionic Leach (ppb)

Panel B: Enzyme Leach (ppb)

Panel C: Bioleach (ppb)

Panel D: Aqua regia (ppm)

Panel E: 4-acid digestion (ppm)

Panel F: Inverse difference hydrogen (IDH)

B-Horizon Soil Geochemistry

For the purposes of this paper, As results were chosen to illustrate the variations in response between the different analytical techniques over the partly basalt-covered areas at Three Firs and the northeast-oriented sample traverse at Deerhorn (Figure 9). Arsenic is a common pathfinder element used in porphyry exploration and accumulates at redox gradients, such as above the edge of mineralization (Hamilton, 1998; Pfeifer et al., 2004). It was chosen because elevated concentrations of it were also observed in amygdules in basalt (Figure 6). At Three Firs, elevated As values occurring in the vicinity of the mineralized zone are most clearly observed in the results obtained from the Bioleach and aqua-regia digestions. Arsenic values at the edges of the mineralized zone are double to triple the values of soils directly above the mineralization. Enzyme Leach and Ionic Leach results are noisy and do not show any recognizable pattern. The response from the 4-acid digestion does seem to mimic the aqua-regia results but the data are of lower contrast near the mineralization. It is noteworthy that the westernmost 4 to 5 samples at Three Firs were collected where basalt is inferred to underlie the glaciofluvial sediments. The results of the Bioleach and aqua-regia digestions reveal that several of these samples contain elevated As (Figure 9). The IDH results are also shown on Figure 9 for comparison. The samples directly above mineralization are about three orders of magnitude lower than on either margin, although the highest value at the western extreme of the sampled line does not coincide with elevated As values in the aqua-regia and Bioleach data.

On the Deerhorn northeastern sample traverse, As concentrations are highest between the two mineralized areas (orange bars on Figure 9). Slightly elevated As values are also evident in the eastern part of the mineralized area, near the location at which the basalt cover is inferred to start. As seen at Three Firs, the aqua-regia and Bioleach results show 2–4 fold increases in As concentrations between the mineralized zones compared to soils directly above mineralization. However, in contrast to Three Firs, Enzyme Leach and 4-acid digestions also show similar patterns; Ionic Leach lacks a recognizable signal for this element. The second sample from the eastern end of the Deerhorn traverse (site DHB021) also exhibits consistently high As concentrations in all extractions, which coincides with a

relatively high IDH value (approximately 2×10^5) and high As concentrations in carbonate-vesicle infill (Figures 6, 7).

Implications for Exploration Geochemistry in Basalt-Covered Areas

Preliminary data analysis suggests that soils directly over basalt-covered areas (i.e., northeast of Deerhorn) have some inherent geochemical characteristics, such as lower H^+ (or elevated pH), that distinguish them from areas only covered by glaciofluvial sediments. This may be explained by the more reactive nature of the relatively mafic Chilcotin Group basalt units compared to the underlying Nicola Group. The high IDH and conductivity values at Three Firs, and less clearly at Deerhorn, may be related to remobilized carbonate at the margins of a possible reduced chimney above mineralization. The IDH response does not appear to be distinct between basalt-covered areas and those that are only covered by glaciofluvial sediment. The analytical results also suggest that the geochemical signal of As can be seen through both types of cover. This is exemplified at Three Firs, where elevated As was detected in soils above basalt cover adjacent to known mineralization.

Both at Deerhorn and Three Firs, the Bioleach and aqua-regia techniques provide good contrast results. Preliminary comparison with SGH and OSG data, and interpretations provided by Activation Laboratories Ltd. (Sutherland, 2012), suggest a positive anomaly of low molecular-weight SGH and sulphur allotrope coincident with high As values.

At Deerhorn, near the eastern limit of the sample traverse, there are coincident IDH, conductivity and soil As responses. All methods, except Ionic Leach, define an interpretable pattern. It is unknown to what extent these responses indicate the presence of underlying mineralization because of the poor precision provided by the field duplicate samples. However, this response cannot be explained as a result of hydromorphic concentration because the sample location does not coincide with a break in slope or poorly drained ground. One possible explanation is that soil anomalies may be influenced by the fracture permeability in the basalt cover. Further sampling is necessary to delineate the small-scale soil geochemical variability and potential significance of this feature.

Although the dataset is limited, results from clay and carbonate amygdules in the basalt suggest that this sample medium may be capable of recording a signal from mineralization under basalt cover. Mobile ions from the underlying mineralization are perhaps being captured by adsorption onto clay, whereas in carbonate some of the elements present in comparatively high concentrations may form part of the calcite-crystal structure (e.g., Mn, Cu). These may reflect the immediate wallrock composition or elements mobilized from below. In the samples studied here, carbonate amygdules have only been encountered where nearby min-

Figure 9. Comparison of As geochemistry using different methods on B-horizon soils taken in partly basalt-covered east-northeast-oriented transects (see Figure 3 for locations), Woodjam prospect, south-central British Columbia. The left column is for the Three Firs area, the right column for the Deerhorn area. The results for different methods are presented, from weak digestion at the top to strong digestion at the bottom: **a)** Ionic Leach; **b)** Enzyme Leach; **c)** Bioleach; **d)** aqua regia; **e)** 4 acid; **f)** inverse-difference–hydrogen (IDH) data are shown for comparison. Pink diamonds depict the analytical values for the field duplicates.

eralization is known or where soils are anomalous in As. Therefore, it can, be hypothesized that vesicle-filling carbonate could be an indication of pH gradients that occur at the margins of reduced chimneys above oxidizing sulphides (cf. Hamilton, 1998). Clearly, further study and more extensive sampling are necessary to confirm the potential use of vesicle and/or fracture infill as a geochemical-exploration tool.

Acknowledgments

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