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CONTRASTING GEOCHEMICAL EXPRESSIONS OF COPPER MINER - ALIZATION AT NAMOSI, FIJI

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ABSTRACT

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Three areas of Cu mineralization have been extensively diamond drilled at Namosi on the island of Viti Levu, Fiji. Two of these areas, Waisoi and Waivaka, were initially located by stream sediment geochemistry whilst the third, Wainabama, provided very little stream sediment geochemical response because of dilution by externally derived material. One-kilometre sample spacing at the first two prospects would produce two or three locations anomalous in either total Cu or cold-extractable Cu.

Despite similar topographic, climatic and geological settings, detailed soil and pit geochemistry was useful in siting drill holes at Waivaka, moderately useful at Wainabama, but of little value at the principal prospect of Waisoi. Two main factors are involved. Firstly, recent superficial cover of both alluvial and "mud avalanche" origin has obscured the surface geochemistry in places. Secondly, the geochemical expression varies as a function of pyrite content, its geometry relative to the Cu mineralization and the relationship of the sulphide mineralization to weathering and drainage. Cu, Pb, Zn, Mo, Au and pH determinations were used to reach these conclusions.

Magnetics and induced polarization showed a good correlation with hydrothermal magnetite and sulphides respectively at Waivaka and, to a lesser extent, at Wainabama, and were used to define and seek extensions of mineralization. A combination of these two geophysical techniques at Waisoi was useful in understanding the generalized geology, but was not directly applicable in the detailed definition of drill targets. Quartz veining density was the other principal quantitative approach used at the three prospects and this proved to be of considerable value.

INTRODUCTION

A large, low-grade copper sulphide system with many features typical of southwestern Pacific porphyry Cu deposits is currently being investigated in Fiji. The geology of this system is briefly outlined, the geochemistry as investigated so far is described, and other exploration techniques employed in the programme are mentioned.

Special Prospecting Licence 1014 was granted to Central Mining Finance (a subsidiary of Australian Anglo American Limited, hereafter referred to as Anglo) in 1968 and originally covered an area of 694 km^2. This has subsequently been reduced to an area of 194 km^2. In 1972 R.S.T. (Fiji) Inc. (with AMAX Exploration (Australia) Inc., hereafter referred to as AMAX, acting as its agent) entered into a joint venture agreement with Anglo and are the current managers of the exploration programme.

DESCRIPTION OF AREA

Location and climate

The prospecting area is located in the headwaters of the Waidina River in the province of Namosi, about 30 km WNW of Suva on the island of Viti Levu, Fiji (Fig. 1). Except for the principal river valley, the area is uninhabited, undeveloped and covered by dense tropical rainforest. Elevations range from less than 100 m above sea level to approximately 1200 m. Annual rainfall exceeds 500 cm. Average monthly maximum and minimum temperatures range from 26 to 33°C and from 18 to 22°C respectively. The area has been without vehicle access, but a road is now being established.

Regional geology

In the Namosi area, Eocene to Lower Miocene basic meta-agglomerates and volcanic flows of the Wainimala Group are unconformably overlain by Upper Miocene-Pliocene andesites, agglomerates and conglomerates of the Namosi Andesite Formation (Rodda and Band, 1967; Gill, 1970). The unconformity is marked by a basal conglomerate 15—60 m thick. The area as a whole represents one of a number of Upper Miocene centres of andesitic volcanicity (Branch, 1972). The Wainimala rocks have been affected by deformation and greenschist facies regional metamorphism. Both the Wainimala and the Namosi rocks have been contact metamorphosed and hydrothermally altered in the vicinity of later intrusives. Quartz diorite porphyries have intruded the Wainimala and Namosi volcanic and volcaniclastic rocks in the Namosi area and these often have associated copper sulphide mineralization. To date, three of the prospects located, Waisoi, Waivaka and Wainabama (Fig. 1), have been diamond drilled.

Waisoi deposit

Geology. The Waisoi deposit, located on Waisoi Creek, is in plan a large oval-shaped system of overlapping zones of intrusion, alteration and mineralization (Fig. 2). So far, eighty-one diamond drill holes have been completed on this prospect revealing two contiguous centres of mineralization, Waisoi West and Waisoi East, separated by a low-grade zone which appears to be structurally controlled by a major SW-NE-trending fault system.

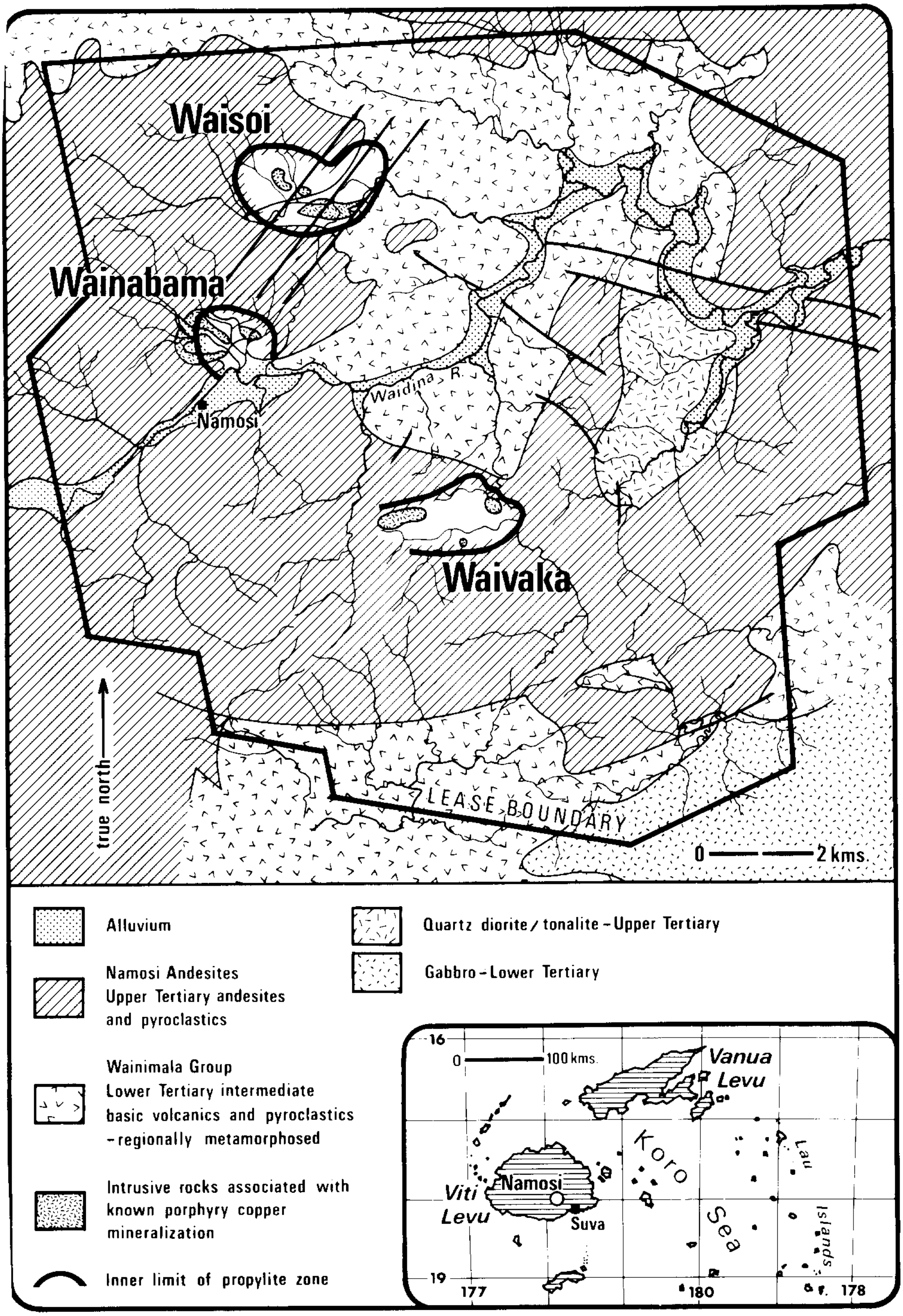


Fig. 1. Location map and generalized geology, S.P.L. 1014, Namosi, Fiji.

Three distinct intrusive types are currently recognized in the drilled area at Waisoi. These are known as the P1 and P2 phases of quartz diorite porphyry, and a quartz porphyry (quartz diorite—diorite porphyry, QP). The P1 phase of the quartz diorite porphyry does not outcrop. Hammond and McKay (1976) record that a number of distinct hydrothermal alteration assemblages occur in the intrusives and wall rocks at Waisoi. Pervasive alteration affects the intrusives in mineralized areas and chlorite-clay-sericite assemblages are developed; in addition, the central portion of the quartz porphyry in Waisoi East has been altered to a quartz-sericite-clay assemblage with associated pyrite. In the wall rocks, the outer alteration at Waisoi is represented by a well-developed and distinctive propylite zone. This is defined by the presence of large amounts of disseminated and fracture-controlled epidote with associated chlorite, calcite and pyrite. A chlorite-sericite alteration assemblage is well developed in wall rock inside the propylite zone and is usually seen in the form of ragged blotches or clots or, less commonly, as narrow selvages adjacent to fractures carrying chalcopyrite-pyrite mineralization. Towards porphyry contacts (P1 and QP), the chlorite-sericite assemblage grades laterally into a biotite-chlorite-sericite assemblage. Chalcopyrite and bornite are the most common sulphides associated with this type of alteration. A strongly foliated biotite-quartz-sericite assemblage has also been noted immediately adjacent to the quartz porphyry. Chalcopyrite, pyrite and bornite in about equal proportions, plus lesser molybdenite, are the sulphide minerals associated with this type of alteration. Superimposed on all alteration types is a clay-chlorite-calcite assemblage associated with steep fault zones, shears and fractures; pyrite is usually abundant, sphalerite and less commonly galena occur, but there is little or no copper sulphide content.

Strong lateral and vertical zonation of primary sulphides is evident at Waisoi. Passing inwards from the strongly pyritic (over 3% by volume) propylitic alteration halo, chalcopyrite becomes dominant over pyrite, traces of bornite appear and the total sulphide content decreases to 1—2% by volume. The inner mineralization on the western side of the Waisoi prospect is marked in places by dominant bornite, in which case pyrite is rarely present. The copper sulphides and pyrite occur as disseminations in intrusives and wallrocks, as dry fracture coatings and in quartz veins.

Oxidation and weathering. Depth of complete oxidation at Waisoi varies from surface to a usual maximum of about 30—80 m below crests of spurs. Partial oxidation can occur to considerable depths (300 m) in deeply fractured rocks. Drill hole data suggest that, on the north side of Waisoi Creek, the base of oxidation reflects an old planar weathering surface dipping fairly gently to the southeast. Oxidation and weathering have been so thorough that the present topography appears to have little effect on the morphology of the base of oxidation. Cu minerals in the oxidized zone include neotocite, cuprite, malachite, chrysocolla and native Cu. Supergene Cu minerals are chalcocite and trace covellite; these occur most commonly in Waisoi East.

Waivaka deposit

The Waivaka deposit, on Waivaka Creek, has an alteration/sulphide system comparable in areal extent with Waisoi (Figs. 2 and 3). However, within this zone, six small concentrations of Cu occur closely associated with quartz veining and in a close spatial relationship with small, discrete, quartz diorite porphyry intrusions. Quartz veining and biotite—K-feldspar alteration are locally intense, but decline very rapidly, resulting in several small, relatively high-grade deposits. The Cu mineralization and zones of high-grade hydrothermal alteration are contained within an indistinct propylite halo and the Waivaka system is best regarded at the present level of erosion as separate, telescoped, partially overlapping, mineralized and altered centres. Nineteen holes have been diamond drilled at Waivaka.

D.P. Taylor (1975) has recorded that mineralization consists of chalcopyrite, bornite, pyrite, magnetite and rare traces of molybdenite, sphalerite and haematite. Chalcopyrite is consistently the most abundant mineral, after magnetite, in the areas of economic interest. Bornite occurs erratically; generally, it is most common in areas of the most intense veining. Cu mineralization is found almost entirely in quartz veins, on fractures and as disseminations from veins and fractures into both porphyry and volcanics. In areas of intense veining and mineralization, magnetite is abundant along vein margins and in the veins themselves. Pyrite is rare in mineralized areas, being either a low percentage vein or fracture mineral, or absent.

Wainabama deposit

At Wainabama (Faga, 1976), where fifteen diamond drill holes have been bored, a larger multi-phase intrusion exhibits pervasively disseminated biotite-chlorite and minor localized K-feldspar alteration with low-grade associated Cu mineralization; local higher-grade Cu sulphides are associated with increased quartz vein density and these are related to a particular intrusive porphyry phase (Fig. 12). Chalcopyrite, bornite and pyrite are the dominant sulphides observed although some minor molybdenite is seen in places. Sulphides occur as vein fillings, fracture coatings and disseminations. Pyrite occurrence is mainly restricted to fault structures. Magnetite is well developed along quartz vein margins and also as thin monomineralic stringers.

Superficial cover

Significant superficial cover of recent origin occurs at both the Waisoi prospect (where it is termed "boulder terrace") and the Waivaka prospect ("landslip deposits") where stabilized "mud avalanche" deposits of andesitic material occur. These rock units are composed of epiclastic/pyroclastic rocks shed from the retreating inner escarpment of the remnant volcanic apron deposits located to the north of Waisoi (Korobasabasaga Range) and the south

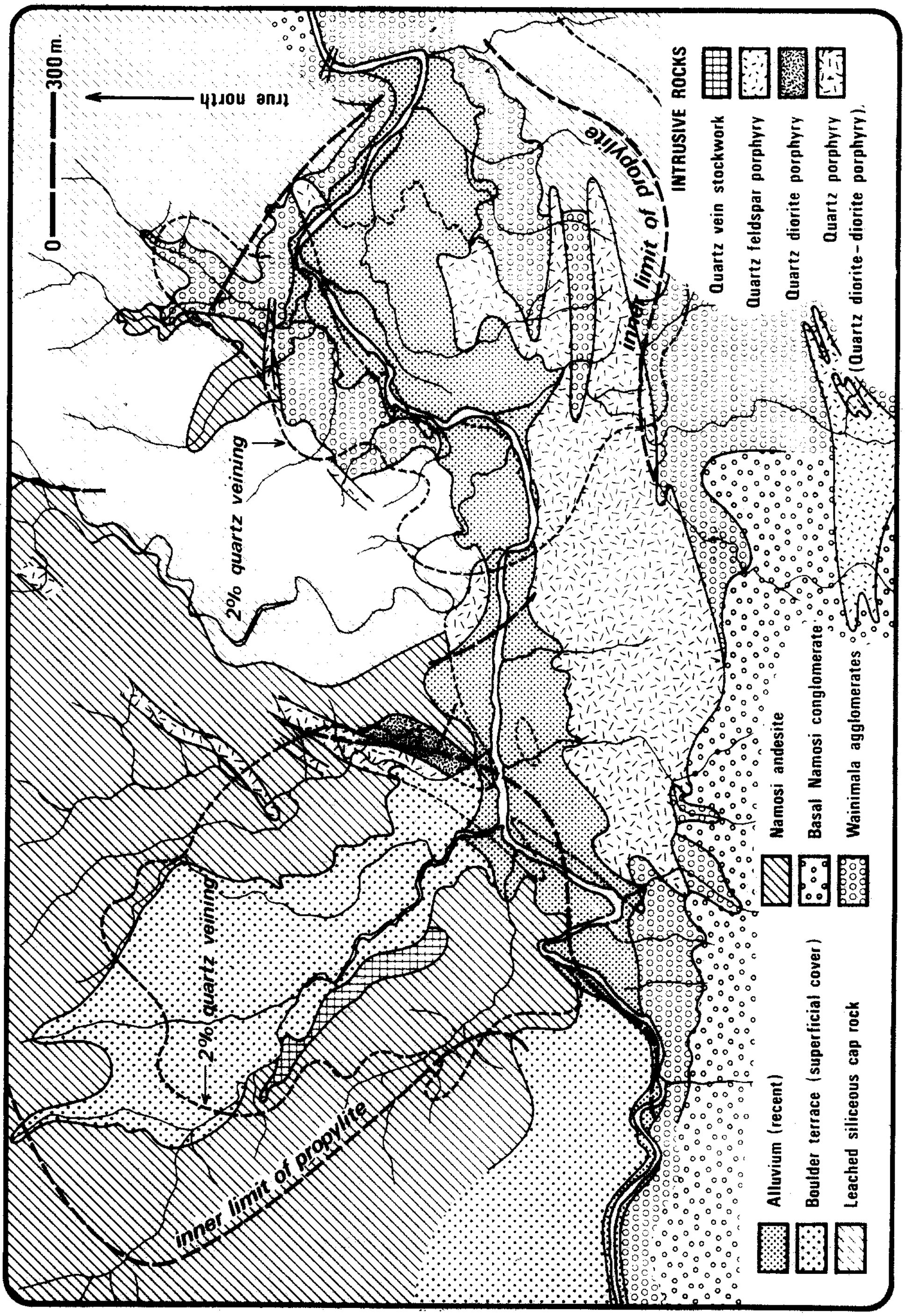


Fig. 2. Geological map and quartz veining, Waisoi prospect.

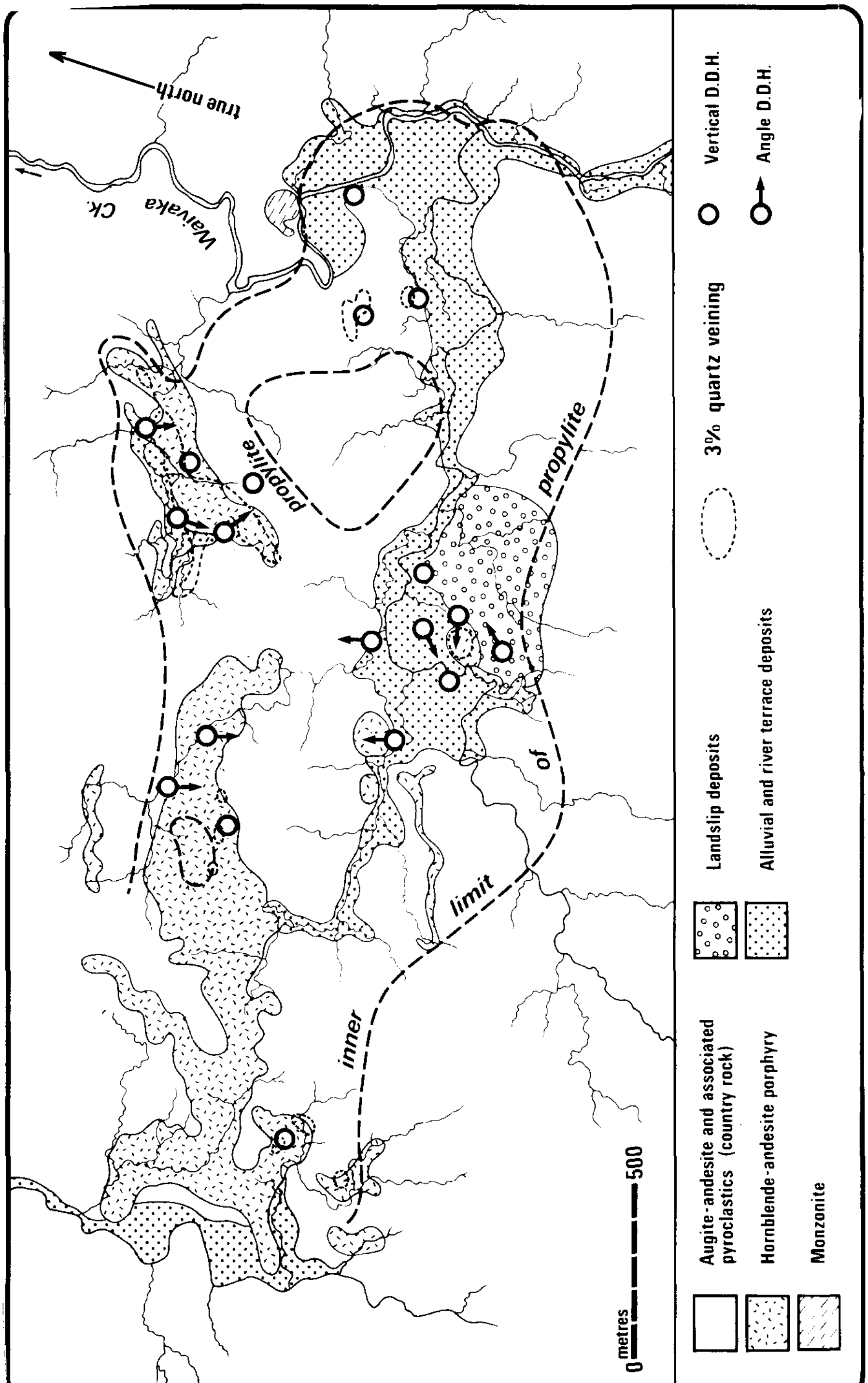


Fig. 3. Geological map and quartz veining, Waivaka prospect.

of Waivaka. Other superficial deposits include alluvial cover (e.g. at Wainabama) and minor landslip cover.

Soils

The soils of the Namosi area, using local terminology (Twyford and Wright, 1965), are mainly steepland soils formed under a tropical climate with no dry season. Two main soil types are developed: firstly, humic latosols derived from parent material of intermediate composition, usually stoney and bouldery clays; secondly, red yellow podzolic soils derived from parent materials of acidic composition and varying from bouldery clays to stoney sandy clays to stoney silty clay loams. An anomalous profile occurs around Waisoi East consisting of pale, severely leached, crumbly to porcellanous cap rock. Hammond and McKay (1976) have shown that this capping corresponds with present topographic highs marginal to the core of copper sulphide mineralization and it is interpreted as being derived from strongly pyritic wall rocks. Limonitic gossans are common and original rock textures are rarely preserved in this profile.

SAMPLING AND ANALYTICAL METHODS

Stream sediments

The early stream sediment work (1968-69) by Anglo had a sample density of 2.4 samples/km^2. Significant tributaries to main drainages were sampled, resulting in approximate sampling intervals of 150 m along the main streams. The minus 0.2-mm (80-mesh) material was analyzed for Cu, Co, Ni, Pb, Zn and cold-extractable Cu (cxCu). Follow-up stream sediment sampling and analysis for Cu, Co, Ni, Pb and Zn but not cxCu, was also performed by Anglo in selected areas using a sampling density of approximately 9/km^2. Corresponding base of slope samples were taken at a depth of about 50—100 cm. Analytical methods used were perchloric acid/atomic absorption spectrometry (AAS) for Cu, Co, Ni, Pb and Zn and citric acid/dithizone papers for cxCu. Re-sampling and analysis were undertaken by AMAX in 1972 at the Waisoi prospect. Initially, nine streams were re-examined and the minus 0.2-mm fraction was analyzed as follows; Cu, Pb, Zn by $HClO_4$/AAS; cxCu using a thick slurry with 0.5*M* HCl; Mo by fusion/AAS; pH on a thixotropic soil mixture prepared with boiled de-ionized water. Recently Mo distribution at Waisoi has been re-studied and stream sediment Au contents have been determined. Mo was analyzed by $HClO_4$ /HNO_3 /AAS; Au by aqua regia/MIBK/AAS.

Ridge and spur and grid soil sampling

Soil samples were collected by Anglo along ridge and spur lines cut up-slope to a major control ridge line. Sample interval was approximately 62 m along lines and sample depth ranged from 20 to 40 cm.

Detailed soil sampling was undertaken by Anglo at a number of anomalous areas, the two most significant being Waisoi and Waivaka. This was carried out along chain and compass cut lines from a surveyed base line on a 400 ft × 50 ft (123 m × 15 m) grid closing down to 100 ft × 50 ft (31 m × 15 m) in places. The minus 0.2-mm soil fraction was analyzed for Cu only by $HClO_4$/AAS.

Analyses of core composites from early diamond drilling at Waisoi led AMAX to use Au and Mo in addition to Cu, Pb and Zn in a second soil sampling programme (46 cm depth) in an attempt to refine potential drilling targets. Grid spacing employed was 123 m × 31 m.

The close spatial association of the andesine porphyry intrusives with mineralization at Waivaka led to the idea of distinguishing between the porphyries and andesites in the often deeply weathered soil profiles at Waivaka by using the Ni-Co fractionation index (S.R. Taylor, 1966). Analyses of appropriate core samples showed, however, that a distinction could not be made on this basis in view of the low levels of Ni and Co and limited variation in concentration. Core composites and some pits from Waivaka have low Mo contents (mostly <15 ppm; maximum for a 15-m interval, 58 ppm) and this suggested that analyses for Mo in surface samples would have been of little assistance.

Pits

Pits were dug at both the Waivaka prospect, where over 200 pits were channel sampled, and Waisoi prospect, where 100 pits were channel sampled and analyzed. Samples were collected over a combination of set intervals and intervals related to soil horizons. Maximum depth rarely exceeded 10 m.

ADDITIONAL EXPLORATION METHODS EMPLOYED

Helicopter magnetometer (Barringer M104 proton precession magnetometer), ground magnetometer (M-700 McPhar fluxgate magnetometer) and induced polarization/resistivity surveys (time domain equipment, pole-dipole array) have been conducted over portions of S.P.L. 1014 and covered the Waisoi, Waivaka and Wainabama prospects in some detail.

In addition, following the work of Fountain (1972), quartz veining density expressed as vol.% was estimated semi-quantitatively in outcrops and pits wherever possible and these data were delineated using 2%, 5% and 10% contours.

RESULTS AND INTERPRETATION

Stream sediments

The Cu threshold for the entire area was estimated statistically as 180 ppm using a probability graph and histograms, but the value of 230 ppm was used as the threshold owing to uncertainty about the nature of the distribution of Cu values. This is approximately lognormal although there may be, in fact, four overlapping populations. S.R. Yardley (written communication, 1969) using histograms, estimated background values for Cu and Zn for the six main rock units within the original prospect area (Table I).

Values up to 1400 ppm Cu and >100 ppm cxCu were recorded at Waisoi and 1300 ppm and >100 ppm respectively at Waivaka. Background for cxCu is ⩽10 ppm and the threshold is approximately 20 ppm. Using a cumulative frequency plot, the threshold value for reconnaissance Zn values was established as 350 ppm. According to S.R. Yardley (written communication, 1969), the regional values for Ni, Co and Pb remained constantly low and fluctuated little.

Reconnaissance and follow-up stream sediment geochemistry by Anglo successfully located and largely defined four prospects, Waisoi, Waivaka, Waisomo and Wainimolaunia. The latter two prospects did not reach the diamond drilling stage and are not discussed further.

Values of 250 ppm total Cu and 50 ppm cxCu were recorded for a location in Waisoi Creek at the junction with the Waidina River, 3 km below the Waisoi prospect. One-kilometre sample spacing using either tributaries or the main stream (Waisoi Creek) would have produced two to three anomalous locations (Fig. 4). Sampling of tributaries to Waisoi Creek at 300-m intervals would have clearly indicated the anomalous zone. This is in contrast to the lack of stream sediment geochemical expression at Wainabama (Fig. 4).

Stream sediments from Waisoi may contain up to 0.35 ppm Au, but the lack of precision of the data, as established by duplicate analyses, precludes its usefulness other than as a general indicator element for this area.

TABLE I

Background stream sediment values for Cu and Zn for various rock units in the original licence area

		Cu (ppm)	Zn (ppm)
Wainimala Group		55	100
Mendrausuthu Group	Namosi Andesites	80	120
(Suva Series)	Sediments	60	100
Tonalite/granodiorite plutonics		15	50
Vango volcanics		40	150
Gabbro intrusive		75	100

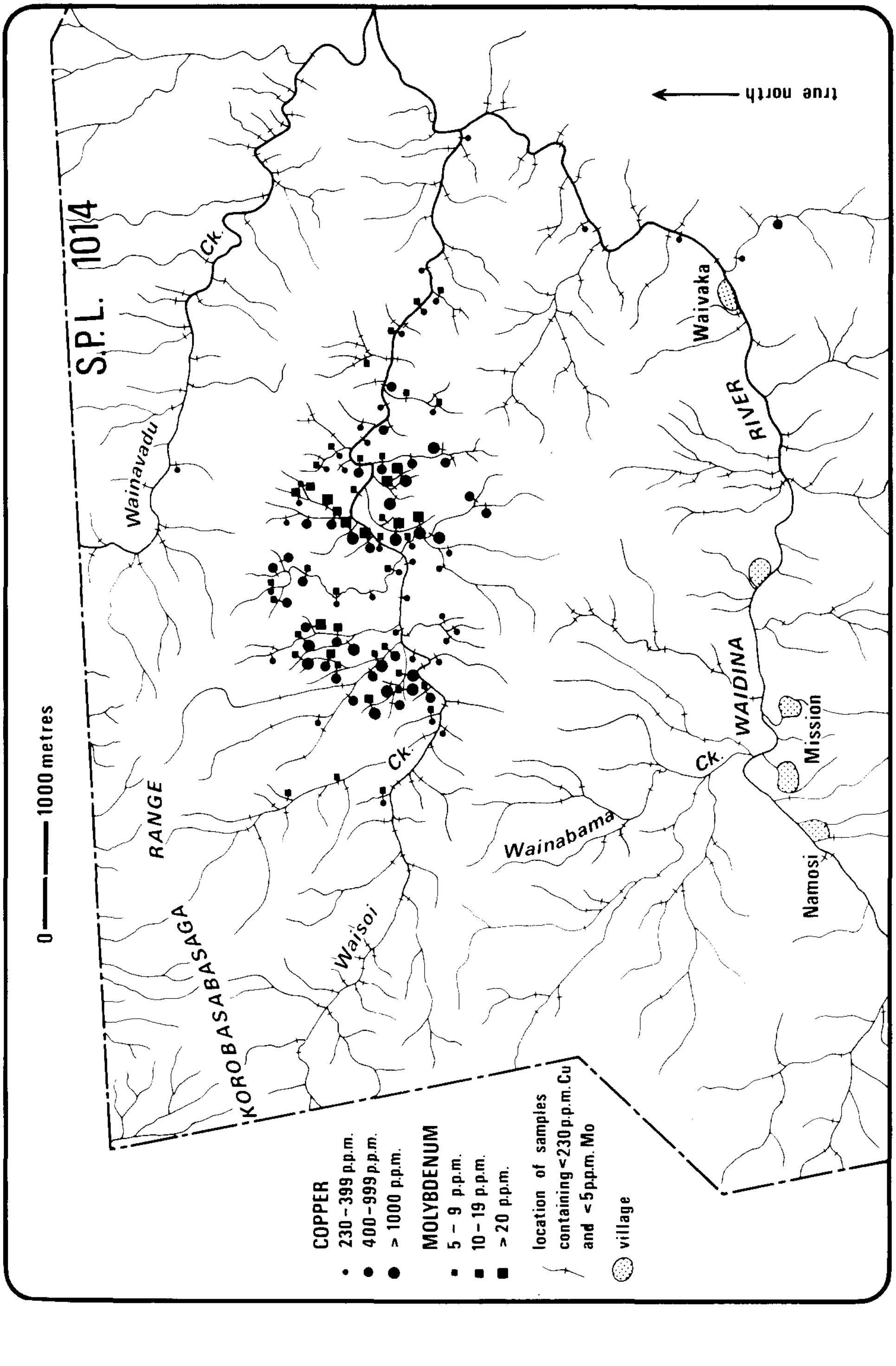


Fig. 4. Stream sediment Cu and Mo values for the Waisoi and Wainabama prospects.

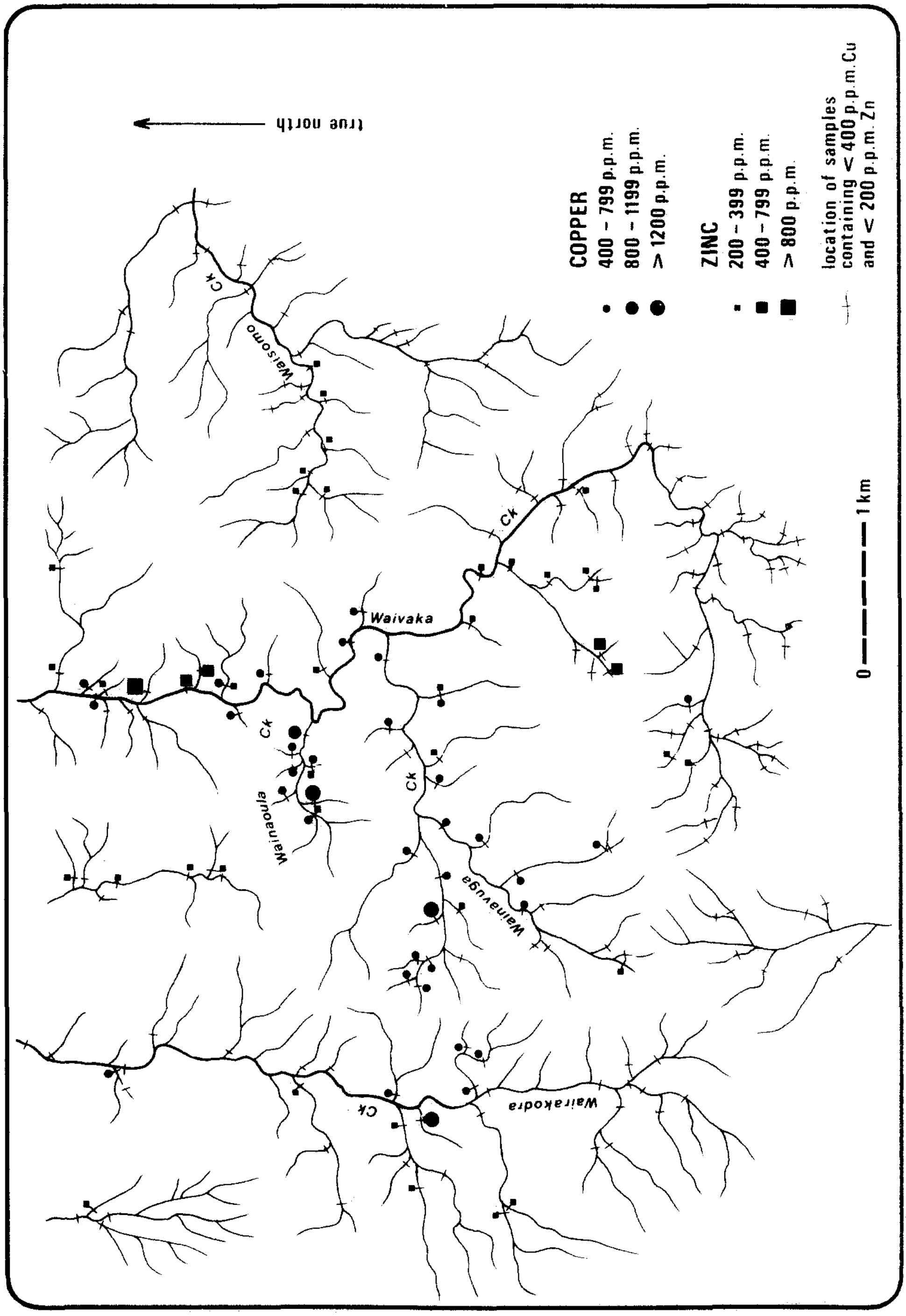


Fig. 5. Cu and Zn values in stream sediments from the Waivaka prospect.

The Mo contrast between the Waisoi and Wainabama areas is fairly striking (Fig. 4). Neither Wainabama nor Wainavadu Creeks have stream sediments containing more than 4 ppm Mo, whereas in Waisoi Creek they can contain up to 34 ppm and a widespread anomalous zone is developed. Mo is a good positive indicator of a porphyry environment, but its absence does not necessarily indicate a lack of Cu mineralization.

The Wainabama prospect was not detected in the regional geochemical stream sediment survey, the maximum Cu value recorded being 180 ppm. Quartz veining in a weathered outcrop was observed by a geologist (R.J. Fountain in 1973) and this led to further examination. The very limited stream sediment geochemical response to the Wainabama mineralization is a function of its position relative to the Waidina alluvial flats — it has been largely swamped by externally derived background material from upstream catchment areas (Fig. 4).

The approximate size of the Waivaka stream sediment Cu anomaly is 4 × 1½ km (Fig. 5). Sampling at 1-km intervals would have successfully located the prospect.

The anomalous stream sediment Cu zone at Waivaka is encircled by a zone of anomalous Zn values. Although the areas of mineralization at Waivaka appear to be discrete, at the spacing employed for stream sediment sampling, the Cu and Zn anomalies are regional in scale. Closer-spaced sampling may reveal smaller discrete patterns. A low-level aeromagnetic survey suggests that the intrusives currently exposed at Waivaka are apophyses to a large intrusive at depth and it is probable that any smaller discrete patterns would be superimposed on the regional scale anomaly.

Systematic stream sediment Mo analysis was not undertaken at Waivaka. The maximum value recorded in some reconnaissance samples was 7 ppm, all other results being 4 ppm or less. No attempt was made to analyze for Au. The Au content at Waivaka, established by drilling, rarely exceeds 0.15 ppm over a 15-m interval. The maximum value for a 15-m intersection was 0.5 ppm Au, with a Cu content of 4%.

Soil and pit sampling, Waisoi

Soil geochemistry. The results of Anglo's base of slope and ridge and spur Cu values at Waisoi are shown in Fig. 6. Although the contour intervals are not strictly comparable, this should be compared with Fig. 7 in which the Cu results of the AMAX soil survey are presented. It can be seen that the refinement provided by the latter probably did not warrant the effort.

During the main soil survey, 1620 samples were collected and analyzed. Au and Mo, in addition to Cu, Pb and Zn, were determined, firstly, because of the probable direct relationship between Cu and Au (as suggested by analyses of drill core composites from the first four holes) and the likelihood that the mobility of Au in the weathering environment is not pH dependent (Learned and Boissen, 1973); secondly, because of the possibility of an in-

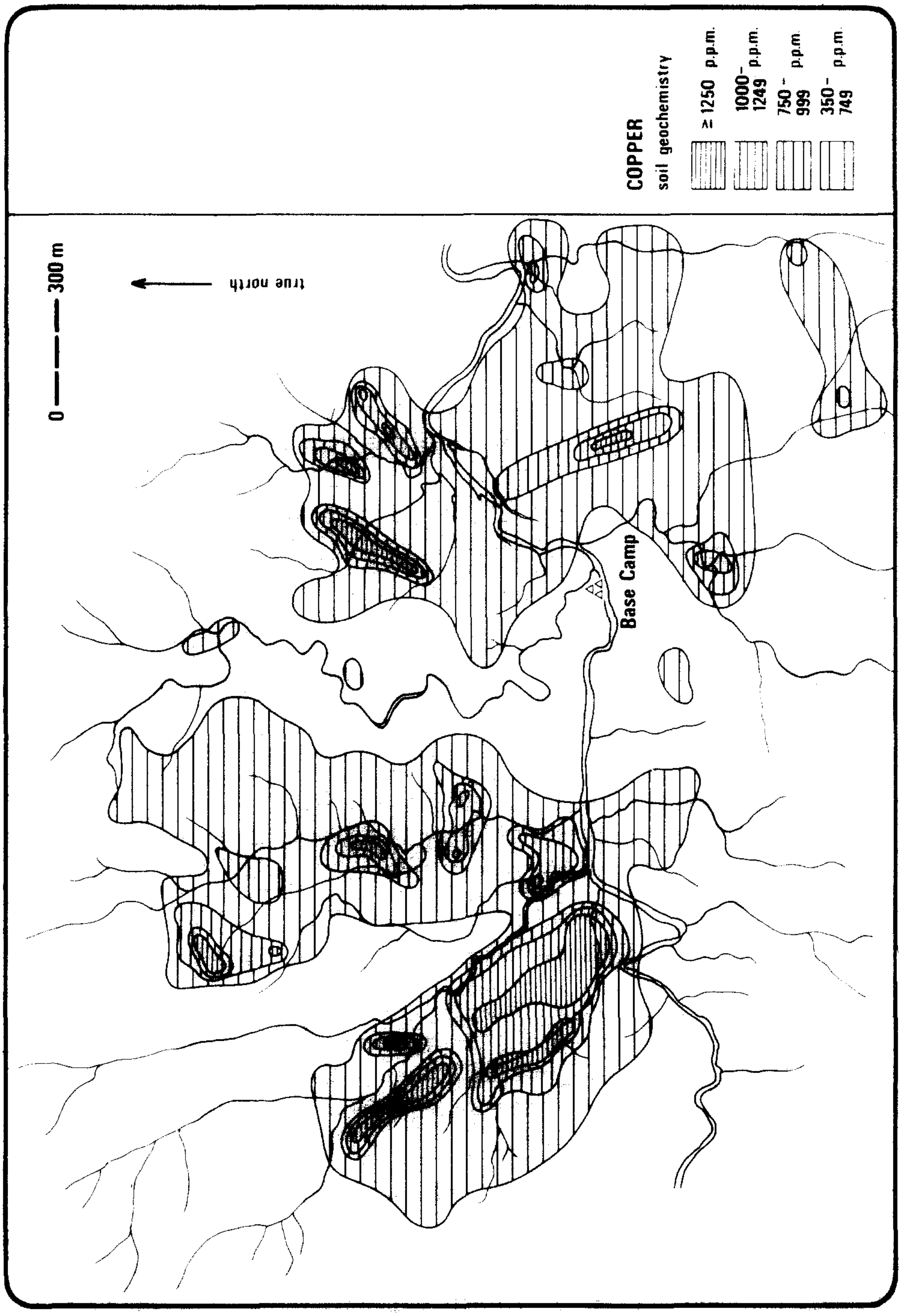


Fig. 6. Ridge and spur soil Cu values, Waisoi prospect.

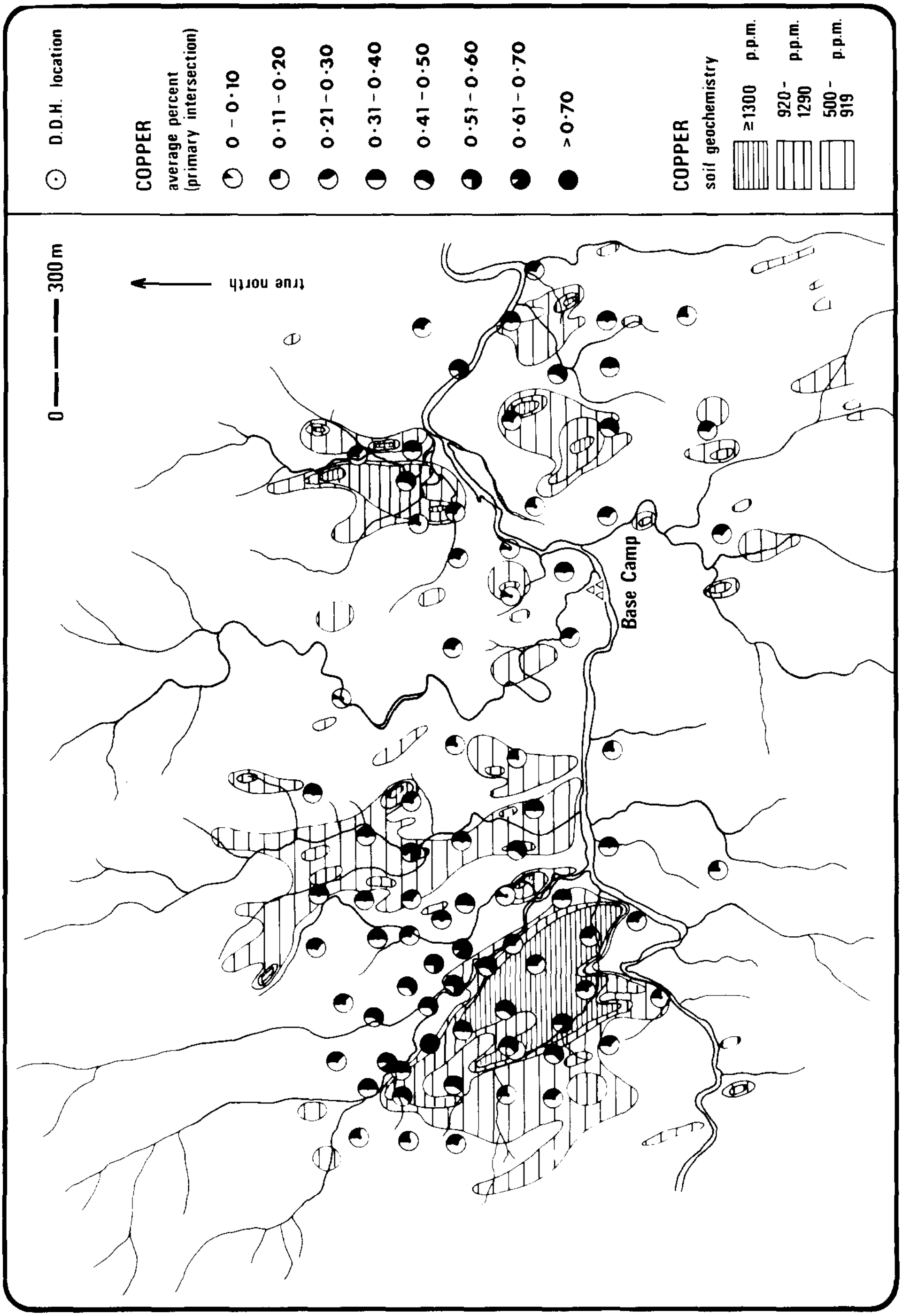


Fig. 7. Grid soil and average diamond drill hole Cu values, Waisoi prospect.

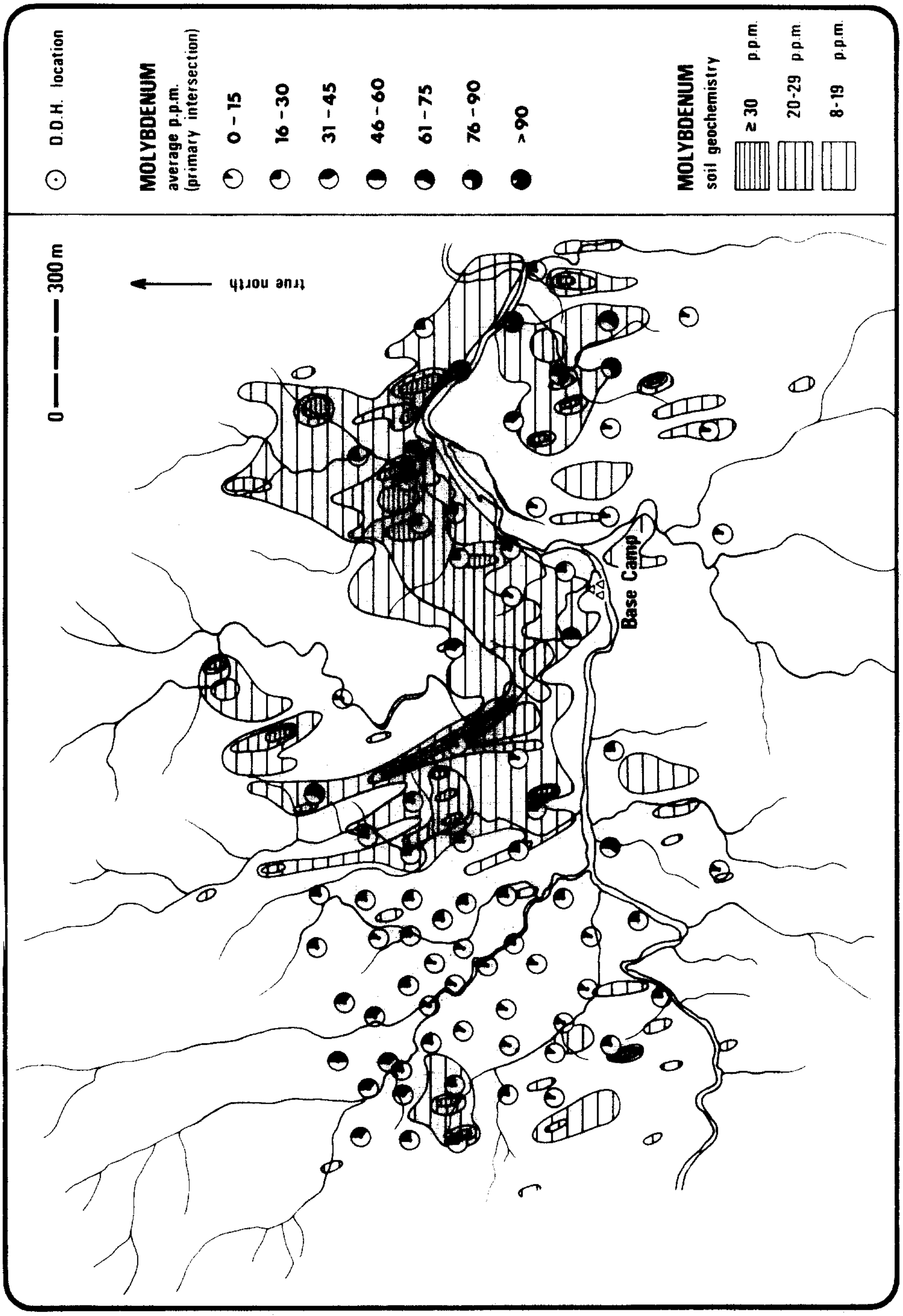
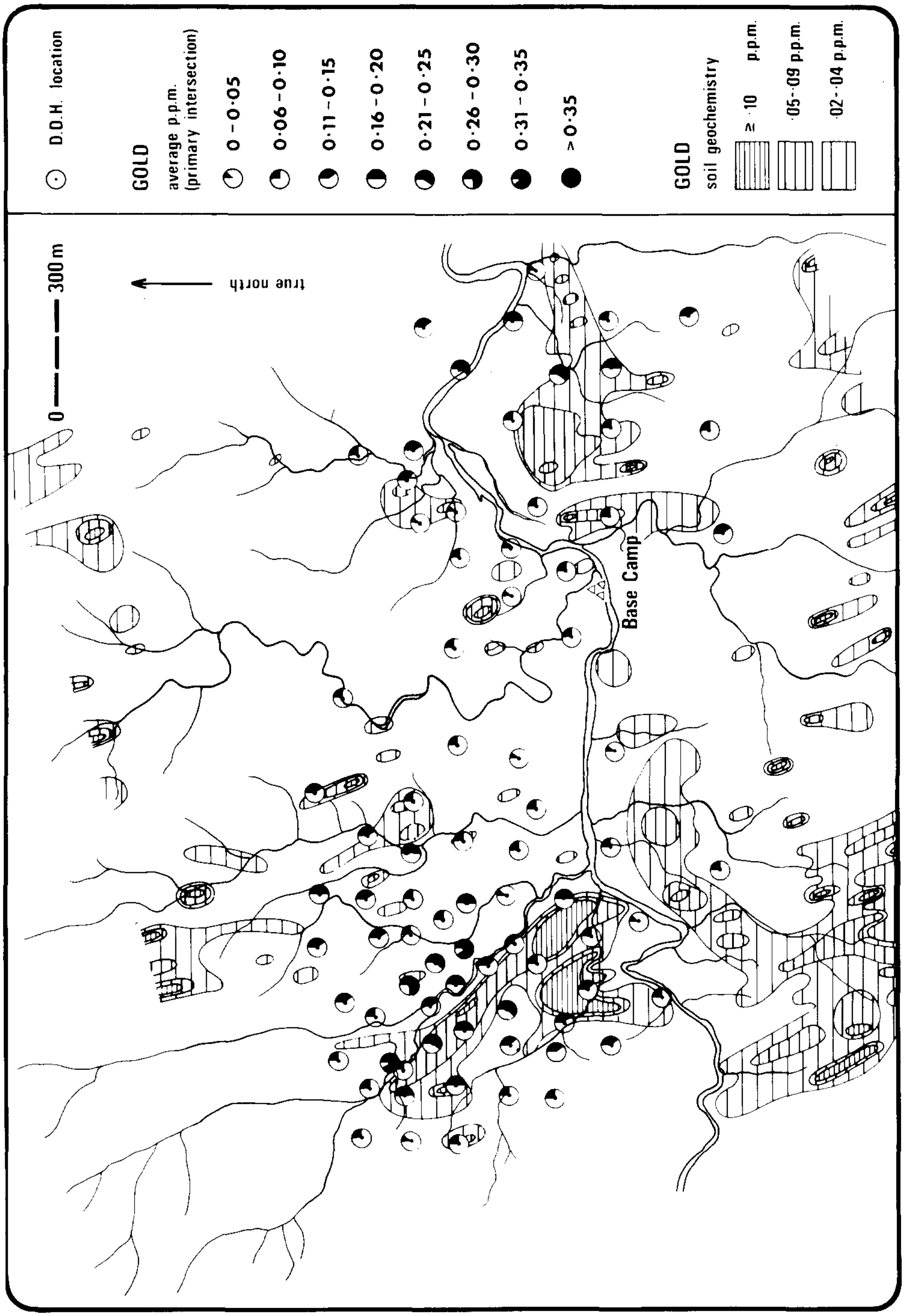


Fig. 8. Soil and average diamond drill hole Mo values, Waisoi prospect.


0
300 m
true north
Base Camp
D.D.H. location
GOLD
average p.p.m.
(primary intersection)
0 - 0·05
0·06 - 0·10
0·11 - 0·15
0·16 - 0·20
0·21 - 0·25
0·26 - 0·30
0·31 - 0·35
> 0·35
GOLD
soil geochemistry
≥ ·10 p.p.m.
·05 - ·09 p.p.m.
·02 - ·04 p.p.m.

verse relationship between Mo and Cu in soils, again as a function of pH (Learned and Boissen, 1973).

Using a 500-ppm soil copper contour, four principal anomalous areas, totalling approximately 2 km × 1 km, are defined. These are probably in fact two main areas, the one to the west of the base camp being divided by a wedge of superficial post-mineralization boulder cover, that to the east being separated by Waisoi Creek alluvium. The maximum soil Cu value recorded was 2800 ppm.

Using a threshold of 8 ppm, the largest and strongest soil Mo anomaly (maximum 232 ppm) lies to the east of the base camp on the north side of Waisoi Creek (Fig. 8). Other anomalous areas are located to the south, on the opposite side of Waisoi Creek, and northwest of the base camp. All three anomalies are only partly coincidental with the Cu anomalies; the strongest soil Cu anomaly largely lacks anomalous Mo values.

A much better coincidence occurs between anomalous Au areas (threshold 0.02 ppm, Fig. 9) and the Cu anomalies, but this is complicated by the occurrence of anomalous Au values in the propylite zone in the agglomerates. In soil, the maximum value was 0.50 ppm Au.

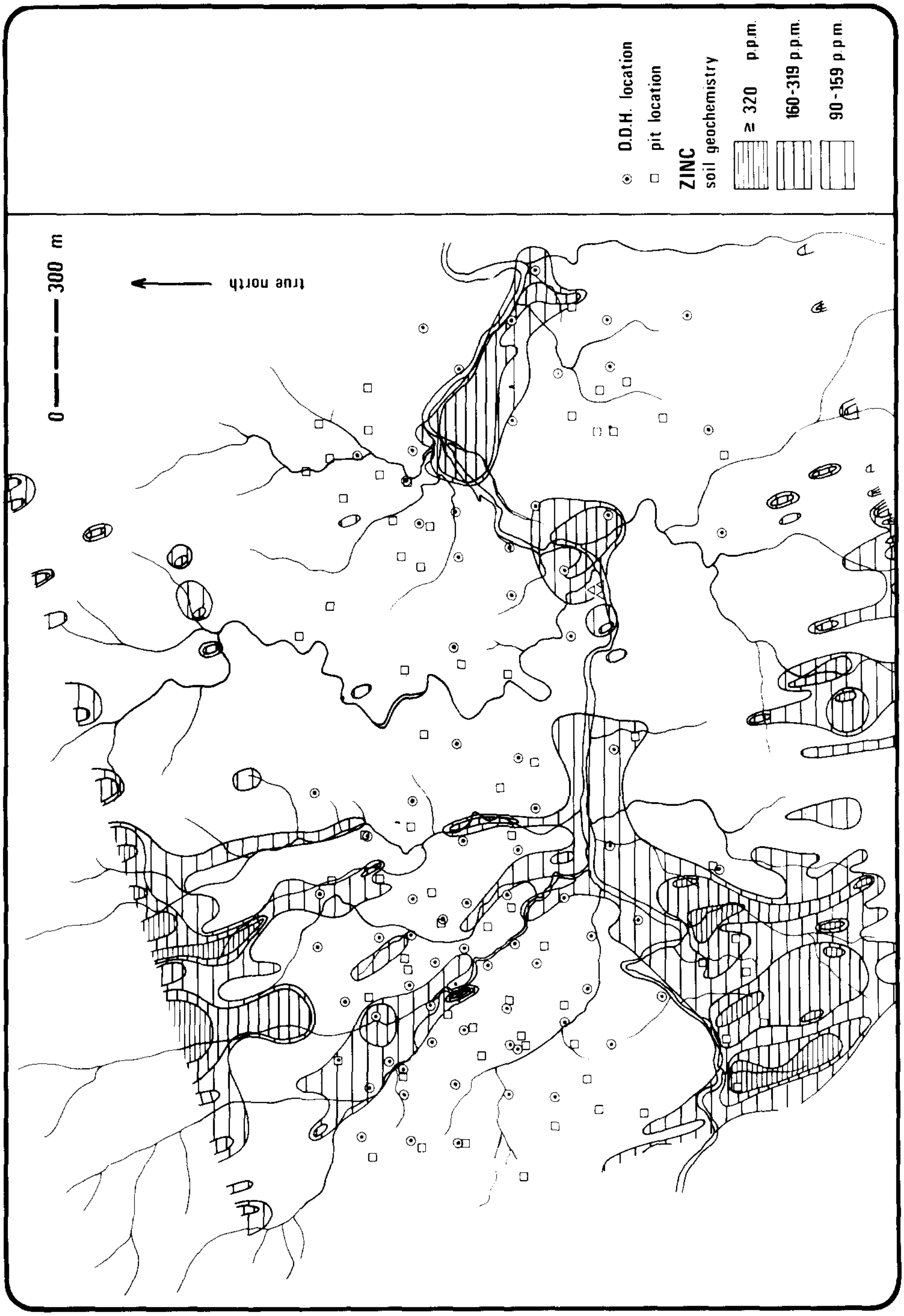
Two types of Zn anomaly (Fig. 10) are found, one located in propylite bounding the Cu anomalies, and the other clearly related to drainage, with anomalies following creeks and associated alluvium. In part, this results from drainage intersecting zinc-rich propylite zones, but it may also be a function of the correlation between Zn content with faulting, and faulting with drainage. Some support for the latter is found in the occasional diversion of stream courses away from linear Zn anomalies.

Pb values are low and distributed rather erratically although tending to be higher in association with Zn in the propylite areas.

Statistical analysis. Prior to the main AMAX soil survey, five east-west lines across the prospect area were re-sampled at 30.5-m centres. These samples, collected by augering to 46 cm depth, were analyzed for Cu, cxCu, Mo and soil pH. The product-moment correlation coefficient matrix for these variables in 164 samples is given in Table II.

The only correlation found was cxCu with total Cu. No apparent relationships exist between the other parameters. The geometric mean for cxCu is 7 ppm, (range 1—140 ppm). The arithmetic mean for pH is 5.08 (standard deviation 0.31; range 4.05—5.86).

An R-mode factor analysis was performed on the soil data from the main survey, eigenvalues were extracted and the cumulative proportion of total variance found. Three factors were chosen which account for 72% of the total variance. This is fairly satisfactory, considering both the large volume and the inhomogeneity of the data. The unrotated factor matrix did not display any particular correlation between factors and elements. However, on rotation to a simple oblique structure (oblimin rotation) the three factors display quite clear associations with the elements. The rotated factor matrix is recorded in Table III.


D.D.H. location
pit location
ZINC
soil geochemistry
≥ 320 p.p.m.
160-319 p.p.m.
90-159 p.p.m.
0 300 m
true north

Cu shows an exclusive dependence on factor 3. Pb has a predominant dependence on factor 1, with a small negative dependence on factor 2. Zn shows a strong dependence on factor 1 also, with a small positive dependence on factor 2. The Au values are spread over the three factors. Mo displays a prime dependence on factor 2. From the above it can be seen that factor 1 is principally a Pb-Zn factor with some Au dependence, factor 2 is principally an Mo factor with minor Zn and a greater Au association than factor 1. Factor 3 is distinctly a Cu factor with moderate influence by Au. Computerized grey-level mapping treatment (Howarth, 1971) of both element and factor data facilitated the interpretation of results.

The above factors make some spatial sense, factor 1 being related to the propylite, factor 2 in part to the quartz porphyry intrusive and factor 3 to the Cu mineralization. Factor 2, however, is not simply a function of the presence or proximity of the quartz porphyry, since a zone of relatively high Mo values is found in soils and, more particularly, in drill core on the northwest side of Waisoi West where there is no known quartz porphyry intrusive.

Soil pH. Studies of pH through soil horizons into weathered bedrock show that the A_0 horizon when present is more acid than the A horizon (arithmetic and geometric mean of 14 pits: 4.70, arithmetic standard deviation: 0.31), which in turn is usually slightly more acid than the B and C horizons (arithmetic mean for both equals 5.01, arithmetic standard deviation 0.48 and 0.25, respectively; the geometric mean for both equals 5.00). Variations in pH found during early trial soil traverse lines were due in part to different soil horizons being sampled at the arbitrary 46 cm depth. The effect of original rock mineralogy, deep leaching, high rainfall and, possibly to a minor extent, superimposed superficial pH caused by humic acid content, has obscured the pH generated by the oxidation and weathering of the sulphide mineralization and thus precluded the establishment of any relationship between Cu, Mo and pH. In fact, pit (C horizon) and drilling data fail to reveal any relationship between Cu and Mo and thus Mo is eliminated as a directly useful element in looking for concentrations of copper sulphides.

Pit geochemistry. Although Cu, Au and Mo values in pits show about a 66—70% agreement with soils in the broad sense of defining anomalous areas (using similar concentration limits for pits as for soils), the agreement is poor when detailed absolute values are compared. It can be concluded that, except where pits penetrated the boulder terrace unit at Waisoi West, pit geochemical data added little useful information to the soil data. In turn, the detailed soil geochemistry was of little assistance in locating mineralization, except to confirm the distribution of the anomalous Cu areas already established by the Anglo ridge, spur and base of slope sampling.

This is in contrast to the Waivaka and Wainabama prospects and is the result of strong leaching at Waisoi. The deep leaching is a consequence of (1) basin-like drainage into the principal Cu mineralized areas from the high pyrite, propylitic rims; (2) considerable fracturing, and (3) a higher pyrite to

TABLE II

The product-moment correlation coefficient matrix for the variables cxCu, Cu, Mo and pH in soils from Waisoi

	cxCu	Cu	Mo	pH
cxCu	1.0000	0.5252	0.0312	0.1169
Cu	0.5252	1.0000	0.1171	0.0917
Mo	0.0312	0.1171	1.0000	−0.0050
pH	0.1169	0.0917	−0.0050	1.0000

TABLE III

The rotated R-mode factor matrix for soil data from Waisoi

Variable	Factor 1	Factor 2	Factor 3
Cu	−0.08662	0.07423	0.94182
Pb	0.82215	−0.16380	−0.03330
Zn	0.77180	0.29762	0.00546
Au	0.21917	−0.44624	0.48487
Mo	−0.11386	−0.89628	−0.03713

total sulphide ratio than at Waivaka or Wainabama. This has caused markedly reduced soil and pit Cu values relative to underlying primary rock contents (Fig. 7). In addition, the most anomalous soil Cu area is significantly displaced from the higher-grade Cu zone. Depletion of Au at surface may have occurred to a minor extent (less than a factor of 2) although downhole variance makes this difficult to establish with confidence. Surface and near-surface Au values cannot be used to predict underlying Cu grades closely, despite the broad linear correlation between the two in the diamond drill core. Except for the northwest corner of Waisoi West, Mo in soils and pits reflects fairly closely the underlying primary rock content (Fig. 8).

Soil and pit sampling, Waivaka

There is very good agreement between anomalous areas defined by soil sampling, pit sampling and ridge, spur and base of slope sampling. There is no consistent trend in Cu values down the pit profile with 30% of the highest values occurring as bottom intervals (average depth 4–5 m), 17% as top intervals (approximately 0–1 m). Leaching of Cu has not occurred and the surface values provide a reliable reflection of underlying primary Cu grades (Fig. 11). Superficial "mud avalanche" or landslip material has obscured the soil geochemistry on the south side of one anomalous area, but "windows", pits and creek exposures enabled some bedrock to be sampled.

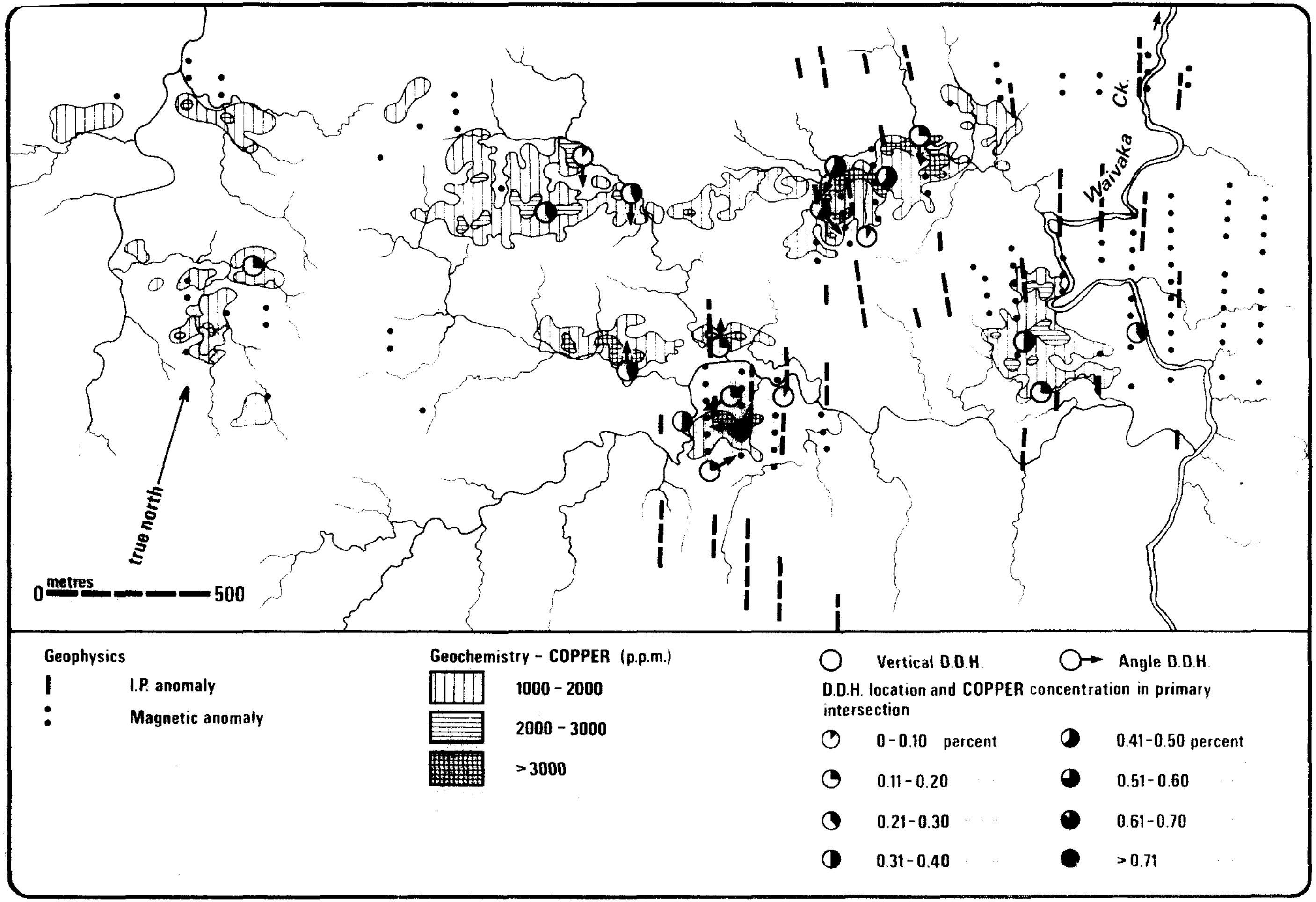


Fig. 11. Soil and average diamond drill hole Cu values, ground magnetic and I.P. anomalies, Waivaka prospect.

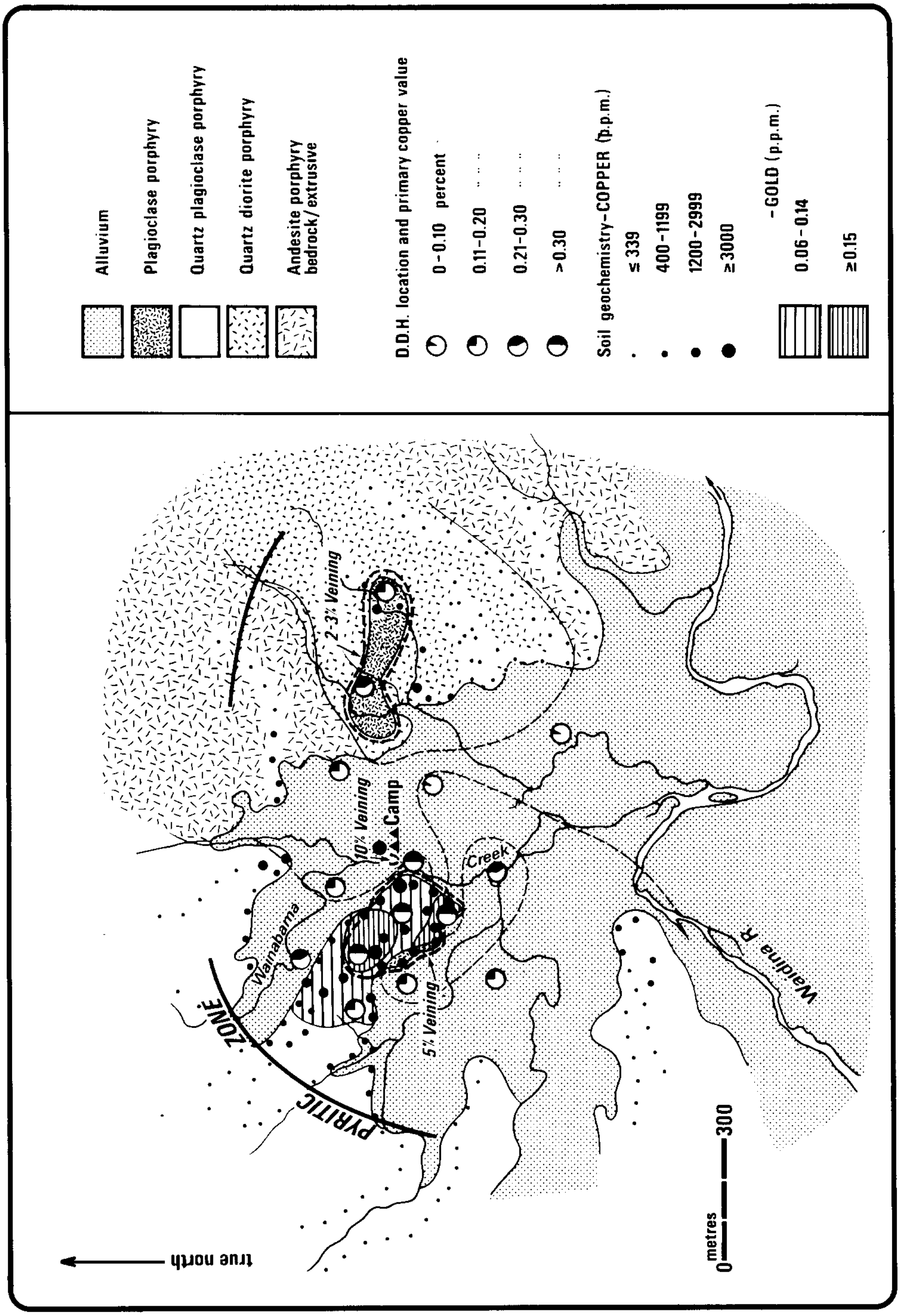


Fig. 12. Soil and average diamond drill hole Cu values, geology and quartz veining, Wainabama prospect.

Soil and pit sampling, Wainabama

The soil Cu values at Wainabama provide an excellent indication of Cu content in the underlying fresh rock (Fig. 12). There is very little pyrite present with the Cu mineralization and no significant leaching has occurred. Surface Au values also correspond well with the Au tenor of the underlying rock. As at Waisoi, the Au variance in core makes it difficult to establish whether minor depletion has occurred at the surface. The Au content of the mineralization at Wainabama is about 1½—2 times as high as that at Waisoi, relative to Cu content. Mo content exceeds an average of 13 ppm in only two diamond drill holes (average 25 ppm in each, maximum value over 15 m: 44 ppm). Both the latter were collared in alluvium. In view of the low, primary rock Mo content, it is not surprising that Mo is largely absent in the soils (detection limit 1 ppm), only six soils recording greater than 4 ppm Mo.

Additional exploration methods

Quartz veining density. This was established as a very useful semi-quantitative measure of Cu grade, particularly at Waivaka and Wainabama. At Waivaka, 70% of pits that contain quartz veining or stockworks have Cu values greater than 2000 ppm. At Waisoi, the relationship between veining and tenor of Cu mineralization is complicated by the presence of at least three generations of quartz veining. Even so, except for the eastern side of Waisoi West, the principal Cu-mineralized zone is located inside the 2% veining contour. There is no obvious correlation of surface and near-surface Mo values with the 2 and 5% quartz veining contours. A possible correlation of Au with higher quartz veining density occurs in the western soil anomaly, except where blanketing by superficial post-mineralization colluvial cover occurs. Au values in soils and pits on the south side of Waisoi Creek, on the extension of the western soil Cu anomaly, are associated with Zn not Cu and, despite a veining density of 2—3%, significant Cu mineralization does not extend very far south of Waisoi Creek. In contrast, despite the sparse quartz veining at the surface in the central soil Cu anomaly, the presence of some Au values suggested that there was the possibility of significant Cu mineralization and this was borne out in the drilling. Quartz veining density was likewise useful at Wainabama (Fig. 12) even though three generations of veining were recognized.

Ground magnetometer survey. This was of most value at Waivaka (Fig. 11) where the mineralized quartz veining carries considerable magnetite. Not only could the favourable rock type (porphyries) be mapped against the andesites (lower magnetic susceptibility), but the ground magnetics provided a basis for discrimination of non-prospective ground. At Waisoi, the situation is more complex. Magnetic relief is small and, although the porphyries generally form "lows", the base of the Namosi andesite forms local "highs" and the agglomerate and andesites produce moderate magnetic response (in contrast to Waivaka), detailed correlations and predictions are difficult. A number of magnetically inferred linears support the presence of a series of prominent NE- and NW-trending faults. At Wainabama, the area of high magnetic susceptibility coincides closely with the principal mineralized area and is very restricted in extent. This is related to hydrothermal magnetite content and compares closely with the Waivaka situation.

Induced polarization surveys. At Waivaka, induced polarization (I.P.) surveys, like the ground magnetics, provided a valuable detailed guide to locating and defining possible extensions to known areas of mineralization (Fig. 11). Other I.P. anomalies, particularly those without coincident magnetic highs and lying outside soil geochemical anomalies and areas of quartz veining, have been interpreted as due to the effect of increased pyrite. At Waisoi, only a gross picture of sulphide zoning was obtained; the I.P. measurements and a complementary resistivity pattern suggest two chargeable rings surrounding lower sulphide zones, with evidence for a pyritized zone between the two. Mapping and drilling confirmed this picture of sulphide distribution. In Waisoi West, the lower sulphide zone carries Cu and virtually no pyrite; in Waisoi East, the chargeable ring is Cu-mineralized and has associated pyrite, whilst the inner core is very poorly mineralized. A related feature is the more widespread occurrence of supergene enrichment in Waisoi East than in Waisoi West. At Wainabama, a crudely horseshoe-shaped I.P. anomaly is centred on the main Cu-mineralized body. The two extending limbs have been shown to be related to pyrite content. A pyritic zone boundary is shown in Fig. 12 rather than a limit of propylite, since the propylite, although partially coincident with the pyritic zone, is harder to define at Wainabama. Surface effects (alluvial cover) eliminated the usefulness of the resistivity values as a guide to rock type or mineralization.

CONCLUSIONS

Within a relatively restricted topographic, climatic and geological environment considerable variation was found in the usefulness of the various exploration techniques and parameters employed in searching for porphyry Cu mineralization.

Cu and cxCu in stream sediments clearly located and outlined the two largest areas of Cu mineralization, but did not locate the third centre because of dilution by background material. Anomalous Mo associated with Cu is a favourable pointer to a porphyry environment. Au content can be ambiguous. Zn is anomalous in a zone peripheral to one porphyry Cu system. Increased care must be taken in assessing major alluvial-filled drainage systems where the stream sediment geochemistry can be obscured.

Ridge and spur soil geochemistry was effective in outlining the mineralized zones at all prospects except where there was landslip or "mud avalanche" cover. The latter feature is not unusual in young volcanic terrains in tropical environments. The efficacy of using detailed soil and pit geochemistry varied as a function of original sulphide content (particularly pyrite), individual elemental concentrations and correlations and weathering history.

As a direct pathfinder for Cu mineralization, geochemical Au determinations are preferred to those for Mo. Depending on the degree of fracturing, the original rock mineralogy and the weathering and leaching history, strongly acid soils can be developed independently of the original sulphide content; pH determinations may therefore be of little value.

I.P. and ground magnetics (rather than aeromagnetics) were valuable in helping to elucidate the geology. When significant amounts of sulphides and hydrothermal vein magnetite are present, geophysical methods can be applied to defining the extent of the mineralization. Quartz veining density is also recommended as a parameter with the qualification that a number of generations of veining, not all sulphide mineralized, may be present.

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