# Geochemistry of wall rock alteration at the Golden Cross deposit, New Zealand

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## Abstract

Golden Cross is a volcanic-hosted, low-sulfidation, epithermal Au-Ag deposit in the Hauraki Goldfield. Irrespective of the rock type (andesite versus dacite), hydrothermally altered wall rocks are enriched in K, Rb, As and Sb around Au-Ag mineralised veins of the Empire Vein System and stockwork. Sodium and Sr are strongly depleted around these veins, whereas Mg and Fe are locally depleted. Calcium and Si display mixed behaviour, varying from unchanged to depleted to enriched. Other elements including Al, Ti, Mn, Zr, Y, and Nb show little change or are immobile during hydrothermal alteration. Element enrichment and depletion trends are directly related to the degree of alteration and the alteration mineralogy. Addition of K and Rb and converse loss of Na and Sr in intensely altered wall rock surrounding veins corresponds to the replacement of igneous plagioclase by hydrothermal adularia. Sodium and Sr occur in moderately altered rocks on the margins or in 'hard bars' that contain plagioclase. Calcium depletion also reflects the destruction of plagioclase although, where Ca is enriched in intensely altered rocks, plagioclase has been replaced by calcite. Locally, elevated Si concentrations and depletion of Mg and Fe adjacent to the Empire Vein System reflects intense silicification of the wall rocks and the replacement of mafic minerals by quartz rather than by chlorite.

Geochemical zoning patterns at Golden Cross are very similar to those at the McLaughlin deposit California, and shallow levels of the Broadlands-Ohaaki geothermal system. Therefore, determination of K, Na, Rb, Sr, and Ca enrichment and depletion patterns provides insight into alteration intensity and mineralogy that is complimentary to traditional trace element analysis of As, Sb, Hg, Au, Ag, Pb, Zn, and Se used in the exploration for shallow level (< 500 m) epithermal Au-Ag deposits.

## Introduction

Exploration for low sulfidation epithermal Au-Ag deposits commonly uses trace element geochemistry of stream sediments, soils and rocks to outline areas of anomalous mineralisation (e.g. Gosowang, Carlile et al., 1998). Most exploration surveys use a variety of trace elements that include Au, Ag, As, Sb, Tl, Cu, Pb, Zn and Se (e.g. White and Hedenquist, 1995; Carlile et al., 1998), whereas major elements are less commonly used (Clarke and Govett, 1990; Sherlock, 1996). Here, we examine wallrock major and trace element zonation and show how this reflects the hydrothermal alteration at the Golden Cross low sulfidation epithermal Au-Ag deposit (Figure 1).

## Regional geology

The Golden Cross deposit occurs within the Coromandel Peninsula (Figure 1), the central subaerial sector of a 200 km long by 35 km wide continental arc known as the Coromandel Volcanic Zone (CVZ) (Skinner, 1986). The CVZ is built upon a basement of Late Jurassic, low rank greywackes, that are unconformably overlain by Miocene andesites of the Coromandel Group that underlie and interfinger with Late Miocene rhyolites of the Whitianga Group (Adams et al., 1994). North-northwest and northeast trending normal faults transect the CVZ, forming a series of block faults (Skinner, 1986). Localised along these faults are over 50 separate low sulfidation epithermal Au-Ag deposits, with mineralisation restricted to steeply dipping quartz veins hosted mainly within andesites and dacites of the Coromandel Group (Christie and Brathwaite, 1986).

## Local geology

Gold and silver at the Golden Cross deposit (Figure 2) was historically extracted from the Golden Cross 1 reef (1895 to 1920) and in more recent times from the Empire Zone (1989 to 1998); combined these have produced more than 750,000 oz of Au and ~2,325,000 oz of Ag. Volcanic rocks of the Waipupu Formation and Waiharakeke Dacite host the deposit and are overlain by the unaltered Whakamoehau Andesite (Figure 2; Caddey et al., 1995; Brathwaite and Christie, 1996).

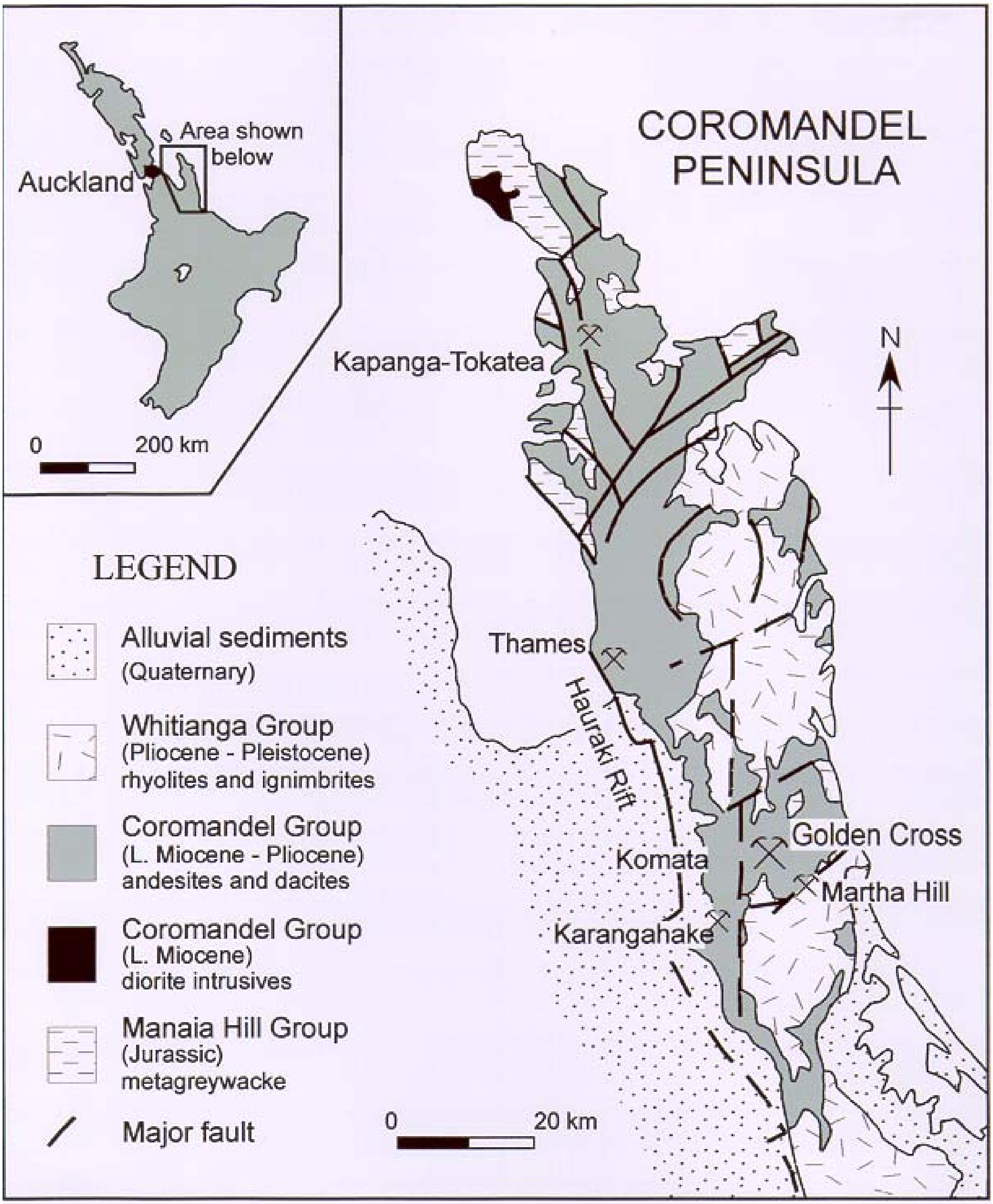


Figure 1. Geological map of the Coromandel Peninsula, displaying the location of Golden Cross deposit and selected major epithermal gold-silver deposits (after Skinner, 1986). The insert shows the location of the Coromandel Peninsula within the North Island of New Zealand.

Recent mining was confined to the Empire Zone where ore was extracted from the Empire Vein System and shallow level stockwork (Figure 2). The north-striking, east-dipping Western Boundary Fault forms the western limit of stockwork veins, although the sense of movement and amount of displacement is uncertain (Keall et al., 1993). The Empire Fault is a north-northeast striking, steeply west-dipping fault, with over 300 m of apparent reverse displacement (Mauk et al., 1998).

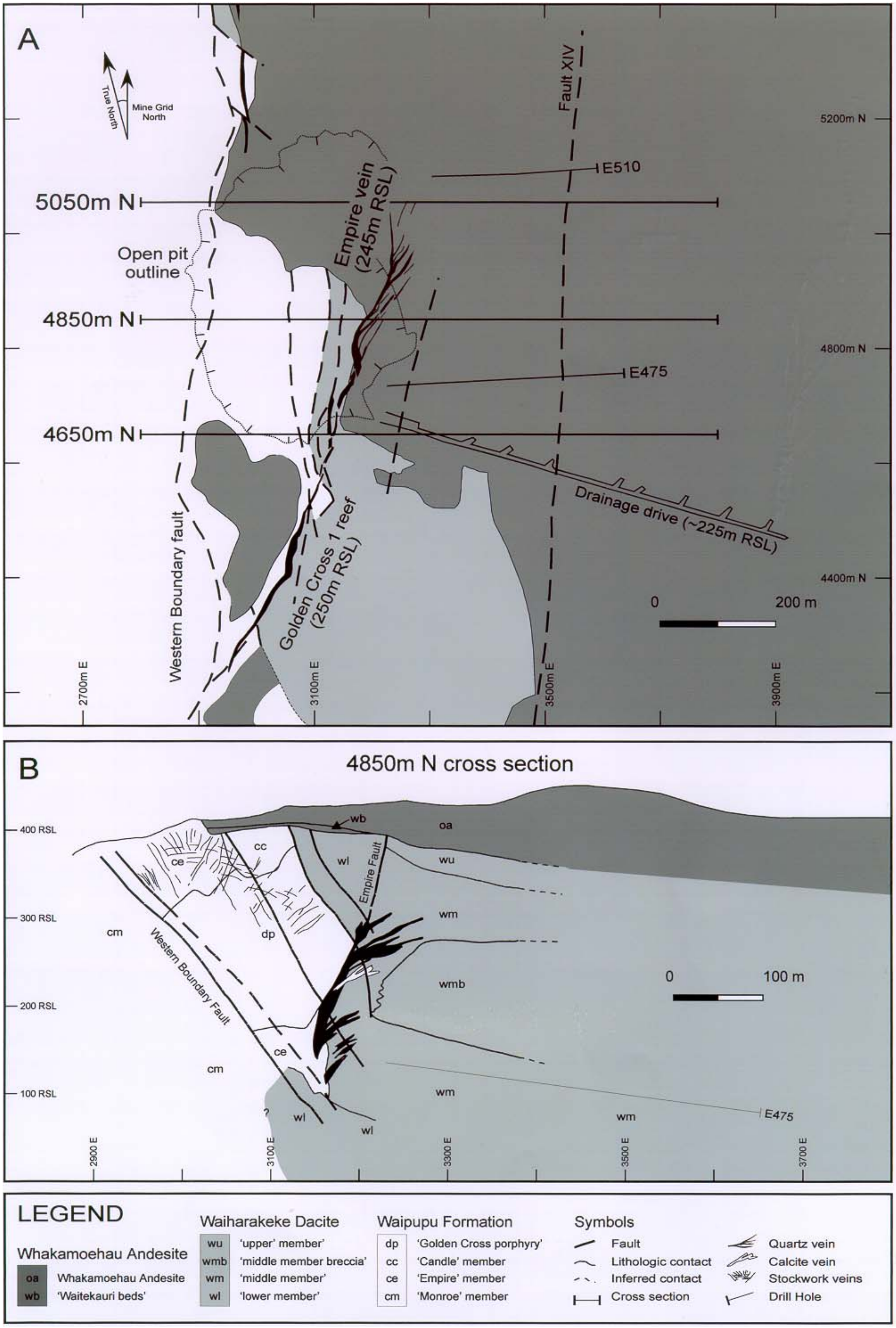


Figure 2. A) Surface geologic map of the Golden Cross mine area showing the locations of the Empire Vein System, Golden Cross 1 reef, and the 5050, 4850 and 4650m N cross sections. B) The 4850m N subsurface cross section displaying geology, structure and veining. Drill hole E475 is projected 100 m north into the 4850m N sections.

## Hydrothermal alteration

Hydrothermal alteration envelops the veins in an area of 3 km by 1.5 km, that is elongated parallel to the veins (Locke and de Ronde, 1987; de Ronde and Blattner, 1988). Wall rocks hosting the Empire Vein System and shallow level stockwork are intensely (97 to 100%) altered, with all the igneous minerals, except quartz, now replaced by alteration minerals. Intense alteration along the drainage drive grades into strong (70 to 98%) and then moderate (40 to 70%) alteration at a distance of 280 m and 570 m east of the Empire Vein System, respectively. Moderately altered rock also occurs in rare isolated lenses of rock (up to 10 m wide), termed 'hard bars' (Bell and Frazer, 1912) which contain unaltered plagioclase and magnetite.

Hydrothermal alteration minerals display distinct zoning around veins (de Ronde and Blattner, 1988), as defined along three sections that cross the Empire Vein System (Simpson et al., 1995). Along these sections, replacement quartz, chlorite and pyrite are ubiquitous, and quartz veinlets are more abundant closer to major veins. Replacement adularia envelops the Empire Vein System and shallow stockwork on each section. It is coextensive with, and is variably replaced by, illite that progressively grades upwards and laterally into a zone of interstratified illite-smectite (I-S) that mantles the deposit (Simpson et al., 1998; Tillick et al., 1999). Replacement calcite and minor siderite formed contemporaneously with, and also overprint the above minerals, whereas late barren calcite veins crosscut mineralised quartz-sulfide veins. Kaolinite ± pyrite veinlets, together with rare, very local alunite, formed during late-stage hydrothermal activity (Simpson et al., 1995, 1998; Mauk et al., 1997).

## Sampling and analytical techniques

Underground workings, the open pit, and over 60,000 m of drill core provided exceptionally good access to hydrothermally altered volcanic rocks and veins in the Empire Zone. Samples were collected along three cross sections (4650, 4850 and 5050m N) perpendicular to the strike of the main veins (Figure 2). Additional samples were collected along drill holes E510, E475, and the drainage drive (Figure 2). Alteration and vein minerals were examined in detail for over 200 samples by using standard petrographic and X-ray diffraction (XRD) techniques.

From these, a suite of 55 samples, representing different competent lava flows and alteration types, was selected for whole rock major and trace element analysis. During sample preparation, veins and factures were avoided so that *only the wall rocks* were analysed. Major and trace element concentrations were determined by X-ray fluorescence (XRF) using a Siemens SRS-3000 sequential X-ray spectrometer at the University of Auckland. Major elements analysis was made on glass fusion disks, with trace elements analysis made on pressed powder briquettes. Concentrations of thirty-one trace elements were also determined by neutron activation analysis (NAA) at a commercial laboratory.

## Geochemical results

Major and trace element concentrations of altered wall rocks exhibit zoning around the Empire Vein System and stockwork. Detailed modelling of mass transfer requires comparison with unaltered rocks. Unfortunately, no unaltered rocks remain at Golden Cross as most have undergone intense (98 to 100%) alteration; even the least altered rocks have only plagioclase and magnetite as remnant igneous minerals. Therefore, this paper considers the overall trends in element enrichment or depletion from non-normalised XRF data. Element enrichment and depletion were determined by comparing altered samples with the least altered rocks (Table 1) and analyses made of unaltered andesite and dacite from the Waihi area (Brathwaite and Christie, 1996).

### Variations in major elements

The following description is listed in order of elemental oxides that are enriched ($K_2O$), those that are depleted ($Na_2O$), and those that display mixed behaviour (CaO). Other elemental oxides show minor change ($SiO_2$, $Al_2O_3$, MgO, and $Fe_2O_3$) or are immobile ($TiO_2$, MnO, and $P_2O_5$).

#### Potassium ($K_2O$)

Based on an average $K_2O$ concentration of 1.5 wt. percent for unaltered andesite and 2.5 wt. percent for dacite (Christie and Brathwaite, 1996), K is enriched in intensely altered wall rock around the Empire Vein System and the stockwork on all three cross sections (Figure 3). The area of K enrichment is very similar to the distribution pattern of hydrothermal adularia ($KAlSi_3O_8$). The greatest enrichment occurs on the 5050m N section (up to 8 wt. %) where adularia is best preserved. On the 4650 and 4850m N sections K enrichment is less extensive and is due to the intense replacement of adularia by illite (Simpson et al., 1998). Due to its K content, illite may also contribute to K enrichment, but our data suggest that it plays a minor role at Golden Cross.

#### Sodium ($Na_2O$)

Moderately altered rocks of the drainage drive and rare 'hard bars' have $Na_2O$ values of 2.5 to 3.5 wt. percent, comparable to values from unaltered andesite and dacite. Intensely altered wall rock around the Empire Vein System and stockwork has Na values that are typically less than 0.2 wt. percent, showing strong depletion (Figure 4). The abundance of $Na_2O$ correlates with the distribution of unaltered plagioclase, which is the main source of this element. None of the samples show Na enrichment, consistent with the observation that there is no hydrothermal albite present.

#### Calcium (CaO)

Altered wall rock is variably depleted and enriched in this element (Figure 5). On the 5050m N section, calcium is variably depleted in the hanging wall of the Empire Fault and in dacites adjacent to the Empire Vein System. It is slightly less depleted on the 4850m N section. In contrast, Ca is enriched in the hanging wall of the 4650m N section. Numerous samples have CaO values similar to that of an unaltered rock (3 to 4 wt. % for dacites, 6 to 7 for andesites).

| A.U. No.[1] | 46553 | 46596 | 46552 | 46630 | 48614 | 48563 | 46609 | 46599 |
|---|---|---|---|---|---|---|---|---|
| Rock type | Andesite | Andesite | Andesite | Andesite | Dacite | Dacite | Dacite | Dacite |
| Unit[2] | ce | ce | ce | ce | wm | wm | dp | wm |
| Alteration | Moderate | Intense | Intense | Intense | Moderate | Intense | Intense | Intense |
| **Major elements (Wt. %)** | | | | | | | | |
| $SiO_2$ | 59.24 | 62.01 | 56.46 | 78.40 | 68.41 | 66.85 | 63.81 | 73.31 |
| $TiO_2$ | 0.65 | 1.18 | 0.70 | 0.50 | 0.63 | 0.65 | 0.54 | 0.50 |
| $Al_2O_3$ | 16.76 | 24.96 | 17.63 | 11.54 | 15.24 | 15.89 | 16.88 | 13.09 |
| $Fe_2O_3$ | 6.85 | 5.30 | 7.13 | 0.74 | 4.71 | 4.76 | 4.78 | 1.28 |
| MnO | 0.08 | 0.04 | 0.20 | 0.00 | 0.09 | 0.14 | 0.09 | 0.00 |
| MgO | 3.84 | 2.79 | 3.16 | 0.15 | 1.43 | 1.83 | 1.99 | 0.08 |
| CaO | 8.21 | 2.35 | 10.60 | 0.08 | 3.73 | 3.10 | 3.81 | 0.22 |
| $Na_2O$ | 2.67 | 0.00 | 0.02 | 0.05 | 2.98 | 0.42 | 0.10 | 0.07 |
| $K_2O$ | 1.19 | 0.29 | 1.32 | 8.30 | 2.53 | 4.46 | 6.12 | 10.83 |
| $P_2O_5$ | 0.12 | 0.18 | 0.13 | 0.02 | 0.13 | 0.14 | 0.10 | 0.11 |
| Total | 99.61 | 99.12 | 97.34 | 99.78 | 99.88 | 98.34 | 98.20 | 99.50 |
| $H_2O$ | 1.23 | 12.27 | 1.91 | 0.50 | 1.77 | 0.85 | 1.33 | 0.15 |
| LOI | 2.23 | 8.56 | 11.60 | 1.66 | 3.33 | 5.33 | 5.41 | 1.25 |
| **Trace elements (ppm)** | | | | | | | | |
| Sc | 19 | 15 | 20 | 9 | 15 | 12 | 14 | 10 |
| V | 155 | 168 | 170 | 61 | 109 | 104 | 88 | 85 |
| Cr | 112 | 5 | 193 | 38 | 5 | 24 | 19 | 5 |
| Ni | 43 | 1 | 46 | 2 | 3 | 2 | 8 | 3 |
| Cu | 15 | 1 | 22 | 1 | 10 | 1 | 13 | 2 |
| Zn | 61 | 50 | 67 | 3 | 49 | 55 | 54 | 65 |
| Ga | 17 | 24 | 15 | 6 | 17 | 27 | 16 | 7 |
| Rb | 40 | 21 | 77 | 332 | 83 | 199 | 225 | 506 |
| Sr | 276 | 74 | 76 | 35 | 216 | 76 | 93 | 75 |
| Y | 19 | 32 | 22 | 39 | 24 | 28 | 32 | 33 |
| Zr | 111 | 241 | 104 | 92 | 144 | 151 | 178 | 134 |
| Nb | 6 | 12 | 6 | 6 | 7 | 8 | 8 | 9 |
| Ba | 365 | 61 | 107 | 467 | 614 | 648 | 1107 | 291 |
| La | 7 | 33 | 10 | 2 | 18 | 1017 | 13 | 18 |
| Pb | 9 | 9 | 7 | 5 | 13 | 10 | 13 | 8 |
| Ce | 37 | 80 | 29 | 18 | 42 | 47 | 36 | 42 |
| Th | 3 | 14 | 4 | 3 | 8 | 9 | 8 | 9 |
| U | 2 | 5 | 2 | 0 | 2 | 2 | 0 | 0 |
| **NAA selected elements (ppm)** | | | | | | | | |
| As | 1.07 | 1.07 | 16.40 | 172.00 | 1.50 | 1.74 | 163.00 | 150.00 |
| Sb | 0.73 | 0.73 | 2.18 | 9.79 | 0.00 | 2.92 | 5.37 | 8.41 |
| Au (ppb) | 18.3 | 18.3 | 0.0 | 608.0 | 0.0 | 0.0 | 0.0 | 223.0 |
| **Density (pyknometer)** | | | | | | | | |
| S.G. ($g/cm^3$) | 2.65 | 2.16 | 2.53 | 2.45 | 2.62 | 2.56 | 2.51 | 2.50 |

| A.U. No. | Unit | Alteration intensity | Alteration Minerals (minerals listed in order of abundance) | Igneous Minerals |
|---|---|---|---|---|
| 46553 | ce | 65 % | Quartz, Smectite, Chlorite, Calcite, Hematite, Siderite | Plagioclase, Magnetite |
| 46596 | ce | 100 % | Interstratified $I_{0.4}$-S, Quartz, Calcite, Kaolinite, Pyrite | None |
| 46552 | ce | 100 % | Quartz, Calcite, Chlorite, Interstratified $I_{0.8}$-S, Adularia, Pyrite | None |
| 46630 | ce | 100 % | Quartz, Illite, Adularia, Kaolinite? | None |
| 48614 | wm | 50 % | Quartz, Calcite, Chlorite, Interstratified $I_{0.3}$-S, | Plagioclase, Magnetite |
| 48563 | wm | 98 – 99 % | Quartz, Calcite, Illite, Chlorite, Adularia, Siderite | Quartz |
| 46609 | dp | 100 % | Quartz, Calcite, Chlorite, Illite, Adularia, Pyrite | None |
| 46599 | wm | 98 – 99 % | Quartz, Adularia, Illite, Pyrite | Quartz, Apatite |

1 = The University of Auckland collection sample number.  2 = ce 'Empire member', wm 'middle member', dp 'Golden Cross porphyry'

Table 1. Representative XRF major and trace element analyses of moderately and intensely altered andesites and dacites from the Empire Zone of the Golden Cross deposit.

This element mainly partitions into calcite, but also occurs in rare smectite in moderately altered rock. Calcium depletion on the 5050m N section reflects a lack of calcite, whereas Ca enrichment on the 4650m N section indicates abundant calcite (Simpson et al., 1995).

### Silicon ($SiO_2$)

Variations in the concentration of Si are mainly related to rock type. Andesites of the Waipupu Formation typically have $SiO_2$ concentrations of 58 to 60 wt. percent, whereas dacites of the Waiharakeke Dacite have approximately 68 wt. percent Si. Elevated concentrations of Si in several rocks adjacent to the Empire Vein System suggest the addition of some Si. However, apparent minor enrichment and depletion (by ~ 2.5 wt. %) for most samples may reflect addition or removal of other components.

### Aluminium ($Al_2O_3$)

This element is relatively immobile with concentrations typical of unaltered andesite and dacite.

### Magnesium (MgO)

Concentrations of MgO in moderately and intensely altered rock are similar to that of their unaltered equivalents (3.0 to 4.0 wt. % for andesite, 1.5 wt. % for dacite). Magnesium is locally depleted in intensely silicified rocks adjacent to the Empire Vein System and in several moderately altered samples towards the end of the drainage drive. In the latter, the apparent depletion may reflect the loss of Mg, or alternatively, the variable concentrations of this element in the dacite. Magnesium mainly partitions into chlorite, which completely replaces igneous pyroxene and amphibole, even in the least altered rocks.

### Iron ($Fe_2O_3$)

Altered rocks at Golden Cross mainly contain Fe in chlorite and to a lesser extent in pyrite and marcasite. In most places, these altered rocks have total Fe concentrations that are very similar to those in unaltered rocks. However, Fe is moderately depleted in rocks adjacent to the Empire Vein System where mafic minerals are replaced by quartz and pyrite rather than chlorite as seen elsewhere.

## Variations in trace elements

Trace elements are listed in order of those that are depleted (Sr) and those that are enriched (Rb, As). Most trace elements show minor changes (Au, Sb, and Ba), or are immobile (Ce, Cr, Cs, Cu, Eu, Ga, Hf, La, Lu, Ni, Nb, Pb, Sc, Sm, Th, U, V, W, Y, Yb, Zn and Zr). Several elements, including Ag, Hg, Mo, Se, and Te, were below the NAA detection limit of 5 ppm.

### Strontium

This element is depleted by approximately 100 ppm in intensely altered wall rock around the Empire Vein System and stockwork and shows the same depletion pattern as Na (Figure 4). Strontium substitutes for Na in igneous plagioclase that is preserved in moderately altered rocks of the drainage drive and local 'hard bars'.

### Rubidium

Rubidium is enriched by 100 to 400 ppm around the Empire Vein System and stockwork on all three sections. Rubidium, which substitutes for K in adularia, shows the same enrichment pattern as K (Figure 3). On the 5050m N section, where adularia is best preserved, Rb values are distinctly enriched. In contrast, on the 4650m N section, the area of Rb enrichment is less extensive due to the near complete replacement of adularia by the less K-rich illite (Simpson et al., 1995).

### Arsenic

Concentrations of As above 10 ppm outline an anomaly centred around the Empire Vein System and the hanging wall stockwork (Figure 6). Arsenic values rapidly diminish to below 5 ppm less than 150 m east of the Empire Vein System and reflect the close association between elevated As concentrations and the proximity to quartz veins.

### Antinomy

The amount of Sb in the wall rock is low and reaches a maximum of 15 ppm. Although the values are low, the wall rock around the Empire Vein System and stockwork show the highest Sb values whereas the least altered rocks in the drainage drive and 'hard bars' contain less than 1 ppm Sb.

### Gold

The wall rock from NAA contains 0 to 608 ppb (0 to 0.6 ppm) Au. Gold concentrations above 50 ppb (0.05 ppm) are spotty and associated with highly silicified wall rock directly adjacent to the Empire Vein System and the stockwork (Figure 6). Even so, all gold grades are subeconomic and indicate that the wall rocks are poorly mineralised.

## Discussion

Wall rocks at Golden Cross show major and trace element enrichment and depletion that reflect their alteration mineralogy, regardless of whether their parent rock is andesite or dacite (Table 1). Potassium, Rb, As and Sb are enriched around Au-Ag mineralised veins of the Empire Vein System and the stockwork. Sodium and Sr are both strongly depleted around the veins, whereas Mg and Fe are locally depleted. Calcium and Si display mixed behaviour, varying from unchanged to depleted to enriched. Other elements, including Al, Ti, Mn, Zr, Y, and Nb, show little change or were immobile during hydrothermal alteration.

Potassium and Rb gain and converse Na and Sr loss in the intensely altered rocks reflects the replacement of igneous plagioclase by hydrothermal adularia. The latter mineral is an indicator of high permeability and forms from upwelling boiling hydrothermal waters that deposit Au-Ag mineralisation in veins (Simmons, et al., this volume). Sodium and Sr occur in moderately altered rocks with unaltered plagioclase on the margin of the deposit and in 'hard bars'. Calcium depletion reflects the destruction of plagioclase and Ca enrichment reflects abundant calcite. Local Si enrichment and coupled Mg and Fe depletion occur immediately adjacent to the Empire Vein System due to intense silicification and the replacement of mafic minerals by quartz.

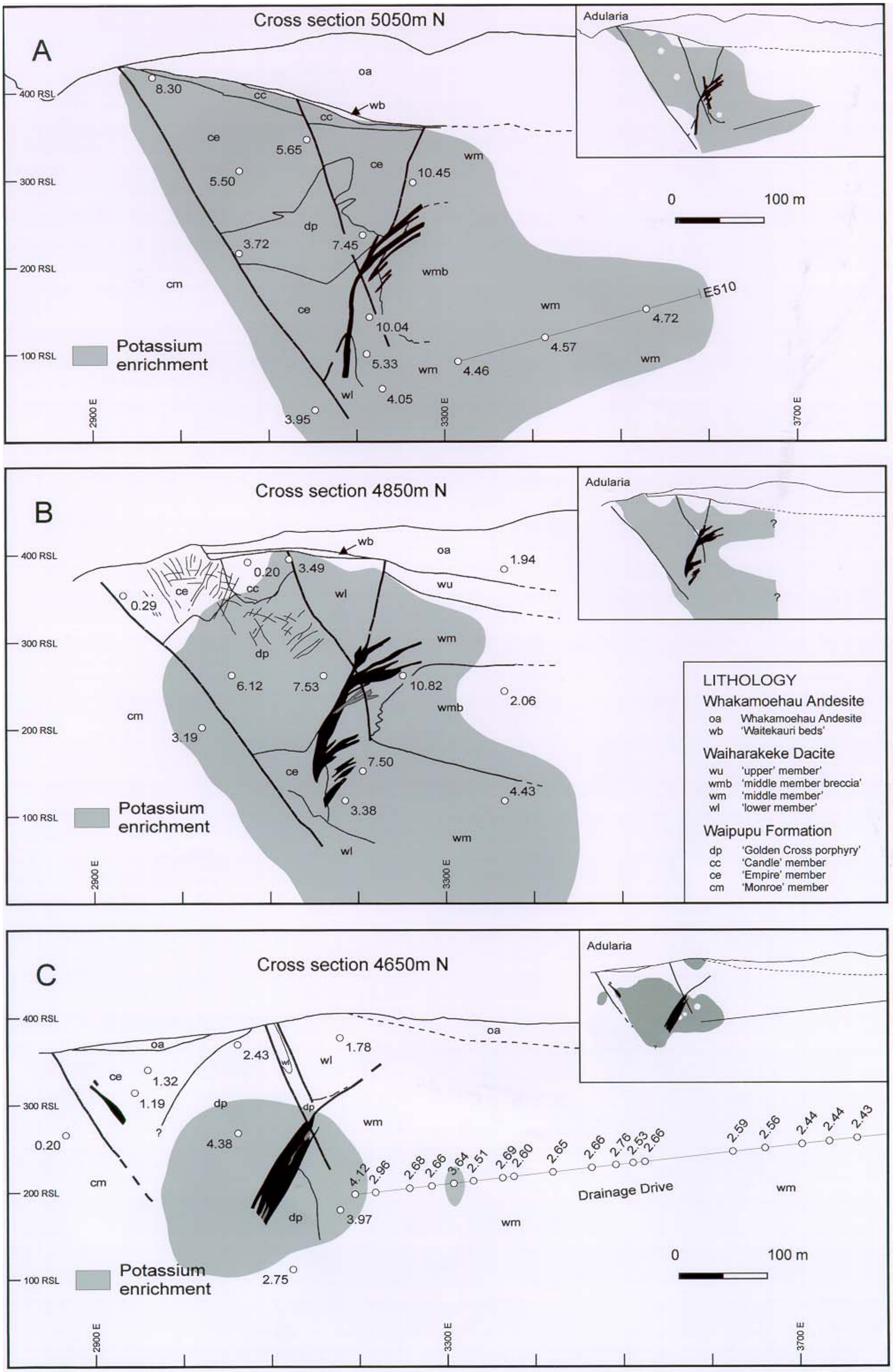


Figure 3. Potassium ($K_2O$) XRF data (in wt. %) plotted on the 5050, 4850, and 4650m N cross sections with inserts showing the distribution of hydrothermal adularia. The shaded zone of enrichment is based on >3 wt. percent $K_2O$ for andesites (unaltered have ~1.5 wt. %) and >3.5 wt. percent $K_2O$ for dacites (unaltered have 2.5 wt. %).

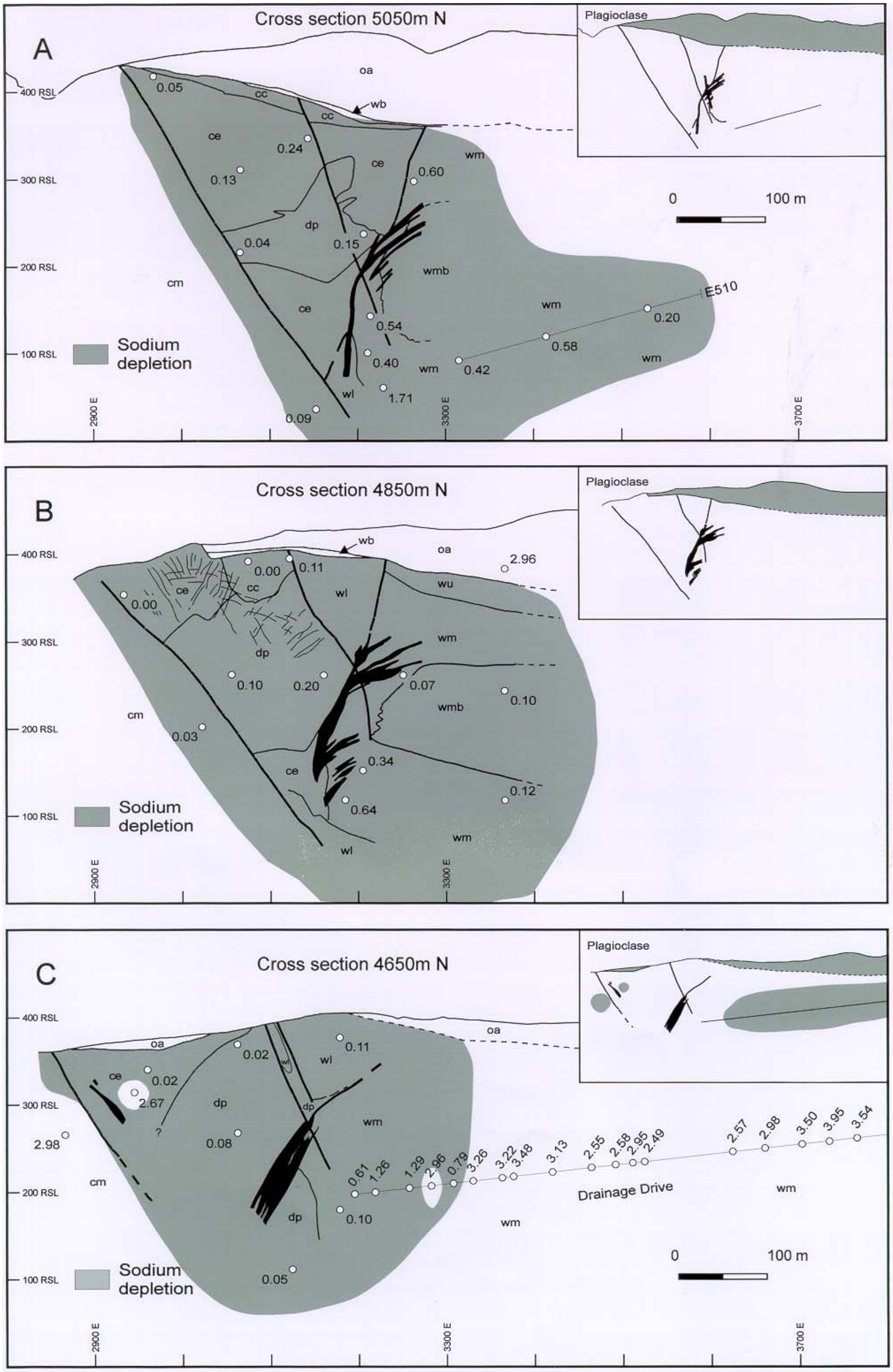


Figure 4. Sodium ($Na_2O$) XRF data (in wt. %) plotted on the 5050, 4850, and 4650m N cross sections with inserts showing the distribution of igneous plagioclase. The shaded zones define areas of Na depletion which contain <1.5 wt. percent $Na_2O$ (unaltered andesite contain 2 to 3 wt. % $Na_2O$ and dacite 2.5 to 3.5 wt. % $Na_2O$).

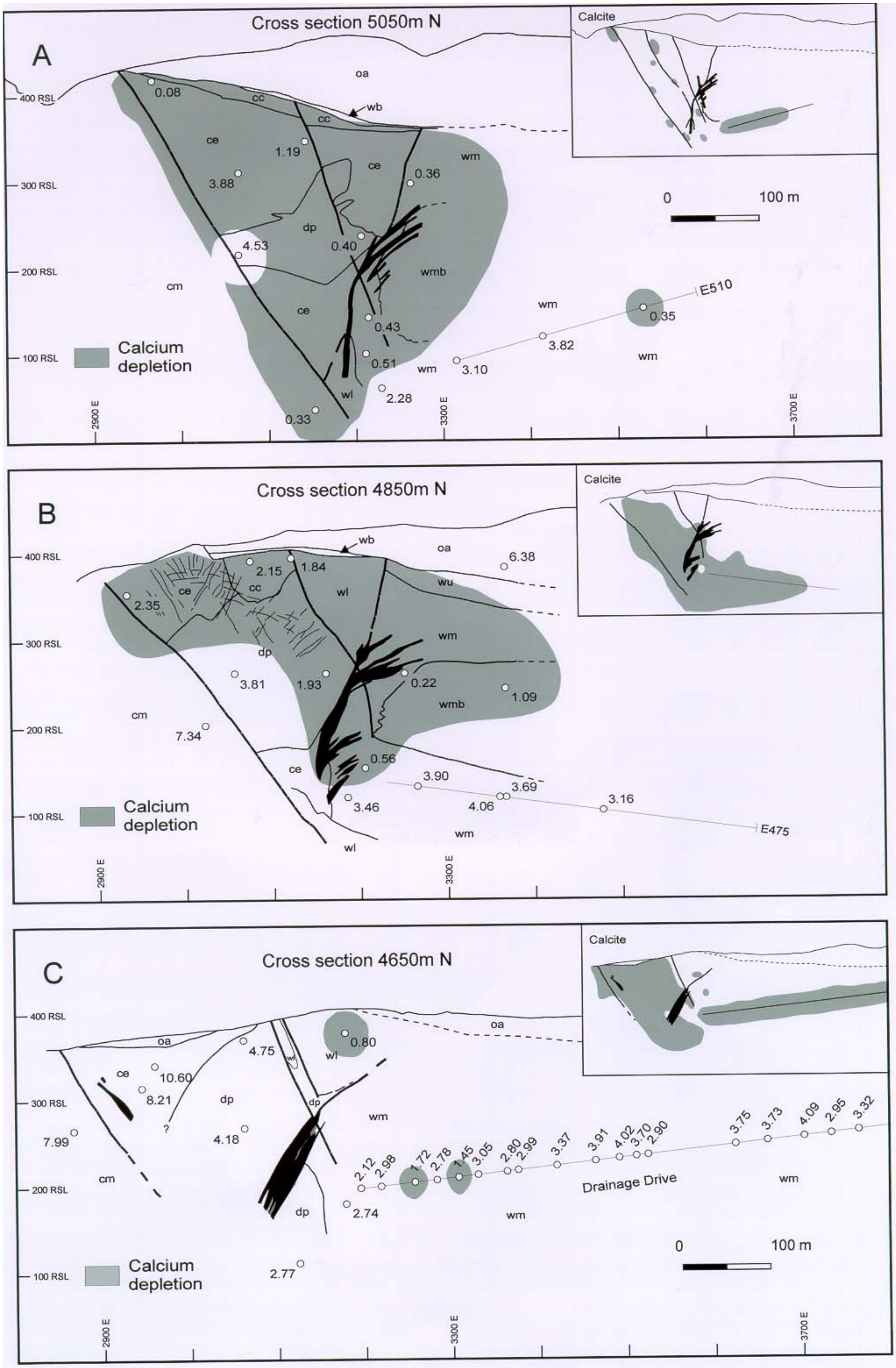


Figure 5. Calcium (CaO) XRF data (in wt. %) plotted on the 5050, 4850, and 4650m N cross sections. Inserts display the distribution of replacement calcite. The zone of Ca depletion is defined by rocks that have <2 wt. % CaO for dacites (unaltered have 3 to 4 wt. %) and <5 wt. % for andesite (unaltered have 6 to 7 wt. % CaO). Many samples have Ca concentrations similar to unaltered rock although rare samples are enriched on the 4650m N section.

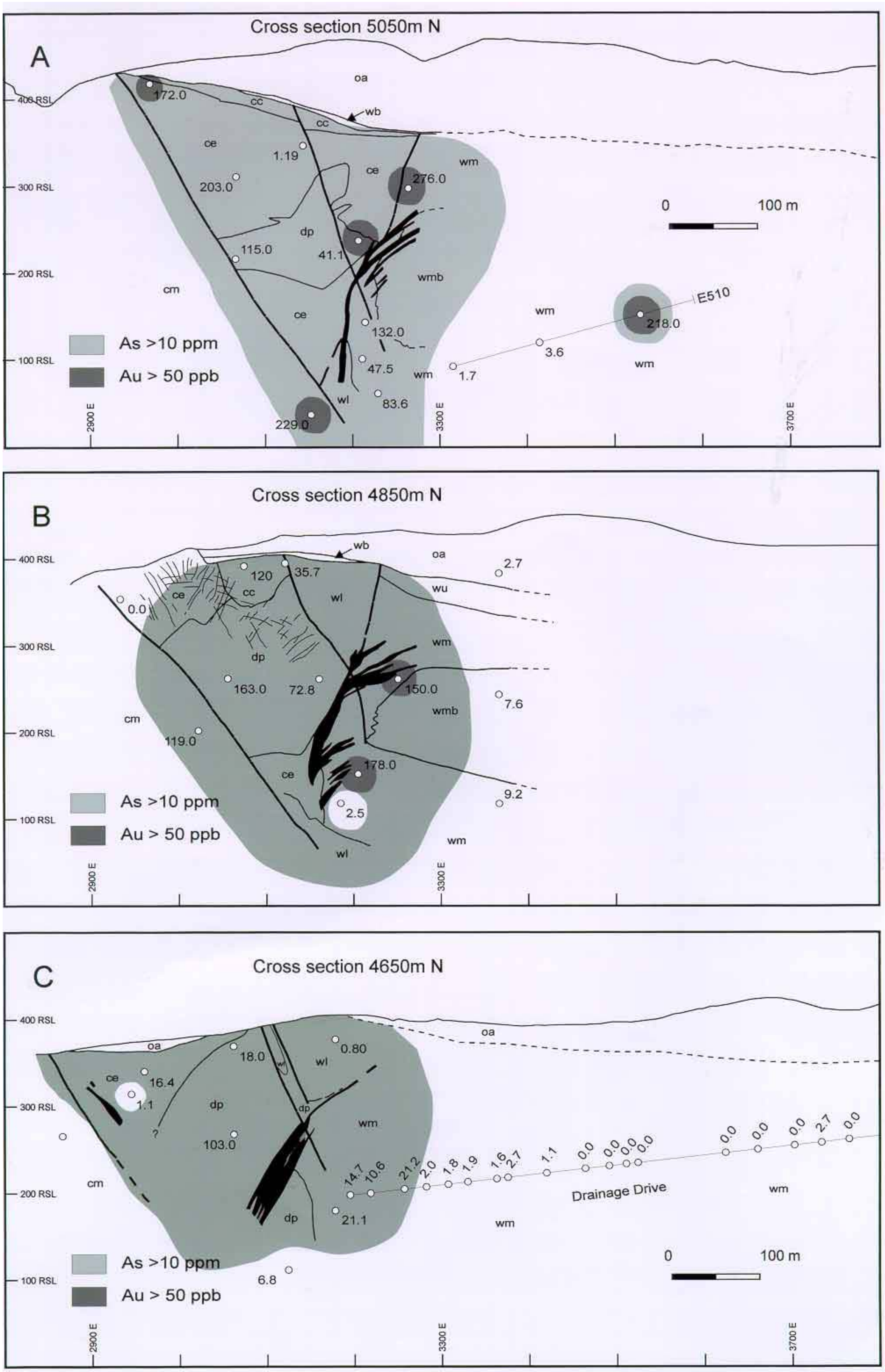


Figure 6. Arsenic NAA data (in ppm) plotted on the 5050, 4850, and 4650m N cross sections. Gold concentrations >50 ppb are also shown.

The geochemistry of the wall rock reflects the composite effect of all alteration events. Where the alteration sequence is complex with several overprinting events, some are not indicated by the geochemistry. For example, plagioclase on the 4650m N section around the Empire Vein System and stockwork has been completely replaced by hydrothermal adularia that has subsequently altered extensively to illite. The initial alteration of plagioclase to adularia would result in K enrichment (as seen on the 5050m N section), however, the replacement of adularia by illite results in slight depletion of K. Thus, these rocks show only slight enrichment in K.

Geochemical trends identified here are very similar to those determined from detailed mass balance studies of the McLaughlin epithermal Au-Ag deposit in California (Sherlock, 1996), and the Broadlands-Ohaaki geothermal system in New Zealand (MacIntosh, 2000). At McLaughlin the intensely altered basalts and ophiolite are enriched in K and Ba, and depleted in Na, Sr, Mg, and Ca (Sherlock, 1996). Similarly, in the shallow (<500 m) part of the Broadlands-Ohaaki geothermal system, mass balance calculations of intensely altered rhyolite in the upflow zone show that K and Rb are enriched, whereas Na, Ca and Sr are depleted (MacIntosh, 2000). Silica, Fe, Sr, and Ba show variable gain and loss whereas Al, Ti, Mg and Mn are relatively immobile. At greater depth (>500 m) elemental zonation changes so that Na, and Ca are enriched, Al and Mg are depleted, and Si, Fe, Ba, Rb, and Sb are variably gained or lost (MacIntosh, 2000). This reflects variable replacement of plagioclase by hydrothermal albite (Simmons and Browne, 2000; MacIntosh, 2000). Although the "brute force" methods used in this study are less elegant than the more elegant studies at McLaughlin and Broadlands-Ohaaki, major and trace element enrichment and depletion patterns are very similar.

In conclusion, K, Na, Rb, Sr, and Ca anomalies reflect alteration intensity and mineralogy in shallow level (<500 m), low sulfidation epithermal Au-Ag deposits. Whole rock geochemical analysis is relatively inexpensive and quick, so exploration programmes may choose to use these elements to provide additional guides towards mineralisation, thereby complementing the traditional trace element analysis of As, Sb, Hg, Au, Ag, Zn, Pb, and Se.

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