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ASPECTS OF HYDROTHERMAL ALTERATION AT THE WAIHI EPITHERMAL AU-AG DEPOSIT, NEW ZEALAND

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ABSTRACT

Hydrothermally altered andesites of Mid to Late Miocene age host mineralization in the epithermal Au-Ag deposit at Waihi. Gold-bearing quartz veins form a complcx braided system within an extensional fracture zone. Several vein-filling events occurred, the main ore stage is seen as comb to cryptocrystalline grey quartz with a minor sulphide assemblage of coarse pyrite, sphalerite, galena, and chalcopyrite. Hydrothermal alteration is dominated by quartz + adularia + illite + chlorite + pyrite enveloping the veins and grades outwards into a chlorite + calcite + smectite + pyrite assemblage. A distinct zoning of clay minerals is observed around quartz veins which correlates with increasing temperatures towards fluid conduits (veins). Steep thermal gradients are indicated by the observed clay mineralogy; such gradients infer alteration at shallow levels. Adularia present in the silicified zone and as a vein-fill indicates high permeability around veining intervals. The abundance of adularia declines sharply into the host andesite, suggesting the paleohydrology was controlled and enhanced by structures such as faults and joints. The Occurrence of lattice-textured calcite and vein adularia indicates that boiling conditions existed. Geochemical results show that with increasing intensity of alteration, silica and potassium were added, while sodium, calcium, and magnesium were lost. Arsenic and antimony increases towards veins suggests these elements may be used as pathfinders to further mineralization at Waihi. The alteration assemblage and geochemical trends apparent at Waihi are similar to those in active geothermal systems. This is characteristic of low-sulphidation, adularia-sencite type deposits.

INTRODUCTION

The Waihi vein system (Fig. 1) is a world-class epithermal Au-Ag deposit. It was the principal producer of gold and silver bullion in the Hauraki Goldfield, a major metallogenic zone within the North Island of New Zealand.

Past production from Waihi (1883-1952) yielded 1100 tonnes of Au-Ag bullion (Au:Ag ratio 1:6) from 10.9 million tonnes of ore, mostly recovered from underground workings. Renewed exploration in the early 1980s led to reopening of the mine in 1988 as an opencut mining operation with an estimated resource of 10 million tonnes at 2.6 g/t Au equivalent (Waihi Gold Co., 1985)

Detailed accounts of the geology and early mining history are outlined in N.Z. Geological Survey Bulletins (Bell and Fraser, 1912; Morgan, 1924), a history of the Hauraki gold mines by Downey (1935), and in an excellent account of the history of mining at Waihi by McAra (1978). More recent work documents the renewed interest in the Coromandel (e.g. Skinner, 1986; Brathwaite, 1980; Brathwaite et al, 1989) and includes a series of theses and related papers (see Clarke et al, 1990a) and exploration company reports.

The area covered by this study , currently being explored by Cyprus Gold (N.Z.) Ltd., is ground directly east and north of the opencut mine. This study presents preliminary results of thin-section, X-ray powder diffraction (XRD), and geochemical analysis of more than 50 core samples obtained from 8 diamond drillholes, and forms the basis of an MSc research project by the senior author.

GEOLOGICAL SETTING

The Hauraki Goldfield contains about 50 distinct gold-silver deposits within a 200 km long zone extending from Great Barrier Island in the north to Te Puke in the south (Fig. 1). These are associated with Miocene to Pliocene volcanic rocks which cover much of the Commandel Peninsula.

Black-faulted Jurassic greywackes and argillites (Manaia Hill Group) form the basement rocks to the Coromandel, but are exposed only in

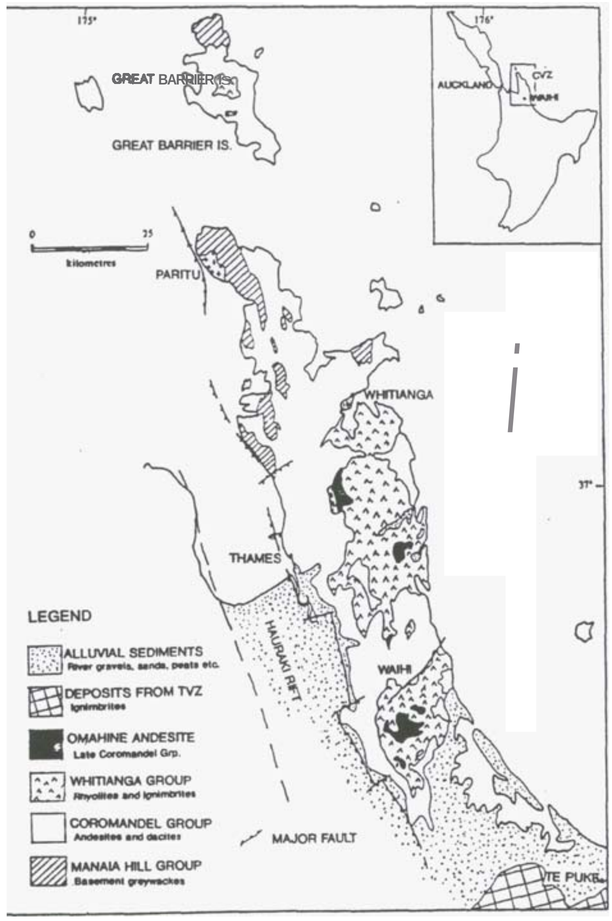

Figure 1. Map showing the dismbution of rock types and principal structural features of the Coromandel Volcanic Zone (CVZ). Coromandel Group rocks are mid to late Miocene, and the basement is Mezozoic (after Skinner, 1986).

the northern part of the peninsula. Unwnformably overlying these rocks are a thick sequence of volcanic and locally intrusive units forming the coromandel Group (Skinner, 1976). The composition of the Coromandel Group volcanics ranges from basaltic andesite to rhyodacite; hypersthene and plagioclase-phyric andesite lava flows, breccias, and tuffs are the dominant rock types. The phyric andesites act as the host to veining in the Waihi area (Fig. 2). Overlying, and in part overlapping with Coromandel Group andesites, are rhyolitic rocks of the Whitianga Group, formed as effusive domes and fragmental silicic rocks associated with the formation of calderas.

Regional fault patterns in the Coromandel Volcanic Zone (CVZ) are dominated by NNW and NE trending block faults inherited from, and controlled by pre-existing faults in the underlying Jurassic greywackes (Skinner, 1986). The peninsula is bounded to the west by the Hauraki Rift, infilled by a thick pile of Pleistocene to Recent sediments (Hochstein, 1986).

GEOLOGY OF THE WAIHI AREA

Volcanic Stratigraphy

Basement greywackes do not crop out in Waihi, nor are they exposed in the deepest mine workings (600 m below present ground surface). Thus the Mid to Late Miocene Coromandel Group andesites form the oldest rocks in the area and occur as prominent inliers (Fig. 2) hosting the vein systems of Martha, Union, and Gladstone Hills.

These andesites are uniformly textured porphyritic flows intercalated with tuffs, laminated carbonaceous mudstones, and siltstones which dip about 40° to the southeast. Such sediments are interpreted as being the deposits from ephemeral lakes present during periods of volcanic quiescence.

Black Hill hornblende dacite (Fig. 2) unconformably overlies altered Coromandel Group pyroxene andesite; the underlying contact is a fossil weathering surface marked by alluvial clays (Brathwaite and McKay, 1989).

Overlying Black Hill Dacite and blanketing Coromandel Group rocks are Late Pliocene to Early Quaternary rhyolitic ignimbrites (Owharoa Ignimbrite; Fig. 2) which form two distinct units; a lower (pumiceous) lenticulite and an overlying fine-grained welded ignimbrite.

Late Quaternary rhyolitic ashes locally underlain by alluvial and eluvial andesite boulder gravels blanket the region to a depth of 1-2 m (Brathwaite et al, 1986).

Structure

Primary structures at Waihi are limited to bedding. The andesites hosting the hydrothermal veins are mostly massive, intercalcated with only a few tuff and carbonaceous siltstone beds, dipping variably to the southeast. Jarman (1915) reports the occurrence of "junctions" (i.e. bedding surfaces) between successive flows but these are rather rare. These beds appear to have little influence in controlling the vein structures.

Joints are commonly observed in the Coromandel Group andesites of the Waihi district. Jarman (1915) described joint sets ranging from 10 cm to 1 m thickness, with the intensity of jointing increasing towards veins and faults, forming subparallel sheeted zones. The Orientation of these joints is consistent with veining, indicating they acted as channels along which hydrothermal fluids flowed, resulting in veins filling joint sets.

Faults which bound the area trend NNE and N-S (Fig. 2), and conform to regional trends. A number of faults are reported in underground workings (Morgan, 1924), although these appear to predate mineralization as no significant vein offset was noted. Abundant slickenside surfaces were seen in drillcore, particularly in the hanging wall of the Martha Lode. These possibly result from the strong contrast in shear strength between the incompetent clay-altered rocks and the silicified and intensely veined units. As a last event, thin carbonate veins transect the striae (McLean and Winter, 1989).

HYDROTHERMAL VEINING AND MINERALIZATION

Veining at Waihi occurs as an extensive braided system (Fig. 2) over a maximum strike length of 1600 m (Martha Lode) and an overall width of *500* m. Four major lodes are recognized, the Martha Lode to the north which strikes 055°, dipping 70-80° to the southeast, and the Welcome, Empire, and Royal Lodes to the south smke subparallel, but dip into, the Martha Lode. Outcrop of the veining is confined to the immediate pit area while the vein system as a whole plunges to the east beneath a thick ignimbrite cover (Fig. 2).

Sibson (1987) interpreted the relationship of the vein and fault orientations in proposing an extensional fault jog model in which dextral strike slip faults caused extensional rupture and opening of an en echelon linkage. However, it has been shown (Gadsby et al, 1990) that vein orientations are controlled by triaxial strain patterns, resulting in both horizontal and steeply plunging vein intersections.

Vein material was examined in order to determine a paragenetic sequence of mineralization. Local complexities and the lack of continuous detailed exposure precludes a definitive sequence; however, a generalized succession (cf. Bell and Fraser, 1912; Christie, 1982) consists of i) wallrock chloritisation and silicification. ii) bulk filling by barren quartz, locally with calcite accompanied by small scale clay veinlets. iii) comb quartz to fine cryptocrystalline grey quartz locally with coarse sulphide deposition. iv) clear hairline quartz, commonly amethystine with late milky calcite.

Vein textures are numerous, ranging from simple dilational veining resulting in crustiform banding to brecciation and recementing of pre-existing vein material or wallrock. Lattice-textured calcite, locally pseudomorphed by quartz or with delicate euhedral quartz crystals coatings are common within the system.

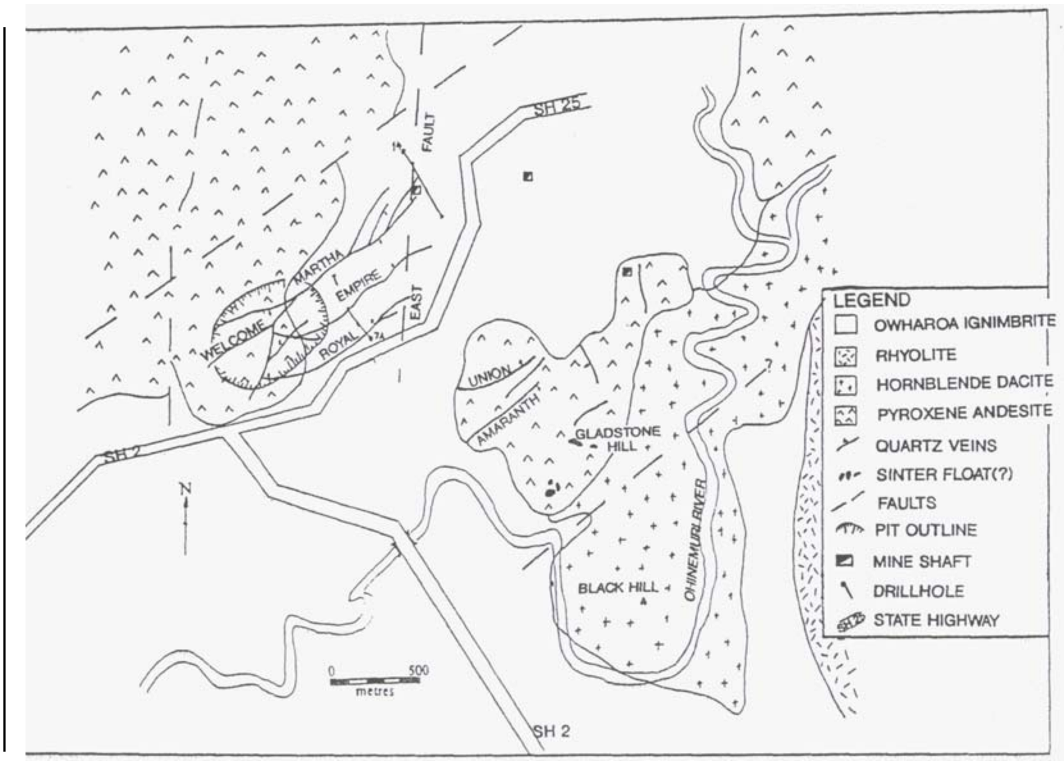

FIGURE 2: Map showing distribution of surface rock types and structural features in the Waihi area. Veins projected to the surface (after Brathwaite et al, 1986).

TABLE 1: Replacement series of primary mineral phases observed at Waihi

Primary Mineral	Chloritic Zone	Interlayered Clay Zone			Quartz-Adularia Zone
		smectite subzone	chlorite subzone	illite subzone	
Quartz	-	-	-	-	-
Plagioclase	-	weak to strong chl + cal	complete alteration to cal + ad + chl ± ill	ad + cal + ill + qtz	ill + ad + qtz + cal (see text)
Orthpyroxene	completely altered to chl + opaq ± cal ± 2°qtz	chl + opaq + cal + qtz	Becoming increasingly difficult to distinguish due to textural destruction		destroyed
Clinopyroxene	weak rim and fracture alteration to chl + py	strong to complete alteration to chl + opaq + cal + qtz	Generally completely altered to a sub-opaque chloritic clay with associated opaques (mainly py) + qtz		destroyed
Magnetite	pyrite ± titanite	pyrite ± titanite	pyrite ± titanite	pyrite ± titanite	pyrite ± titanite
Apatite					
Groundmass	devitrification to smectitic clay	interlayered sm + chl (sm > chl)	interlayered chl + sm (chl > sm)	ill interlayered with chl or sm + mosaic qtz + ad	mosaic qtz + ad + chl + ill

The major gangue minerals infilling veins are quartz, adularia, and calcite. The main sulphide mineral present is ubiquitous pyrite. Lesser amounts of sphalerite (Fe content 2.7 - 3.2% by microprobe analysis), galena, and chalcopyrite, with trace amounts of marcasite and arsenopyrite also occur. Gold is present (Brathwaite and McKay, 1989) as electrum, typically fine-grained (1-80 μ), as free grains in quartz veins and as inclusions in pyrite, sphalerite, and galena. In this study gold has also been detected by microprobe analysis as submicroscopic inclusions in pyrite. Acanthite is associated with pyrite and galena and is selenium bearing (Christie, 1932).

In wallrock, veining becomes increasingly common with increased intensity of alteration. Outside major vein intervals (defined as those intervals >25% veining), veins are most abundant within the quartz-adularia zone (see below), with stringers off the principal veins up to 5 cm aperture. Vein fill is dominated by quartz with lesser pyrite, adularia, calcite, and rare chlorite. In the interlayered clay zone the degree of veining is proportional to the rank of alteration. The low-rank smectite subzone is generally only weakly veined in contrast to the strong presence of veins in the illitic style of alteration. Wider veins (up to 3 mm aperture) within this alteration zone are dominated by vuggy quartz and later carbonate, with or without chlorite. Within the least altered chloritic zone veining is only weakly developed and consists predominantly of discontinous hairline chlorite veins. In several wider veins (up to 2.5 mm aperture) there is a filling sequence of chlorite - opaques - calcite - quartz.

HYDROTHERMAL ALTERATION

Primary Mineralogy

The primary mineralogy consists of plagioclase, quartz, hypersthene, and augite. Plagioclase (labradorite-andesine) is the dominant mineral, occurring as euhedral phenocrysts 2-3 mm in size, and commonly displaying oscillatory and primary melt inclusion zoning. Rare quartz phenocrysts up to 4 mm in size occur and are everywhere embayed. Pyroxenes (hypersthene and augite) occur as euhedral to subhedral phenocrysts up to 2 mm in size and show glomeroporphyritic textures. Accessory minerals include apatite and magnetite.

The groundmass is hyalopilitic, with flow-banded microlaths of plagioclase and microlites of mafic minerals present.

Alteration Mineral

Four distinct types of alteration are identified at Waihi based on observed mineralogy; (1) chloritic, (2) interlayered clay, (3) quartz-adularia, and (4) kaolinitic. The downhole dismbution of alteration minerals observed in thin section and through interpretation of X-ray powder diffraction traces are shown in Figs. 3 and 4. The hydrothermal minerals that replace primary phases are summarized in Table 1.

Chloritic (Least Altered) Type

Chloritic-altered rocks are the least altered in the Waihi vein system. They occur as isolated pods and at stratigraphically higher levels within the drillcore sequences (Figs. 3 and 4); their mineralogy approaches that of fresh rock (Table 1). The groundmass is mostly altered to a brown smectitic clay, with crystallites of magnetite altering to pyrite and rarely titanite. Hypersthene is moderately to intensely altered to chlorite + opaques (most commonly pyrite). augite is everywhere less intensely altered than hypersthene, its alteration generally limited to chlorite and opaques along rims and fractures.

Interlayered Clay Type

This type of alteration is extensive in drillcores (Figs. 3 and 4), forming a wide belt surrounding more intense alteration and grading outwards into chloritic-altered rock. Three subzones are recognised on the basis of their being dominated by smectite, chlorite, or illite respectively (largely determined by X-ray diffraction techniques). In detail, the extent of interlayering (based on criteria outlined in Brindley and Brown, 1980) and the composition of the clays display a distinct zonation around veining intervals, with the general succession (with increasing intensity of alteration) being smectite to chlorite-smectite to interstratified illite (with smectite or chlorite) to illite. This is clearly seen in Figs. 3 and 4. The degree of interlayering is variable and is directly proportional to the intensity of alteration. In the interstratified illite subzone, interlayering between smectite and illite varies from 60% illite to above 90% illite moving towards more intensely altered intervals. Chlorite is ubiquitous throughout.

Plagioclase phenocrysts are weakly to completely altered to adularia + calcite + illite + quartz, while mafic minerals are completely replaced by chlorite + calcite + opaques + quartz, or are destroyed.

Vitrinite reflectance measurements on carbonaceous samples from the smectite subzone (pers. comm. P Crosdale, 1990) range from 0.2-0.5 R_{ord}, indicating maximum temperatures of 140-160°C assuming no significant burial took place (Teichmuller, 1987).

Quartz Adularia Type

This intense alteration envelopes veins and extends to a maximum distance of 30-40 m from veins. Embayed quartz, and accessory apatite, where present, are the only surviving primary phases (Table 1). Plagioclase is completely altered to adularia + illite + quartz, calcite, while ferromagnesian minerals are destroyed. Adularia is a common groundmass and vein-fill phase in this alteration type. Within the groundmass it is seen as small colourless rhombs (usually <0.5 mm in size) which show variations in optical characteristics within a single grain (i.e. sector twinning). Vein adularia tends to be larger, with grains of up to 2 mm diameter. Intense silicification, seen as mosaic quartz within the groundmass, and pyrite are ubiquitous features of this alteration type.

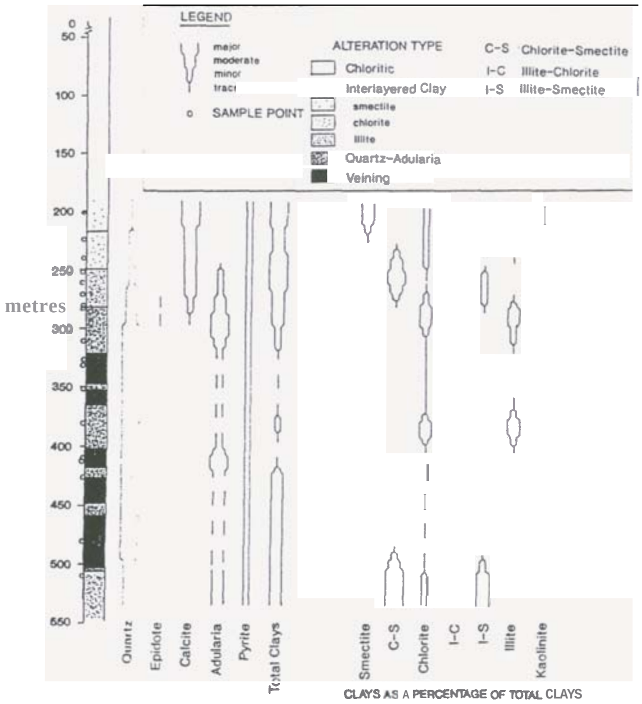

Figure 3. Spindle diagram for drillhole WH7A showing the downhole distribution of hydrothermal rninerlas present in cores. Veining intervals *are* considered those where veining exceeds 25%.

Kaolinitc Type

Kaolinite is noted within the hanging wall shear zone of the Martha Lode and at structurally higher levels in drillcores. Mineralogical characterisation is difficult due to their broken, puggy character. Generally they appear to **be** dominated by a clay-rich, subopaque groundmass with abundant, fine-grained pyrite and lesser secondary quartz.

Oxidation

Oxidation is a common feature in the upper levels at Waihi. Lodes and shear zones provided channels for the descent of oxygenated meteoric waters, resulting in limonitic and manganese oxide staining of vugh faces to depths of **400** m below present ground surface.

GEOCHEMISTRY

Preliminary geochemical results from X-ray fluorescence and neutron activation analyses *are* presented in Appendix 1. Chloritic alteration shows little variation from the fresh rock compositions reported by de Ronde (1985) from Golden Cross, indicating that this style of alteration is essentially isochemical.

As alteration intensifies silica and potassium increase whereas calcium, sodium, and magnesium decrease.

Trace element analyses indicate that arsenic, antimony, and gold are enriched with increasing intensity of alteration. Arsenic in particular, *becomes* elevated at low to moderate levels of alteration. Base metals show little enrichment in wallrocks (Pb, Zn) or else are apparently depleted (Cu). Rubidium and strontium follow potassium and calcium respectively, i.e. enrichment of rubidium and depletion of strontium **occurs** with increasing alteration intensity.

DISCUSSION

Alteration Zonation

Hydrothermal alteration occurs as a response to fluid-rock interaction. The presence **of** some hydrothermal minerals is **used** in estimating the past conditions of the hydrothermal fluid (Browne, 1989). Temperature and the pattern of fluid circulation appear to control the style and intensity of alteration **as** has been documented in a number oi active geothermal systems (Browne, 1978; Cole and Ravinsky, 1983).

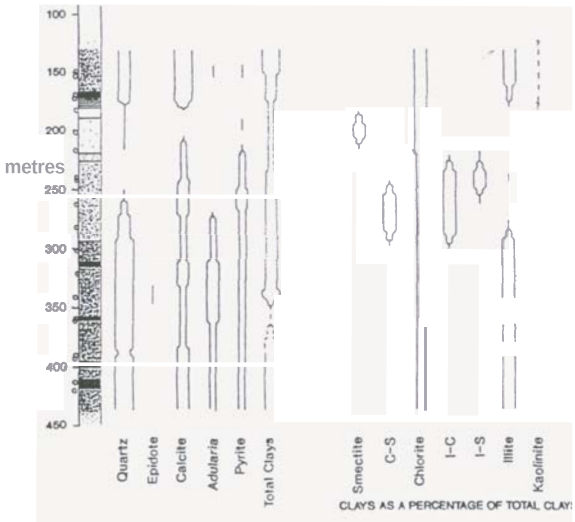

Figure **4.** Spindle diagram for drillhole WH14. See figure 3 for legend.

Temperatures

Smectite occurs at <140°C as a discrete phase and where interlayered with chlorite indicates temperatures of **<200°C** (Kristmannsdottir, 1977). Illite-smectite interlayering infer temperatures of formation on the order of 140-220°C while illite indicates temperatures >220°C (Browne, 1989). Thus estimated temperatures of formation of clay minerals present at Waihi indicate a steep increase in temperatures towards conduits (veins). Changes in clay species at Waihi can occur over vemcal intervals of ***50*** m, suggesting thermal gradients of **1.2°C/metre.** Such **steep** gradients indicate shallow levels **of** alteration and **are** in agreement with shallow-level thermal gradients **of** active geothermal systems (e.g. **400** m level, Broadlands; Simmons and Browne, this volume). Vitrinite reflectance measurements (see above) are also consistent with this observed temperature zonation.

Permeability

The marked zoning of these hydrothermal minerals around fluid channels also reflects the permeability of the host rock. The Occurrence of adularia, Iimited to intensely altered zones, closely parallels permeable fissure channels at Broadlands, which are similarly characterised (Browne, 1970). The marked decrease of adularia abundance away from major vein intervals (Figs. 3, **4)** reflects a sharp decline in the permeability of the host **rock.** This clearly indicates that secondary permeability (faulting, jointing, etc.) dominated in the flow of hydrothermal fluids at Waihi, and the distribution of alteration types is principally controlled by their proximity to major veining intervals. Lattice-textured calcite and adularia observed in veins suggest that boiling occurred in veins, possibly during periods of repeated hydraulic fracturing. Such textures are observed in active geothermal systems where boiling is known to occur (Browne, 1978).

It is not known whether kaolinite is the result of a late-stage overprint in which acid condensates descended down veins and fault zones, or is a function of the deep oxidation along permeable channels and consequent weathering of clays.

Geochemical Zonation

Systematic variations in the major element geochemistry within altered rock at Waihi directly reflect the observed mineralogical zonation. Depletion of sodium and calcium with associated increases in potassium content mirror the progressive alteration of plagioclase to adularia and illite as is commonly seen in many epithermal deposits (eg. Clarke and Govett, 1990; Simmons and Browne, 1990).

Zonation of some **ore** minerals, particularly arsenic and antimony, is well developed around major veining intervals (Appendix 1). The lack of significant base-metal enrichment (locally there may be depletion) in the alteration suite is suprising in view of base-metal sulphide deposition **occurring** within the quartz veins, but is **a** feature which has been documented elsewhere in the Hauraki Goldfield (Clarke et al, 1990b).

Arsenic appears to be the most sensitive indicator of mineralization at Waihi given the availahle detection limits (Appendix 1). No widespread low-level (>5 ppb) Au anomaly is observed, and thus As (and to a lesser extent Sb) provides the best pathfinder to delineate further mineralisation at Waihi; this is consistent with observed trace element zonations in similar epithermal systems of the Hauraki Goldfield (Clarke et. al, 1990b) and elsewhere (Silberman and Berger, 1985), and in active geothermal systems (Ewers and Keays, 1977).

CONCLUSIONS

From studying the alteration assemblages and geochemical trends, the chemical nature of the hydrothermal fluids responsible for the alteration can be discerned.. The mineral assemblage present at Waihi (quartz + adularia + illite + chlorite + calcite + pyrite) is characteristic of near-neutral pH alkali-chloride fluids of the low-sulphidation, adularia-sericite type deposits (Hayba et al, 1985; Hedenquist, 1986).

The features observed at Waihi can be compared to those observed in active geothermal systems. Further work will be aimed at refining and testing models previously proposed (eg. Hedenquist, 1986) that highlight the similarities between active geothermal systems and extinct geothermal (epithermal) deposits. This will provide a further understanding of the geological and geochemical processes leading to the formation of this type of deposit.

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APPENDIX ONE: Selected chemical analyses for andesitic host rocks and vein material at Waihi. X-ray fluorescence (XRF) analyses were performed at the University of Auckland whik neutron activation analyses (NAA) were conducted by Bequeral Laboratories, Sydney.
XRF majors an given in wt%, XRF traces are given in ppm. and NAA traces an given in ppm unles otherwise indicated. Fresh rock has been calculated on an anhydrous basis. All rocks are from coromandel Group andesite. LOI = loss on ignition, * = partial analysis (due to high amounts of modal sulphide).

		Fresh	Chloritic	Interlayered clay		Quartz-adularia		Vein	Kaolin
Sample No.		de Ronde	WH 30-12	WH 3-11	WH 26-10	WH 3-15*	WH 26-7	WH 30-6	WH 30-5*
XRF Majors		(1985)		(east)	(west)	(east)	(west)		
SiO_2		59.31	57.33	68.50	*59.64*	67.41	63.20	94.60	51.77
TiO_2		0.75	0.80	0.54	0.63	0.39	0.49	0.00	0.54
Al_2O_3		17.04	17.10	15.59	15.68	12.57	15.22	1.03	14.28
Fe_2O_3		7.36	7.04	4.89	6.18	4.45	4.58	0.54	8.17
MnO		0.12	0.12	0.10	0.10	0.07	0.25	0.04	0.15
MgO		4.35	3.37	3.42	3.54	2.36	3.44	0.47	4.03
CaO		6.99	7.05	4.36	0.47	2.28	0.19	1.69	4.40
Na_2O		2.38	2.64	1.77	0.18	0.88	0.10	0.12	0.09
K_2O		1.55	1.76	2.27	3.60	4.03	5.41	0.07	2.31
P_2O_5		0.15	0.18	0.10	0.14	0.07	0.07	0.03	0.08
H20-		0.00	1.01	1.09	3.29	0.56	1.70	0.14	3.89
LOI		0.00	1.27	4.51	5.83	2.15	4.80	0.78	8.29
TOTAL		100.00	99.67	99.16	99.28	98.08	99.46	99.50	98.01
XRF TRACES	D.L.								
Ba	8	360	433	370	473	650	756	n.d.	277
Cr	4	37	31	78	109	112	46	n.d.	135
Cu	4	38	*9*	12	nd	n.d	13	8	19
La	4	14	20	17	17	11	20	n.d.	11
Nb	1	8	8	6	6	4	5	2	6
Ni	4	27	nd	11	18	27	19	n.d.	15
Pb	3	11	13	9	7	7.	12	349	21
Rb	[illegible]	43	58	97	164	In	210	3	154
Sr	2	238	324	117	35	83	57	19	55
Th	3	7	7	8	10	9	4	n.d.	5
V	6	153	138	116	143	93	89	n.d.	151
Y	2	22	25	16	15	13	19	n.d.	11
Zn	3	69	90	53	83	46	190	628	38
Zr	2	135	149	118	115	83	104	nd	98
NAA TRACES									
	5.0		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
As	2.0		n.d.	57.0	120.0	16.0	18.0	8.0	241.0
Au (ppb)	5.0		n.d.	n.d.	n.d.	n.d.	24.0	310.0	n.d.
Ba	100.0		330.0	410.0	430.0	770.0	800.0	n.d.	370.0
Ce	2.0		45.0	27.0	30.0	20.0	38.0	n.d.	22.0
Co	1.0		30.0	18.0	23.0	28.0	16.0	30.0	21.0
Cs	1.0		1.7	18.0	17.0	10.0	14.0	1.7	17.0
Eu	0.5		0.9	0.8	0.9	n.d.	1.0	n.d.	0.7
Fe (%)	0.05		4.4	2.9	4.1	2.8	2.9	0.3	5.3
Hf	1.0		3.8	3.1	3.4	2.8	3.4	n.d.	3.0
La	0.5		21.0	14.0	16.0	11.0	19.0	n.d.	10.0
Lu	0.2		0.4	0.3	0.3	0.3	0.4	n.d.	0.3
Mo	5.0		n.d.	n.d.	n.d.	n.d.	n.d.	5.5	n.d.
Rb	20.0		79.0	78.0	170.0	170.0	200.0	n.d.	150.0
Sb	0.2		n.d.	n.d.	0.9	1.5	4.3	7.5	5.9
Sc	0.1		24.6	16.7	19.4	14.6	14.2	0.2	23.5
Sm	0.2		5.2	3.0	3.5	2.2	4.8	n.d.	2.5
Th	*0.5*		7.6	6.3	7.2	5.2	8.1	n.d.	4.9
Yb	*0.5*		2.1	1.6	1.0	1.3	1.9	n.d.	1.4