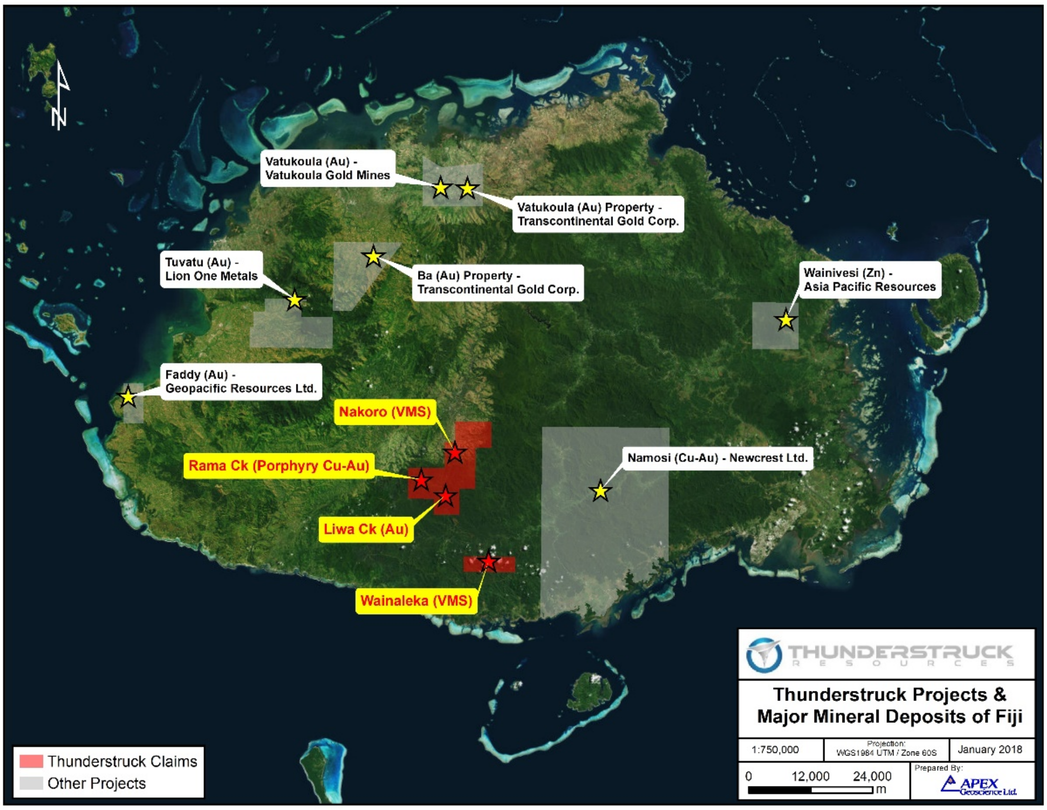
# Review of Fijian Volcanic-hosted Massive Sulfide (VHMS) Prospects





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## Executive Summary

- Thunderstruck Resources has the Wainaleka and Nakoro, high-grade, zinc-copper VHMS prospects – neither of which have been significantly explored in the nearly 40 years since their discovery.

- The scope of the report assess the geology and mineral deposits of the prospects, review the exploration program, and evaluate potential for further mineral deposit discovery.

- Based on geologic characteristics, the Fijian exploration areas contain numerous polymetallic, lens/sheet style, sub-seafloor, replacement-type VHMS prospects, with a high likelihood of further discovery.

- As the Wailaleka and Nakoro prospects are sub-seafloor, replacement-style VHMS prospects, this expands the exploration space within the Wainimala Group. With sub-seafloor, replacement-style VHMS deposits, mineralisation often occurs within a particular strata, but not always at the same position, hence increasing discovery space and opportunity.

- The Wainaleka and Nakoro mineralisation is open in many directions, hence further drilling is recommended to fully ascertain the size and extent of the prospects/deposits.

- Overall, the Fijian VHMS exploration program is sound and based on the solid geological, geochemical, geophysical, economic and logistical criteria, however the exploration program can be enhanced with new data and information.

- I suggest an improved exploration model be developed, and utilised, to aid in prospect discrimination, and drive exploration into the most favourable areas. The exploration model should include; lithology, lithogeochemistry, structure, alteration, metal zoning, exploration geochemistry, ore equivalent horizon, and geophysical attributes.

- Structure need more attention. It is apparent there is a discrepancy in the deformational models for the project areas, which will affect exploration targeting.

- Lithogeochemical analyses are required for chemostratigraphy, in order to determine the most favourable host rocks. Lithogeochemistry can also be utilised to interpret hydrothermal alteration, separate fertile from barren alteration, and determine proximity to prospects. Obtain SWIR analyses on all altered rocks on surface and from drill holes.

- Utilise an increased trace element suite in the surficial geochemistry program to determine the overall geochemical signature of the prospects and the proximal-distal footprint of the mineralisation.

- EM and IP geophysical methods, both on surface and downhole, should be incorporated into the exploration program.

- Continuation of a vigorous exploration program is warranted.

## Scope

At the invitation of Bryce Bradley, President/CEO, Thunderstruck Resources, I was invited to review the exploration program for volcanic-hosted massive sulfide (VHMS) deposits on their exploration claims in Fiji. The scope of the review was to assess the geology and mineral deposits of the prospects, review the exploration program, and evaluate potential for further mineral deposit discovery. Specifically;

- Review of the documentation provided on the background of the Nakoro and Wainaleka volcanic-hosted massive sulfide (VHMS) projects in Fiji.

- Provide expert advice relating to geological, geochemical and geophysical aspects of the Nakoro and Wainaleka (VHMS) projects in Fiji, highlighting any recommendations that would lead to an anticipated improvement in exploration outcomes.

The exploration history has been covered in various reports (e.g. Golder Associates, 1980; Rugless, 1983; Wolstencroft, 2014; Page, 2014) and I will not go over that material again. However, Page (2014) noted there has only been only limited interpretation of the mineralisation types, volcanic environment, possible depositional environment of the sulfides, and a structural interpretation. I will concentrate on these features in this report.

## Activities

This desktop review was completed in the June, 2018.

## Information Provided

This interpretations and conclusions contained in this report are based on a review of the following information provided by Bryce Bradley.

- Reports, assays, figures, maps etc. from Thunderstruck Resources data room.

In addition, relevant material (academic papers, conference abstracts and presentations, etc) was sourced from my library and the internet. I have not visited the Fijian sites, nor looked at any rocks, core, maps or databases apart from that provided.

## Background

Thunderstruck Resources owns 100% of two confirmed, high-grade, zinc-copper VHMS prospects (Nakoro and Wainaleka) drilled by Anglo Pacific in the 1970s – neither of which have been significantly explored in the nearly 40 years since their discovery.

## Regional and Local Geology

The Fiji Platform currently sits within the plate boundary and is located at an unusual reversal of convergence direction: the Tonga subduction zone dipping west, the New Hebrides zone dipping east, and the central Fiji zone with no subduction at all. The geology and mineralisation of the island is dominated by extensive island arc volcanic and intrusive igneous activity (Page, 2014). The Fiji Platform records the complex history of an intra-oceanic subduction zone, including a reversal of arc polarity, arc fragmentation, rapid rotation, and development of flanking backarc basins. This tectonic history is paralleled by a complicated magmatic evolution that progressed from low-K tholeiitic to medium-K calc-alkalic to shoshonitic to alkali OIB magmatic affinities (Orovan, 2016).

Geologically, Viti Levu has been subjected to a complex series of crustal plate rotations and the geological history is dominated by island arc development and later rifting similar to that seen in the neighbouring Pacific Rim countries. The geology of Viti Levu can be simplified into pre-orogenic and post orogenic rocks (Figure 1). The pre-orogenic rocks of Late Eocene to Oligocene age mainly occur in the southern part of Viti Levu and consist of volcanic and sedimentary rocks, with the former dominating. In the Late Tertiary there was a period of intense orogenic activity during which the pre-orogenic rocks were extensively folded and faulted. The post orogenic rocks of Late Tertiary age consist predominantly of volcanics, mainly basalt.

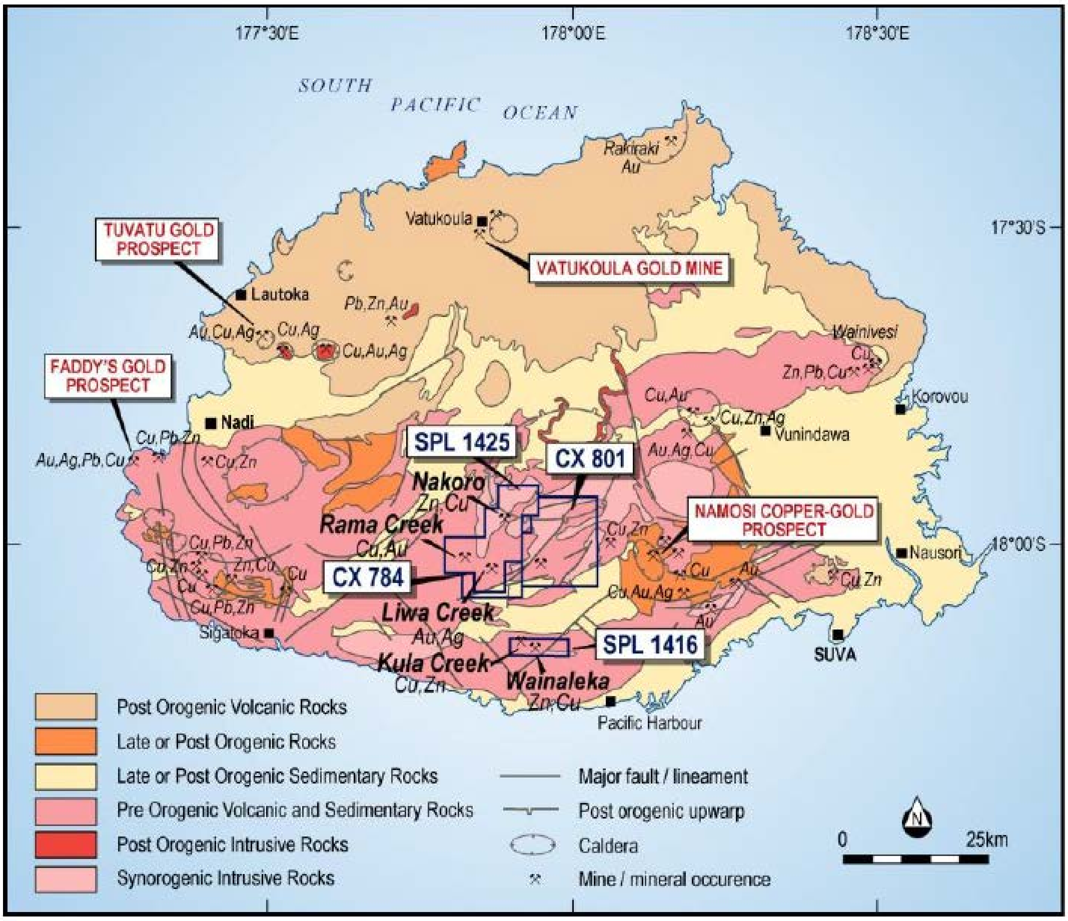


Figure 1: Orogenic rock units on Viti Levu and location of Thunderstruck Resources licences. The Nakoro and Wainaleka VHMS prospects occur in pre-orogenic volcanic and sedimentary rocks (Page, 2014).

Magmatism and precious and base metal mineralisation occurred episodically throughout the evolution of the Fiji Platform. The oldest mineral occurrences were emplaced during the early arc stage of the Vitiaz Arc (Early to Middle Miocene) and are hosted within low-K tholeiitic volcanics of the Wainimala Group (Figure 2). These mineral occurrences are predominantly base-metal rich volcanic-hosted massive sulfide (VHMS) deposits/prospects (e.g., Colo-i-Suva, Nakoro, Wainaleka and Wainivesi) that are concentrated in southeastern Viti Levu (Figure 3). Manganese deposits also formed during the early arc phase (Orovan, 2016).

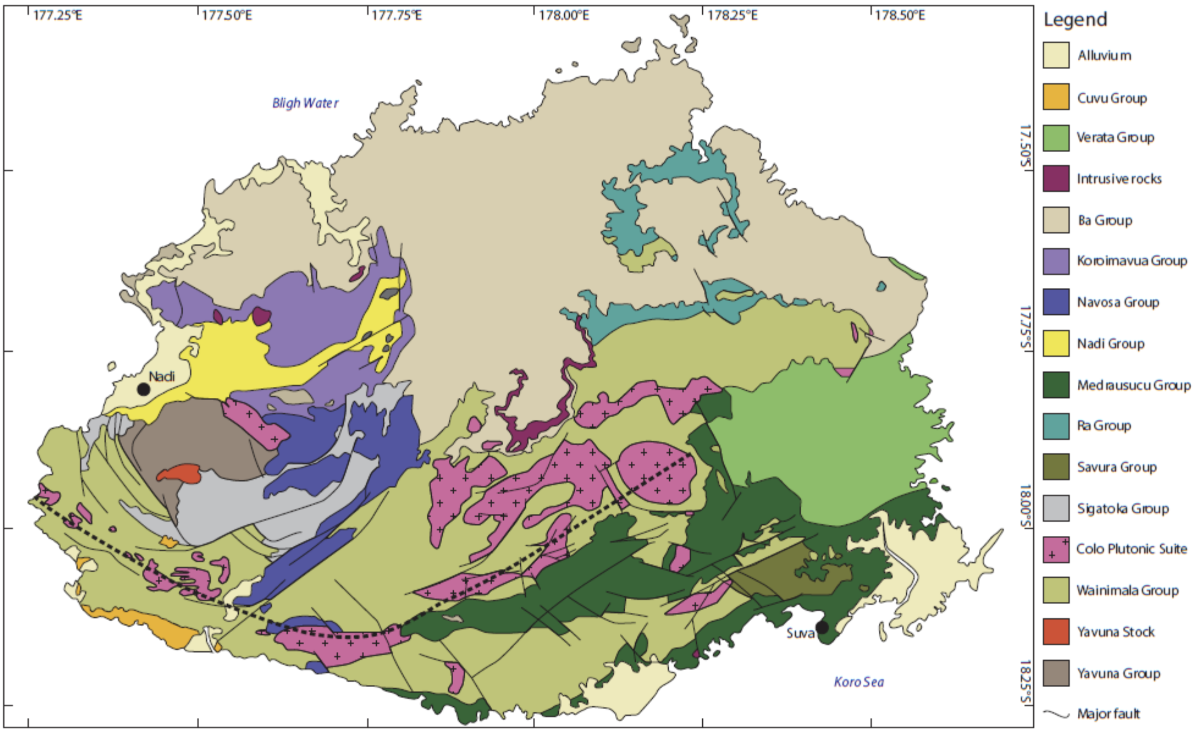


**Figure 2:** Simplified geological map of Viti Levu, Fiji. Black dashed line is the trace of the Wainimala Oroclinal Flexure. Thunderstruck Resources' VHMS prospects are hosted in the Wainimala Group. (From Orovan, 2016).

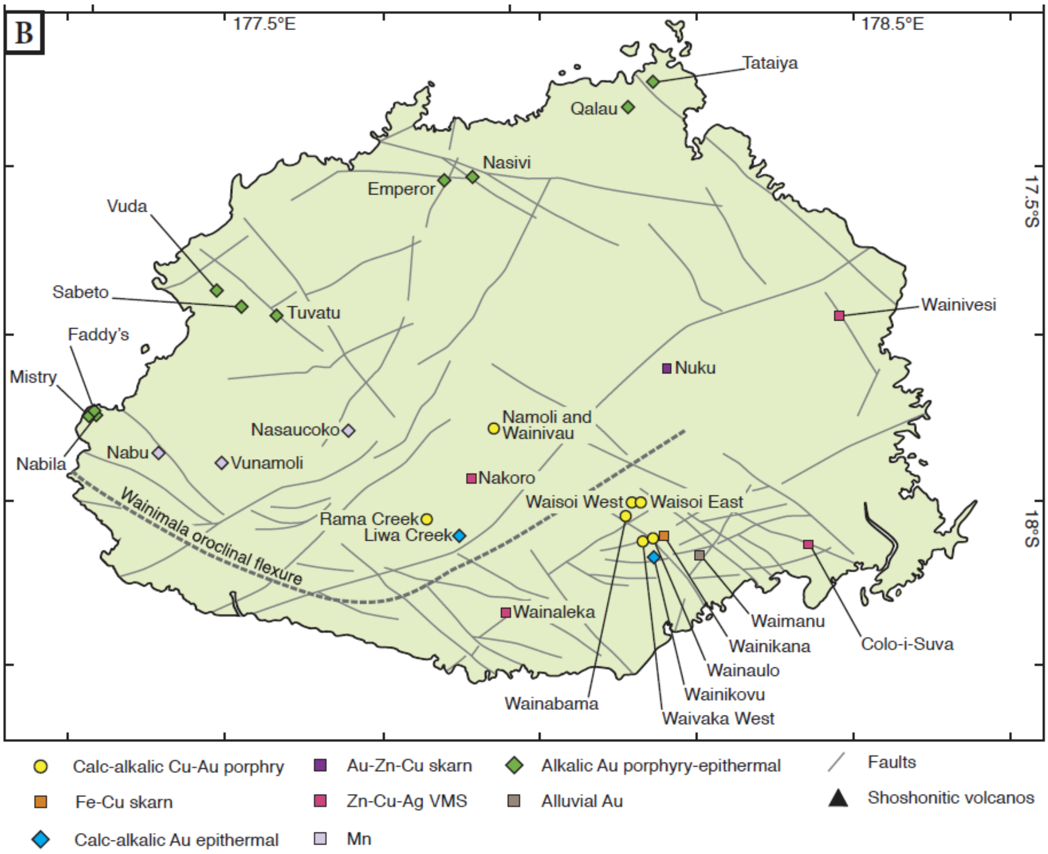

**Figure 3:** Metallogenesis of Viti Levu. Early arc stage mineralization consists of Zn-Cu-Ag VHMS deposits and prospects in southeastern Viti Levu. Mature arc stage mineralization consists of calc-alkalic porphyry, epithermal and skarn deposits along the Wainimala Oroclinal Flexure (dashed black line). Early rifting stage consists of calc-alkalic Cu-Au(-Mo) porphyry deposits of the Namosi district and alkalic Au-Ag porphyry-epithermal deposits and prospects along a 250 km-long corridor in northern Viti Levu. (Modified from Orovan, 2016).

The Thunderstruck project areas are in the Wainimala Group of Late Oligocene to Middle Miocene age (Figure 4). This group consists mainly of basaltic volcanic rocks, with subsidiary dacite and rhyolite, and to a much lesser extent sedimentary rocks. During the Middle to Late Miocene, orogenic activity affected this group, with extensive folding and faulting. The major event during this orogeny was the emplacement of the Colo Plutonic suite, (sometimes referred to as Tholo Plutonic Suite). Generally, this suite consists mainly of gabbros, tonalites and trondjhemites (Page, 2014).

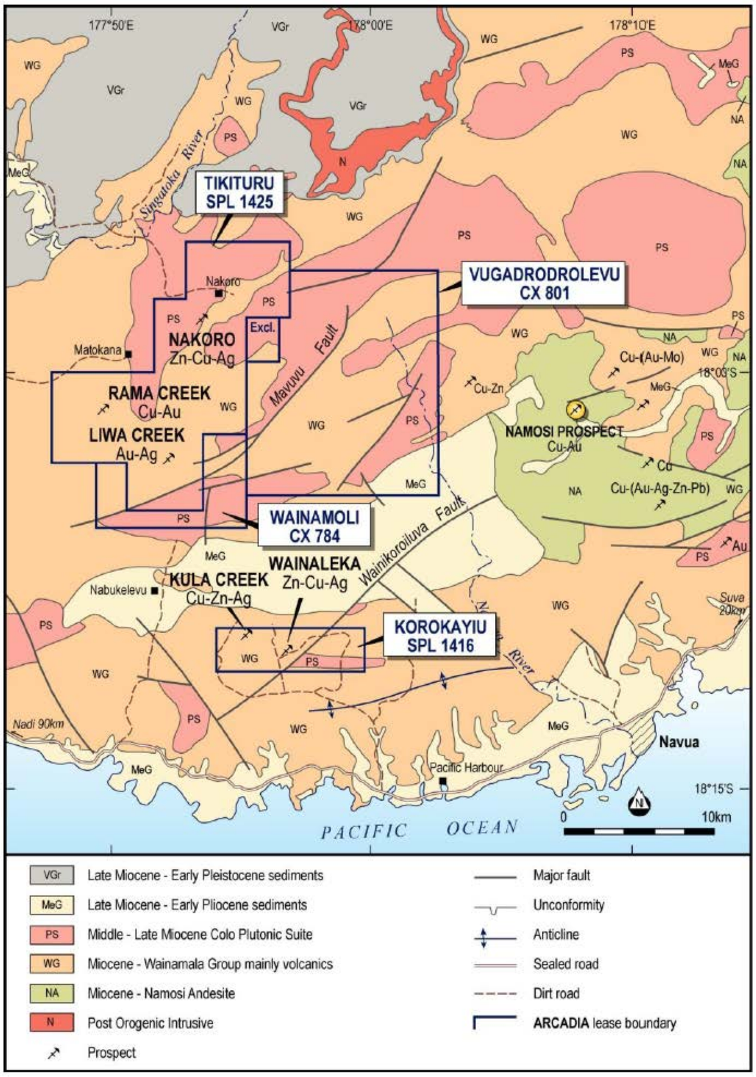


**Figure 4:** Regional geology of the Nakoro and Wainaleka prospect areas. (Page, 2014)

**Wainaleka Prospect**

<u>Geology</u>

Geology of the Wainaleka prospect is shown in Figure 5. Two-volcano-sedimentary suites are recognised (Rugless, 1983). A basement assemblage of intercalated spilitised, tholeiitic basalt and indurated grey to pink pelagic mudstone is overlain by younger assemblage comprising tholeiitic basalts, sodic rhyolite, andesite and associated fragmental rocks (Rugless, 1983). The andesitic unit of the younger suite, and the underlying basement units have been intruded by a 6 km long and 1,5 km wide, pervasively altered subvolcanic to volcanic rhyolite dome complex (Rugless, 1984).

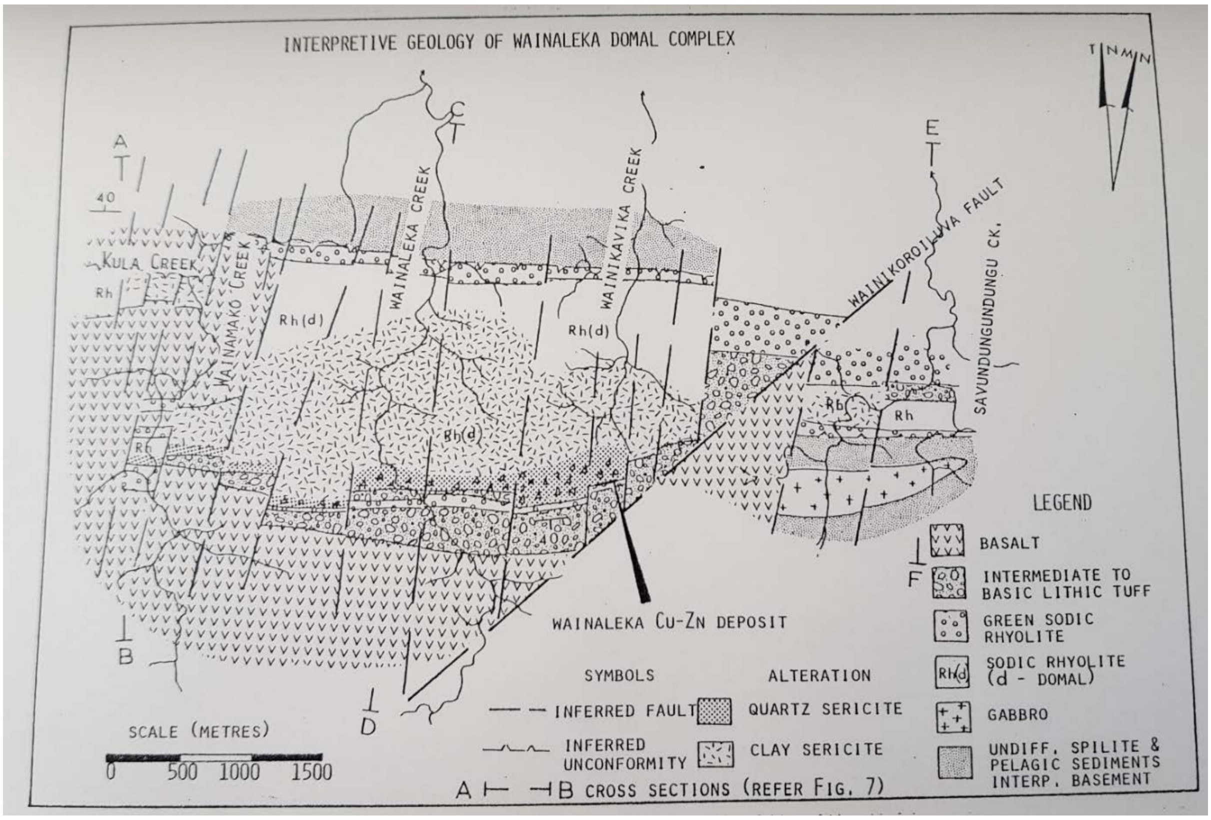


**Figure 5**. Interpretative geology of the Wainaleka dome complex (Rugless, 1983).

A fragmental unit containing coarse to lapilli size rhyolitic lithic clasts (Figure 6) overlies a sodic rhyolite along the southern flanks of the dome complex. This fragmental unit hosts the VHMS mineralisation and is locally thicker (up to 250m) in the Wainaleka area (Rugless, 1983).


Figure 6. Two examples of altered footwall volcaniclastic rocks (called lapilli tuff) (Rugless, 1983). These units would have been porous and permeable at the time of mineralisation.

<u>Alteration</u>

The VHMS mineralisation is accompanied by extensive hydrothermal alteration (Figure 7) occurring within the host dome complex and adjacent volcanic-volcaniclastic host rocks (Rugless, 1983). Alteration affects the dome complex and up to at least 1000 m stratigraphically below the mineralised lens (Rugless, 1983). Low-grade alteration of the hangingwall lithologies was observed (Rugless, 1983).

The following description of the alteration is from (Rugless, 1983);

Zone I. Quartz-sericite (phyllic) alteration occurs along approximately 2000 m of the mineralised contact and extends 300 m below the mineralised lens.

- Type 1. Intense quartz-sericite alteration (silicification) closely associated with mineralised lens and underlying stockwork zone. It occurs as a 20 to 25 m wide zone associated with strong mineralisation, thinning to a 5 m wide zone associate with weaker mineralisation peripheral to the main mineralised lens.
- Type 2. Quartz-sericite-clay alteration peripheral Type 1 and represents main type of alteration within Zone 1.
- Type 3. Quartz-chlorite alteration gradational to Type 2.

- Type 4. “Jasper” chlorite alteration peripheral to Type 3 (considered a variation of Type 3).
- Type 5. Gypsum-chlorite-clay alteration peripheral to the stockwork mineralisation.

Zone II. Clay-sericite (argillic) alteration that envelopes Zone I, as broad as 4000 m long, 800 m wide affecting both fragmental and coherent lithologies within the dome complex.

Zone III. Clay-carbonate±chlorite±epidote alteration peripheral to Zone II within the dome complex and underlying country rocks. It extends at least 1000 m below the mineralised lens.

Zone IV. Chlorite-albite-carbonate±epidote±zeoloite (intermediate to basic lithologies) and montmorillonite-carbonate (felsic lithologies) propylitic alteration that occurs in the hanngingwall rocks extending at least 500 m above the mineralised lens.

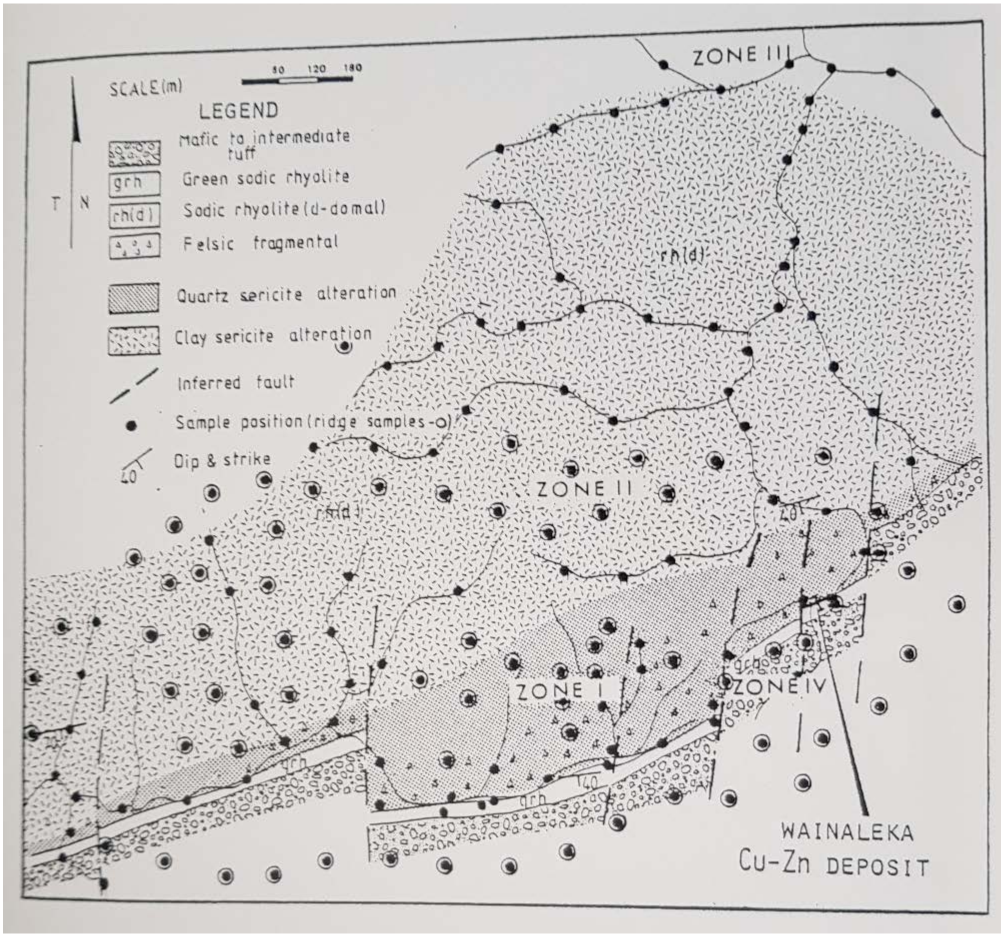


**Figure 7.** Map of alteration zones at Wainaleka (Rugless, 1983). Note the stratabound nature of the alteration along the favourable contact.

Mineralisation

At Waineleka, the base metal massive sulfides and strong sericite-clay pyrite alteration are concentrated at the contact between footwall rhyolites and hangingwall mafic volcanic and basalt. The lithologies and mineralisation dip to the south and southeast (Page, 2014). The mineralised lens has dimensions of 100 m strike length, 5 m average width and 120 m maximum down dip extension (Rugless, 1983).

The mineralised lens exhibits mineralogical and metal zoning. A top consists of granular sphalerite in a siliceous matrix underlain by massive pyrite that grades into disseminated chalcopyrite and sphalerite (Figure 8). The textures shown in Figure 8 are typical of replacement textures in a porous and permeable, syn-minerlaisation host rock. Low tenor chalcopyrite and pyrite stockwork mineralisation occurs below the mineralised lens, but does not form a well-defined pipe. Gypsum veining occurs laterally to the disseminated mineralisation (Rugless, 1983).

Field and core inspection by Page (2014) at Wainaleka showed massive pyrite, sphalerite and chalcopyrite associated with either kaolin or sericite depending on depth of the exposure. Footwall mineralization consists of pyrite-chalcopyrite stringers and disseminations, in silica-kaolin/sericite alteration that is zinc poor and form a second distinct copper-rich mineralization type. Chlorite or talc appears not to have been observed, which means the true feeder zone may not yet been found.  Lascelles (2018) report that for Wainaleka, sphalerite, covellite, and chalcopyrite are the main minerals of interest. Other sulfide minerals are pyrite, bornite, tetrahedrite/tennantite/enargite, and chalcocite. These minerals and textures are typical for VHMS deposits.

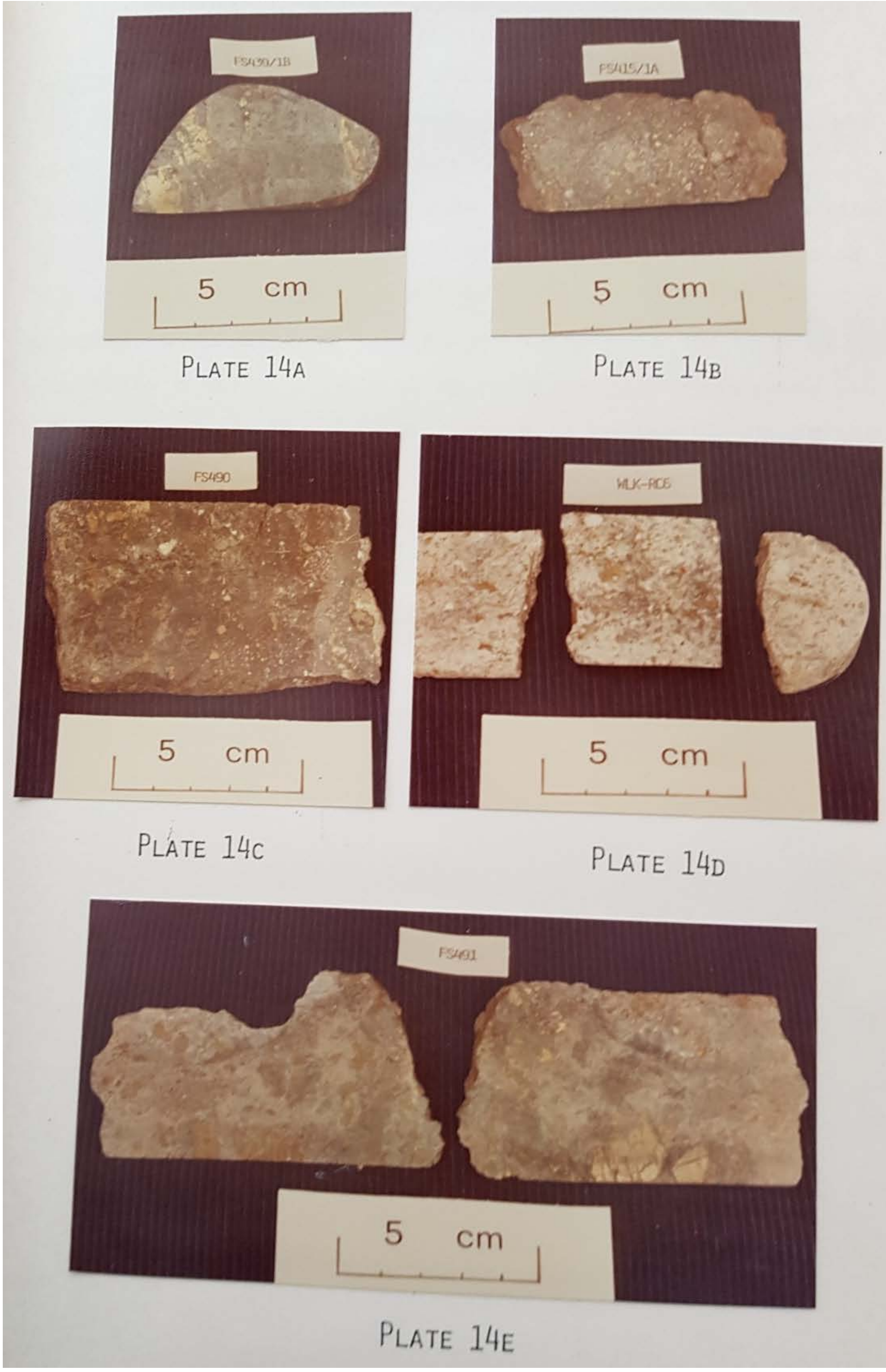


**Figure 8.** Sulfide mineralisation styles. Plate 14A (WLK 1B, 55.10 m) Massive sphalerite associated with pyrite as small pod at top of mineralised lens. Plate 14B (WLK 1A, 64.70 m) Sphalerite and interstitial pyrite within strongly altered tuffaceous matrix within Zn-rich portion of mineralised lens. Plate 14C (WLK 4, 47.20 m) Disseminated sphalerite, chalcopyrite and pyrite in strongly altered tuffaceous matrix with in Zn/Cu-rich portion of mineralised lens. Plate 14D (WLK 1B, 71.30 m) Blebs and stringers of chalcopyrite and disseminated pyrite in quartz-sericite altered tuffaceous host in Cu-rich stockwork below mineralised lens. Plate 14E (WLK 4, 48/75 m) Disseminated sphalerite associated with chalcopyrite and pyrite in strongly altered (quartz-sericite-clay) tuffaceous host near bas of mineralised lens. From Rugless (1983).

Drilling conducted by Anglo indicates a southerly 40-60 degree dip and a southwesterly plunge to the mineralisation. There is good continuity of mineralisation between holes (Figures 9 and 10). The massive sulfide zone was drilled to a depth of about 75 metres and is approximately 5-7 metres thick. The copper-rich disseminated/stringer zone has been drilled to a depth of about 150 metres and is some 2-5 metres thick. Both zones were intersected over a strike length of about 300 metres and are open at depth and to the west (Page, 2014).

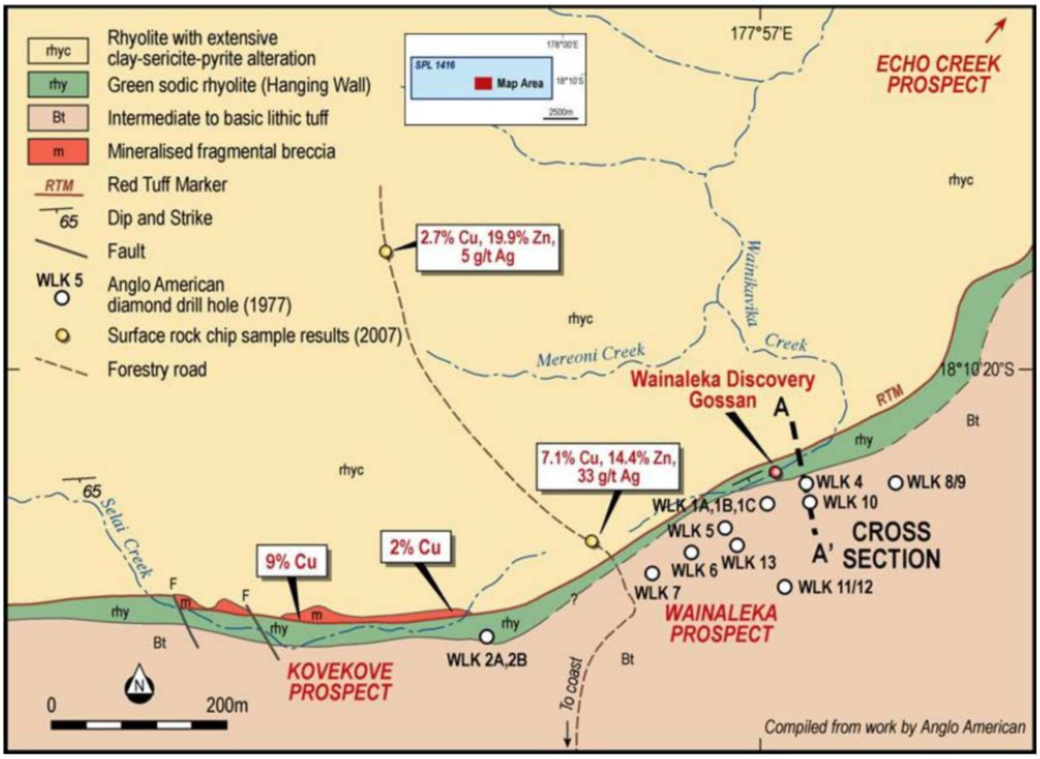


**Figure 9.** Surface geology and drill locations, Wainaleka prospect (Page, 2014).

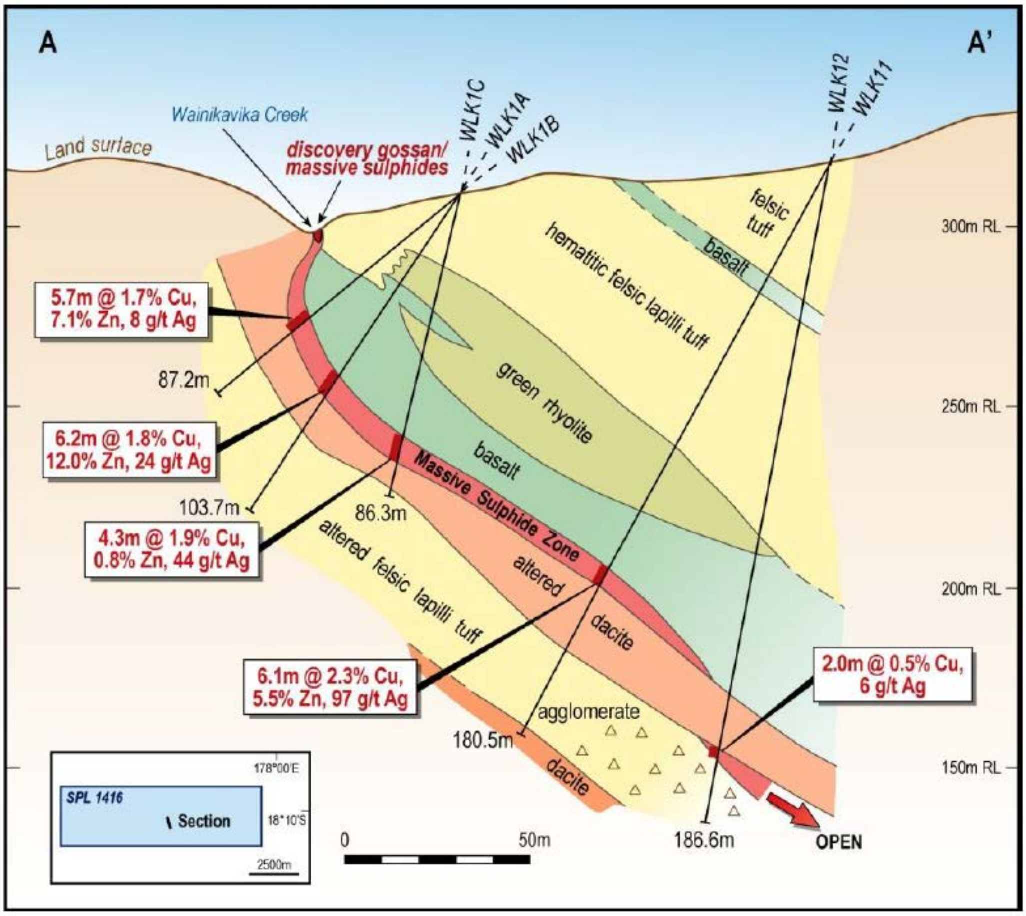


**Figure 10.** Cross-section at Wainaleka looking east

**Nakoro Prospect**

Geology of the Nakoro prospect area is dominated by the Wainimala Group and the Colo Plutonic Suite, sometimes referred to as Tholo Plutonic Suite. The Nakoro Prospect area contains several prominent limonitic gossans over a strike length of 700 m (Figure 11). Beneath the gossans there is intense silicification and argillic, phyllic alteration with the silicification being the more extensive. The mineralisation is hosted by trachyte close to the contact with an overlying andesite (Figure 12). Little lithological information was found to determine the nature of the host rocks (i.e. coherent vs volcaniclastic rocks), although the geological cross section (Figure 12) shows the mineralisation within a fragmental rock or breccia (similar to Wainaleka). Drilling showed the zone to strike NE (i.e. similar strike to the gossans) with an interpreted shallow dip of 100 to the southeast (Page, 2014).

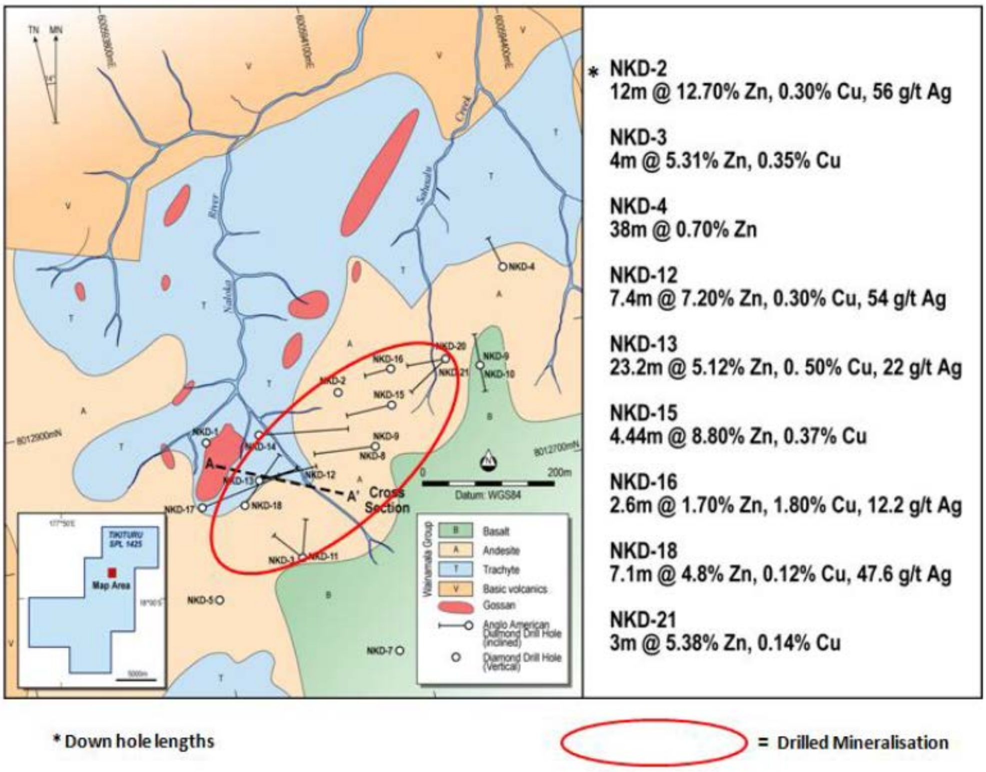


**Figure 11.** Nakoro prospect geology and significant drill intercepts (Page, 2014).

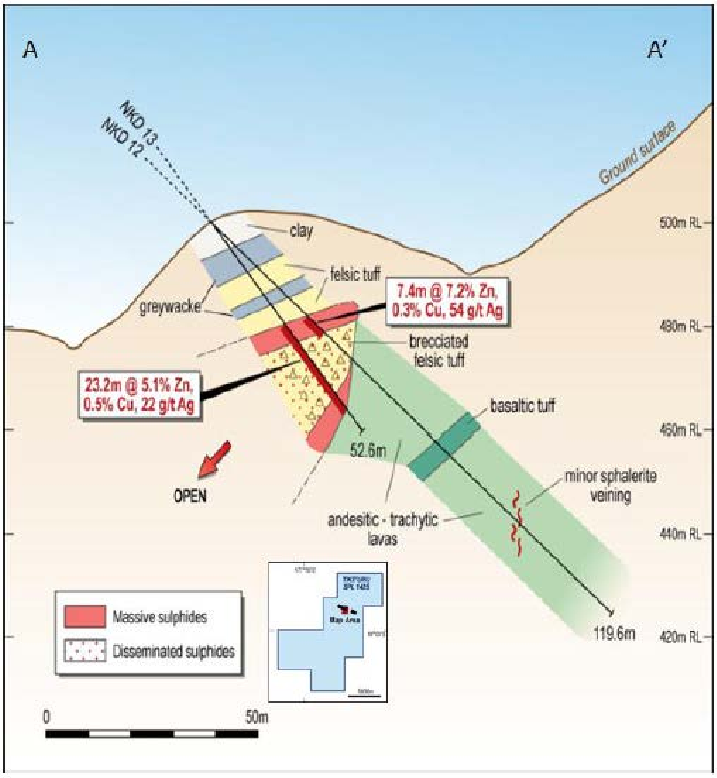


**Figure 12.** Nakoro cross section (Page, 2014). The mineralisation appears to be in a volcaniclastic or breccia unit, a similar setting as Wainaleka.

Sulfides occur as disseminations in the silicified rocks, as veinlets and massive sulfide. Common minerals include pyrite, sphalerite, barite, chalcopyrite, bornite and covellite, with minor galena and tetrahedrite-tennantite. Pyrite is the most common and earliest formed sulfide phase, forming up to 5% of the silicified rock. Sphalerite is of several generations, forming massive to weakly banded material, clots in fine grained pyrite-sericite rocks and as replacement textures. Sphalerite may also be locally abundant in shear zones, concentrated in argillic fault pug or banded fissure fillings.

At Nakoro, field and core inspection by Page (2014) showed massive pyrite, with varying amounts of sphalerite and minor chalcopyrite, associated with either kaolin or sericite depending on depth of the exposure. The mineralisation occurs at the contact of trachyte and more mafic, andesite hangingwall. The massive sulfide zone was drilled to a maximum depth of about 125 metres. Widths appear to average around 7 m and were drilled over a strike length of some 300 m and open in all directions. Therefore, the copper rich feeder zone probably has not been defined yet (Page, 2014).

**Types of VHMS Deposits**

The types/morphologies of VHMS deposits can be broadly divided into two categories;

1. Mound deposits (Figure 13A) -- high aspect ratio, narrow and elongate massive sulfide with a well-developed, funnel or carrot-shaped stringer zone and alteration system directly beneath the mound. The mound style of deposits are formed above a footwall, host rock sequence dominated by coherent volcanic rocks (e.g. lavas, domes, sills). Hangingwall alteration is absent or rare. This style of VHMS deposit is formed by hot, minersalising fluids exhaling onto the seafloor.

2. Lens and blanket deposits (Figure 13B) -- low aspect ratio with dominant zinc-rich massive sulfide lens and subordinate stringer zone. The lens or blanket style are formed above a footwall, host rock sequence dominated by porous and permeable, volcaniclastic or sedimentary rocks. There is a variation from thin and extensive blankets with no stringer zones to thicker lenses with

laterally extensive strata-bound stringer zones and footwall hydrothermal alteration. Hangingwall alteration is common. This style of VHMS deposit is formed by a combination of hot, minersalising fluids replacing the volcaniclastic host rocks (sub-seafloor replacement) and hot, minersalising fluids exhaling onto the seafloor.

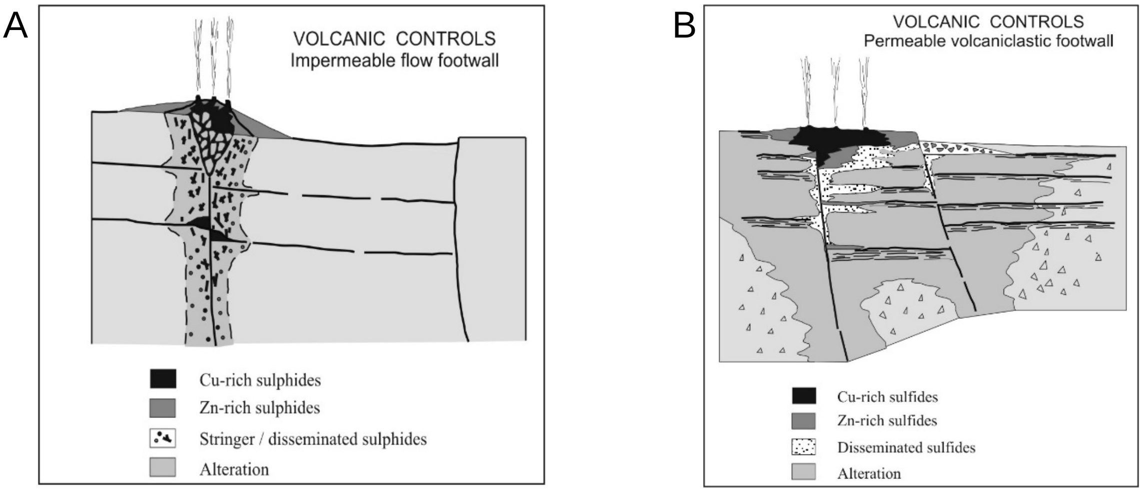


Figure 13. Differing styles of VHMS deposits A. Mound-style. B. Lens or blanket-style.

VHMS deposits can also be characterised by metal contents. Figure 14 show the fields for Cu, Cu-Zn and Cu-Pb-Zn type VHMS deposits. Figure 15 indicates that the Wainaleka prospect is a Cu-Zn-type VHMS deposit. Nakoro has a similar metal tenor.

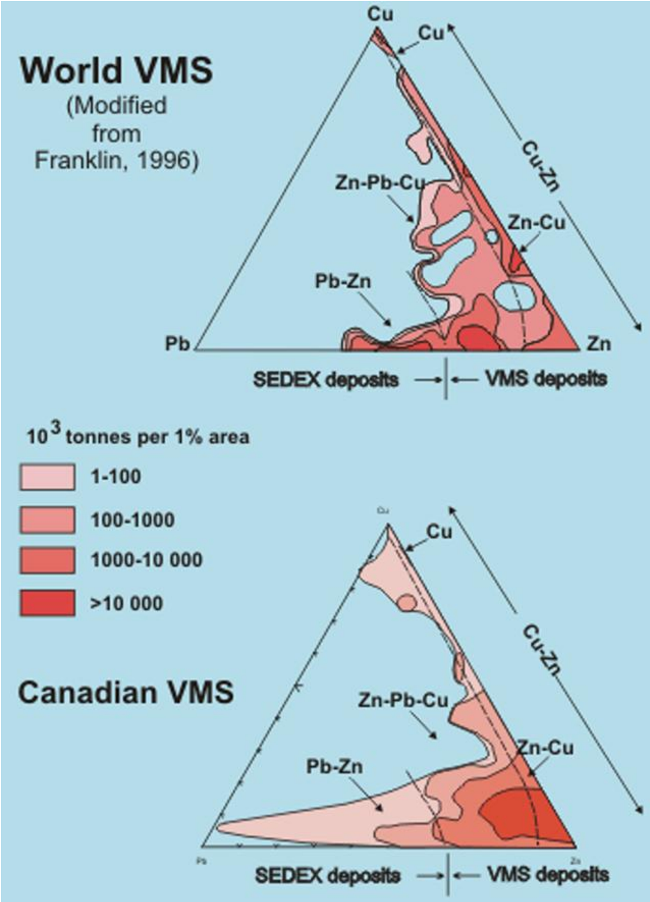


**Figure 14.** Plots of average metal content of worldwide and Canadian VHMS deposits from Franklin (1996).

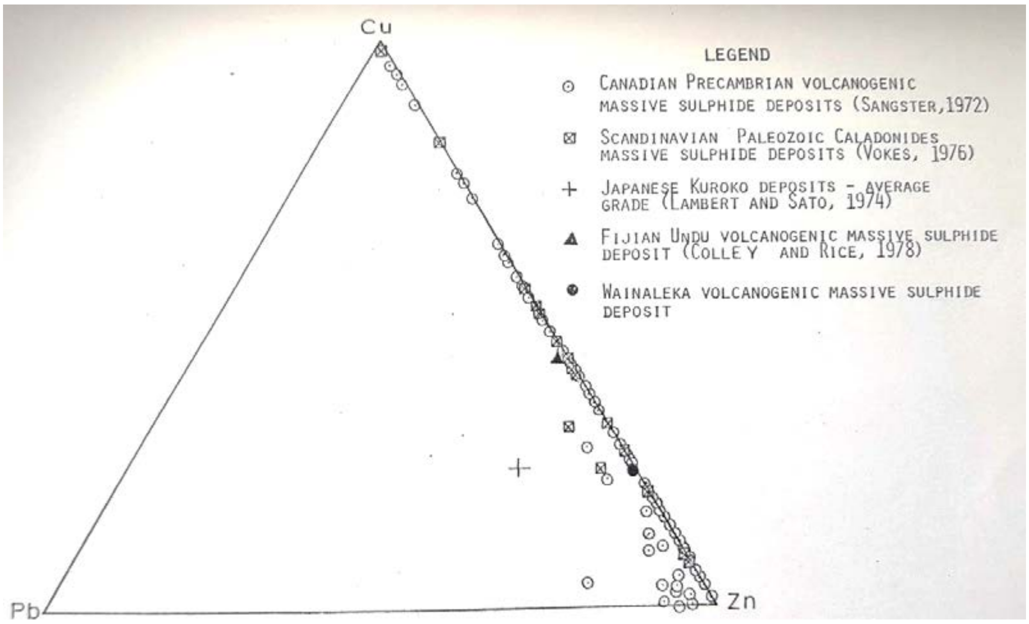


**Figure 15. P**lots of average metal content of VHMS deposits from Rugless (1983). The Wainaleka prospect (black circle) falls in the Cu-Zn VHMS field.

World-wide, VHMS deposits commonly occur in clusters within districts, with one or two large deposits and many smaller deposits/prospects (Figure 16). Figure 17 illustrates the cluster of VHMS prospects in the Wainaleka area. Once this area is explored thoroughly, I am confident more discoveries will be made.

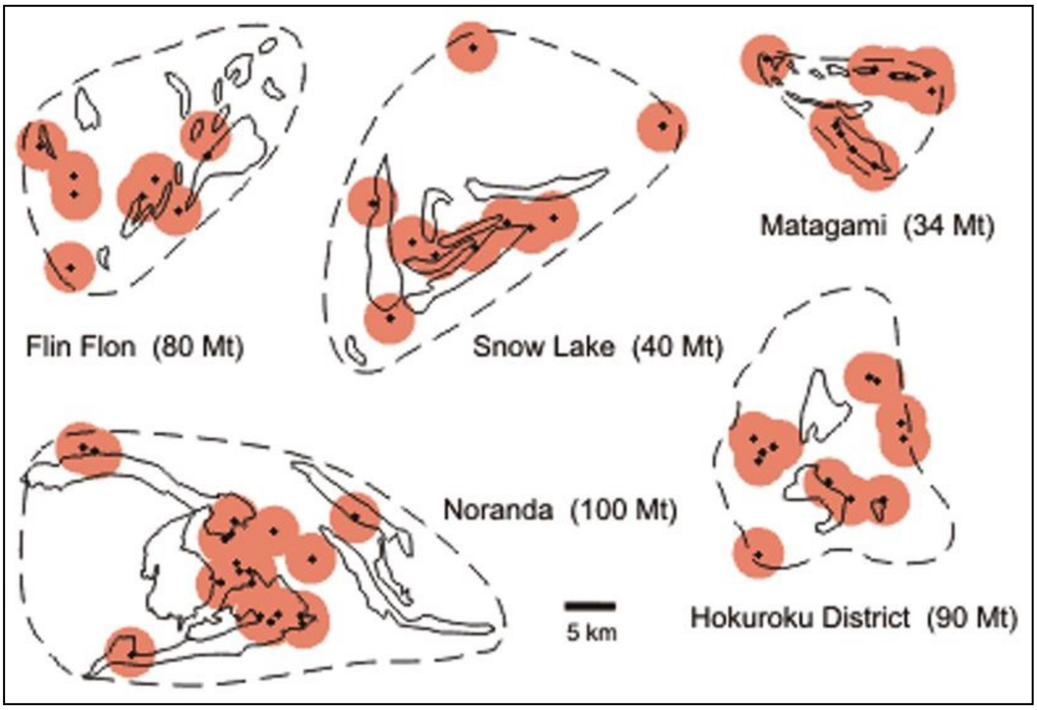


**Figure 16.** Various VHMS districts illustrating how deposits occur in clusters.

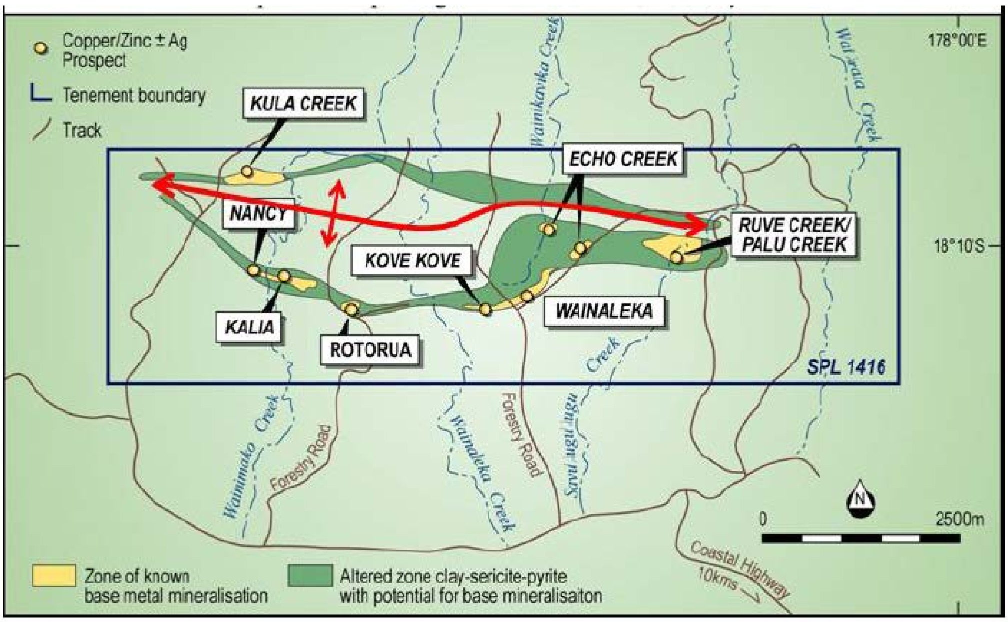


**Figure 17.** Distribution of VHMS prospects in the Wainaleka area, showing clustering.

## Implications

The Wainaleka and Nakoro VHMS prospects have;

- Host rocks – porous and permeable, volcaniclastic footwall lithologies

- Alteration – broad, stratabound distribution, not funnel/carrot shaped. Zonation from quartz-sericite proximal to mineralisation to chlorite and clay distal.

- Mineralisation shape – lens or blanket-shaped, minor pods.

- Sulfide mineralogy – sphalerite, covellite, chalcopyrite, pyrite, bornite, tetrahedrite-tennantite, galena, enargite, and chalcocite. It is highly likely that covelite and chalcocite are supergene minerals, developed from the weathering of chalcopyrite.

- Sulfide textures – disseminated sulfides, minor massive sulfide pods, replacement of host volcaniclastic host rocks, and stringer veins/veinlets.

- Ore equivalent horizon – gossans from weathering of sulfides, hematitic marker horizon at Wainaleka (exhalite?)

Based on the above characteristics, Wainaleka and Nakoro can be classified as sub-seafloor, replacement-style, Cu-Zn VHMS prospects.

## Technical Advice

The Thunderstruck Resources exploration strategy and objectives for the Fijian project areas are sound and there is good potential to discover further mineral resources.

As the Wainaleka and Nakoro prospects are characterised as sub-seafloor replacement-style VHMS deposits, this expands the exploration space within the host rock package. With sub-seafloor, replacement style VHMS deposits, mineralisation often occurs within a particular strata, but not always at the same position, hence increasing exploration space.

Sub-seafloor replacement-style VHMS deposits tend to be more sheet or lens-like, have more diffuse stringer zones and often are enveloped by alteration, compared to mound-style VHMS deposits that have well-developed stringer and alteration zones. Exploration techniques should be tailored to this style of mineralisation within the Fijian project areas.

In order to develop an appropriate exploration strategy/model, it is important to utilise geologic information, in combination with the geochemical and geophysical attributes of the mineralisation and alteration.

I suggest that following attributes be combined;

- Lithology
- Lithogeochemistry
- Structure
- Alteration (mineralogy, assemblages, textures, SWIR, geochemistry)
- Metal zoning
- Exploration geochemistry
- Ore equivalent horizon
- Geophysics

All this information can be combined to develop an exploration model for the VHMS mineralisation in the Fijian project areas, and aid in the development of a robust exploration program.

## 1. Lithology

To date, all mineralised prospects have been found in the Wainimala Group, therefore specific units are of the highest priority for further work, particularly if these prospects are along strike or mapped in a similar horizon. Is there a particular unit or package of units within the Wainimala Group Formation that hosts mineralisation? I suggest refining the stratigraphy within the Wainimala Group, and target the most prospective horizons.

## 2. Lithogeochemistry

Lithogeochemistry is an effective tool in petrology, chemostratigraphy, and mineral exploration of VHMS deposits, even in altered host rocks (Gifkins et al., 2005). There are three main applications of lithogeochemistry in mineral exploration:

(1) identification or discrimination of prospective and non-prospective areas and lithological units
(2) recognition of large alteration and geochemical halos to increase the size of exploration targets
(3) definition of exploration vectors based on compositional gradients around ore deposits

Major element compositions are routinely used to classify volcanic rocks in terms of petrogenesis and tectonic setting. However, the same method is not applicable to altered rocks because many of the major elements, especially Si, Fe, Mg, Ca, Na and K, are relatively mobile during alteration. Fortunately, several elements are chemically immobile during most types of alteration and these can be reliably used to classify and correlate altered volcanic rocks (Gifkins et al., 2005).

The high-field-strength elements Ti, Zr, Nb and Y are relatively immobile during hydrothermal, diagenetic and weathering alteration, and during regional metamorphism up to mid-amphibolite facies. Many studies of VHMS deposits have shown that Al, Ti, Zr, Nb, Y, heavy REE (Lu, Yb), Hf, Ta and Th, and in some cases P, Sc, V and Cr, remain essentially immobile during alteration. In practice, Ti and Zr are the most reliably immobile elements (Gifkins et al., 2005).

I suggest a review of any existing lithogeochmical data, in combination with the acquisition of new data, on the rocks for the Wainamala Group in order to determine the lithogeochemical signature of differing units. Many criteria are useful in using lithogeochemistry to characterise volcanic or volcano-sedmentary rocks (Gifkins, 2005), but Ti/Zr ratios are very good starting point. This information may yield results that will narrow down the unit or package of units that are more susceptible to hosting VHMS mineralisation.

Conventional X-ray fluorescence (XRF) analysis is an accepted technique for the acquisition of accurate, precise, and robust lithogeochemical data. However, this method suffers from poor spatial resolution due to high analytical costs, extensive time lag between sample collection and laboratory results, and is sample destructive. Field-portable X-ray fluorescence (pXRF) analysers are proving to be an effective, real-time tool for the fit-to-purpose acquisition of lithogeochemical data in the mineral exploration industry, although they do not do all elements and the detection limits can be problematic at times.

**3. Structure**

The background information (above) highlighted the discrepancy between previous structural interpretations for Fijian prospect area. Rugless (1983) shows abundant faulting offsetting the mineralised horizon (Figure 5) at Wainaleka, but the Page (2014) diagrams (Figures 9 and 10) do not illustrate faults. An interpretation by Page (2014) suggests that there is a major doubly plunging anticline that has Wainaleka on the south side and other prospects on the north limb (Figure 18). At Nakoro, a fold structure is interpreted by (Page, 2014), but there is little evidence to back up this interpretation (Figure 19).

Clearly sorting out the structure for the prospect areas is key in aiding exploration.

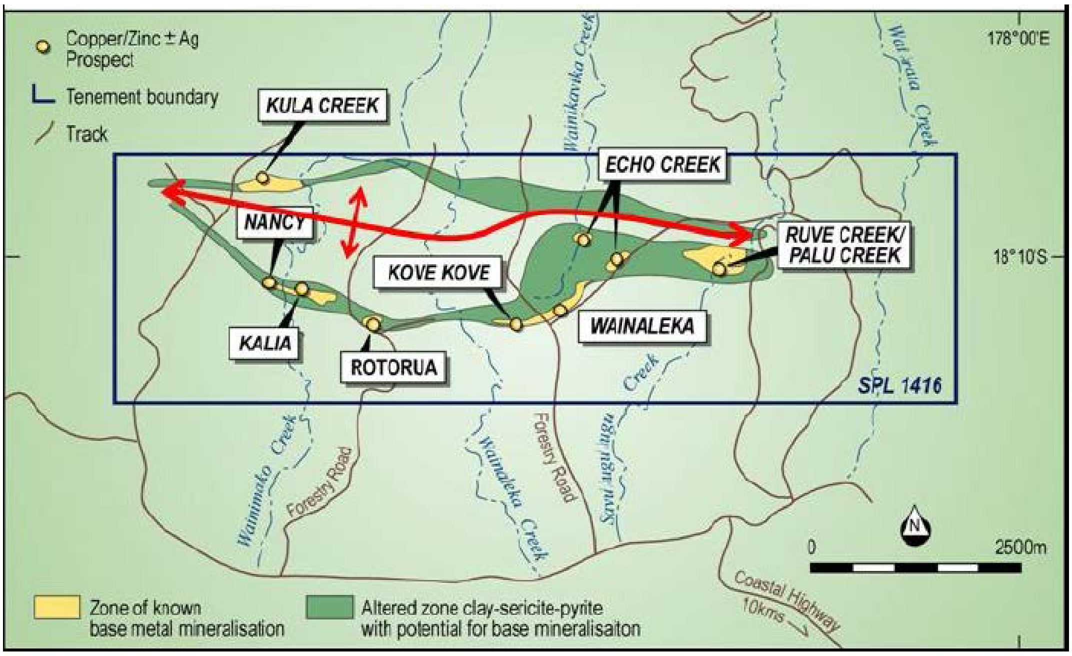


**Figure 18.** Interpreted doubly plunging anticline at Wainaleka (Page, 2014).

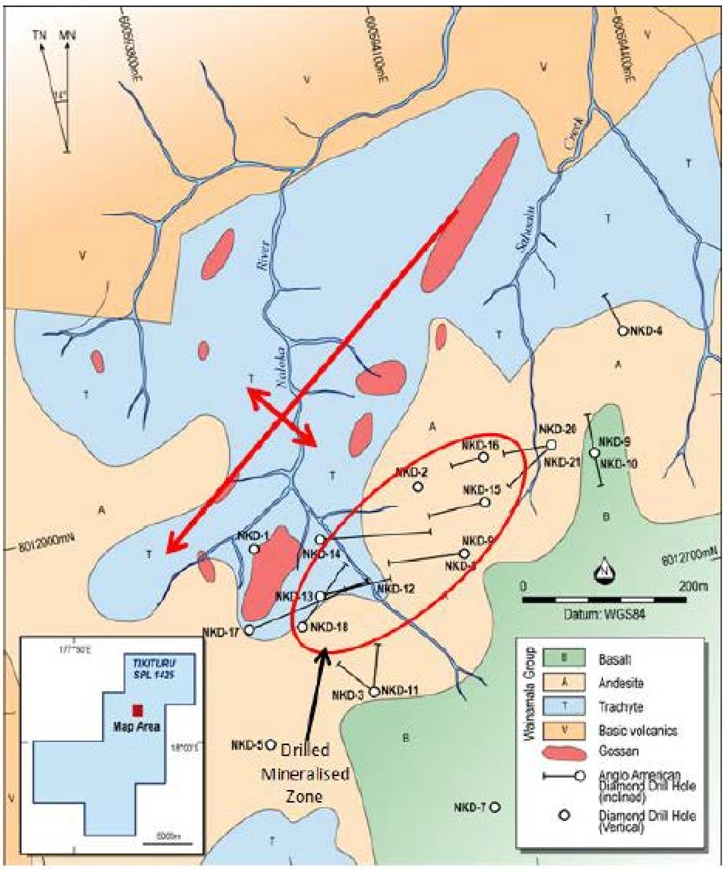


**Figure 19.** Possible south-west plunging anticline at Nakoro (Page, 2014).

## 4. Alteration

Hydrothermally altered rocks are a key in mineral exploration and hydrothermally altered zones around VHMS deposits provide much larger targets than the deposits themselves. The mineral assemblages, and in some cases the chemical composition, of the altered rocks may provide indications of the proximity of an ore deposit, and thus vectors towards mineralised rock. The results of alteration studies are commonly incorporated into models used in mineral exploration. Thus, the identification and interpretation of alteration facies should be a routine part of exploration for VHMS deposits.

### Mineralogy/Assemblages/textures

I recommend that alteration minerals (especially chlorite, sericite, quartz, carbonate, albite, clays, epidote) be identified, and grouped into consistent assemblages as observed. Sulfide distribution, particularly pyrite, is an important exploration technique, as VHMS deposits commonly have extensive footwall zones of disseminated pyrite. The ratios of quartz to phyllosilicates, sericite to chlorite, and carbonate to silicates are systematically-zoned around VHMS deposits, and recognition of the zonation patterns can provide useful exploration vectors (Large et al., 2001).

The texture of the alteration (pervasive, selective or fracture-fill) should also be noted. This information can be plotted on maps or sections to determine the zonation of the alteration mineralogy/assemblages/textures. Zonation is the key to determining proximity to mineralisation. Mineral chemistry of the alteration minerals can also give information on sites of potential mineralisation. For example, as ore is approached the Mn and/or Fe content of carbonate increases, (Mg + Fe) content of white mica increases, Ba content of white mica increases, and the Mg/(Mg+Fe) molar ratio of chlorite generally increases (Large et al., 2001; Gifkins et., 2005).

### SWIR Study of Alteration Minerals

Short wavelength infrared (SWIR) spectrometry has been used to identify fertile hydrothermal alteration zones around volcanic-hosted massive sulfide (VHMS) orebodies worldwide. At many deposits and districts hydrothermal alteration assemblages are uniformly dominated by fine-grained white mica and/or chlorite, - SWIR spectrometry is an ideal exploration tool for characterizing this fine-grained hydrothermal alteration, quantifying the intensity of alteration, trends in mineral compositions, and zonation at regional, district, or deposit scales. In general, AlOH wavelength of white mica decreases (SWIR) and FeOH wavelength of chlorite decreases (SWIR) towards mineralisation.

At the Myra Falls VHMS district, British Columbia, Canada, SWIR spectrometry on drill core (Fig. 20) has identified subtle shifts in the wavelengths of the AlOH absorption feature of white mica, corresponding to compositional changes in altered rhyolite distal and proximal to ore (Jones et al., 2005). AlOH absorption occurs at shorter wavelengths (<2,198 nm) and corresponds to lower Fe, Fe + Mg, and Si/Al and higher Na/(Na + K) in strongly altered samples proximal to ore (slightly sodic muscovites). AlOH absorption occurs at longer wavelengths (>2,206 nm) and corresponds to higher Fe, Fe + Mg, and Si/Al and lower Na/(Na + K) in samples distal to ore (nonsodic slightly phengitic muscovites). Chlorite compositions, identified by SWIR, also show systematic changes with intensity of alteration and distance from ore. The average wavelength of the FeOH absorption feature for chlorite in rhyolitic samples proximal to ore is 2,241 nm (intermediate Mg chlorite), whereas wavelengths in background samples average 2,247 nm (intermediate Fe chlorite). This information has aided exploration targeting at Myra Falls.

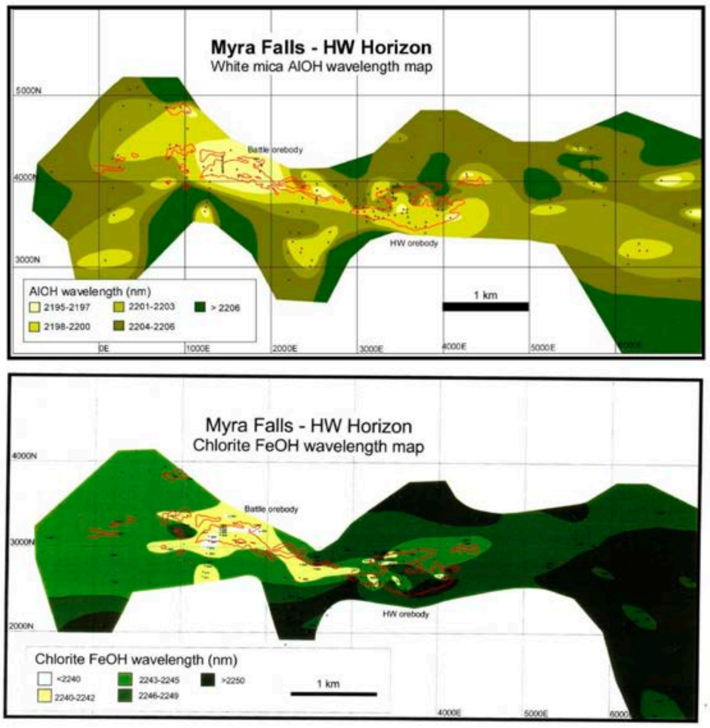


**Figure 20.** White mica AlOH and chlorite FeOH from SWIR data for the Myra Falls VHMS district, BC, Canada (Jones et al., 2005).

Airborne SWIR surveys have also been very effective in identifying VHMS-related hydrothermal alteration minerals and their characteristics in several VHMS districts. Figure 21 shows the results of the HyMapper survey done by the CSIRO over the My Lyell district Tasmania. The denuded hills surrounding My Lyell makes this type of survey applicable. At Mt Lyell, VHMS alteration (chlorite and sericite), advanced argillic alteration (pyrophyllite and topaz), as well as weathered sulfide-bearing waste rock (jarosite) can easily be identified. However, due to the thick tropical vegetation in Fiji this type of SWIR survey will be of little use.

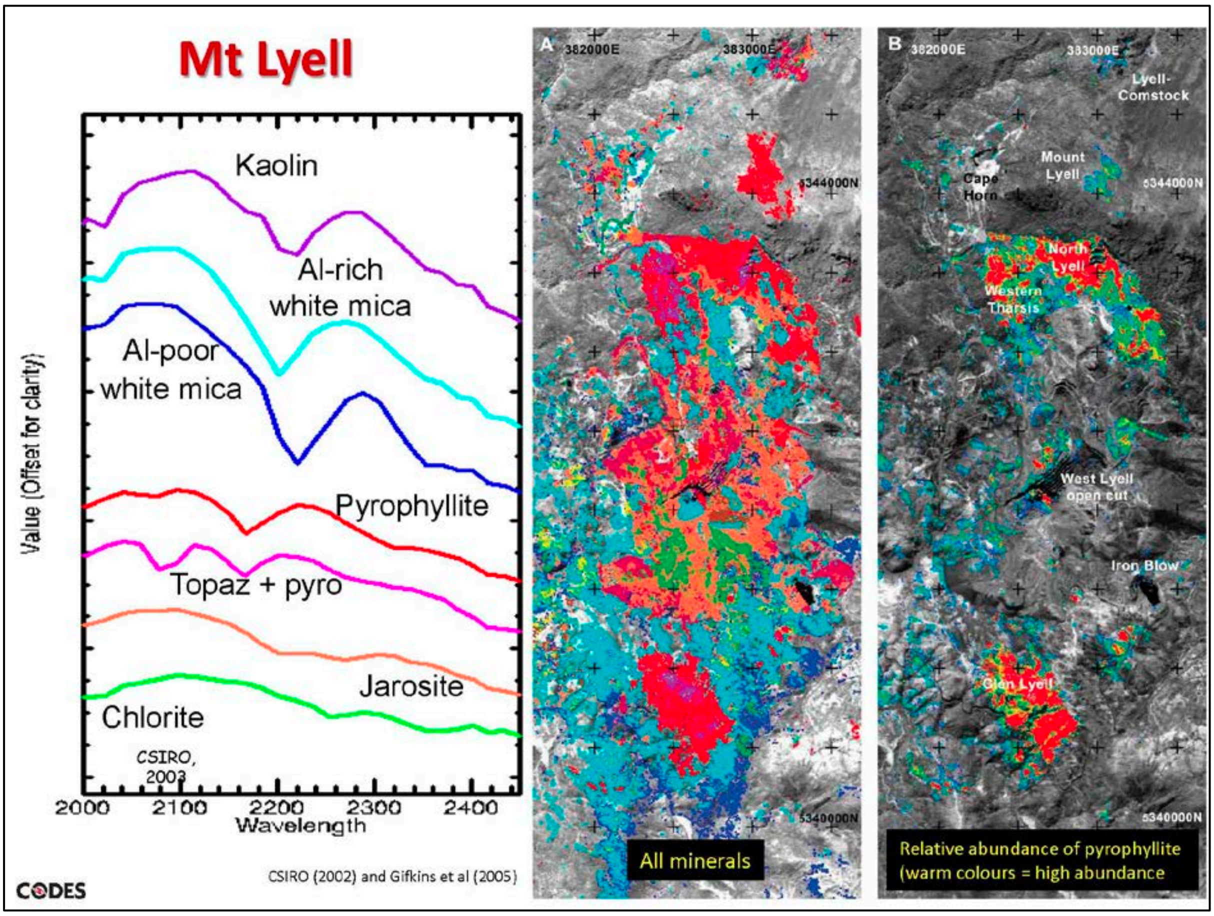


**Figure 21.** HyMapper alteration maps for the Mt. Lyell VHMS district, Tasmania. The SWIR data clearly shows the distribution of VHMS alteration (chlorite and sericite), advanced argillic alteration (pyrophyllite and topaz), as well as weathered sulfide-bearing waste rock (jarosite).

At the deposit scale, a SWIR study of the Henty VHMS deposit in Tasmania (Figure 22) by Howard (2004) showed that AlOH gradient with main alteration facies systematically increased into the mineralised zone. In addition, the Mg/(Mg + Fe) of white mica increases with alteration intensity.

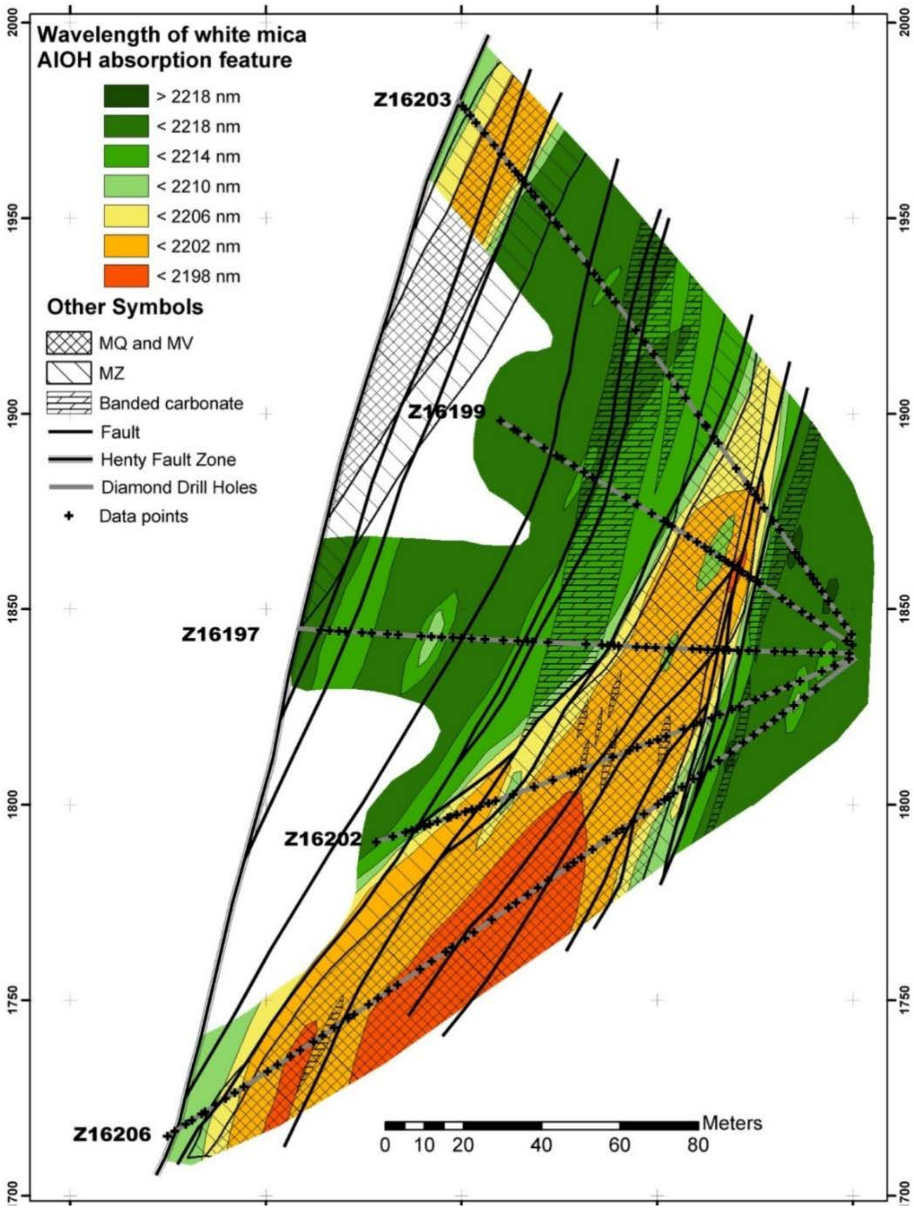


**Figure 22.** Distribution of SWIR white mica AlOH absorption feature and zonation to ore at the Henty VHMS deposit, Tasmania (Howard, 2004).

At the Fijian VHMS prospects, routine SWIR analyses should be collected from surface rocks and core. I recommend that once the mineralogical, textural and geochemical alteration zonation is established, it should be incorporated into the exploration model.

Geochemistry

Lithogeochemistry can also be utilised to interpret hydrothermal alteration, determine fertile from barren alteration, and suggest proximity to ore bodies. It can frequently help to identify minerals and quantify compositional changes even in less intensely altered rocks that contain incipient, overprinting or domainal alteration minerals. Analysis of whole-rock samples to determine major element abundance is a way of supporting and augmenting estimates of mineral proportions and alteration intensity, which have been determined visually or by other methods.

Whole-rock geochemical data (major and minor elements) should be collected from proximal to distal altered rocks, and into unaltered lithologies. It is important to understand the background geochemistry to ascertain the chemical variations in the altered rocks.

Single element variations are the first part of the interpretation. Decreases in $Na_2O$ contents of volcanic rocks in footwall alteration zones, for instance, are usually related to increasing sericite or chlorite at the expense of plagioclase. $Na_2O$ depletion is a popular and reliable vector used in VHMS exploration. Distribution of increasing $K_2O$ contents is often related to increasing sericite alteration. Variations in carbonate content, both increases and decreases, are typically evident in $CO_2$ data and in CaO, MgO or $Fe_2O_3$, depending on the carbonate species.

However, relating the zonation lithogeochemical elements is often much more easily determined by using element ratios. For example; the Ishikawa alteration (AI) index (($K_2O$+MgO/($K_2O$+MgO+CaO+$Na_2O$)), Chlorite-carbonate-pyrite (CCPI) index ((FeO+MgO/(FeO+MgO+$Na_2O$+$K_2O$)), S/$Na_2O$, Ba/Sr and/or Rb/Sr ratios and Tl and Sb elemental distribution are all useful parameters. All of these can be calculated, interpreted and plotted from lithogeochemical data.

An example of the usefulness of the Ishikawa alteration (AI) index in determining highly altered zones (and hence sites of potential mineralisation) throughout a VHMS district is shown in Figure 23. I suggest that this approach could be applied to the Fijian project areas.

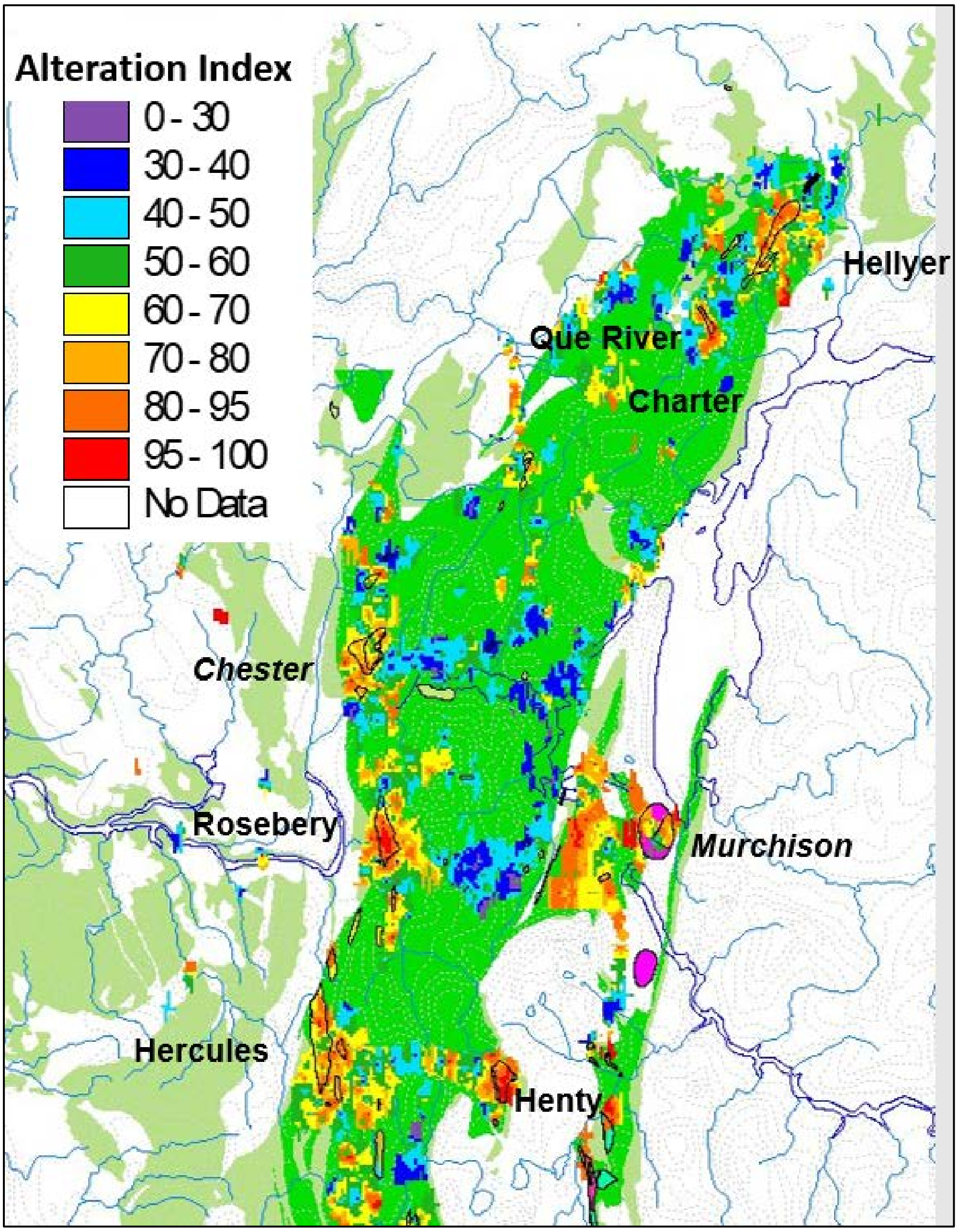


Figure 23. Whole rock data contoured for "Alteration Index" (($K_2O$+MgO/($K_2O$+MgO+CaO+$Na_2O$)) values. High values indicate highly altered rocks and proximity to potential VHMS mineralization. This Alteration Index effectively quantifies intensity of alteration in the large altered zones around known ore deposits. However, the AI also picks out Chester ('barren' VHMS – HS epithermal hybrid) and Murchison (granite-related K-rich alteration). Diagram from Gifkins et al. (2005).

In addition, volatile elements, such as Sb and Tl, have proven useful in extending the footprint of mineralised systems (Figure 24). Distribution of the more volatile elements surrounding the Fijian prospects may expand the alteration geochemical footprint and aid the exploration program.

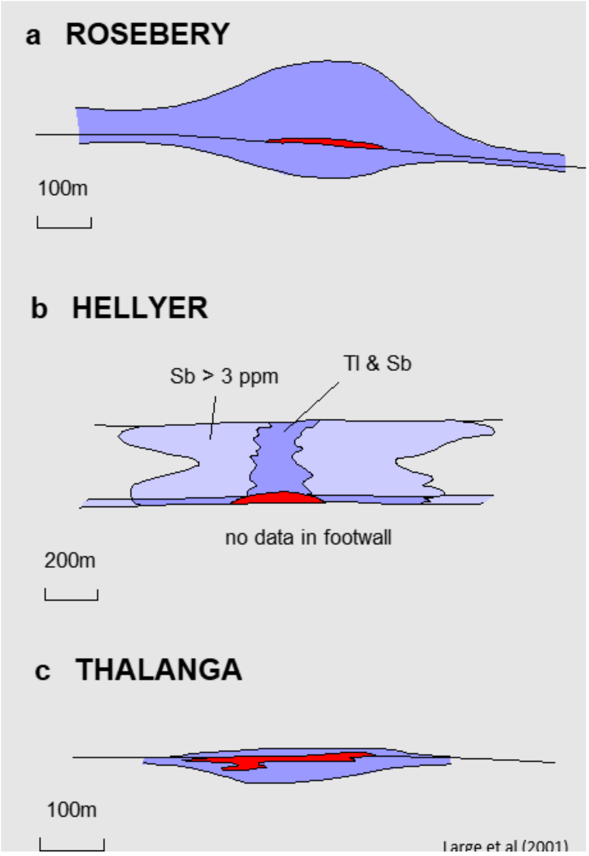


**Figure 24.** Tl and Sb distribution surrounding selected polymetallic VHMS deposits. A) Rosebery - up to 100 ppm Tl and Sb proximal to ore and 1-10 ppm within extensive halo zone. B) Hellyer - Sb and Tl halo within favourable horizon and extending vertically and laterally into hanging-wall. C) Thalanga - Tl (> 1 ppm) up to 50 m into hanging-wall and footwall and along favourable horizon. Diagram from Large et al. (2001).

## 5. Metal Zoning

VHMS deposits (ore and footwall stringer) are zoned in major (Figure 25) and trace elements (Figure 26). This zonation is very well constrained and repetitious throughout VHMS deposits world-wide in both mound and lens/blanket styles of mineralisation.

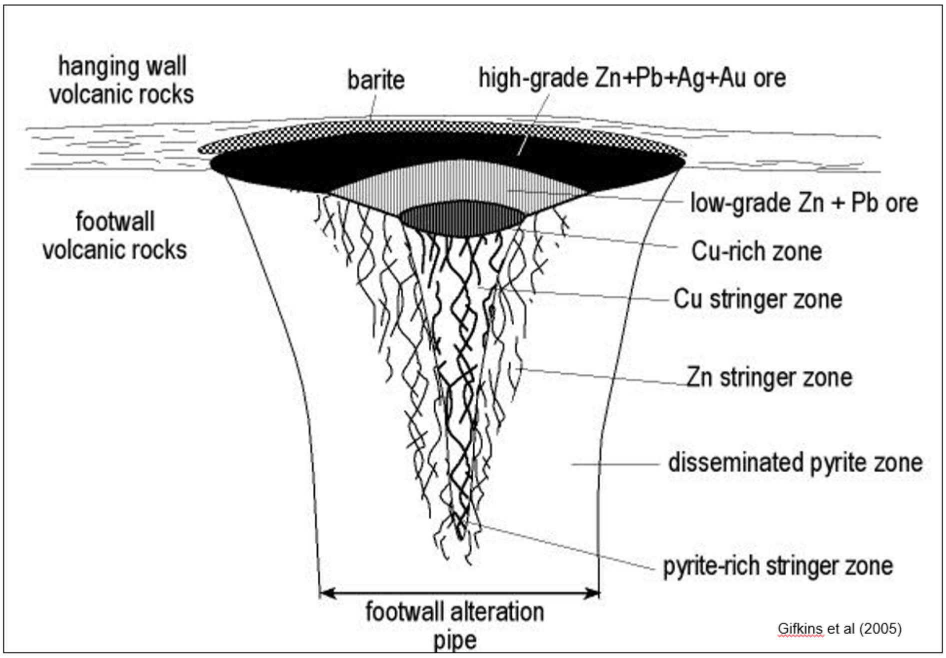


**Figure 25.** Schematic representation of metal zoning in VHMS orebody and underlying stringer zone.

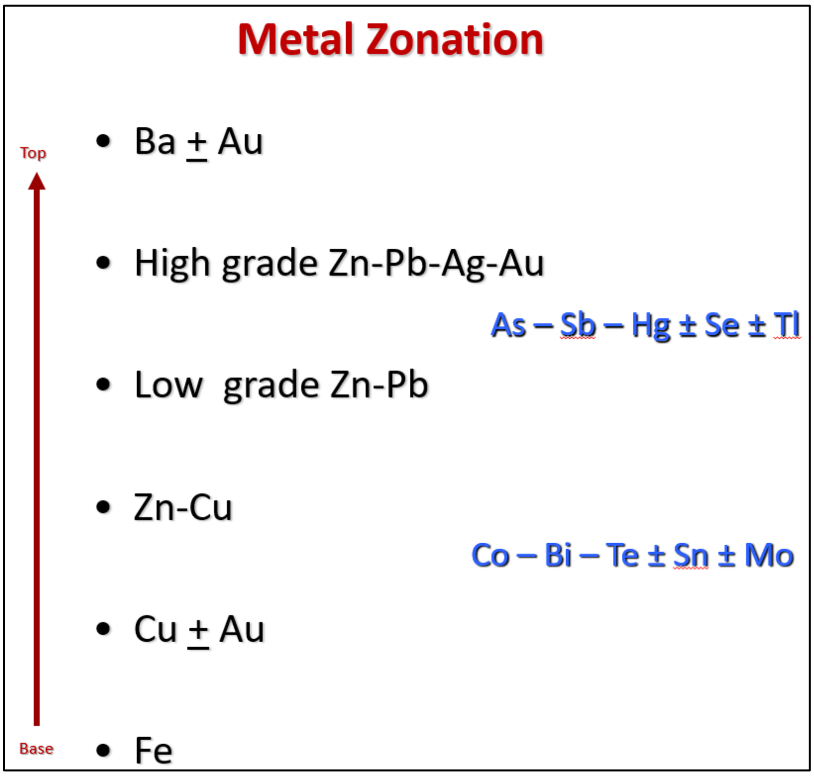


**Figure 26.** Vertical metal zonation, both major (black) and trace elements (blue), within VHMS deposits.

At Nakoro and Wainaleka, adding a full minor and trace element geochemical suite, will aid in geometallurgical characterisation of the ore, and metal zonation studies that will help in characterising the mineralised bodies and aid in exploration.

In addition, I recommend utilising the element suite to plot elements and element ratios, such as Cu/(Cu+Zn) or Zn/(Zn+Pb) down drill holes (on sections), on long section, and in 3D to understand the element distribution in the ore bodies, as well as in the footwall alteration zones. This information will help in determining the “hot” from “cool” parts of the systems.

## 6. Exploration Geochemistry

Anglo Pacific Prospecting Limited discovered the Wainaleka prospect during a -80 mesh stream sediment sampling programme. Follow up work included break-of-slope sampling, river bank sampling, ridge and spur sampling, rock and outcrop sampling and soil sampling on a 20 x 5 m grid. The samples were assayed for copper, zinc, lead and barium (Page, 2014). It is important to note there are limited Ag and Au results. Aljen (Pacific) Limited also undertook exploration geochemical sampling. None of the material provided should the distribution of these elements and how the correlate or relate (distal halos) to the primary Cu-Pb-Zn anomalies.

Modern VHMS exploration geochemistry would analyse for Cu, Pb, Zn, Ag, Au, as well as a host of minor and trace elements, such as As, Bi, Ca, Cd, Hg, In, Mo, Pb, Rb, Sb, Se, Sn, Sr, Te, and Tl. I suggest investigating these elements further to see what the full geochemical signature of the Fijian prospects are, and if these additional elements provide pathfinders or extent the footprint of the surficial geochemical anomalies.

## 7. Ore Equivalent Horizon

The ore equivalent horizon or favourable horizon within the host volcanic pile is commonly defined by a characteristic sediment or exhalite. In broad terms, these favourable horizons fall into three groups; 1) iron oxide-silica horizons (exhalites), which comprise red and purple hematite-rich jaspers, hematitic silitstones and quartz-hematite±magnetite rocks, 2) sulfide-bearing volcaniclastic rocks, which range from pyritic volcanogenic siltstones and cherts, to coarse polymict submarine mass flows horizons with sulfide clasts and 3) black pyritic shales and carbonaceous shales (Large, 1992).

At Wainaleka, a red tuff marker horizon is mapped (Figure 9). This is likely an ore equivalent horizon and exploration should initially be focussed along this unit and below into the footwall rocks. At Nakoro, there is less information about an ore equivalent horizon, but numerous gossans are observed (Figure 11).

Question – have all the gossans or exhalite horizons in the project areas been mapped and analysed? Mineralogical and geochemical characteristics of gossans can be used for discrimination. Separating fertile from barren gossans can help focus the exploration effort.

**8. Geophysics**

VHMS deposits typically have strong geophysical contrasts with their host rocks because of the substantial differences in physical and chemical properties between the deposits and the rock in which they form. Based on the shape and depth of the ore body, the sulfide content in the ore produces significant geophysical signatures. Such properties include density, magnetic intensity and susceptibility, gravity, electrical resistance, and acoustical velocity. Electrical self potential or transient responses to time-varying electromagnetic fields can also be used to detect buried sulfide deposits.

For VHMS deposits, contrasts in magnetic, electromagnetic, and gravitational (density) properties become direct exploration vectors; gamma-ray spectroscopy provides an indirect technique based on chemical contrasts associated with near-surface alteration mostly as potassium enrichment or depletion within and surrounding the deposit.

Page (2014) noted that consulting geophysicist Graham Elliot reviewed available public data, including airborne magnetics and radiometrics from Placer Pacific that covered Thunderstruck's Licenses and that a number of targets for all mineralisation types (VHMS, gold, and porphyry Cu) were interpreted. He recommended that future exploration conduct airborne heli-TEM and ground IP that will generate immediate targets for prioritized follow-up of massive sulfide conductors.

I agree with the recommendation that EM and IP should be incorporated into the exploration program.  Both field and downhole surveys would be useful. As the Nakoro and Wainaleka mineralisation does not contain magnetite or pyrrhotite, a magnetic survey would be less useful as a direct detector of mineralisation, but magnetics is very useful in determining different rock types and their distribution.

**Exploration Vector Models**

Combining the geological, geochemical and geophysical attributes of the Fijian VHMS prospects will allow for the development of a new, robust exploration model. As an example of how these diagrams can be developed, schematic summaries by Large et al. (2001) of the mineralogical, and lithogeochemical, vectors useful for VHMS exploration are given for mound-style (Fig. 27) and sub-seafloor replacement-style (Fig. 28) Zn-rich stratiform polymetallic VHMS deposits are below.  Large et al. (2001) suggests that the most useful mineralogical and geochemical vectors for Zn-rich ores are Na depletion; the alteration index (AI); the chlorite-carbonate-pyrite index (CCPI); Mn content of carbonate; whole-rock Tl, Sb, and Ba/Sr ratio; and $\delta^{34}S$ of pyrite and whole-rock $\delta^{18}O$.

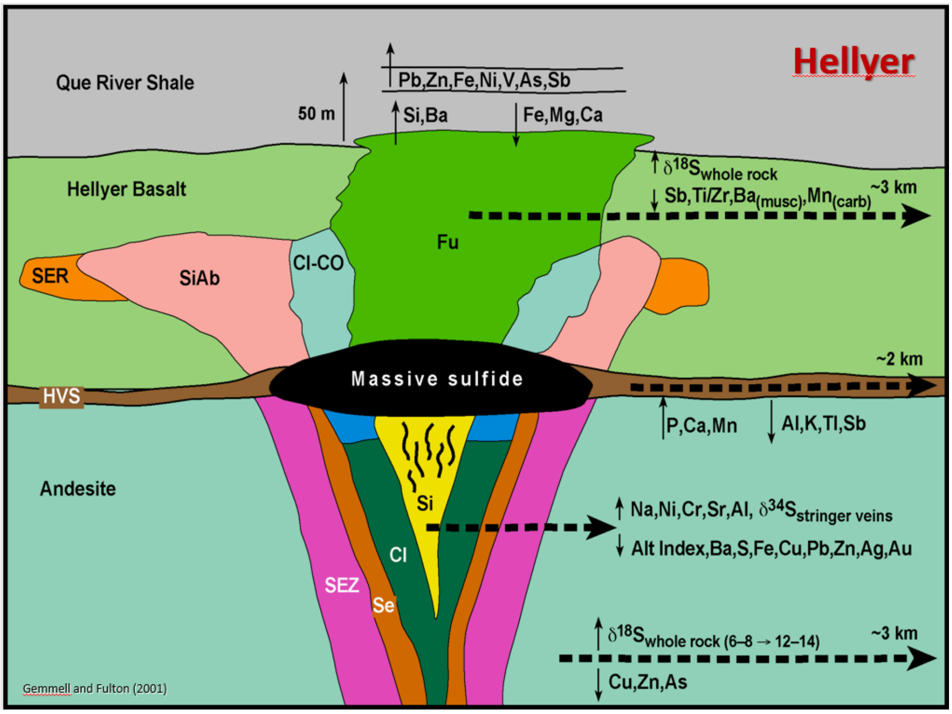


**Figure 27.** Vectors to mineralisation diagram for a mound-style VHMS deposit. This diagram based on the characteristics of the Hellyer deposit, Tasmania (Gemmell and Fulton, 2001).

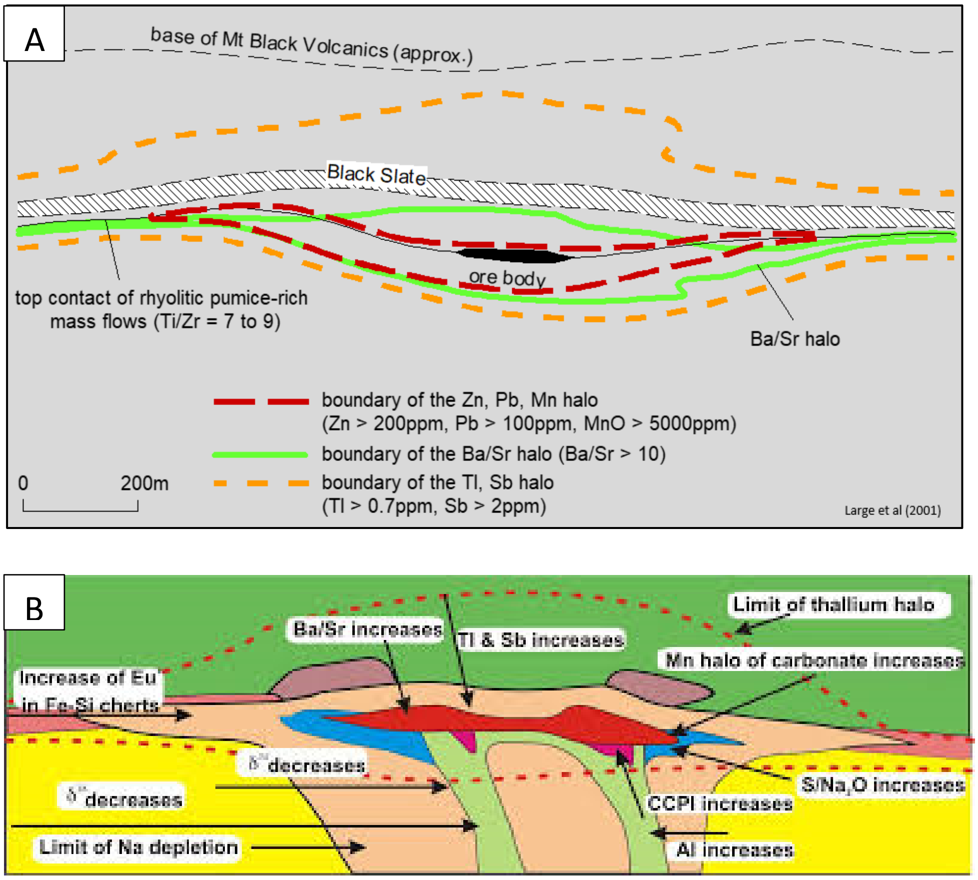


**Figure 28.** Two examples of vectors to mineralisation diagram for a sheet-style VHMS deposit. This diagram based on the characteristics of the Rosebery deposit, Tasmania (Large et al., 2001).

At Nakoro and Wainaleka, as the lithological, alteration, and geochemical characteristics, surficial geochemical footprint and geophysical attributes are determined, this information can combined to produce a Fijian VHMS exploration vectors diagram.

## Recommendations

- The Fijian prospect areas contains numerous polymetallic, lens/sheet style, sub-seafloor, replacement-type VHMS mineralisation, with a high likelihood of further discovery.
- As the Wainaleka and Nakoro prospects are sub-seafloor replacement-style VHMS prospects, this expands the exploration space within the Wainimala Group. With sub-seafloor, replacement style VHMS deposits, mineralisation often occurs within a particular strata, but not always at the same position, hence increasing discovery opportunity.
- As the Wainaleka and Nakoro mineralisation is open in many directions, further drilling is recommended to fully ascertain the size and extent of the prospects/deposits.
- Overall, the exploration program is sound and based on the solid geological, geochemical, geophysical, economic and logistical criteria, however the exploration program can be enhanced with new data and information.
- I suggest an improved exploration model be developed, and utilised, to aid in prospect discrimination, and to concentrate the exploration effort into the most favourable areas.
- The exploration model should include; lithology, lithogeochemistry, structure, alteration, metal zoning, exploration geochemistry, ore equivalent horizon, and geophysical attributes.
- Structure need more attention. It is apparent there is a discrepancy in the deformational models for the project areas, which will affect exploration targeting.
- Lithogeochemical analyses are required for chemostratigraphy - in order to determine the most favourable unit/package within the host rock formation.
- Lithogeochemistry can also be utilised to interpret hydrothermal alteration, determine fertile from barren alteration, and proximity to prospects. Obtain SWIR analyses on all altered rocks on surface and from drill holes.
- Utilise an increased trace element suite in the surficial geochemistry program to determine the overall geochemical signature of the anomalies and the proximal-distal footprint of the mineralisation.
- EM and IP geophysical methods, both on surface and downhole, would be useful in the exploration program.

- A combination of geological, geochemical and geophysical attributes can be used to produce a Fijian project area "vectors to mineralisation" diagram.

- Continuation of a vigorous exploration program is warranted.

Additional Recommendations

1) I give a short course on VHMS deposits to the Thunderstruck Resources exploration team.

2) If you have not already done so, purchase several copies of *Volcanic Textures* and *Altered Volcanic Rocks* from CODES, University of Tasmania, Australia. These publications will aid your understanding of the rocks and alteration in the Fijian VHMS project areas.

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