Ore Shoot Targeting in the Gosowong Vein Zone, Halmahera, Indonesia.

by

Daniel J. Olberg, B.Sc.

Submitted in fulfillment of the requirements for the degree of MEnGeol.

University of Tasmania
August 2001
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ABSTRACT

Gosowong is located in the Maluku province of eastern Indonesia, on the north arm of the island of Halmahera. It is a classic example of a volcanic-hosted, low-sulfidation, epithermal quartz vein deposit. Due to the relatively short mine life, there is a very limited time frame for increasing ore reserves before mining ceases. Therefore a great emphasis has been placed on exploring the strike extent of the structure that hosts the Gosowong deposit. This mineralized structure is known as the Gosowong Vein Zone (GVZ) and has been traced along strike for 2 km, though the Gosowong deposit encompasses only a 400 m section of the total strike length. The primary aim of this study is to identify additional high-grade ore-shoots along the GVZ. To this end, a multi-faceted approach has been implemented incorporating structure, stratigraphy, vein textures, alteration zoning, fluid inclusions, and metal zoning, with the ultimate aim being to construct a system model that will allow predictive targeting of high-grade ore-shoots along the GVZ. Most data are presented on a longitudinal section of the GVZ.

High-grade mineralization at the Gosowong deposit occurs within two gently south-plunging ore shoots: the Quartz-Adularia zone (QA) and the Quartz-Chlorite zone (QC). The interplay between structure and stratigraphy is thought to be one of the main controls on the emplacement and distribution of high-grade mineralization at Gosowong. A distinct mappable volcanic stratigraphy has been recognized within generally intermediate to mafic coherent volcanic and volcaniclastic rocks of Miocene age. The preferential host rocks to faulting and subsequent quartz veining are the Gosowong Volcaniclastics, a package of resedimented volcaniclastic rocks with interbedded ignimbrite and andesitic lava. This unit dips moderately to the south, striking roughly perpendicular to the strike of the GVZ. The intersection between the volcaniclastic stratigraphy and the Gosowong fault is thought to be the key factor in the deposition of high-grade mineralization.

A study of quartz vein textures along the GVZ has shown that high-grade mineralization is generally developed in discrete shoots within lower grade or barren mineralization. The vein texture most commonly associated with high-grade mineralization is poly-compositional crustiform/colloform/cockade banding. The presence of bladed calcite pseudomorphs at various levels in the system is a positive indication of boiling, though they do not always carry significant Au grades. Banded chalcedony and phreatic breccia deep in the system perhaps indicates further potential at depth.

Alteration zoning was mapped out with the use of a PIMA mineral analyzer. The alteration in the GVZ is typical of low-sulfidation, epithermal deposits. Illite-group minerals are
dominant in the ore horizons while propylitic assemblages are usually associated with weakly mineralized veining. Illite-group minerals and chlorite display a distinct zoning along the fluid flow pathway, from illite-chlorite → illite → illite-smectite → smectite-illite with decreasing depth. Alteration zoning mimics stratigraphy, as indicated by gently south plunging paleo-isotherms. Mineralizing fluids are postulated to have ascended the Gosowong fault and then spread out laterally along the permeable volcaniclastic horizon.

Fluid inclusion analyses indicate that mineralizing fluids have a typical epithermal signature: dilute (generally <1.0 eq. wt. % NaCl) and low temperature (generally 175-265°C). Coexisting vapor-rich and liquid-rich primary fluid inclusions indicate that boiling processes have taken place in the GVZ. Trapping temperatures in the QA zone suggest that quartz deposition took place 100-350 m below the paleo-water table. The variation in trapping temperatures between the QA (210°C) and the QC (236°C) may indicate multiple mineralizing events. Paleo-isotherms mimic the stratigraphy, plunging gently to the south, indicating a component of horizontal fluid flow through the permeable volcaniclastic units.

The GVZ appears to display most of the typical vertical metal zoning common in low-sulfidation epithermal systems: base metals dominant deep in the system, precious metals dominant at shallow levels. Base metal values are generally very low, averaging 125 ppm Cu, 53 ppm Pb, and 83 ppm Zn. Lead is the base metal most closely associated with Au mineralization. The distribution of high Au and Ag values indicates a gentle southerly plunge to the precious metal-rich horizon. Increasing Cu/Zn, Zn/Pb, and precious-metal/base-metal ratios may indicate vectors to ore-grade mineralization.

It appears that the southerly plunge of the strata, ore-shoots, paleo-isotherms, alteration zoning, and metal zoning may be in part due to the post-mineral tilting of the GVZ. It is believed that pre-mineralization deformation has rotated the strata approximately 25-30° to the south, while post-mineralization deformation has added an additional 10-15° to the overall rotation of the strata. Thus, deeper levels of the system are exposed closer to the surface on the north end of the GVZ.

A Gosowong specific “prospectivity matrix” has been constructed based on the sum total of the relative prospectivities of each of the components analyzed in this study. This matrix indicates that the most prospective area of the GVZ (outside of the Gosowong deposit area) is the area deep and to the south of the deposit. Additional, slightly less prospective areas have been delineated and a total of 5 drill holes have been targeted on these zones of interest.
ACKNOWLEDGEMENTS

I would like to thank Newcrest Mining Limited for all the support, financial and otherwise, during the course of this study and to acknowledge the contributions of the large number of geologic staff, consultants, and field assistants who have worked on the Gosowong exploration program over the past 8 years. In particular, I would like to thank Dan Wood, Ray McLeod, Dave Pearson, and Grant Davey for their support of my educational endeavors. In addition, I would like to thank Bruce Gemmell for his guidance and useful draft reviews and to Handono for his assistance in drafting a number of the figures in this report.
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1. INTRODUCTION

1.1 BACKGROUND

Gosowong is a classic example of a low-sulfidation epithermal quartz vein deposit. Economic mineralization is limited to a strike length of approximately 400 m and is predominantly hosted in two gently south-plunging ore shoots along an east-dipping normal fault. The indicated resource at the commencement of mining was estimated at 0.99 Mt at 27 g/t Au and 38 g/t Ag for a total of 870 000 ounces Au, using a cut-off grade of 2 g/t Au (Olberg et al, 1999).

The Gosowong gold mineralization was discovered by Newcrest Mining Limited in May of 1994 as a result of a rigorous ground reconnaissance program in northern Halmahera, targeting epithermal gold-silver and porphyry style gold-copper mineralization. The deposit was discovered and tested using basic exploration techniques commonly applied in the rugged tropical terrains of Indonesia. (Davey et al, 1997 & Carlile et al, 1998). Construction of the mine infrastructure began in 1998, and production commenced in July of 1999. As of January 31, 2001, more than 400 000 oz of gold had been produced at a reconciled grade of 33 g/t.

The mine is projected to have a relatively short life, with the cessation of mining activities due sometime in early 2002. Milling of both high-grade and low-grade stockpiles will continue into mid 2003. This being the case, there is a very limited time frame for increasing ore reserves before mining finishes. Thus, the principal focus of the current exploration work in Halmahera is to find additional mill feed for the Gosowong mill. All exploration efforts are concentrated in an area of 5 km radius around the mine. The most prospective areas are thought to be both to the north and south along the strike of the Gosowong Vein Zone, as well as other small satellite epithermal style veins in the immediate vicinity of the mine.

Because milling facilities and mining infrastructure are already in place, there would be very little additional capital cost requirement associated with the mining of a satellite deposit. Thus it is feasible that a satellite deposit could be mined at a much smaller size and grade than would otherwise be required for a stand-alone deposit. As a general guide to the economics of mining a satellite deposit, a recent satellite target study has indicated that only mineralization with potential to contain greater than 150 000 oz, with grades of over about 20 g/t Au, should be subject to more detailed evaluation (Whincup, 1999).
1.2 LOCATION

The Gosowong Deposit is located on the north arm of the island of Halmahera in the North Maluku province of eastern Indonesia, at approximately 1° 09’ north latitude and 127° 42’ east longitude (Figure 1.1). The deposit is approximately 2400 km north-east of the national capital, Jakarta, and 55 km north-east of the provincial capital of Ternate. Access to the mine is via Manado, a small city on the northern tip of the island of Sulawesi. Commercial flights connect Manado to Jakarta and Singapore daily and four times weekly respectively. From Manado, a company chartered fixed-wing aircraft makes the 75-minute flight to the site airstrip. This is followed by a short 15-minute drive to the mine village.

![Figure 1.1. Halmahera and Gosowong location map.](image)

The topography of the area is steep but not extreme, with elevations of between 80-260 m above sea level. Vegetation consists of primary tropical rainforest, some of which has been logged on a selective basis. The area has a tropical climate, receiving an annual rainfall of about 3000 mm, which can be divided into two somewhat indistinct seasons: a wet season from October to April and a less wet season from May to September.

1.3 PREVIOUS WORK

The following papers/studies have been carried out prior to the author’s current work on the Gosowong Vein Zone:
- Structural/stratigraphical studies of the Gosowong deposit were conducted by Marjoribanks, 1996; Rayner et al, 1997; and Marjoribanks, 2000.
- The geology of the Gosowong deposit is discussed in Olberg et al, 1999.
- Petrological studies of the Gosowong area were conducted by Bogie, 1994; Coote, 1995; Coote, 1996a; Coote, 1996b; and Coote, 2000.
- The geology and mineralization of the Gosowong district are discussed in Marjoribanks, 1997; Olberg et al, 1997; and Leach, 1998.
- Age dating of host rocks and alteration was carried out by Vasconcelos, 1998.

1.4 AIM OF THE INVESTIGATION

- The primary aim of this study is to identify additional high-grade ore shoots along the structure that hosts the Gosowong deposit.

Though the Gosowong Vein Zone (GVZ) strikes for more than 2 km, economic mineralization is confined to an approximately 400 m interval within that 2 km strike. Wide-spaced drilling (100-200 m spacings) along the GVZ to the north and the south of the mine has so far been unsuccessful in delineating additional ore zones, and in fact, outside the Gosowong resource area, Au grades exceeding 1 g/t Au are rare. Both the strike and depth extent of the vein zone have yet to be determined, as the vein zone is still present in the northern-most, southern-most, and deepest drill holes. Surface indications of the GVZ beyond the extent of current drilling are absent, but this is, at least in part, due to the presence of widespread advanced argillic alteration capping the vein zone at higher elevations.

Most of the data used in this study come from 222 diamond drill holes from the drill-out phase of the exploration program. Additional drill hole data comes from 10 diamond drill holes drilled during subsequent mine site exploration. Very little surface data is available outside the deposit area, due to the concealed nature of the GVZ to the north and south of the deposit. Through the focus of this project will be to analyze existing diamond drill hole data, an attempt will be made to look beyond the realm of existing drilling, and incorporate all existing surface data into the final exploration model.
In bonanza-grade vein deposits such as this, very large quantities of gold may be contained within narrow ore-shoots that may be missed by wide-spaced drilling. Highly mineralized ore shoots may be missed altogether or perhaps just clipped at the edge, with only a very subtle indication of the adjacent high-grade mineralization. Using various geochemical and mineralogical indicators from existing surface and drilling data, vectors to mineralization may be deduced, and potential zones of ore may be outlined for drill testing.

As stated above, the primary aim of this study is to identify additional high-grade ore shoots along the structure that hosts the Gosowong deposit. In the process, it is hoped that a greater understanding of the paleohydrology, alteration history, and vein paragenesis of the Gosowong system will be attained.

1.5 SCOPE OF THESIS

The scope of this thesis entails a detailed investigation of the geology, mineralogy, geochemistry, and paleohydrology of the GVZ. The ultimate goal is to construct a model that will allow predictive targeting of high-grade ore shoots along the GVZ. One of the fundamental questions to be asked is: What controls the emplacement of the high-grade ore shoots and can we predict where along the GVZ might we find similar controls? In order to answer this, the relationship between the structure and the volcanic stratigraphy (the primary controls) within the high-grade zones will be analyzed and then these principles applied to the remainder of the GVZ. In addition, the geochemical, mineralogical, and textural signatures of the low-grade stockwork mineralization peripheral to the high-grade ore shoots will be characterized and these signatures applied to the rest of the GVZ in hopes of identifying additional high-grade ore shoots along strike.

Based on the results of this investigation, recommendations will be made on where to focus attention in an attempt to locate and define additional ore shoots.

The following multi-faceted approach was taken:

- **Mapping and logging of stratigraphic and structural relationships.** The interplay between local stratigraphy and regional and local structures has been seen to play a major role in the
emplacement of mineralized zones and the distribution of grade. A greater understanding of this relationship outside the deposit area, through surface mapping and core logging, will be attained during this study.

- **Quartz vein textural zoning.** The variations in epithermal quartz vein textures may indicate relative levels within the epithermal system and thus, the most prospective zones on which to focus exploration work. Quartz vein textural zones will be mapped out along the vein zone, producing vectors to the most texturally prospective portions of the system. Textures in both hand-specimen and thin section will be incorporated into the model.

- **Alteration zonation.** The zonation of alteration along the Gosowong vein zone and in the surrounding district may be an important indicator of potentially mineralized zones. A Portable Infrared Mineral Analyzer (PIMA) will be used to detect subtle variations in clay crystallinity and compositions not commonly observed in hand specimen, which may lead to the vectoring to ore-grade mineralization.

- **Fluid inclusions - temperature and salinity variations.** Temperature and salinity variations within the quartz veining may provide clues as to the fluid origins and paleo-hydrology of the system. As most ore-grade epithermal mineralization occurs within a certain temperature and salinity range, zones of optimal thermal and chemical characteristics may be delineated and targeted.

- **Metal zoning.** Variations in the metal content and metal ratios in the vein zone will provide additional clues to the paleo-hydrology of the area. Various metal ratios will be plotted on longitudinal section and will be analyzed in an attempt to reconstruct the paleo-hydrology of the system and to formulate a geochemical zoning pattern of the GVZ.

Each of these components will be individually analyzed and then synthesized into a predictive exploration model that can be used to facilitate the planning of further exploration work in the GVZ. It is intended that this thesis work be a useful and practical component of the ongoing exploration program around Gosowong.
Figure 1.2. The Gosowong district pre-mining. The old exploration camp is located in the center of the photo. The surface trace of the Gosowong Vein Zone is indicated. July, 1996.

Figure 1.3. Active Mt. Gamkonora, looking south down the Halmahera Arc. May, 2000.

Figure 1.4. The Gosowong mill and village. May, 2000.
Figure 1.5. The Gosowong North exploration camp, 1 km north of the Gosowong pit. June 2000.

Figure 1.6. Grade control rigs on the floor of the pit. The strongly oxidized Gosowong Vein Zone is clearly visible behind the drill rig. May, 2000.

Figure 1.7. View of the Gosowong pit from the top of the south wall. April, 2001.
Figure 1.8. Gold pour,
2. DEPOSIT GEOLOGY

A thorough understanding of the geology of the Gosowong deposit is a vital component to the scope of the ongoing exploration program in the Gosowong District. The mechanisms controlling the emplacement of the veining, and more importantly, the localization of the high-grade ore shoots within the deposit, must be fully understood in order to successfully utilize the vast amount of geological data available for the prediction of new ore locations. Physical features controlling the mineralization, such as faults of certain orientation and/or favorable strata, must be identified and analogous features must be sought out elsewhere in the district. This section summarizes the known geology of the Gosowong deposit, incorporating data derived from both drill-hole logging and pit mapping, and has been updated from the author's original work (Olberg et al, 1999).

2.1 TECTONICS

The island of Halmahera straddles the equator midway between the islands of Sulawesi and New Guinea, in the center of a complicated mosaic of microplates at the boundary between Australasia, Eurasia, and Pacifica (Figure 2.1). The odd "K" shape of this island is very similar to that of Sulawesi, reflecting the similar tectonic histories of these islands.

![Figure 2.1. Southeast Asia tectonics (after Hall, 1995). Halmahera lies just to the east of a double subduction zone.](image-url)
The Maluku Sea, west of Halmahera, is a zone of collision between the opposing Sangihe and Halmahera volcanic arcs. The Maluku Sea microplate is actively being subducted out of existence due the convergence of North Sulawesi and Halmahera. This zone of double convergence is thought to be the only active example in the world of an arc-arc collision zone.

Eastward subduction of the Maluku Sea plate beneath Halmahera and the Philippine Sea plate since the Paleogene has produced four superimposed volcanic arcs in west Halmahera (Figure 2.2). These four volcano-sedimentary formations have been termed the Bacan Formation (?Paleogene), the Gosowong Formation (?Upper Miocene) the Kayasa Formation (Pliocene), and the Quaternary Volcanic Formation, which remains active to this day (Marjoribanks, 1997). The formations are separated by major regional angular unconformities that represent significant hiatuses (Marjoribanks, 1997).

Figure 2.2. Halmahera regional geology. The western arms of Halmahera comprise a series of four superimposed Neogene magmatic arcs (Oberg et al., 1999).
2.2 DISTRICT GEOLOGY

The Gosowong Formation, host to the Gosowong Deposit, occurs as an inlier within the younger Kayasa Formation, exposed in the core of a north-north-east trending elongate dome (Figure 2.3). This dome is believed to have formed as a result of forceful upward intrusion of magma focused by deep-seated fracturing of the crust (Marjoribanks, 1997). Arrays of north-south extensional joints and faults formed as accommodation structures accompanying uplift of the dome. Subsequently, during the Quaternary, regional east-west extension produced fault-bounded blocks and basins and linked northeast and northwest transfer structures. These late structures control the Quaternary volcanic activity and are active today.

The Gosowong Formation is dominated by andesitic to dacitic volcanic rocks and subordinate volcaniclastic rocks. Radiometric age dating ($^{40}$Ar/$^{39}$Ar) of basaltic-andesite from the Gosowong Formation has yielded ages ranging from 5.4 Ma to 2.6 Ma (Vasconcelos, 1998). The large age range is probably the result of argon loss during the extensive post-deposition tectonic, intrusive, and alteration events that have affected the Gosowong Formation. The geological evidence indicates that the oldest date (5.4 Ma or late Miocene) should be taken as a minimum age for the Gosowong Formation. The Gosowong Formation is unconformably overlain by volcanic rocks of the Pliocene Kayasa Formation and by Quaternary pyroclastic flows and airfall deposits. In the late Pliocene, the Gosowong and Kayasa volcanic sequences were locally intruded by andesite porphyry and quartz diorite.

Two styles of mineralization are present within the Gosowong District: low-grade porphyry copper-gold and epithermal gold-silver veining. Four sub-economic porphyries - Bora, Tobobo, Ngoali, and Matat - are located within a 7 km radius of Gosowong (Figure 2.3). Low-grade epithermal vein style mineralization occurs at Ruwait, while at Toguraci, erratic gold grades occur in, narrow, epithermal quartz veins, telescoped onto older porphyry mineralization. All of these examples of mineralization occur within a 10 km long, 4 km wide, north-north-east trending corridor, centered about the long axis of the Gosowong Dome.
2.3 DEPOSIT GEOLOGY

2.3.1 Lithology

The Gosowong Deposit is hosted by a succession of predominantly intermediate volcanic and volcaniclastic rocks of the Gosowong Formation. These rocks consist of polymictic conglomerate, sandstone, hematitic siltstone, and pyroclastic flows, intercalated with andesite domes and flows.
The bedding of the volcaniclastic rocks generally strikes west to southwest and dips moderately to the south. The oldest units - competent, well-bedded, volcaniclastic conglomerate, sandstone, and hematitic siltstone - are exposed at the north end of the deposit. This sequence, the Tobobo Sandstone, has a minimum stratigraphic thickness of about 350 m, and grades into the primary and re-sedimented pyroclastic sequence of the Gosowong Volcaniclastics (Figure 2.4). The Gosowong Volcaniclastics have a thickness of 150 m and consist of a wide variety of lithologic units, including mudstone, siltstone, fine to coarse-grained sandstone, polymictic pebble to cobble conglomerate, and dacitic ignimbrite. The mudstone units act as rough marker beds, but sometimes occur in irregular and discontinuous lens shaped bodies with variably gradational boundaries. They commonly act as aquicludes to mineralizing fluids, forming abrupt vein margins. The Gosowong Volcaniclastics are the preferential host for most of the mineralization.

The Gosowong Volcaniclastics and Tobobo Sandstone were intruded by multiple phases of plagioclase-phyric andesite bodies, thought to be the ūrages of a large laccolith or cryptodome centered to the south of the deposit. Irregular contacts characterized by hyaloclastite, peperite, and quenched margins indicate that these andesite bodies intruded and flowed over wet unconsolidated sediments. Augite-phyric basaltic andesite and plagioclase-phyric andesite dikes intrude the sequence at deeper levels, particularly at the north end of the deposit. Beyond the southern edge of the deposit, the andesite becomes laterally and vertically extensive. A medium to coarse-grained pyroxene dacite flow caps the andesite. These massive andesite and dacite units are termed the Ridge Volcanics (Marjoribanks, 1996).

The proposed depositional regime for the sequence of volcaniclastic rocks is a regressive, subaqueous, near-shore environment. The stratigraphic succession is characterized locally by rapid facies changes, indicating a very dynamic and complex depositional environment with multiple episodes of deposition and re-sedimentation. The presence of palagonite within the andesite and the pre-hydrothermal hematization of the mudstone indicate a subaqueous environment of deposition (Coote, 1996).

Immediately to the east and north of the deposit, the Tertiary volcanic rocks are unconformably overlain by a subaerial, flow-deposited, intermediate ignimbrite of the Quaternary Dufadufa Pyroclastics sequence. This unit forms a blanket up to 60 m thick on the ridge tops and
is post-mineralization, as no hypogene alteration or mineralization is observed. Mineralized eluvium, up to 3 m thick, overlies the eastern flank of the deposit.

Figure 2.4. Gosowong deposit stratigraphy. The Gosowong Volcaniclastics formation is the preferential host for most of the mineralization. Modified from Marjoribanks (1996).

2.3.2 Structure

Gold and silver mineralization at Gosowong is controlled primarily by the north-striking, east-dipping, Gosowong Fault. It is a normal fault, is interpreted to be the western edge of a half-graben, formed during the uplift of the Gosowong Dome. This fault has a characteristic listric profile, dipping at 70° east near the surface, and progressively flattening with depth to about 30° east (Figure 2.5). Joint arrays within the core of the adjacent elongate dome lie parallel to the long axis and are thought to be tensional fractures produced during the uplift of the dome. These fractures focused fluid flow derived from a postulated coeval intrusive body (Marjoribanks, 1997).

The Gosowong Fault cuts a lithologically and rheologically varied sequence of volcano-sedimentary rocks at a high angle. These variations provide the main controls on the size, shape, and complexity of the fault zone as well as the grade and distribution of ore within the fault. Lithological units of differing competencies failed in different ways during fault propagation and subsequent movements: competent andesite bodies through high-angle brittle fracture,
incompetent mudstone units through low-angle ductile shear (Marjoribanks, 1996). A further effect of contrasting rheologies can be seen in the downward deflection of low-angle, mudstone-hosted shears around the contacts of competent andesite bodies (Figure 2.5) (Rayner et al, 1997). During normal fault movement, the net effect is that steeper portions of the fault zone receive maximum dilation, while in the flat lying portions, fault movement is taken up as shearing (Marjoribanks, 1996).

Figure 2.5. Gosowong vein cross-section geology: section 10,200N

Adjacent to the fault zone, the orientation of the bedding was rotated to a north-south strike due to normal fault drag, as the weakly consolidated sedimentary rocks were "dragged out" and rotated down the fault zone during normal fault movement (Marjoribanks, 1996). A penetrative shear fabric is observed in all rock types throughout the deposit area, but is concentrated mainly in weakly consolidated volcaniclastic rocks (Coote, 1995 & 1996).

The bulk of the mineralization occurs where the fault plane intersects the hematitic volcaniclastic sedimentary rocks of the Gosowong Volcaniclastics. The theoretical trace of these units on the fault surface forms an envelope that broadly contains the gold mineralized areas (Figure 2.6) (Marjoribanks, 1996). On longitudinal section, this ore envelope gently plunges to
the south. The variable geometry of the fault plane, due to rheological contrasts within the host rock sequence, has provided abundant dilational traps for quartz-gold deposition. In addition, recent pit exposures and grade control data indicate that cross-cutting east-northeast structures may in part act to localize high-grade mineralization in the quartz-adularia zone (Barber, 2000).

![Diagram](image)

Figure 2.6. Gosowong vein longitudinal section: grade * width contours, stratigraphy and fault plane dip isogons.

The change in the stratigraphic sequence from the Gosowong Volcaniclastics to the overlying Ridge Volcanics is thought to be responsible for the moderately plunging southern termination of the ore body (Marjoribanks, 1996). The massive, impermeable nature of this andesite unit helped to focus fluid flow, and thus mineralization, into the Gosowong Volcaniclastics. The gradual decrease in grades to the north is likely due to a gradational transition from the Gosowong Volcaniclastics to the underlying Tobobo Sandstone. Here, the fault has simpler geometry and there is a marked decrease in the density and complexity of the hangingwall splays. Only minor dilation occurs because most movement is taken up by bedding plane shears within the hemiaticit mudstone.

There is little evidence for the mineralization being significantly displaced by post-mineral faulting. Minor post-mineral tectonic brecciation and partial sealing of the vein zone occur, but no significant offsets are observed. Well-developed, rhythmically banded quartz
veining within the fault zone indicates that fault movements are poly-episodic and predominantly pre to syn-mineralization.

2.3.3 Alteration

Three major types of hypogene alteration are recognized at Gosowong: 1) silicification (quartz-illite-adularia-pyrite) within the immediate vein zone, 2) argillic (illite-quartz-pyrite) alteration enveloping the vein zone and, 3) propylitic (chlorite-epidote-albite-calcite-pyrite) alteration within the footwall and distal to the vein zone. Radiometric age dating ($^{40}$Ar/$^{39}$Ar) of adularia grains from the vein zone has yielded a late Pliocene (~2.8 Ma) age for epithermal alteration (Vasconcelos, 1998).

Silicic alteration is characterized by varying amounts of quartz, illite, adularia, pyrite, and chlorite, and rarely penetrates more than 1-2 m into the country rock. It is tightly structurally controlled and there is a gradual decrease in silicification along strike away from the strongly mineralized portion of the vein.

Structurally controlled argillic alteration envelopes the main fault zone and subordinate shear zones. Illite and quartz with lesser and variable amounts of pyrite, chlorite, K-feldspar (adularia), and titanium oxides characterize this alteration (Coote, 1995). It may occur for tens of meters into the hangingwall, while the footwall has a more abrupt contact. As with silicic alteration, the intensity of argillic alteration decreases with depth and away from the strongly mineralized portion of the vein zone. Early argillic and propylitic alteration show evidence for later quartz-adularia-illite alteration overprinting as the hydrothermal system evolved through time.

Alteration distal to mineralized structures is dominantly propylitic, forming a regional halo around the Gosowong District. The establishment of this regional propylitic halo is believed to coeval with early argillic alteration and vein formation (Coote, 1995). Among the volcanic rocks, an albite-chlorite-epidote-pyrite assemblage comprises the alteration mineralogy, while among the more permeable volcaniclastic rocks, the alteration mineralogy consists of chlorite-calcite-illite-pyrite-quartz. With increasing depth and increasing distance to the north, propylitic alteration persists into the vein zone.
2.3.4 Mineralization

Economic gold-silver mineralization primarily occurs in poly-episodic banded quartz-adularia and quartz-chlorite veins, breccias, and peripheral stockworks. All economic mineralization is hosted within a 400 m long section of the greater Gosowong vein, extending from surface to a vertical depth of 200 m (Figure 2.7). The mineralization is controlled primarily by the Gosowong Fault with secondary controls provided by low angle shears intersecting the main structure (Rayner et al., 1997). The steeper portions of the fault zone generally contain high percentages of vein quartz and high gold grades, while the opposite is true for the flat lying portions (Marjoribanks, 1996). Where the dip of the vein drops below 30°, economic mineralization is generally absent (Figure 2.6).

Semi-continuous, hydrothermal breccia and banded vein quartz characterize the central vein zone, with quartz stockwork veins protruding into the hangingwall and footwall. Individual stockwork veins are generally sub-vertical and north-south striking, as dilation zones opened up at about 45° to the strike of the fault plane (Rayner et al., 1997). Mineralization is strongest in the hydrothermal breccia and crustiform banded zones. The age of mineralization decreases from the vein margins to the center of the vein. Crosscutting vein relationships indicate that the main mineralizing events are late stage (Rayner et al., 1997).

The Hangingwall Vein, located approximately 100 m east of the Gosowong Vein, is controlled by a splay off the main Gosowong Fault (Figure 2.5). This vein is sub-parallel to the Gosowong Vein and was formed by the steepening of the gently east dipping upper Gosowong shear (Marjoribanks, 1996). The vein is lens shaped with a strike length of about 200 m and a down dip extent of over 100 m. Average thickness is about 5 m and grades are generally modest.

Gold occurs in its native form, is usually less than 20 μm in size, and is interstitial to and intergrown with quartz, adularia, pyrite and minor amounts of sphalerite, galena, and chalcopyrite (Coote, 1996). Gold to silver ratios are highly variable depending on location, but average about 1:1.5.
The Gosowong mineralization is divided into three ore domains (Langmead et al., 1996). Each domain is based on the dominant style of quartz veining and mineralogy present and is a reflection of the physico-chemical conditions of deposition. The three domains are described below (Figure 2.7, Table 2.1):

1. Quartz-Adularia Zone (QA)

Massive to semi-massive, adularia-rich, banded quartz veins and breccias occur over a 150 m strike length, from surface to about 50 m depth in the southern end of the deposit between 10100N and 10250N. The formation of this high-grade pod appears to have been controlled by the locally steep dip of the Gosowong Fault and the intersection of a low angle hangingwall shear, thus producing a sub-vertical zone of maximum dilation and mineralization (Rayner et al., 1997). This zone is visually distinct as chalky, white, crustiform and colloform banded veins and breccias, rarely with very fine-grained visible
gold. Bonanza grades are associated with dark, fine-grained, sulfide-rich banding, but may be, in part, caused by supergene effects (Leach, 1998).

This type of mineralization was deposited mainly in response to the boiling of hydrothermal fluids at shallow levels, as indicated by the rhythmic crustiform banding, abundance of adularia, and abundant platy calcite pseudomorphs.

2. Quartz-Chlorite Zone (QC)

Semi-massive to stockwork style quartz-chlorite-illite veins and breccias occur throughout the strike length of the deposit, but form a discrete zone near surface at the northern end of the deposit, plunging gently south to about 135 m below surface at the southern end. The mineralization is visually distinct in the high-grade areas as dark green, finely banded chalcedony and chlorite veins with occasional very fine-grained visible gold. This style of mineralization was thought to have formed in a less permeable, confined environment (Coote, 1996) in response to deep level boiling, forming narrow zones of bonanza grades. The mixing of upwelling mineralized fluids with surficial oxidized waters may have played a minor role in the formation of bonanza grades (Leach, 1998).

3. Low-Grade Stockwork Zone (QS)

Crystalline or chalcedonic vein stockworks occur peripheral to and overlapping the above two zones throughout the deposit, from surface to depths of up to 150 m at the south end of the deposit.

The three styles of mineralization are not mutually exclusive in their extent and have indistinct margins, reflecting the gradational range of original depositional conditions (Langmead et al, 1996). In addition to these three mineralized zones, other areas of significant quartz veining occur which do not carry significant gold values. Most notable of these is the chalcedony veining that crops out between the upper QA and the lower QC, from 10250N to 10325N in the center of the deposit. Barren quartz stockworks are also found at depth along the entire strike length, beneath the keel of ore-grade mineralization. They are visually indistinct from the mineralized
stockwork veins. With these zones being the exception, a rough positive correlation can be made between quartz vein intensity and gold grades.

<table>
<thead>
<tr>
<th>Quartz vein textures</th>
<th>Quartz-Adularia</th>
<th>Quartz-Chlorite</th>
<th>Quartz Stockwork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average vein width (m)</td>
<td>14</td>
<td>10</td>
<td>variable</td>
</tr>
<tr>
<td>Au grade (g/t)</td>
<td>42</td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>Ag grade (g/t)</td>
<td>24</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>Gold:silver ratio</td>
<td>2:1</td>
<td>1:1 to 1:5</td>
<td>1:10</td>
</tr>
<tr>
<td>Copper (ppm)</td>
<td>96</td>
<td>152</td>
<td>123</td>
</tr>
<tr>
<td>Lead (ppm)</td>
<td>66</td>
<td>75</td>
<td>45</td>
</tr>
<tr>
<td>Zinc (ppm)</td>
<td>32</td>
<td>108</td>
<td>95</td>
</tr>
<tr>
<td>Arsenic (ppm)</td>
<td>13</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Antimony (ppm)</td>
<td>&lt;4</td>
<td>&lt;4</td>
<td>&lt;4</td>
</tr>
</tbody>
</table>

Table 2.1. Ore domain characteristics and average metal values.

2.4 DEPOSIT HISTORY

Olberg et al (1999) outlined a five-stage history of the Gosowong District (Figure 2.8):

Stage 1: Late Miocene (possibly older) – extrusion and deposition of the Gosowong Formation.
Stage 2: Late Miocene to early Pliocene – folding, uplift, and erosion of the Gosowong Formation.
Stage 3: Mid-Pliocene – extrusion and deposition of the Kayasa Formation.
Stage 4: Mid- to late Pliocene – intrusive event, initiation of hydrothermal fluid flow and formation of the Gosowong Dome. Due to rapid uplift, the Gosowong Formation was exposed and epithermal systems were locally telescoped onto older porphyry mineralization.
Stage 5: Quaternary volcanism, continuing to the present day.

The fourth stage of the deposit history is the most significant with respect to the events leading to the formation of the Gosowong Deposit. The intrusive event that initiated the uplift of the Gosowong Dome, likewise initiated the flow of hydrothermal fluids, producing the porphyry
and epithermal mineralization within the district (Marjoribanks, 1997). Normal faulting associated with dome formation focused the flow of ascending hydrothermal fluids that were driven by heat from a deeper level igneous intrusion.

**Figure 2.8.** Gosowong district genesis: **Stage 1)** Extrusion and deposition of the Gosowong Fm. **Stage 2)** Folding, uplift, and erosion of the Gosowong Fm. **Stage 3)** Extrusion and deposition of the Kayasa Fm. **Stage 4)** Intrusion of porphyry, uplift of the Gosowong Dome. Further uplift and erosion, epithermal system overprints porphyry system. **Stage 5)** Half-graben formation, post-mineral volcanism.

The timing relationship between the three vein domains has been one of the long-standing enigmas of the Gosowong vein zone. It was postulated by Olberg et al (1999) based on crosscutting relationships in the drill core, that the QS mineralization was the first phase of vein formation in the Gosowong vein zone. Recent geological mapping in the Gosowong pit has largely supported this hypothesis. The timing relationship between the QA and QC mineralization on the other hand was not observed in drill core, as there were no conclusive examples of crosscutting relationships or overlap between the two zones. Even with the opening of the Gosowong
pit, no timing relationships have been observed between the two high-grade ore-shoots. There are three possible scenarios for the timing of the deposition of the QA and QC ore zones:

1. The QC predates the QA
2. The QA predates the QC
3. The QA and QC formed at the same time.

The first possibility, that the QC predates the QA, is not well supported. One would assume that the explosive hydrothermal events that formed the widespread multi-phase hydrothermal breccias in the QA would have fragmented and forced up the underlying QC style of mineralization, forming a breccia comprising QC clasts surrounded by a matrix of QA material. Conclusive evidence for this was not observed in drill core nor has it been observed in the open pit. Of course the absence of evidence should not be assumed to be evidence for absence, but the likelihood of this scenario occurring is very low.

The second possibility, that the QA predates the QC, is the more likely scenario. It is postulated that the deposition of the QA during the first pulse of mineralization formed a seal to the hydrothermal system. Subsequent over-pressuring of the system during the second pulse of hydrothermal activity led to the formation of the QC immediately subjacent to the QA. Post-mineral faulting observed within the QA may have formed during the QC mineralizing events.

The third possibility, which the QA and QC formed at the same time from the same mineralizing fluids, is another possible scenario but is not well supported. The obvious geochemical, mineralogical, and visual differences between the two types of mineralization do not lend credence to the idea that these two zones formed from the same fluid at the same time. Though it is possible, it is not thought to be as likely as the second scenario.

Based on geological observations, the following vein paragenesis has been constructed (Figure 2.9):

A. Initial normal faulting and hydrothermal fluid flow resulting in silicification and sealing of the zone. Brittle fracturing and formation of footwall and hangingwall quartz vein stockworks.
B. Hydrostatic over-pressuring of the system resulting in multiple episodes of boiling, hydrothermal brecciation and crustiform/colloform banding. Precipitation of the quartz-adularia mineralization. Formation of an acid-sulfate altered zone from the condensation of hydrothermal volatiles in the water table.

C. Second major pulse of hydrothermal activity resulting in the precipitation of the quartz-chlorite mineralization.

D. Rapid erosion during the life of the hydrothermal system resulting in an acid-sulfate alteration assemblage overprinting the quartz-adularia mineralization. Subsequent erosion exposes the heart of the quartz-adularia zone.

Figure 2.9. Gosowong vein paragenesis. A. Initial normal faulting and hydrothermal fluid flow. Formation of footwall and hangingwall quartz vein stockworks. B. Hydrostatic over-pressuring of the system. Precipitation of the quartz-adularia mineralization. Formation of an acid-sulfate altered zone. C. Second major pulse of hydrothermal activity resulting in the precipitation of the quartz-chlorite mineralization. D. Rapid erosion during the life of the hydrothermal system resulting in acid-sulfate alteration overprinting the quartz-adularia mineralization.
3. RESULTS OF THE INVESTIGATION

This investigation focuses on the strike extent of the Gosowong Vein Zone (GVZ), or more precisely, along the strike of the structure that hosts the Gosowong deposit. Therefore, much of the data will be plotted, interpreted, and presented on a longitudinal section of the GVZ, commonly called the Gosowong long section.

The Gosowong long section is the projection of the GVZ onto a plane striking roughly north-south and dipping 45° to the east. The reason for using a 45°E dipping plane rather than a vertical plane as is usually done, is that the Gosowong fault is a listric fault, changing dip from 75°E near surface, to 30°E with depth. If all data were projected onto a vertical plane, there would be an extreme and artificial crowding of data points in the deeper parts of the system as the dip of the vein zone flattened out to 30°E. Likewise, the projection of the GVZ onto a horizontal plane would distort the spread of data points in the upper part of the system. Thus, projecting the data points onto a 45°E dipping plane produces a more accurate representation of the spread of data along the long section. It must be remembered, however, that numerical values on the Y-axis of the long section represent meters down the dip of the vein rather than RL.

The upper boundary of the Gosowong long section is a topographical profile along the outcropping vein zone, and where the vein zone does not crop out, the profile has been constructed by projecting the vein zone up-dip to the surface. The long section extends for a distance of approximately 2 km, encompassing all drilling data points, from 9500N to 11,450N. The final pit boundary outline has been superimposed onto the long section to act as a point of reference. Likewise, all drill hole pierce points have been plotted to show the distribution and density of the data points. Northing and meters down-dip are plotted on the X and Y-axes respectively, and a 200 x 200 m grid has been superimposed over the section (Figure 3.1).

Drill hole locations are shown in Appendix I and the GVZ database is shown in Appendix II.
The following five chapters will introduce each of the various facets of this investigation, with explanations of the methods used, presentation and discussion of the results, and conclusions for each of the facets. Following that, discussion and conclusions of the results as a whole will be presented and recommendations for exploration will be made based on these conclusions.
3.1 STRATIGRAPHY & STRUCTURE

3.1.1 Introduction

The interplay between stratigraphy and structure - namely the intersection between the plane of the Gosowong fault and the rheologically variable volcanic stratigraphy - is thought to provide the main control on mineralization within the Gosowong deposit (Olberg et al., 1999). As noted by Sillitoe (1993), much of the geometric variability in epithermal deposits may be attributed to the effects of permeability differences in the host rocks, controlling the sites of fluid flow and resulting precious metal deposition. It is these permeability differences that produce the characteristically irregular fault surface geometry and resultant mineralization that is typical of the Gosowong fault zone.

By understanding the main controls on vein emplacement and mineralization in the Gosowong deposit, insights may be gained on the geological variables controlling vein emplacement and mineralization peripheral to the deposit. It is hoped that the structural/stratigraphical variables known to control precious metal mineralization within the deposit can be identified and explored for along the GVZ, and that predictive models can be formulated using existing surface and drilling data. In order for this to be accomplished, a thorough analysis of the stratigraphy and structure along the GVZ outside the deposit must be carried out.

3.1.2 Methodology

All diamond drill holes located outside of the immediate Gosowong deposit (approximately 40 drill holes from between 9500N-9950N and 10,575N-11,450N) were included in this investigation. Both drill logs and drill core photos were used to plot and interpret cross-sectional geology along the GVZ to the north and south of the Gosowong deposit. Core inspections were carried out as needed during the course of the study. Surface geology from detailed grid-based mapping was incorporated into the interpretations. These data were integrated with the data derived from the Gosowong resource geological interpretation (Rayner et al., 1997), which included all of the drill hole data from between 10,000N and 10,500N. A comprehensive stratigraphical and volcanological model of the GVZ was constructed from these data by the author, except where noted and referenced. Geological cross-sections are shown in Appendix III.
3.1.3 Stratigraphy

A stratigraphic model for the Gosowong District was first proposed by Marjoribanks (1996) in which the strata were broken down into four volcano-sedimentary formations. These four formations were termed (from oldest to youngest): Ruwait Volcanics, Tobobo Sandstone, Gosowong Volcaniclastics, and Ridge Volcanics. This early model was well supported and recent variations differ only in the details. The stratigraphic model has recently been reviewed and modified incorporating a number of recent findings, but the major stratigraphical units remain unchanged (Figure 3.1.1). In addition, a series of seven stratigraphic columns constructed at regular intervals along the GVZ has been produced, illustrating the transitional nature of the volcano-sedimentary environment (Figure 3.1.2)

![Diagram of stratigraphy]

**Figure 3.1.1.** Generalized stratigraphy of the Gosowong Formation volcanics and volcanoclastics. Though veining occurs within all of the units, economic mineralization ($) occurs only within the Gosowong Volcaniclastics. Approximate thicknesses are listed in the left-hand column. Modified from Olberg et al. (1999) and Marjoribanks (1996).

### 3.1.3.1 Ruwait Volcanics

The Ruwait Volcanics formation consists of andesitic to dacitic flows intercalated with a wide assortment of volcaniclastic sediments (Olberg et al., 1997). This formation does not host any significant mineralization, but epithermal style quartz veining is common. This formation crops out just north of the northernmost extent of the GVZ and thus does not feature prominently in this study.
Figure 3.1.2. GVZ stratigraphy illustrating stratigraphical correlation along the strike of the GVZ. Northing and stratigraphic thickness are indicated on the X- and Y-axes respectively.

3.1.3.2 Tobobo Sandstone

The Tobobo Sandstone formation is a series of megaturbiditic mass-flow units, with rock types ranging from siltstone to boulder conglomerate (Figure 3.1.3). These units are usually very competent, well bedded, and exhibit normal grading, with a conglomeratic base and generally fine-grained sandstone to siltstone top. Some individual megaturbidites may exceed 30 m in thickness and are andesitic to basaltic in composition. This type of deposit is indicative of a moderate to deep subaqueous setting with a large influx of volcanic sediment from proximal volcanic edifices (McPhie et al., 1993). This formation is found at depth in the southern portion of the GVZ and crops out from the Tobobo River to the north, having a total thickness exceeding 350 m (Figure 3.1.2).
3.1.3.3 Gosowong Volcaniclastics

The Gosowong Volcaniclastics formation is a series of interbedded resedimented volcanioclastics, ignimbrite, and volcanic flows/intrusions. Volcaniclastic rock types comprise a wide range of conglomerate, sandstone, siltstone, and mudstone, often with an ash-rich hematitic matrix (Figures 3.1.4 to 3.1.6). Individual beds may range from centimeters to tens of meters in thickness. Peperitic contacts between andesite and volcaniclastic sediments are common. The average thickness of this formation is about 150 m.

Within the Gosowong Volcaniclastic formation, a number of distinct individual units can be traced between drill holes on adjacent sections. Multiple beds of a hematitic, fine-grained sediment and dacitic ignimbrite can be correlated from one drill section to the next (Figure 3.1.2). The genetic origins of these units and the possibility of subsequent transport have long been debated, but there now appears to be general consensus on these issues.

- **“Hematitic Siltstone”:** The brick-red unit popularly termed the “hematitic mudstone” or “hematitic siltstone” is interpreted to be a mafic-rich airfall unit that has settled through a water column forming an continuous subaqueous ash-rich layer at the time of deposition. Support for this interpretation is given by Coote (1996a) based on petrological analyses. The presence of dominantly ash-sized particles and euhehedral, fragmented crystals are evidence for
a volcanioclastic rather than volcanogenic origin. The source of this ash is thought to be relatively proximal, either from multiple phreatomagmatic eruptions at the growing volcanic edifice, or perhaps from a nearby stratavolcano contributing airfall debris into the submarine environment. The hematization is thought to be due to thermal oxidation of the relatively mafic ash upon eruption into an oxygenated environment. Semi-continuous marker beds formed where these layers settled and remained undisturbed. But in most cases, the beds of hematitic ash were eroded, cut, and redistributed by contemporaneous mass flow processes. This produced the andesite boulder and pebble conglomerates with a hematitic ash-rich matrix, commonly seen throughout the Gosowong area (Figure 3.1.4). Rather than being deposited as thin continuous beds, thick pods and lenses are the norm, as these units were redeposited into low areas and against the toes of coherent flows. In some areas of the pit, hematitic ash-rich beds grade along strike into a conglomerate with a hematitic ash-rich matrix.

- **Ignimbrite**: The presence of a dacitic, welded ignimbrite interbedded in this subaqueous sedimentary sequence has been the source of considerable confusion, leading some to believe that the ignimbrite is a rafted block, carried from the subaerial environment into the shallow subaqueous setting. The ignimbrite units are actually a series of two (possibly three) in situ welded pyroclastic flows that make up part of the Gosowong stratigraphy (Figure 3.1.2). They have been identified in numerous drill holes from around 10,200N to at least 9700N in distinct stratigraphic positions. There is a definite pod-like shape to these units as they are interpreted to have infilled low areas of the paleotopography, and thus are not always of uniform thickness between adjacent drill holes. The eutaxitic bedding indicators generally agree with bedding of the surrounding sedimentary units (Figure 3.1.5). Welded ignimbrites are generally only deposited in the subaerial environment but can occur in the shallow subaqueous environment (McPhie et al, 1993). In this circumstance, sufficiently hot and thick deposits will weld just as they would on dry land. The main requirements are low offshore gradients and very shallow water depths (McPhie et al, 1993). The provenance of this dacitic ignimbrite is obviously different from that of the coherent volcanics and volcaniclastics with which it is interbedded. A proximal dacitic eruption center is interpreted to be coeval with the Gosowong andesitic eruptions.
3.1.3.4 Ridge Volcanics

The Ridge Volcanics formation consists dominantly of andesitic to dacitic coherent volcanic rocks, with a notable lack of interbedded volcanioclastic material (Figure 3.1.7). This formation is the youngest formation in the Gosowong stratigraphy, immediately overlying the Gosowong Volcanioclastics. Individual flows may exceed 10 m in thickness and the flow margins
are often characterized by autobrecciation. The dominance of coherent andesite and paucity of volcaniclastics indicates very rapid effusive dome growth, which is thought to be, in part, subaerial. This formation exceeds 350 m in thickness.

Figure 3.1.7. Plagioclase-phyric andesite flow from the Ridge Volcanics formation. DSD-004, 47.0 m.

3.1.3.5 Environment of Deposition

The majority of the strata are believed to have been deposited in a regressive subaqueous environment. There is a transition from a moderately deep subaqueous environment, as represented by the Tobobo Sandstone formation, to the shallow subaqueous environment of the Gosowong Volcaniclastics through to the possibly subaerial environment of the Ridge Volcanics (Figure 3.1.2). This regressive transition was caused either by the gradual decrease in water level or the gradual uplift of the basin and growth of the volcanic edifice, or a combination of both processes. The presence of palagonite within the volcanic lithologies and the pre-hydrothermal hematization of the mafic ash (siltstone/mudstone) likewise indicate a subaqueous environment of deposition (Coote, 1996a). In addition, peperitic contacts between coherent andesite and volcaniclastic sediments lend further evidence to this assertion. Whether the sequence is marine or lacustrine is not certain, but the absence of limestone/reef material may indicate a lacustrine setting. The settling and preservation of ash-rich airfall deposits and the preservation of welded ignimbrites indicates a low energy environment, supporting a lacustrine or lagoonal setting.

3.1.3.6 Volcanological Model

The genetic volcanological model for the immediate Gosowong area is shown in Figure 3.1.8. This model is based on surface and drill hole data, and represents one of many possible
generalized interpretations of the GVZ volcanological setting. A section line has been drawn diagonally across the figure representing the tilting of the strata and the approximate current level of erosion. This section line represents the Gosowong long section and the respective formation names have been included on the diagram.

The oldest portion of the volcanic edifice comprises a mixture of interbedded coherent lava flows/intrusions, volcaniclastic sediments, and primary pyroclastic rocks. The coherent lava eruptions are interpreted to be subaqueous flows and shallow level intrusions, plowing their way over and through wet sediments, forming peperite, hyaloclastite, and auto-brecciated margins. Volcaniclastic sediments were deposited over and around the margins of the coherent flows, accumulating in greater thicknesses along the toes of the flows/intrusions, causing the great apparent disparities in sediment thicknesses observed between adjacent drill holes. In addition, the deformation of the soft sediments by andesitic intrusions may likewise add to this disparity. Late in the eruption history, an apparent increase in effusive eruptions led to the rapid growth of the volcanic cone, forming a thick sequence of subaqueous and possibly subaerial andesitic flows with no associated interbedded volcaniclastic units. Mass-flow units overlying the Ridge Volcanics indicate a subaqueous environment.

![Volcanological model of the GVZ](image)

**Figure 3.1.8.** Volcanological model of the GVZ. The diagonal line represents the current erosional surface, taking into account the tilting of the strata. Approximate northings and formation names are indicated.
3.1.4 Structure

A complete structural interpretation of the GVZ is not a trivial task. The lack of oriented drill core and the fact that all of the drilling outside of the Gosowong Deposit has been unidirectional (east to west angled holes) has greatly increased the level of difficulty. Thus, it is impossible to identify structures in the E-W orientation and the only structures that can be identified with any confidence are dominantly N-S oriented. Fortunately, the most important structures, both locally and regionally, appear to be in a roughly N-S orientation, subparallel to the main vein orientation. A structural analysis of the Gosowong deposit was carried out shortly after the completion of the resource drill-out (Rayner et al, 1997). The results of that study have been discussed previously in Deposit Geology (Chapter 2). The methods, procedures, and results of that analysis were incorporated into the wider structural analysis of the GVZ by the author. Due to the very limited exposure of surface structural data, the majority of the data used in this analysis are derived from drill holes.

3.1.4.1 Faulting

The dominant structural feature in the GVZ is the N-S striking Gosowong fault, which can be confidently traced throughout the deposit area and extending both to the north and south along the GVZ (Figure 3.1.9). In the southern GVZ, the fault zone, as well as the quartz veining, is still readily identifiable at depth, though there is little surface indication of the structure. The vein zone here is very broad but generally contains only low-intensity, quartz stockwork mineralization, indicating a subtle feathering out of the structure southward from the deposit. There is however an abrupt increase in both the width of the vein envelope as well as the dilation of the fault on the southernmost drill line, section 9500N, which may have implications for the exploration potential in the deep southern GVZ (Figure 3.1.10[A]).
Gram * meter values show a strong positive correlation between dilation and Au mineralization throughout most of the GVZ, though only low-grade (generally <1 g/t Au) mineralization is present within the broad vein zones in the extreme southern GVZ. Also evident in Figure3.1.10[B] is the gently south plunging zone of increased dilation through the center of the deposit area corresponding to the quartz-chlorite (QC) style of high-grade mineralization.

Section 9700N (Figure 3.1.11) illustrates the typical GVZ morphology south of the pit. The vein zone is well developed in the deeper reaches of the system but pinches out with increasing RL. The fault zone does not contain any significant veining at shallow levels, but the
structure itself is clearly visible as a zone of intense clay (advanced argillic) alteration and vuggy quartz.

**Figure 3.1.10.** A. Vein zone thickness based on the <5% volume quartz vein envelope with Au gram * meter values. B. Total structural dilation based on the amount of quartz vein infill.

Moving north from the deposit area, the width and complexity of the fault zone and the quartz vein intensity begin to rapidly decrease with each consecutive section to the north of section 10,850N. On sections 11,250N and 11,450N, the Gosowong structure cannot be confidently identified either in drill holes or on surface and there is very little evidence of faulting of any kind regardless of orientation. There is a distinct and obvious feathering out of the structure to the north, typical of what occurs near the terminations of normal fault zones (Marjoribanks, 2000b). Figure 3.1.10 shows the gradual decrease in vein zone thickness and structural dilation north of about 10,800N. An increase in vein thickness and structural dilation at 10,800N is the result of the structural intersection between the GVZ and the southwest trending Anggrek splay (Figure 3.1.9). The feathering out of the GVZ is evident even within the northern portion of the Gosowong pit, as discussed in the previous chapter, and becomes more obvious.
with increasing distance to the north. No holes have been drilled north of 11,450N, and likewise there are no surface indications of the GVZ past that point. The GVZ structure appears to terminate against the Ruwait vein structure (Figure 3.1.9).

![Diagram of GOSOWONG VEIN SECTION 9700N](image)

**Figure 3.1.11.** Section 9700N geology.

The change in the dip of the vein zone plays an important part in controlling vein deposition and Au mineralization. During normal fault movement, the steepest parts of the vein zone receive the greatest amount of dilation, while in the flatter portions, fault movement is accommodated mainly by shear. Figure 3.1.12 illustrates the relationship between gold grades and vein zone dip. The highest gold grades correspond to the steepest portion of the vein zone, while the flatter portions contain only traces of mineralization. Comparison between total structural dilation (Figure 3.1.10) and vein zone dip (Figure 3.1.12) indicates that steeper dip equals greater dilation, and thus greater mineralization, along the GVZ.
Figure 3.1.12. Gosowong vein zone dip isogons, indicating a flattening of the vein zone with increasing depth. Gold grade meter values indicate that the steeper portions of the vein zone generally contain higher Au grades and wider vein intercepts, while the reverse is true for the flatter portions.

3.1.4.2 Bedding

Bedding within the Gosowong Formation is oriented roughly E-W, dipping moderately to the south. This is the general orientation of the bedding based on hundreds of surface measurements, but locally the bedding orientations may vary from the norm. This appears to be the case along the GVZ, as there appear to be several significant deviations from the typical E-W strike and moderate southerly dip (Figure 3.1.9).

The trace of the bedding on the GVZ is illustrated in Figure 3.1.13. The moderate southerly dip of the strata is immediately obvious. Throughout the Gosowong deposit, bedding appears to be shallowly south dipping and striking roughly E-W. The bedding rotates south of 9800N, exhibiting a general N-S strike and moderate dip to the east, subparallel to the GVZ. As a consequence, the strata appear to be thick and steeply dipping at the southern end of the GVZ, but this is due entirely to the rotation of bedding to the N-S orientation. This correlates well with surface data south of the Gosowong area and is thought to be due to the warping of the bedding by the intrusion of the Bora diorite (Figure 3.1.9) (Marjoribanks, 2000a). A similar scenario of rotated bedding is observed in the north Anggrek area but there is no known intrusive body in that area to cause the warping. The shallow dipping nature of the bedding within the deposit area may be due in part to fault drag along the Gosowong fault zone. Evidence for fault drag is most pronounced around the deposit area, where the maximum amount of displacement has taken place. The bedding appears to steepen immediately to the north and south of the deposit ranging
from around 30-60°S. Again, this may be due to a lesser amount of fault displacement and thus fault drag, relative to the deposit area.

![Diagram](image)

**Figure 3.1.13.** The trace of bedding on the Gosowong fault plane. Immediately obvious is the moderate southerly dip of the strata. The final Gosowong pit boundary is indicated. Note that the ore-grade mineralization is hosted almost entirely within the Gosowong Volcaniclastics.

## 3.1.5 Discussion

Tertiary calc-alkaline volcanic rocks are the most common host rock in low-sulfidation epithermal systems with andesite most commonly hosting ore grade mineralization (Buchanan, 1981). The preferred host rock to ore-grade mineralization at Gosowong is the Gosowong Volcaniclastics formation, comprising volcaniclastic sedimentary rocks of andesitic composition. Epithermal mineralization hosted within sedimentary units is relatively uncommon, and Heald *et al* (1987) have gone so far as to exclude sediment-hosted epithermal deposits from their comparative study of epithermal systems. Hedenquist *et al* (2000), however, indicate that permeable clastic units may preferentially host disseminated ore. It is clear that ore-grade mineralization may occur in a wide range of rock types, implying that the composition of the host rocks is not a controlling factor. The lack of a genetic tie to the host is further implied by the fact that ore deposition usually occurs more than 1 million years after the formation of the host rock.
(Hayba et al., 1985). Though epithermal mineralization in rock types other than coherent volcanics may be less common, a number of examples show that epithermal mineralization can occur in nearly any type of rock, implying that host rock type should not be a major consideration in the exploration for epithermal mineralization.

The reason that the sedimentary units at Gosowong are preferentially mineralized over the brittle and coherent volcanic rocks is likely due in part to the increased permeability and lower competency of the clastic units. Competency and permeability contrasts between adjacent rock types are thought to be the main controls on high-grade mineralization along the GVZ. When faulting originally occurred at Gosowong, it is thought that the least competent, more permeable rheologies were most affected by the fault stress and associated fluid movement. Permeable clastic units often provide excellent fluid flow conduits in the epithermal system, as noted by Hayba et al. (1985) at Creede (USA) and by Sillitoe (1993) at Round Mountain (USA).

The Tobobo Sandstone formation, north of the Gosowong pit, is not significantly veined or mineralized. This may be due to the uniform, brittle nature of these rocks, which do not lend themselves to enhanced permeability. The brittle faulting that occurred along the GVZ served only to fracture the rocks over a wide area, forming broad zones of low-grade or barren stockwork veining. In addition, fault movement and resultant brittle fracture decreases with increasing distance to the north, indicating the termination of the Gosowong fault around 11,400N. The point of termination appears to coincide with the intersection of the Ruwait structure, implying that this structure may have been a factor controlling the dilation on the GVZ structure (Figure 3.1.9). The decrease in fault zone development and the competent, uniform nature of the Tobobo Sandstone do not lend support for the possibility of additional ore-grade mineralization to the north of the Gosowong pit.

The southern portion of the GVZ has a very similar host stratigraphy to that of the Gosowong Deposit (Figure 3.1.13). This is, namely, being interbedded volcanioclastics, ignimbrite, and coherent andesite of the Gosowong Volcaniclastic formation. The upper, near-surface portion of the fault-zone though is dominated by massive uniform andesite, and the vein zone is not developed within this rock type. The deeper portions of the southern GVZ do, however, display characteristics in common with the Gosowong deposit stratigraphy. The vein zone in the southern GVZ is well developed, with broad zones of generally low to moderate intensity stockwork veining, but with very little precious metal mineralization. Like the northern
GVZ, the vein in the southern GVZ appears to be feathering out into stockworks south of the pit, perhaps indicating proximity to the southern termination of the Gosowong fault. But, the abrupt increase in vein envelope thickness and structural dilation around 9500N and 9600N is a positive indication with respect to the exploration potential of the southern GVZ (Figure 3.1.10). Likewise, an increase in the dip of the GVZ in the same area provides additional prospectivity (Figure 3.1.12). The entire strike length of the Gosowong fault appears to be 2-3 km, centered about the Gosowong deposit, the point of maximum displacement on the fault.

Throughout most of the deposit, the bedding strikes roughly E-W and dips gently to the south. Outside of the deposit area, the bedding rotates to a general N-S orientation with a moderate dip to the east. The angle at which bedding intersects the fault zone may play a minor part in the localization of mineralization. Areas with coincident E-W bedding and N-S faulting may be more prospective for mineralization.

Although ENE cross structures have been identified as possible mineral controls in the Gosowong pit (Barber, 2000), no evidence for this has been observed outside of the pit area. All evidence to date suggests that mineral controls along the GVZ are similar to those observed in the deposit area, namely the interplay between lithology and structure. Variation in the rock types intersected by the Gosowong fault have lead to a very complex and irregular fault geometry in areas of high rheological variability, resulting in elevated gold grades. In the more uniform and competent rock types, the fault geometry is much simpler, forming broad zones of stockwork fracturing and very little resultant gold mineralization.

3.1.6 Conclusions

A thorough understanding of the GVZ stratigraphy and structure is an integral component of any prospectivity analysis, as it is felt that these geological factors play a major role in the localizing of ore-grade mineralization. As stated above, the purpose of this study is to ascertain which parts of the GVZ structure appear to be the most prospective for ore-grade precious metal mineralization. Through this analysis, a greater understanding of the stratigraphical-structural framework has been attained and conclusions can be drawn concerning the prospectivity of the GVZ.
• A distinct mappable volcanic stratigraphy has been recognized and can be traced between drill sections along the length of the GVZ.

• The majority of the strata have been deposited in a subaqueous environment interpreted as a low-energy lacustrine or lagoonal setting. Syn-sedimentary andesitic dome growth is indicated by interbedded andesite flows and shallow intrusions.

• The preferential host rocks to faulting and subsequent quartz veining are the Gosowong Volcaniclastics: resedimented volcaniclastic rocks of intermediate to mafic composition. Only rarely does significantly mineralized veining occur within rheologically competent units such as andesite and welded ignimbrite.

• The N-S striking, east-dipping Gosowong fault can be traced along the length of the GVZ and is the main control on vein emplacement. Normal dilational fault movement is indicated.

• The amount of dilation along the GVZ structure is strongly related to the dip of the vein zone. During normal fault movement, steeper portions of the GVZ show greater dilation than the flatter portions.

• Maximum fault displacement occurs within the Gosowong deposit area and in general feathers out both to the north and south with increasing distance from the deposit. The GVZ structure appears to terminate north of 11,250N against the Ruwait structure and may likewise terminate to the south, past the point of current drilling.

• The trace of bedding on the Gosowong fault plane indicates a southerly plunge to the preferential host rocks, the Gosowong Volcaniclastics. The preferred host rock package is found at depth in the southern GVZ.

• The southern GVZ appears to be the most prospective area to explore for ore-grade mineralization. The preferred host rock package in the deposit, the Gosowong Volcaniclastics, plunges to the south beneath the Ridge Volcanics. In addition, an abrupt increase in both vein envelope thickness and structural dilation adds to the prospectivity of the far southern GVZ. Though the area has been partially tested in the past, scope still remains for further exploration work there.

• The northern GVZ and the area deep beneath the deposit do not appear to be prospective. The competent, impermeable nature of the Tobobo Sandstone formation combined with the structural feathering out and eventual termination of the Gosowong fault do not suggest mineral prospectivity in these areas.
3.2 QUARTZ VEIN TEXTURES

3.2.1 Introduction

Quartz vein textures provide the field geologist with a rapid reconnaissance tool in the exploration for mineralized vein systems. Certain vein textures are not only diagnostic of low-sulfidation epithermal vein systems, but can provide useful information in determining mineralized loci within the vein systems (Dowling & Morrison, 1990). Detailed work on low-sulfidation epithermal systems over the last several decades suggests that there is a characteristic suite of quartz vein textures common to most systems. In simple veins there is a consistent pattern of distribution of textures and consistent assemblages of textures that can be used to define a vertical textural zoning model. Such a model can be rationalized in terms of fluid evolution in boiling geothermal systems and hence directly compared with the model of Buchanan (1981) to define the position within the system and the most likely locus of gold (Morrison et al, 1991).

Many different, and in some cases conflicting, quartz vein textural models have been proposed over the last century. Adams (1920) provided the earliest detailed description and classification of the morphology and microscopic characteristics of quartz in hydrothermal systems. He recognized chalcedony, flamboyant and banded quartz as typical shallow level quartz vein textures (Bobis, 1994). Subsequently, numerous other workers have attempted describing, classifying, and constructing various quartz vein textural models. One of the most recent and comprehensive quartz vein textural models today is that of Morrison, et al (1991) which provides a very useful classification system and functional textural model. It is hoped that by classifying quartz vein textures along the strike and dip of the GVZ, vertical textural zoning will be evident and a textural model can be constructed. Comparison with existing textural models will be conducted and the resulting analysis will act as a framework for targeting the most prospective portion (i.e. boiling zones) of the GVZ.

3.2.2 Methodology

All data for this study were collected from drill core and surface trench samples along the GVZ. Quartz vein descriptions were gleaned from drill logs, providing the majority of the quartz vein textural data. In addition, large amounts of drill core from various locations along the GVZ were inspected, described, and sampled for petrological examination.
Each quartz vein intercept within the GVZ was assigned a code for the dominant quartz vein texture present, based on visual estimation. It should be noted that within any single vein intercept there were multiple quartz vein textures developed, but only the most dominant vein textures were recorded. Each vein intercept was then assigned to a superzone, based on the classification system of Morrison, et al (1991). All results were then plotted on the GVZ long section, interpreted, and compared with published quartz vein textural models.

3.2.3 Results

In the following sections, each of the dominant quartz vein textures in the GVZ will be described and the significance with respect to the mineral potential will be explained.

3.2.3.1 Crustiform/Colloform Banded Quartz

At Gosowong, the crustiform, colloform, and cockade banded quartz veining is intimately associated with ore grade Au-Ag mineralization, and is the vein texture dominantly explored for within the district (Figures 3.2.1 & 3.2.2). Within the GVZ, it is uncommon for high-grade (>10g/t Au) mineralization to be related to any vein texture other than banded quartz (Figure 3.2.3). Though the development of crustiform/colloform banding is important, it is the mineralogical composition of the bands that is perhaps diagnostic for significant gold grades. Where banding is mono-compositional, for example banded chalcedony (only) or banded crystalline quartz (only), gold grades are relatively low, generally less than 10g/t Au. Poly-compositional banding on the other hand, where alternating bands of quartz, chalcedony, adularia, chlorite, and fine-grained sulfides have been progressively precipitated, usually contains the vast majority of the economic gold mineralization (>1 g/t Au). Hence, it appears that although the presence of banded quartz vein is a favorable sign in exploration, it is the composition of the banding that is the determining factor for precious metal deposition.
Figure 3.2.1. Crustiform/colloform banded quartz vein. A & B. Crustiform/colloform banded quartz-adularia-sulfide vein from the QA. 10,150N, 155RL. C. Cockade banded quartz-adularia-sulfide breccia from the QA. 10,200N, 155RL. D. Cockade banded chalcedony-chlorite-sulfide breccia from the QC. 10,275N, 95RL. E & F. Colloform chalcedony-chlorite-sulfide banding from the QC. Fine-grained dendritic gold is contained within brown colored colloform bands. 10,275N, 95RL.
Banded quartz is a primary growth texture, indicative of open-space deposition. Banded quartz is so common in epithermal precious metal deposits that it has been considered a diagnostic feature (Buchanan, 1981). Repetitive bands of differing composition or texture reflect fluctuating concentrations of elements in solution and fluctuating fluid conditions during precipitation. These fluctuations are commonly ascribed to periodic boiling of the hydrothermal fluid (Morrison et al., 1991):
3.2.3.2 Bladed Calcite Pseudomorphs

Within the GVZ, the presence of bladed calcite pseudomorphs is widespread both horizontally and vertically. Within the Gosowong pit boundary, this texture is commonly associated with high-grade ore mineralization, occurring extensively within the QA and to a lesser extent in the QC (Figure 3.2.4). A feature of the vein textures in the QA is the presence of discrete crustiform bands of quartz after bladed calcite, indicating coeval formation of bladed calcite and depositional banding during boiling. In some places the bladed calcite is replaced by acicular and bladed adularia (Coote, 2000). Bladed calcite pseudomorphs are also present in a more massive form throughout the QA.

Outside of the Gosowong pit boundary, zones of bladed calcite pseudomorphs are found to the north, south, and beneath the known areas of economic mineralization. Though the vein textures indicate that boiling has taken place, there is no precious metal precipitation associated with these boiling events. These zones of bladed calcite pseudomorphs are much narrower and the blades themselves are much finer and not as spatially dense as those observed within the pit. This may indicate that the boiling events here did not have the intensity to significantly alter the fluid chemistry to the extent that precious metals precipitated. Alternatively, these boiling events may not be related spatially or temporally to those events that deposited the Au-rich
mineralization in the pit area. Thus the hydrothermal fluid may have been barren and no amount of boiling, regardless of intensity, could precipitate precious metals.

Figure 3.2.4. Bladed calcite pseudomorphs. A. Massive bladed calcite pseudomorphs from the QA. Note the "spongy" nature of the quartz resulting from incomplete quartz infilling. 10,125 N, 160 RL. B. Bladed calcite pseudomorphs, vugs indicate interstitial space between clusters of blades. GSD-173, 156.3 m. C. Photomicrograph showing quartz replacing lattice bladed calcite. Black areas indicate interstitial space between individual blades. GSD-154, 332.3 m. D. Photomicrograph showing quartz and adularia replacing lattice bladed calcite. Interstitial areas have been filled with quartz. GSD-043, 4.8 m.

Bladed calcite pseudomorphs are a replacement texture, indicative of boiling and subsequent cooling of hydrothermal fluids. In the boiling zone, rapid loss of CO₂ upon boiling causes the precipitation of calcite as thin tabular plates (Simmons & Christenson, 1994). Further loss of CO₂ and continued cooling will lead to its dissolution, leading to the replacement of
calcite by quartz, producing bladed calcite pseudomorphs. This is consistent with the retrograde solubility of calcite and the prograde solubility of silica. Thus the presence of bladed calcite and its pseudomorphs is a definitive indication that boiling has taken place (Simmons & Christenson, 1994). Though the presence of bladed calcite pseudomorphs is favorable from the exploration prospective as an indication of boiling, precious metals will not always be precipitated within the bladed calcite interval during a boiling event.

3.2.3.3 Crystalline Quartz

Crystalline quartz is the dominant vein type throughout the GVZ and is generally characteristic of low-grade stockwork veining peripheral to the high-grade ore-shoots, and barren stockwork veining peripheral to the Gosowong pit area (Figure 3.2.5). Crystalline quartz veining is found at all levels of the GVZ, but becomes increasingly dominant and coarser grained with increasing depth.

Crystalline quartz is a primary growth texture, indicative of open space filling and slow cooling of the hydrothermal fluid under stable conditions. It is typically formed from a hydrothermal solution that is slightly supersaturated with respect to quartz but undersaturated with respect to chalcedony. Zoned crystals imply mildly fluctuating conditions during crystal growth, marked by zones of fluid inclusions and impurities in the crystal (Morrison et al., 1991). For exploration purposes, crystalline veining is not thought to be particularly prospective, but is a positive sign in that fractures have been opened and filled with potentially mineralizing fluids.
Figure 3.2.5. Crystalline quartz vein. A. Coarse-grained, crystalline, dogtooth quartz from the discovery outcrop in the Tobobo River. B. Crystalline quartz stockwork veins in drill core. GSD-136, 155.5 m. C. Photomicrograph of crystalline quartz growing perpendicular to wallrock contacts. The center of the vein has been infilled with fine mosaic quartz. GSD-168, 285.1 m. D. Narrow crystalline quartz veinlet in chlorite altered wallrock. GSD-210, 87.4 m.

3.2.3.4 Chalcedony

Extensive zones of chalcedony are uncommon along the GVZ. Chalcedony often occurs within banded quartz veins, alternating in bands with quartz, chlorite, adularia, and sulfides, comprising much of the high-grade mineralization. The main occurrence of dominantly chalcedonic vein material is within a narrow sub-horizontal shoot, juxtaposed between the
overlying QA and the underlying QC, within the narrow "neck" zone. This zone exhibits well-developed crustiform and colloform banding, but due to the mono-compositional nature of the bands, gold grades are minimal (Figure 3.2.6). This chalcedonic zone is interpreted to be an early phase of silica deposition, as brecciated fragments of banded chalcedony are commonly observed within the overlying QA mineralization. Another zone of chalcedonic veining is observed in the deepest drill hole of the GVZ, DFD-009 (Figure 3.2.6). The extent of this zone is as yet unknown.

Figure 3.2.6. Banded chalcedony. A. Cockade banded chalcedony within a vein breccia. DFD-009, 393.5 m. B. Banded chalcedony and silicified sediments within a vein breccia. DFD-009, 387.2 m. C. Photomicrograph of very finely colloform banded, botryoidal chalcedony. GSD-112, 143.1 m. D. Photomicrograph of finely colloform banded chalcedony-chlorite-sulfide from the QC. GSD-015, 46.2 m.
Vein chalcedony is a primary growth texture, indicative of rapid cooling and low temperature of deposition. Chalcedony is characteristic of low-sulfidation epithermal deposits, often forming under undisturbed hydrostatic conditions at shallow depths (White, 2000) and under conditions of slight silica supersaturation with respect to quartz (Morrison et al., 1991). Chalcedony itself is not thought to be particularly prospective for precious metal mineralization, but it may indicate a relatively shallow, cool, and thus high level within the epithermal system, leaving open the possibility of encountering ore-grade mineralization at depth.

3.2.3.5 Vuggy Quartz

Along the GVZ, vuggy quartz has been recognized in two locales. The first zone lies immediately beyond the southern edge of the Gosowong pit as an extensive zone of advanced argillic alteration capping the top of Gosowong ridge (Figure 3.2.7). This advanced argillic alteration is thought to have formed in the steam-heated zone stratigraphically above the boiling epithermal system, forming an extensive blanket of acid leaching over the top of the ridge. The second zone of vuggy quartz occurs to the north of 11,600N, at high elevation north of the theorized termination of the Gosowong structure. It has not yet been determined whether this vuggy quartz zone is related to shallow epithermal processes or to the formation of nearby porphyry Cu-Au mineralization. Although this type of silica is generally void of mineralization (<0.1g/t Au), it is thought of as a positive sign, due to its known relationship with boiling zones in epithermal systems.

Vuggy quartz, though not actually a form of quartz vein, is commonly found in the overprinted, steam-heated, advanced argillic altered zones of low-sulfidation epithermal systems, where preserved. Although this type of quartz is more commonly associated with high-sulfidation epithermal systems, its presence within steam-heated zones in the low-sulfidation epithermal environment is well documented (White, 2000). The boiling of ascending fluids results in the formation of H₂S bearing steam that condenses into cool groundwater. H₂S oxidation to sulfate then takes place in vadose zones above the paleo-water table. The resulting steam-heated acid fluids cause advanced argillic alteration with a characteristic porous, spongy texture (Sillitoe, 1993). Typical epithermal metals other than mercury and arsenic are generally absent because they do not undergo significant volatile transport at the low temperatures involved.
3.2.4 Textural Zoning Model

The results of the quartz vein textural study can best be viewed in long section format (Figure 3.2.8). Immediately apparent is the concentration of crustiform/colloform banded quartz vein within the confines of the pit boundary, illustrating the intimate relationship between banded quartz and high gold grades. Outside the pit boundary, quartz vein textures dominantly comprise crystalline quartz veining with intermittent horizons of quartz after bladed calcite pseudomorphs. The GVZ appears to contain most of the characteristic epithermal quartz vein textures, and a distinct textural zoning is observed. The origin of these textures can be interpreted in terms of fluid conditions and physico-chemical processes affecting silica and calcite solubilities prior to and coeval with cooling and/or vigorous boiling of hydrothermal fluids (Bobis and Aquino, 1995).

By comparing the Gosowong textural model to the textural model proposed by Morrison et al (1991) (Figure 3.2.9), similarities emerge, but the published model cannot explain many of the nuances observed within the GVZ. Furthermore, conflicting opinions between different
It is generally accepted in most textural models that ore-grade mineralization is most commonly associated with crustiform/colloform banded quartz, equating to the boiling zone in most systems. This appears to be precisely the case at Gosowong where the vast majority of ore-grade mineralization is associated with the colloform and crustiform banding of the QA and QC. Though banded quartz exists throughout the GVZ, only the poly-compositional banding is related to the deposition of precious metals. Only zones of poly-compositional banding are indicated on Figure 3.2.8. Based on the textural model of Morrison et al. (1991), the crustiform/colloform-banded zone represents the middle level of the epithermal system (Figure 3.2.9).

![Diagram showing textural banding](image)

**Figure 3.2.8.** Zones of the dominant quartz vein textures along the GVZ.

According to the Morrison et al. (1991) model, bladed calcite pseudomorphs exist within the upper levels of the system, above the precious metal bearing interval. Though this may be the case in some epithermal systems, the GVZ does not conform to this model. The occurrence of fluctuating boiling zones during repeated hydrothermal events may lead to the formation of multiple bladed pseudomorph zones within the epithermal system. In the GVZ, most bladed calcite pseudomorphs occur directly within or beneath the crustiform/colloform banded zone.
(boiling zone). Cooke & Simmons (2000) believe, based on studies conducted in active geothermal systems, that the formation of bladed carbonate occurs deeper in the epithermal system than the precious metal horizon. Different hydrothermal gases boil off at different rates based on their volatilities. Carbon dioxide, one of the most volatile gases, boils off quicker than the H₂S, meaning that bladed carbonates are formed slightly deeper in the boiling zone where phase separation begins, before the ascending fluids have a chance to lose H₂S and precipitate precious metals. Therefore gold is precipitated late along the fluid boiling path, at a higher level in the boiling zone (Cooke & Simmons, 2000). The textural zoning in the Gosowong pit area appears to conform to this theory. Zones of bladed textures peripheral and subjacent to the near surface QA may be associated with the QA precious metal horizon, while bladed textures within the QA may have been formed during a separate boiling event, perhaps associated with precious metal deposition at a higher level in the system. Another alternative to the formation of barren bladed calcite zones in the GVZ is that peripheral bladed calcite pseudomorph zones may be due to the draw down and subsequent boiling of carbonate-rich waters during the collapse of the hydrothermal convection cell, forming late-stage, barren, bladed calcite zones (Simmons & Christenson, 1994).

![Figure 3.2.9. Schematic model for zoning of quartz vein textures, alteration, and mineralogy in a typical epithermal vein system.](image)

Figure 3.2.9. Schematic model for zoning of quartz vein textures, alteration, and mineralogy in a typical epithermal vein system. The interpreted relative position of the GVZ is indicated. After Morrison et al (1991), based on the model of Buchanan (1981).

Crystalline quartz, which generally indicates a deeper more static fluid environment, is ubiquitous throughout the GVZ with the exception of the banded quartz and bladed calcite zones.
This conforms relatively well to the Morrison et al (1991) textural model, which shows crystalline quartz to dominate the deeper reaches of the epithermal system (Figure 3.2.9). Likewise, White (2000) has interpreted crystalline and comb quartz to be indicative of the deeper portion of an epithermal system.

Chalcedony is generally thought to form at low temperatures in the upper levels of the epithermal system. Due to the lack of extensive massive chalcedony along the GVZ, it is interpreted that most of the upper portion of the Gosowong system has been eroded, exposing the top of the boiling zone mineralization on surface. Contrary to the generally accepted models, the deepest vein intercept within the GVZ intersected banded chalcedony, phreatic breccia, and silicified fine-grained sediments at a depth of ~600 m down the dip of the vein (Figure 3.2.10). Anomalous gold grades (0.1-1.0 g/t) are associated with this veining. It is thought that this zone of chalcedonic veining is not temporally related to the Gosowong mineralization and may indicate the upper boiling zone of a separate, unrelated epithermal system.

**Figure 3.2.10.** Banded chalcedony and phreatic breccia from DFD-009, approximately 600m down-dip from surface A. Clasts of banded chalcedony and wallrock in a silica and rock flour matrix. 391.3 m. B. Wallrock fragments supported in a cockade banded chalcedony matrix. 393.5 m.
3.2.5 Conclusions

Quartz vein textural models are not intended to provide exact, inflexible models that must be rigidly adhered to in all epithermal vein systems. They are, instead, models based on generalizations of all observations made during the studies of epithermal systems and active geothermal systems. These generalizations can be loosely applied to other epithermal systems and may assist in the assessment of prospectivity of the system or portions of the system. Though current quartz vein textural models have their limitations and fundamental disagreements exist between various authors, certain conclusions can be drawn regarding general textural observations within the GVZ.

- Ore-grade mineralization is generally developed in discrete shoots within lower grade or barren mineralization. Ore shoots can generally be distinguished from adjacent shoots based on the dominant quartz vein textures.
- The texture most commonly associated with ore-grade mineralization is crustiform/colloform banding, but it is the composition of the banding that is the determining factor. Poly-compositional alternating bands of quartz, chalcedony, adularia, chlorite, and sulfides generally contain high-grade mineralization. Mono-compositional quartz or chalcedony bands are generally low-grade or barren.
- The presence of bladed calcite pseudomorphs within and beneath the precious metal horizon does not conform to earlier textural models, but recent studies have produced new data contradicting the old models, placing the bladed calcite zone within and subjacent to the ore horizon.
- Bladed calcite pseudomorphs within crustiform bands in the QA indicates a close genetic relationship between these textures.
- Chalcedony and phreatic breccia deep in the system is enigmatic, perhaps representing an unrelated phase of mineralization. It is thought that this veining represents the top of a much deeper, blind epithermal system.
- The abundance of crystalline quartz in the deeper and peripheral portions of the GVZ indicates relatively static hydrothermal fluid conditions in those areas.
- Vuggy quartz at high elevation south of the Gosowong pit is due to steam-heated alteration by condensed acidic volatiles liberated during episodic boiling.
• Comparison to published models (Morrison et al, 1991, Bobis, 1994, White, 2000) shows the GVZ to represent the middle to deeper portions of an epithermal system. Shallow epithermal features such as massive chalcedony and sinter are absent.

• The portion of the GVZ north of the Gosowong pit does not appear prospective. Dominantly crystalline textures likely indicate static hydrothermal fluid conditions common at deep levels and areas peripheral to mineralization.

• The portion of the GVZ south of the pit appears only modestly prospective. The presence of widespread bladed calcite pseudomorphs is favorable, indicating boiling has taken place, but so far there are very few indications of related precious metal mineralization.
3.3 ALTERATION ZONING

3.3.1 Introduction

Alteration zoning is a common characteristic of epithermal mineral systems. Both the deposition of epithermal veins and the associated hydrothermal alteration form in response to physico-chemical changes in the nature of the fluid as it ascends to shallow levels, progressively cools, and interacts with the surrounding country rocks and any meteoric water they may contain (Baker, 1993). The stability ranges of hydrothermal minerals have been determined based on direct measurement active geothermal systems and fluid inclusion studies of extinct hydrothermal systems (Bogie, 2000). Because most hydrothermal alteration minerals are stable over limited temperature and pH ranges, the distribution of the minerals may be mapped out in three dimensions, allowing the thermal zoning patterns to be deduced. A model of the hydrology of the extinct hydrothermal system can then be constructed.

Epithermal fluids generally decrease in temperature with decreasing depth and with increasing distance away from the fluid conduits. Paleotherms and fluid conduits can be deduced by the mapping of the dominant hydrothermal alteration mineralogy in vein material and wallrock. In this fashion, alteration mineral geothermometry can be used to determine the level of exposure of the system; areas with indications of low paleotemperatures are encouraging, while indications of high paleotemperatures suggest that the depth extent of the epithermal ore may be limited (Hedenquist et al, 1996). Thus, the alteration zoning can be used as a pointer towards the most prospective parts of the epithermal system (White & Hedenquist, 1995).

The purpose of this alteration zoning analysis is to provide an indication as to the paleohydrology (fluid flow directions, source area, fluid conduits, etc.) of the fossil hydrothermal system that produced the Gosowong mineralization. The alteration zoning patterns enveloping the high-grade ore-shoots and peripheral low-grade mineralization will be characterized and it is hoped that zoning patterns will emerge which may lead to the discovery of additional ore-grade mineralization along the strike of the GVZ.
3.3.2 Methodology

All alteration data used in this study have been derived from drill core samples, and to a lesser extent, surface samples, from the GVZ. A total of 412 alteration samples from 75 drill holes were collected from the Gosowong drill core. Approximately 60% of these samples were collected from within the vein zone intersections, generally 2 to 3 samples per vein intercept, from the most intensely altered material. The remainder of the samples were collected from the surrounding wall rocks. A portable infrared mineral analyzer (PIMA II) was used to analyze the alteration samples and *The Spectral Geologist* v2.0 (Ausspec International) software was used for the identification of the mineral spectra. All PIMA spectra were manually checked for accuracy of identification and were then plotted onto cross section and related to the logged alteration types. The dominant alteration mineralogy within the vein envelope was compiled for each vein intercept and plotted onto long section. These data were then modeled, forming a long section alteration zoning model. Silicate phases such as quartz and adularia, and sulfides are unidentifiable by PIMA and were not considered in the construction of the GVZ alteration model. The point of this study is not to perform a detailed petrological analysis of alteration styles within the GVZ, but to use logged alteration and PIMA mineral identification to construct an alteration zoning model that may be used for exploration purposes.

In addition to PIMA determinations, a total of 14 XRD analyses were included from previous petrological studies (Bogie, 1994; Coote, 1995; Coote, 1996a; Coote, 1996b; Coote, 2000). Complete PIMA results can be found in Appendix IV.

3.3.3 Results

Three major types of alteration are recognized in the Gosowong deposit: 1) silicification (quartz-adularia-illite-pyrite) within the immediate vein zone, 2) argillic (illite-quartz-pyrite) alteration enveloping the vein zone and, 3) propylitic (chlorite-epidote-albite-calcite-pyrite) alteration within the footwall and distal to the vein zone (Olberg *et al*, 1999). These same alteration types and alteration zoning patterns occur throughout the GVZ, with argillic assemblages dominant in the southern portion of the GVZ and propylitic assemblages dominant in the north. In addition, a fourth major type of alteration, advanced argillic (kaolinite-dickite±titanite), is found at shallow levels south of the Gosowong deposit.
Since silicate phases such as quartz and adularia cannot be identified with the PIMA, the first major alteration type mentioned above, silicification, will not feature in this zoning model. Instead, this study will focus on the zoning of the clay, mica, and hydrous silicate minerals within the argillic, advanced argillic, and propylitic zones of the GVZ.

Alteration assemblages as determined from spectral analyses and logged geology have been grouped into six different categories:

1. Kaolinite-dickite±alunite
2. Smectite-illite
3. Illite-smectite-carbonate
4. Chlorite-smectite-carbonate
5. Illite±chlorite±carbonate
6. Chlorite-epidote±carbonate

The distribution of these alteration assemblages within the GVZ is illustrated in Figures 3.3.1 and 3.3.2. Each of the dominant alteration assemblages will be described in the following sections.

Figure 3.3.1. Alteration zoning within the Gosowong Vein Zone. The Quartz-Adularia (QA) and Quartz-Chlorite (QC) ore zones are indicated.
Figure 3.3.2. Interpreted cross-sectional alteration zoning patterns along the GVZ. Sections are approximately 300m apart, from south to north.
3.3.3.1 Kaolinite-Dickite=Alunite

A zone of strong advanced argillic alteration, characterized by kaolinite-dickite=alunite and minor vuggy quartz, overlies the southern end of the GVZ as well as the area to the north of the GVZ. In addition, this style of alteration is generally found at high elevations along ridge tops around the Gosowong district. The blanket-like morphology of this alteration zone along the ridge tops indicates that at one time this alteration may have formed an extensive layer over the district. Subsequent erosion has dissected the terrain and extensive ridge-top zones are the only vestiges of this once extensive alteration blanket. Though generally tabular in form, kaolinite-dickite alteration often descends major structures such as the GVZ, overprinting earlier quartz veining and smectite-illite alteration. No ore-grade vein material is associated with this ore type, though anomalous Au (0.1-0.5 g/t) and As (~32 ppm) assay results have been attained within veined intervals.

![Figure 3.3.3. Kaolinite-dickite=alunite altered volcanic rocks. A. Soft, clay-rich kaolinite-dickite altered andesite. DSD-003, 38.9 m. B. Acid-leached volcanics within the kaolinite-dickite=alunite zone, forming residual vuggy quartz. DSD-003, 29.3 m.](image)

The kaolinite-dickite=alunite altered rock usually has a white to gray, soft, clay-rich appearance (Figure 3.3.3[A]). The degree of alteration is generally intense, with pervasive alteration of both the phenocrysts and the groundmass of the volcanic host rock. Thin, sub-horizontal, tabular bodies of intensely acid-leached volcanic rock are present within the kaolinite-
dickite±alunite zone (Figure 3.3.3[B]). These zones of residual vuggy quartz have formed after complete replacement of all minerals (except quartz phenocrysts) by quartz, pyrite, and Ti-oxides. Sites of leached phenocrysts are lined with fine quartz, kaolinite/dickite, and alunite (Coote, 1996b).

### 3.3.3.2 Smectite->Illite

Smectite dominant alteration assemblages occur at shallow depths in the southern portion of the GVZ, just south of the high-grade QA mineralization and immediately subjacent to the kaolinite-dickite±alunite assemblage (Figure 3.3.1). Smectite dominant alteration assemblages are relatively rare and mainly occur within several of the shallower drill holes immediately to the south of the Gosowong pit. Alteration is generally intense with total replacement of both phenocrysts and groundmass but primary volcaniclastic textures are clearly visible (Figure 3.3.4). Replacement minerals are dominantly interlayered smectite-illite with minor amounts of quartz, pyrite, and Ti-oxides. Primary fractures and cavities are sealed with quartz and illite-smectite (Coote, 1996b). Pre and syn-alteration shearing and brecciation are evident within most samples. Ore-grade mineralization is not associated with this style of alteration.

![Figure 3.3.4](image.jpg)  
**Figure 3.3.4.** A. Smectite-illite-pyrite altered ignimbrite. The eutaxitic texture formed by the flattened pumice clasts can clearly be seen. GSD-128, 210.5 m. B. Smectite-illite-pyrite altered volcaniclastic rock GSD-128, 209.8 m.

### 3.3.3.3 Illite->Smectite±Carbonate

An illite->smectite±carbonate assemblage is associated with some of the shallow veinway along the GVZ, particularly on the periphery of the southern QA style of mineralization. The
main zone of illite-smectite dominant alteration extends from surface in the QA, plunging southward to deeper levels in the far southern portion of the GVZ, immediately subjacent to the smectite dominant zone and the kaolinite-dickite-alunite zone. In addition, a second small wedge of illite-smectite alteration occurs beneath the keel of the northern end of the pit boundary (Figure 3.3.1). Only minor ore-grade material is associated with this style of alteration.

Alteration is generally intense with interlayered illite-smectite (90%-10%) totally replacing both phenocrysts and groundmass (Bogie, 1994). Other replacement minerals include significant amounts of quartz and adularia with minor amounts of pyrite and Ti-oxide. Adularia in most places is moderately to strongly altered to illitic clay. A late smectite is also observed, overprinting earlier veining and alteration (Coote, 1996b). This style of alteration is very similar in appearance to the other styles of illitic clay alteration within the GVZ.

3.3.3.4 Chlorite-Smectite-Illite

Chlorite-smectite-illite alteration is not a common feature of the GVZ and is observed in only a small number of drill holes (Figure 3.3.5). This style of alteration is not associated with ore mineralization and occurs in areas peripheral to the Gosowong pit, both to the north and south of the deposit, often at the transition zone between the illite-chlorite and illite-smectite alteration zones (Figure 3.3.1). In addition, a small zone of chlorite-smectite alteration occurs as an enclave within illite-chlorite alteration beneath the keel of the Gosowong pit. This style of alteration was defined exclusively by the PIMA. The chlorite-smectite assemblage and was not differentiated in the geological logging and there are no XRD or petrological samples analyzed from these areas.
3.3.3.5 Illite±Chlorite±Carbonate

Illite (±chlorite±carbonate) is the alteration type most commonly associated with ore-grade veining in the GVZ. Illite alteration mineralogy features prominently in both the QA and QC mineralization, while chlorite content generally increases with increasing depth, being much more abundant in the deeper QC mineralization. The distribution of this alteration type is widespread though most of the Gosowong pit boundary, extending on surface to about 10,800N (Figure 3.3.1). This alteration zone plunges gently to the south immediately subjacent to the illite-smectite zone and is still found at depth south of 10,000N.

Illite alteration within the vein zone in generally intense, affecting both framework clasts and matrix. The complete alteration assemblage is dominated by illite and quartz which are accompanied by lesser and variable amounts of chlorite, adularia, pyrite, and Ti-oxides (Coote, 1995). Primary textures are often preserved. At deeper levels, chlorite becomes increasingly the dominant mineral phase while illite and adularia contents decrease (Coote, 1996). The physical appearance of this style of alteration ranges from white to light gray within the illite rich zones to pale mottled green at deeper levels where chlorite is more abundant (Figure 3.3.6).
3.3.3.6 Chlorite-Epidote±Carbonate

Alteration distal to mineralized structures is dominantly chlorite-epidote±carbonate (propylitic), forming a regional halo around the Gosowong district. Within the GVZ, this style of alteration is generally not associated with ore-grade mineralization and does not occur within the confines of the pit boundary. With increasing depth and increasing distance to the north, propylitic alteration persists into the vein zone, a gradual transition from the illite±chlorite alteration described above (Figure 3.3.1).

Propylitic alteration within the vein zone generally comprises an albite-chlorite-epidote assemblage within non-permeable coherent volcanic rocks, while in more permeable fragmental lithologies, the assemblage is dominated by chlorite-calcite-illite-quartz (Coote, 1995). Within strongly propylitic altered volcanioclastics, localized fracturing is sealed with epidote, calcite and quartz. Propylitic altered rocks are generally very competent, dark green in color, and crosscut by
yellow epidote-quartz-calcite filled fractures (Figure 3.3.7). In more permeable fragmental lithologies, secondary epidote and calcite occur as disseminations.

Figure 3.3.7. Propylitic (albite-chlorite-epidote-calcite) altered andesite volcaniclastic mass flow units. The upper specimen is medium-grained volcaniclastic sandstone (GSD-209, 189.1 m). The lower specimen is a polymict pebble conglomerate (GSD-209, 180.3 m).

3.3.4 Alteration: Conditions of Formation

The alteration assemblage kaolinite-dickite±alunite may be indicative of alteration caused by near-surface steam-heated waters. In the low-sulfidation epithermal environment, kaolinite and alunite are commonly deposited from low temperature acidic waters, generally around 100°C (White & Hedenquist, 1995) with a pH of 2-3 (Lawless et al, 1997). Dickite on the other hand, commonly indicates acidic fluids, but generally higher temperatures then are normally associated with steam-heated waters. The presence of dickite within this apparent low-temperature steam-heated assemblage is enigmatic, as no documentation has been found illustrating other occurrences of dickite as a steam-heated overprint in low-sulfidation epithermal systems.

Depth/temperature relationships of illite-smectite group minerals are well documented. Illite and smectite generally form from near-neutral to slightly acidic fluids (pH=5-6) (Lawless et al, 1997) over a wide temperature range. Smectite generally forms at low temperatures, from <100-150°C, and with increasing temperatures, gives way to interstratified smectite-illite (Corbett & Leach, 1998). Interstratified smectite-illite assemblages are interpreted to indicate fluid
temperatures in the range of 160-220°C (Lawless et al., 1997). Alteration with a dominantly illite assemblage indicates fluid temperatures in the range of 220-270°C (Lawless et al., 1997). Whereas illite is generally stable at temperatures greater than 220°C, decreasing temperatures promote the stability of smectite. Thus the ratio of illite to smectite in the alteration assemblage can provide a reasonably accurate approximation of the temperature of the hydrothermal fluids. Illite is generally more abundant in permeable zones with increasing amounts of chlorite indicating decreasing permeability (Lawless et al., 1997).

Chlorite-smectite alteration assemblages generally occur under near-neutral fluid conditions (pH=6-7). Interlayered chlorite-smectite occurs at low temperatures, grading to chlorite at higher temperatures (Corbett & Leach, 1998). The temperature range for interlayered chlorite-smectite is not as well defined as for illite-smectite, but is thought to be in the neighborhood of 150-220°C, with lower temperatures indicating higher smectite contents. This style of alteration is usually abundant where there is only minor circulation of hydrothermal fluids in relatively non-permeable host rocks (Bogie, 2000).

Chlorite is not a good indicator of paleo-temperature, forming from fluids of ambient temperatures to temperatures greater than 300°C, but it does indicate a near neutral fluid pH of around 6-7 (Lawless et al., 1997). In epithermal deposits, chlorite usually indicates a lack of intense metasomatism, and is therefore found in distal, but relatively hot zones (Bogie, 2000). Epidote, on the other hand has a fairly well defined temperature range, usually greater than 240°C. But within less permeable host rocks distal to veining, the presence of epidote (+chlorite) may indicate decreased metasomatism and higher pH relative to the argillic zones proximal to the vein zone rather than a temperature gradient (Bogie, 2000).

The alteration types listed above are representative of variations in the temperature and pH of the mineralizing fluids that reacted with the host rock, resulting in the respective alteration assemblages. There may be significant overlap between the various alteration types, as indicated by the presence of the same alteration minerals in adjacent alteration types. Transitions between adjacent alteration types are often gradational over distances of up to 50 m. Table 3.3.1 shows the approximate temperature and pH stability ranges for the identified alteration assemblages. Wallrock alteration assemblages within the vein zone and corresponding temperatures of stability have been plotted on the Gosowong long section (Figure 3.3.8).
<table>
<thead>
<tr>
<th>Alteration Assemblage</th>
<th>Temperature Stability Range</th>
<th>pH stability Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Kaolinite-dickite±alunite</td>
<td>Low T steam-heated alteration</td>
<td>2-3</td>
</tr>
<tr>
<td>2 Smectite-illite</td>
<td>120-160°C</td>
<td>5-6</td>
</tr>
<tr>
<td>3 Illite-smectite-carbonate</td>
<td>160-220°C</td>
<td>5-6</td>
</tr>
<tr>
<td>4 Chlorite-smectite-carbonate</td>
<td>150-220°C</td>
<td>6-7</td>
</tr>
<tr>
<td>5 Illite±chlorite</td>
<td>220-270°C</td>
<td>5-6</td>
</tr>
<tr>
<td>6 Chlorite-epidote±carbonate</td>
<td>&gt;240°C</td>
<td>6-7</td>
</tr>
</tbody>
</table>

Table 3.3.1. Alteration mineral interpreted temperature and pH stability ranges (based on data from Lawless et al., 1997 and Corbett & Leach, 1998).

Figure 3.3.8. Alteration zoning along the Gosowong Vein Zone and interpreted alteration mineral temperature stability ranges (based on data from Lawless et al., 1997 and Corbett & Leach, 1998).

3.3.5 Alteration Zoning Model

Alteration assemblages at Gosowong can be split up into two major groups: hypogene alteration caused by upwelling near-neutral chloride waters interacting with volcanic wallrock, and alteration caused by near surface steam-heated acidic waters overprinting prior alteration assemblages. The Gosowong alteration model will be discussed in the following sections.
3.3.5.1 Hypogene Alteration

Alteration zoning along the Gosowong Vein Zone is illustrated in Figure 3.3.8. One of the most striking characteristics of this model is the gentle southerly plunge of the alteration mineral isograds. The north end of the GVZ is dominated by a typical propylitic assemblage of chlorite-epidote-carbonate. This propylitic zone plunges gently southward beneath the keel of the Gosowong deposit. This style of alteration, though containing epidote, a mineral generally thought to indicate high fluid temperatures, does not necessarily represent a high-temperature style of alteration. It may instead indicate a lack of intense metasomatism due to low water/rock ratios in distal portions of the system (Bogie, 2000), representing a more conductive transfer of heat: alteration is likely to have been more isothermal in nature (Coote, 1996b). Though this style of alteration may not necessarily indicate a temperature gradient, it more importantly indicates a distal location with respect to major hydrothermal fluid conduits and thus ore-grade mineralization.

Illite group minerals are one of the most useful and best-documented paleo-temperature indicators. Figure 3.3.8 shows the distribution of illite group minerals along the GVZ. Illite ±chlorite is most abundant immediately above the propylitic alteration assemblage, common at surface along the northern end of the Gosowong deposit and for several 100 meters to the north. Within the illite±chlorite zone, the ratio of chlorite to illite increases with increasing depth. With decreasing depth, illite gives way to illite>smectite and then to smectite>illite. Smectite is most abundant at shallow levels at the extreme south end of the GVZ. This progression in thermal stability commonly results in a clear upward and outward zonation of minerals in low-sulfidation epithermal systems (White & Hedenquist, 1995). This alteration zoning pattern is consistent with low-sulfidation epithermal system models proposed by various researchers (Buchanan, 1981; Baker, 1993; White & Hedenquist, 1995). A schematic section constructed by Baker (1993) shows the typical alteration zoning patterns of low-sulfidation epithermal veins in SE Asia (Figure 3.3.9). The resilient Buchanan model is illustrated in Figure 3.3.10.

Cross-sectional alteration patterns along the GVZ closely resemble published epithermal alteration models (Figure 3.3.2). Typical cross-sectional alteration zoning generally consists of a central zone of quartz-adularia-carbonate at shallow levels. This assemblage is interpreted to precipitate as a result of an increase in fluid pH upon boiling off of CO$_2$ and H$_2$S gases. Outward from this central zone is the argillic assemblage (illite-smectite group minerals) which indicates
fluid temperatures of 100-270°C depending on the illite: smectite ratios. Fluid pH associated with these mineral assemblages generally ranges around 5-6, indicating highly permeable fluid conduits (Lawless et al., 1997).

Figure 3.3.9. Schematic section showing typical zoning patterns in low-sulfidation epithermal veins in SE Asia (Baker, 1993).

Figure 3.3.10. The Buchanan model of the epithermal system, based on a study of over 60 epithermal systems in the SW USA (after Buchanan, 1981).
Argillic alteration is generally strongly structurally controlled. It may occur for tens of meters into the hangingwall, while the footwall has a more abrupt contact. The intensity of argillic alteration decreases with depth and away from the strongly mineralized portion of the vein zone. Early argillic and propylitic alteration show evidence for later quartz-adularia-illite alteration overprinting as the hydrothermal system evolved through time. Argillic alteration grades into the enveloping propylitic style of alteration characterized by an epidote-chlorite-carbonate±smectite mineralogy.

Figure 3.3.11 shows postulated fluid flow conduits along the GVZ. It is interpreted that mineralizing fluids ascended the Gosowong structure in the vicinity of 10,000N. Upon intersecting the permeable and structurally complex Gosowong Volcaniclastic sequence, mineralizing fluids penetrated laterally both to the north and south along the structural/lithological intersection, forming the gently south-plunging alteration mineral zoning characteristic of the GVZ. As the fluids boiled or otherwise cooled through conduction, illite-chlorite assemblages gave way to illite, illite-smectite, and smectite alteration with increasing distance from the fluid conduit.

![Figure 3.3.11](image.png)

**Figure 3.3.11.** Alteration zoning along the Gosowong Vein Zone and interpreted alteration mineral temperature stability ranges (based on data from Lawless et al., 1997 and Corbett & Leach, 1998). Postulated fluid flow pathways are indicated.
3.3.5.2 Steam-Heated Alteration

As hydrothermal fluids boil, gases such as $\text{H}_2\text{S}$ are released into the structure and travel upward in the steam column and condense into cool groundwater. The $\text{H}_2\text{S}$ then oxidizes to form $\text{H}_2\text{SO}_4$ in the vadose zone above the paleo-water table. The resulting steam-heated acidic fluids cause advanced argillic alteration and leach cations out of the rocks, leaving a skeleton of residual quartz (acid-leach) (Baker, 1993). Acid-stable alteration minerals such as kaolinite and alunite are formed, leading to the apparent paradox of acidic alteration in association with low-sulfidation ore (Hedenquist et al, 1996).

The presence of dickite within this low-temperature steam-heated alteration assemblage is enigmatic. A plausible explanation for the presence of dickite in the alteration assemblage is that dickite may be more common within steam-heated zones than previously thought, but hasn’t been properly identified through XRD methods. Noel White (pers. com.) contends that dickite has a very distinct infrared spectrum and is easily and accurately identified by PIMA, while it is very difficult to identify through XRD analyses. Bogie (2000) supports that assertion, stating that both halloysite and dickite have often been misidentified and included with kaolinite in petrological studies, and that much material previously described as kaolinite may contain appreciable amounts of dickite. It requires very careful XRD analysis to discriminate these phases. With the increasingly widespread use of PIMA infrared analyses, it may be that dickite, often mistaken for kaolinite, will be found to be a relatively common mineral within steam-heated alteration zones.

Another possibility is that the presence of dickite indicates a “hot-spot”, formed by the channeling of acid-sulfate waters down permeable structures deep into the hydrothermal system, being neutralized due to rock reaction and heated up as the waters enter hotter conditions in the hydrothermal system (Leach, 1998). This assertion is supported by Reyes (1990) who documented structurally controlled acid-leaching as well as kaolinite, dickite, and pyrophyllite alteration at depths of 500 m in Philippine geothermal systems.

In either case, it is apparent that the fluids that produced this acid-stable alteration assemblage at Gosowong were not of hypogene origin. There is no evidence petrologically to support the case of acid alteration as a result of upwelling acid fluids generated by the mixing of magmatic volatiles and groundwater (Coote, 1996b).
Due to the presence of four Cu-Au porphyries in the area, the extensive acid-sulfate alteration may be part of the porphyry alteration system. Though this may explain the widespread distribution of this alteration style, it is thought that this is unlikely that the partially eroded acid-sulfate alteration and the deeply eroded porphyry mineralization are genetically related. The 200-300 m elevation difference between the acid-sulfate cap and the porphyry system could not account for the very different levels of erosion (Leach, 1998). Furthermore, Ar\(^{40}/\text{Ar}^{39}\) age dating on alunite grains within the acid-sulfate alteration north of Gosowong indicate an age of 2.8-2.9 Ma, which closely matches the age date of 2.9 Ma for epithermal alteration within the GVZ (Vasconcelos, 1998). Porphyry alteration/mineralization within the Gosowong District generally dates to about 3.5 Ma. This evidence suggests that the extensive zones of acid-sulfate alteration within the Gosowong District are genetically related to the epithermal mineralization event and not the porphyry event.

Significant erosion may occur in volcanic arcs during hydrothermal activity, resulting in collapse of the system and the formation of a steam-heated alteration overprint to shallow ore (Hedenquist et al, 1996). This scenario is illustrated in Figure 3.3.12 showing how a falling water table can cause the shallow ore to be overprinted by an acid-sulfate alteration assemblage. If acid condensates drain downward from the zone of acid leaching, they cause kaolinite alteration, which may overprint precious-metal-associated alteration. The kaolinite commonly is controlled structurally and may even fill remnant open spaces in veins (Sillitoe, 1993).

![Figure 3.3.12](image)

*Figure 3.3.12. Shallow manifestation of an epithermal system with a falling water table during mineralization (Sillitoe, 1993).*
The above-described scenario appears to be the case in the GVZ. Section 9800N illustrates the typical relationship between hypogene alteration/mineralization and the steam-heated overprint (Figure 3.3.2). Hypogene illite/smectite alteration and mineralization is overprinted by a kaolinite-dickite assemblage. Alunite is not common in any great abundance as an overprinting alteration mineral, but is relatively abundant in areas peripheral to the illite/smectite alteration halo. This may be due largely to the lack of alkali metal within the previously illite-smectite altered andesitic volcanics. The morphology of the steam-heated alteration zones in the areas peripheral to the GVZ is generally blanket-like, apparently mimicking the paleo-water table. But where highly permeable structures, such as the GVZ, intersected the acid fluid-rich zones, the condensates percolated down the structure and overprinted the precious-metal-associated alteration and mineralization. Acid-sulfate alteration extends more than 150 m down the GVZ structure.

3.3.6 Conclusions

Alteration zoning is a common feature of low-sulfidation epithermal systems. Many hydrothermal minerals are stable over only a very limited temperature and pH range and thus provide an indication as to the fluid conditions of the paleo-hydrothermal system. The mapping of hydrothermal alteration mineral distribution in the epithermal system may produce vectors to highly mineralized zones and may provide vital information for determining the level of exposure of the system. The distribution of the alteration mineralogy in the GVZ has provided very useful information on fluid flow vectors and ore-shoot targeting as well as the general paleo-hydrology of the extinct hydrothermal system.

- The GVZ exhibits typical low-sulfidation epithermal alteration patterns. Comparison between the Gosowong model and various published models shows striking similarities.
- Alteration distal to the vein zones and at depth is dominated by a propylitic assemblage of chlorite-epidote-carbonate, indicating low water to rock ratios and near-neutral pH fluids. This style of alteration is not an accurate indicator of fluid temperatures.
- Significant Au mineralization is not generally hosted within propylitic altered rocks.
- Within the vein envelope, alteration is dominated by illite-group clay minerals and chlorite, indicating slightly acidic fluid pH (5-6).
• Illite-group minerals and chlorite display a distinct zoning along the fluid pathway within the GVZ: illite-chlorite ⇒ illite ⇒ illite-smectite ⇒ smectite-illite with decreasing depth. This zoning is related to decreasing fluid temperature along the fluid flow pathway.

• Most significant Au mineralization is associated with illite-smectite, illite, and illite-chlorite alteration, indicating fluid temperatures of 150-220°C within the QA zone and 220-270°C in the QC zone.

• Alteration within the central vein zone of the QA mineralization consists of quartz-adularia-carbonate. This is an indication of high pH fluids due to the loss of volatiles during vigorous boiling.

• Illite-smectite alteration is generally structurally controlled and grades into the enveloping propylitic style of alteration.

• Hydrothermal fluids are postulated to have ascended the Gosowong vein structure in the vicinity of 10,000N and spread out laterally along the permeable, south-plunging volcaniclastic horizon.

• Steam-heated alteration, consisting of kaolinite-dickite±alunite and vuggy quartz, overprints shallow ore and ore-related alteration in the southern end of the GVZ. This is interpreted to indicate rapid erosion of the system and a lowering of the water table, resulting in a telescoping of the alteration styles.

• Additional steam-heated alteration occurs to the north of the GVZ, past the limit of current drilling, perhaps indicating a subsurface boiling zone.

• $^{40}$Ar/$^{39}$Ar age dating indicates that the steam-heated alteration is genetically related to the epithermal mineralizing event in the GVZ.
3.4 FLUID INCLUSIONS

3.4.1 Introduction

Knowledge of any aspect related to the deposition of ore-grade mineralization may be very helpful in exploration. Fluid inclusion analyses can provide very useful information and may be used as an exploration guide in the search for mineralized systems. These analyses can be very accurate indicators of the physical and chemical environments of mineral deposition in the epithermal system.

The purpose of this fluid inclusion study is to provide an indication of the paleo-hydrological conditions at the time of the vein formation over the entire GVZ. These data may be useful in the recognition of vertical or horizontal thermal gradients along the GVZ, and may delineate feeder channels and the flow direction of ore-forming fluids. The recognition of boiling of hydrothermal fluids in the epithermal system through fluid inclusion analyses may indicate conditions conducive to ore deposition. The desired outcome of this study is to provide additional information on the source, flow direction, and temperature of the mineralizing hydrothermal fluids, in hopes that it will provide clues as to the most prospective zones in which to focus further exploration work. This may be summed up as: “The more one knows about a given process of ore deposition, the better one knows where (or where not) to look for more ore” (Roedder, 1982).

3.4.2 Methodology

Quartz vein samples were collected from vein intercepts in drill core on site. Vein samples were selected from each of the three ore domains: banded quartz from both the QA and QC and crystalline quartz from the QS. A wide vertical and horizontal spread of the sample points was desired, in an attempt to provide a complete picture of the paleo-thermometry of the Gosowong vein system. Samples were collected from section 9500N through to 11,450N, representing the entire 2 km of known strike length. Likewise, sampling was conducted down the dip of the vein extending 600 m down-dip from surface. A total of 34 quartz vein samples were originally collected for this study.

The quartz vein samples were sent to the University of Tasmania for slide preparation. All preparation work was carried out in the geology department lapidary workshop. A total of 34 doubly polished thin sections (100 μm thick) mounted on glass slides were produced.
Preliminary petrology work was then conducted on the fluid inclusion slides, consisting of a brief description of the quartz vein material, ore domain classification, and locations of both primary and secondary fluid inclusions (Appendix V). Due to time constraints, only 16 of the samples were described during this stage of the study. The slides were then returned to the lapidary workshop and soaked in acetone to dissolve the glue holding the thick section to the glass slide.

Microthermometry was carried out on a Fluid Inc. heating/freezing stage at the University of Tasmania. Previously mapped primary fluid inclusions were relocated and slowly heated in a stepwise fashion until the vapor bubble homogenized with the liquid phase. The heating process was then halted and the maximum temperature recorded (T_h). Following the heating process, the fluid inclusions were supercooled to a temperature of ~60°C and allowed to slowly heat up. The temperature at which the final ice melted (T_m) was noted and recorded. The temperature of first ice melting (the eutectic temperature) could not be confidently observed. The data are reproducible to ±3°C during heating and ±0.2°C during freezing point depressions. The system’s trendicator was calibrated at 274°C and −10°C using synthetic fluid inclusion standards. The T_m and T_h of each individual fluid inclusion were correlated for use in temperature versus salinity plots.

In order to complete the GVZ data set, an additional series of 13 fluid inclusion slides were sent out to consulting petrologist Anthony Coote. Anthony was requested to carry out the routine task of heating and freezing the fluid inclusions but to provide no further interpretation of the significance of the results. This work, combined with the author’s work and all previous work (Bogie, 1994; Coote, 1998; Coote, 2000a; Coote, 2000b) provides a meaningful picture of the paleo-hydrological conditions of the Gosowong system.

3.4.3 Results

The results of all previous and current fluid inclusion work, a total of 413 heating measurements and 199 freezing measurements, are given in Appendix V and summarized in Table 3.4.1. All fluid inclusion data, both past and current, will be discussed in the following sections.

Primary, secondary, and pseudosecondary fluid inclusions were distinguished based on criteria proposed by Roedder (1994). All fluid inclusions were hosted by medium to coarsely crystalline quartz (Figure 3.4.1). Three general types of fluid inclusions were observed at room temperature:
1. Two-phase, liquid-rich, primary fluid inclusions along crystal growth faces.

2. Two-phase, vapor-rich, primary fluid inclusions, coexisting with coeval liquid-rich fluid inclusions along crystal growth faces.

3. Two-phase, liquid-rich, secondary fluid inclusions within fractures cutting across crystal boundaries.

Type 1 and 2 inclusions are closely associated, being spatially and temporally related. Fluid inclusions are generally irregular in shape and range in size from 3 to 40 μm. Traces of CO₂ were often but not always identified within the type 2 fluid inclusions as a characteristic bubble within a bubble. The main emphasis was on studying primary fluid inclusions (types 1 & 2), but temperatures of melting and homogenization for secondary fluid inclusions (type 3) fall within a similar range.

<table>
<thead>
<tr>
<th>Ore Domain</th>
<th>T₁, Range °C</th>
<th>T₃, Average °C</th>
<th>n=</th>
<th>T₃, Range °C</th>
<th>T₃, Average °C</th>
<th>Salinity Wt% NaCl</th>
<th>n=</th>
</tr>
</thead>
<tbody>
<tr>
<td>QA</td>
<td>170-260</td>
<td>210</td>
<td>71</td>
<td>-0.2 to -0.9</td>
<td>-0.45</td>
<td>0.80</td>
<td>19</td>
</tr>
<tr>
<td>QC</td>
<td>199-273</td>
<td>236</td>
<td>65</td>
<td>-0.1 to -0.5</td>
<td>-0.24</td>
<td>0.42</td>
<td>25</td>
</tr>
<tr>
<td>QS</td>
<td>190-363</td>
<td>242</td>
<td>277</td>
<td>0.4 to -0.8</td>
<td>-0.28</td>
<td>0.50</td>
<td>155</td>
</tr>
</tbody>
</table>

Table 3.4.1. Summary of Gosowang fluid inclusion results, from 1994 to present. QA = Quartz-Adularia, QC = Quartz-Chlorite, QS = Quartz-Stockwork.

3.4.3.1 Heating Studies

Homogenization temperatures are presented uncorrected for pressure. In the relatively low pressure epithermal environment, fluid inclusion homogenization temperatures require little or no temperature correction to obtain the trapping temperature. Thus, homogenization temperatures provide a good approximation of the mineralization temperature and are not usually subject to errors in interpretation (Bodnar, 1985). Furthermore, the co-existence of fluid-rich and vapor-rich inclusions indicates the trapping of a boiling fluid (Roedder, 1984), and thus the system is interpreted to be under hydrostatic pressure, meaning that homogenization temperatures may be considered reasonable approximations to hydrothermal fluid trapping temperatures. Homogenization temperatures were obtained from the type 1 liquid-rich fluid inclusions, as these are presumed to represent the approximate temperature of boiling.
Figure 3.4.1. Fluid inclusion photomicrographs. A. Type 1 primary fluid inclusions along crystal growth face, from the QC. GSD-027, 89.4 m. B. Euhedral type 1 primary fluid inclusions, from the QS. GSD-168, 287.0 m. C. Type 2 coexisting liquid-rich and vapor-rich primary fluid inclusions, from the QS. GSD-086, 7.0 m. D. Type 3 secondary fluid inclusion trails along fractures, from the QC. GSD-015, 46.2 m. E. Zoned crystal, dark outer rims rich in primary fluid inclusions, from the QS. GSD-173, 168.3 m. F. Primary fluid inclusion trails along crystal growth faces, from the QC. GSD-187, 136.4 m.
Fluid inclusion geothermometry indicates that the fluids responsible for quartz deposition ranged between 170°C and 363°C. The wide range in homogenization temperatures reflects the great vertical extent of sample points within the vein system. All fluid inclusion results are summarized in Figure 3.4.2.

Figure 3.4.2. Fluid inclusion temperature of homogenization results, categorized into the three ore domains.

Figure 3.4.3. Fluid inclusion temperature of homogenization versus relative level within the system.

The fluid inclusion samples were classified into the three ore domains: quartz-adularia (QA), quartz-chlorite (QC), and quartz-stockwork (QS). The average temperature of homogenization of the QA is 210°C, significantly lower than both the QC and QS, which average 236°C and 242°C respectively. The temperature gradient between the QA and the subjacent QC may be due purely to differing vertical positions within the system, but may also indicate that the two styles of mineralization were deposited during separate hydrothermal events from fluids of differing temperatures. The QS shows the widest range of homogenization temperatures, due mainly to the wide vertical and horizontal distribution of this vein type throughout the system. Figure 3.4.3 shows the overall relationship between fluid inclusion temperature of homogenization and relative level in the system. A trend of increasing temperatures with decreasing RL is clearly evident in the results.

The spatial distribution of the fluid inclusion temperatures along the strike of the GVZ is illustrated in Figure 3.4.4. The most obvious trend in distribution is the increase in temperature with decreasing RL. There also appears to be a horizontal distribution in fluid inclusion temperatures. Superimposed paleo-isotherms illustrate the gently southward plunge in the distribution of the temperatures. The highest fluid inclusion temperatures are generally found in the northern portion of the
GVZ, but with increasing distance to the south, lower fluid inclusion temperatures are found at progressively deeper levels in the system.

Many studies of individual veins have shown horizontal temperature gradients that presumably indicate source regions and at least some horizontal component of fluid flow (Roedder, 1982). Horizontal temperature gradients in the GVZ are not great (1.3-3.1°C/100 m), but they may indicate that there was a small horizontal component of fluid flow along the vein structure. A vertical temperature gradient of 7-16.4°C/100 m indicates that the vertical component of fluid flow was the dominant flow vector.

![Figure 3.4.4. Distribution of average fluid inclusion temperatures along the GVZ.](image)

### 3.4.3.2 Freezing Studies

Freezing studies are best and most readily used to measure the salinity of fluid inclusions because the lowering of the freezing point of pure water is directly proportional to the amount of salt in solution. This is achieved by measuring the final ice melting temperature on reheating the frozen inclusion (Shepherd et al., 1985). Fluid inclusion melting temperatures and calculated salinities are summarized in Table 3.4.1. Salinities have been calculated using formulas based on the freezing point depression experimental data of Hall et al. (1988).

As was done in the heating study, the fluid inclusion samples were classified into the three ore domains: quartz-adularia (QA), quartz-chlorite (QC), and quartz-stockwork (QS). Final ice melting
temperatures fall within the narrow range of 0.4° to -0.8°C (average = -0.3°C), indicating that inclusion fluids are dilute, containing less than 1.4 eq. wt. % NaCl (average = 0.5 eq. wt. % NaCl).

Though there is a strong correlation between fluid inclusion temperature and relative level within the system (Figures 3.4.3 & 3.4.4), the correlation between salinity and relative level within the system is more subtle. Figure 3.4.5 shows the results of all salinity measurements in the GVZ. Immediately apparent is the higher calculated salinity of the QA with respect to the QC and QS. The QC and QS possess very similar calculated salinities. The distribution of fluid inclusion salinities along the GVZ is illustrated in Figure 3.4.7. The highest salinities are generally located in the upper portion of the system while the lower salinities are generally found deeper in the system. This general relationship between salinity and relative level within the system is shown in Figure 3.4.6. An average vertical gradient of 0.4 eq. wt. NaCl / 600 m is indicated from the data.

**Figure 3.4.5.** Fluid inclusion freezing point depression results, categorized by ore domain.

**Figure 3.4.6.** Fluid inclusion salinity versus relative level within the GVZ.
3.4.4 Discussion

The evidence for boiling obviates the need to apply pressure corrections to the temperature data. These data can then be very easily transformed into depths below the paleo-water table. Average temperatures in the QA, the upper-most ore zone, range from 173°-234°C (average 210°C). Assuming that the quartz veining was deposited under hydrostatic pressure and an average fluid salinity of 0.8 eq. wt. % NaCl, this temperature range equates to a level of 100-350 m (average 225 m) below the paleo-water table (Haas, 1971) (Figure 3.4.8). By making similar assumptions for the QC, the average temperature range of 220°-253°C equates to a paleodepth of 275-475 m (average 350 m) for this style of mineralization. Due to the wide vertical distribution and average temperature range of the QS (205°-265°C), estimating the paleodepth likewise produces a wide range, between 190-625 m. The paleodepth estimate based on fluid inclusion homogenization temperatures appears to be a reasonable approximation and is in general agreement with other geological data discussed in this study.

Fluid inclusion salinity calculations show a slight difference between QA salinities and QC & QS salinities. This salinity variation may be due to increased and prolonged boiling of the hydrothermal fluids in the QA with respect to the QC and QS, thus concentrating the non-volatile components of the QA fluid and increasing the salinity. This difference also may be due to a slightly more saline fluid being responsible for the QA mineralization, possibly indicating two major mineralizing pulses during the formation of the GVZ.
Alternatively, the difference may not be significant for technical reasons. All QA fluid inclusion analyses were carried out by Bogie (1994) at the University of Auckland, while the other analyses of the QC and QS fluid inclusions were carried out jointly between Olberg & Coote (this study) on separate heating/freezing stages, between which there is good correlation. As the apparent temperature difference amounts to only 0.2°C, it is likely that a small nuance in machine calibration or user technique may be responsible for the miniscule temperature variation.

Temperature versus salinity plots indicate that the fluids in the GVZ are typically epithermal in nature, characteristic of deeply convected chloride waters with near-neutral pH (Figure 3.4.9). Traces of CO₂ observed within some individual fluid inclusions might act to depress the final ice melting temperatures. Hedenquist and Henley (1985) have pointed out that dissolved CO₂ can contribute to freezing point depressions in a similar manner to dissolved salts, and thus these calculated salinities indicate a maximum value. Because the measured final ice melting temperatures are so close to the freezing point of pure water, it is unlikely that the presence of CO₂ has any significant effect on the calculated salinity.

Fluid inclusion temperature versus salinity plots show that there is no obvious correlation between temperatures of homogenization and fluid salinity (Figure 3.4.10).

Figure 3.4.8. Boiling point for depth curve showing the ranges of fluid inclusion temperatures within the three ore domains in the GVZ. A 0.8 eq. wt. % NaCl fluid was assumed (after Haas, 1971).
3.4.5 Conclusions

This fluid inclusion study has proven to be a very helpful tool in the continuing exploration program at Gosowong. The information gleaned from this study has greatly facilitated the overall interpretation of the GVZ paleo-hydrology and vein paragenesis. These factors, along with the increased knowledge of the physico-chemical conditions of vein deposition, will act as an exploration guide during further exploration work along the GVZ. The following bullet points summarize the main conclusions of this study:

- Fluid inclusion analyses indicate mineralizing fluids to have a typical epithermal signature: dilute (generally less than 1.0 eq. wt. % NaCl) and low temperature (generally 175-265°C).
- The ubiquitous presence of coexisting vapor-rich and liquid-rich primary fluid inclusions indicates that boiling processes have taken place in the GVZ.
- The QA zone contains significantly lower fluid inclusion T_h, reflecting the high level within the system and significant heat loss due to rapid boiling.
- The QS zone exhibits a wide range of fluid inclusion T_h, reflecting the wide distribution of this style of mineralization throughout all levels of the system.
- The distribution of fluid inclusion T_h along the GVZ indicates a dominantly vertical thermal gradient with a very small horizontal component. The thermal gradient suggests a small component of
southward flow along the GVZ, possibly indicating a fluid source to the north. Gently south-plunging isotherms along the long section illustrate the apparent thermal gradient.

- Fluid inclusion trapping temperatures in the QA suggest that quartz deposition took place 100-350 m below the paleo-water table.
- Fluid inclusion salinities appear to be fairly uniform throughout the GVZ and fall within a narrow range of values, generally 0.2 – 0.9 eq. wt. % NaCl. There is, however, a subtle correlation between increasing salinity and increasing RL.
- Slightly higher salinities within the QA with respect to the QC and QS is likely due to the concentration of non-volatiles into the liquid phase during intense and prolonged boiling in the QA.
- The optimal temperature for the deposition of ore-grade mineralization ranges from 175-225°C.
- The most prospective area appears to be the southern zone of the GVZ. The paleo-hydrothermal conditions in the south appear to be most similar to those of the Gosowong deposit (T_h = 175-225°C).
- The least prospective areas appear to be the area to the north of the deposit and at depth beneath the deposit. Fluid inclusion T_h indicate higher than optimal temperatures for the deposition of significant Au mineralization.
3.5 METAL ZONING

3.5.1 Introduction

Both vertical and lateral zonation is a common characteristic of metal distribution in epithermal gold deposits (Clarke, 1989). Metal zoning in epithermal systems can be studied at various scales, from regional to prospect to ore-shoot scale. Patterns of metal zoning within an epithermal system, once established, can serve as a guide to the discovery of additional ore bodies within the district or perhaps within another district entirely. In addition, once the metal zoning and mineralogy within an epithermal system have been established, inferences can be made as to the paleo-hydrology and relative level of the system. The generalized metal distribution in low-sulfidation epithermal deposits is shown in Figure 3.5.1.

![Diagram of metal zoning](image)

**Figure 3.5.1.** Low sulfidation epithermal Au-Ag system. Relative levels of deposition for each of the major elements are indicated on the right hand side of the figure (Corbett & Leach, 1998).

Metal zonation commonly observed in epithermal systems is the result of the mechanisms of transportation and deposition of these metals and their relative solubilities under variable

Chapter 3.5 – Metal Zoning
physico-chemical conditions. The different environments that mineralized fluids encounter at progressively shallower crustal levels is interpreted to produce the observed zonation in precious, base, and toxic metals (Corbett & Leach, 1998).

The purpose of this metal zoning analysis is to provide an indication as to the hydrology (fluid flow directions, source area, etc.) of the paleo-hydrothermal system that produced the Gosowong mineralization. A trace element zoning pattern along the GVZ will be established using single element values as well as elemental ratios. The metal zonation patterns of the high-grade ore-shoots and peripheral low-grade mineralization will be characterized and it is hoped that these geochemical signatures can act as an exploration guide to additional high-grade mineralization along the GVZ. In addition, comparison of the geochemistry of the three ore types will be conducted in an attempt to determine the elemental relationships between the three zones.

### 3.5.2 Methodology

All geochemical data used in this analysis have been derived from routine assaying of drill core during the Gosowong drillout and subsequent exploration. The size of most of the drill core was HQ with lesser amounts of PQ and rarely NQ in the deepest drill intercepts. Core was split on site using a diamond saw and half-core was routinely sampled at nominal 1 m intervals through the mineralized zones and sent for assay. All samples were routinely assayed for Au, Ag, Cu, Pb, Zn, As, and Sb. Table 3.5.1 summarizes the assay methods and detection limits for the Gosowong drill-core.

<table>
<thead>
<tr>
<th>Element</th>
<th>Au</th>
<th>Ag</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>As</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>FAS</td>
<td>AAS</td>
<td>AAS</td>
<td>AAS</td>
<td>AAS</td>
<td>XRF</td>
<td>XRF</td>
</tr>
<tr>
<td>Det. Lim. (ppm)</td>
<td>0.005</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 3.5.1. Assay methods and detection limits for Gosowong drill-core. FAS = Fire Assay, AAS = Atomic Absorption Spectrometry, XRF = X-ray Diffraction.

For this project, assay results for each core were compiled and the width and grade of the mineralized vein intercepts were calculated for each individual drill hole. The widths of the mineralized vein intercepts were based on the Au values, using a >1 g/t Au cutoff for intercepts within the ore zones and a >0.1 g/t Au cutoff for intercepts outside of the ore zones. The average element values of Au, Ag, Cu, Pb, Zn, Sb, and As within the mineralized zone were then
calculated for each vein intercept. The results of these calculations were entered into an Excel spreadsheet where a variety of element ratios were calculated (Appendix II). In cases where assay values less than the detection limit were included in the calculations, the value of half the respective detection limit was entered. For example, Ag values of <1 ppm were converted to 0.5 ppm, and Sb values of <4 ppm were converted to 2 ppm. Within vein intercepts where more than 50% of the individual assays for a certain element were less than the detection limit, the interval was discarded for that particular element. This problem occurred mainly with Sb values and to a lesser extent with Ag values. In cases where multiple Au-mineralized intercepts within a single drill hole were encountered, the values were composited and plotted using the average RI of the intercepts.

The metal values and calculated ratios were then plotted as drill hole pierce points and contoured on the Gosowong long section using Surfer software. The data points were contoured by kriging, using a linear variogram model with an anisotropy ratio of 1.0, and a 10 m x 10 m grid spacing. Drill hole pierce points were then posted over the contoured image to show data density. Surface topography and the approximate final pit outline were then superimposed over the image.

In a related exercise, the individual drill hole intercepts were categorized based on the dominant ore type present: Quartz-Adularia (QA), Quartz-Chlorite (QC), and Quartz-Stockwork (QS). These data were then plotted onto X-Y scatter plots for each element and elemental ratio, with 3 different colors representing the 3 different ore types.

3.5.3 Results

The results of this metal zoning analysis will be presented and discussed in the following format:
1. Single element plots showing the composite elemental values for each vein intercept and the resultant zoning patterns.
2. Metal ratio plots illustrating relative values of the elements within the GVZ and the resultant zoning patterns
3. Scatter plots showing comparative geochemistry between the three vein domains.
3.5.3.1 Single Element

Single element plots are presented in Figures 3.5.2 to 3.5.8. The purpose of the single element plot is to illustrate the absolute metal values of the GVZ as a prelude to presenting and discussing the metal ratio zoning within the system. The average metal values for each of the individual vein zones and the entire GVZ have been summarized in Table 3.5.2.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Width (true)(m)</th>
<th>Au (ppm)</th>
<th>Ag (ppm)</th>
<th>Au/Ag</th>
<th>Cu (ppm)</th>
<th>Pb (ppm)</th>
<th>Zn (ppm)</th>
<th>As (ppm)</th>
<th>Sb (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QA</td>
<td>13.4</td>
<td>73</td>
<td>43</td>
<td>1.7</td>
<td>144</td>
<td>110</td>
<td>45</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>QC</td>
<td>10.0</td>
<td>29</td>
<td>54</td>
<td>0.5</td>
<td>177</td>
<td>80</td>
<td>121</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>QS</td>
<td>7.6</td>
<td>1.4</td>
<td>10</td>
<td>0.15</td>
<td>105</td>
<td>32</td>
<td>82</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Entire GVZ</td>
<td>9.0</td>
<td>18</td>
<td>24</td>
<td>0.7</td>
<td>125</td>
<td>53</td>
<td>83</td>
<td>12</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 3.5.2. Average metal values for the GVZ, categorized into the individual vein zones

- **Au**: At Gosowong, Au is by far the most effective pathfinder element when prospecting for additional Au mineralization. The most striking features of the Gosowong Au plot are the two high-grade ore shoots: the quartz-adularia zone (QA) at the surface near 10,150N and the gently south-plunging quartz-chlorite zone (QC) cutting across the center of the deposit (Figure 3.5.2). Mineralized quartz-stockwork veining (QS) is outlined just south of the river around 10,400N. A general southerly plunge to all Au mineralization is evident, from north of the river (10,800N) to the far-southern, deep reaches of the GVZ. Apparent surface mineralization north of 10,800N is purely a product of the software kriging algorithms. Supergene enrichment of Au is not likely a major factor in near-surface Au mineralization.

Figure 3.5.2. Au, average grade contours (ppm) within the GVZ.
• **Ag**: Ag and Au are the only metals of economic significance to be extracted from the Gosowong ore. The contoured average grade plot for Ag closely resembles that for Au (Figure 3.5.3). Moderate to high Ag values are indicated for the QA and QC, but the zone that contains the highest Ag grades is the QS at 10,400N. As with Au, the Ag mineralized contours plunge gently to the south but grades drop off very quickly south of the pit boundary. Within the surficial QA (10,150N), Ag levels appear slightly depleted with respect to the underlying QA mineralization. This is likely due to the leaching of the more mobile Ag in the supergene environment.

In some cases, the majority of the Ag values from a single vein intercept were less than the detection level (<1 ppm) and thus the intercept has not been plotted. This situation is prevalent in both the far northern and southern portions of the GVZ.

![Figure 3.5.3. Ag, average grade contours (ppm) within the GVZ.](image)

• **Cu**: Base metal contents are, in general, low throughout the GVZ. The average Cu grade over the entire GVZ is around 125 ppm and even in the high grade ore shoots, the average Cu values do not exceed 180 ppm. The only Cu mineral observed in the GVZ is chalcopyrite. Cu values are generally higher within the ore shoots than in the surrounding quartz stockwork veining. Within the peripheral stockwork veining there is no significant drop off in Cu grade with depth (Figure 3.5.4). Cu appears to have been leached out of the surficial vein material, forming a Cu-depleted blanket over the vein zone. A layer of elevated Cu values immediately underlying the blanket of Cu depletion may be, in part, due to supergene enrichment, though no Cu-oxide and sulfide minerals have been observed. Several spot Cu highs occur throughout the GVZ, but are not thought to be significant for exploration potential.

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**Pb:** Pb appears to be the base metal most closely associated with precious metal mineralization. Over the entire GVZ, Pb grades average about 53 ppm, and within the ore zones, Pb levels generally rise to around 110 ppm. The dominant Pb mineral is galena, common within fine, dark, sulfide bands, but rarely visible except in thin section. Pb does not appear to be leached from surface vein material, as it is much less mobile than either Cu or Zn (Figure 3.5.5). Zones of elevated Pb values roughly correlate with high-grade precious metal mineralization, particularly within the QC ore shoot; the relationship is less obvious within the QA. A zone of high Pb values occurs just beneath the north end of the pit, associated with Ag-Au mineralized stockwork veining. Pb values drop off rapidly outside the deposit area and diminish with increasing depth.

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Figure 3.5.4. Cu, average grade contours (ppm) within the GVZ.

Figure 3.5.5. Pb, average grade contours (ppm) within the GVZ.
- **Zn**: Zn values along the GVZ tend to mimic Cu values in both distribution and magnitude. GVZ wide, Zn values average approximately 85 ppm, rising to an average of 120 ppm within the QC ore shoot. Sphalerite is the most common Zn mineral, commonly occurring with both galena and chalcopyrite in dark, fine-grained, Au-rich, sulfide bands. Zn, being a highly mobile element, is depleted from the surface vein material, indicated by a surficial blanket of low Zn values (Figure 3.5.6). Immediately underlying the depleted zone, there appears a horizontal zone of elevated Zn levels, perhaps formed in part by supergene enrichment. This pattern of supergene depletion and enrichment has strong similarities with the Cu distribution along the GVZ (Figure 3.5.4). In general, Zn values tend to increase slightly with depth.

![Figure 3.5.6. Zn, average grade contours (ppm) within the GVZ.](image)

- **As**: Arsenic distribution appears much more enigmatic than the precious and base metal distribution. Arsenic content does not appear to correlate with any particular style of veining nor does it appear to be related to the distribution of the other pathfinder elements. Arsenic levels are generally low, averaging around 12 ppm throughout the GVZ, increasing to an average of 17 ppm within the QA. The most striking feature is the high arsenic zone overlying the southern end of the GVZ (Figure 3.5.7). Though very little quartz veining is present, this zone of intense advanced argillic alteration appears to carry high As values. The southern GVZ contains generally elevated As values, which gradually decrease northward, away from the pit.
**Sb:** Sb values throughout the GVZ are very low, averaging 3 ppm, rising to 5 ppm within the QA ore shoot. In many drill holes, the majority of the Sb assays were less than the detection level (>4 ppm) and thus the absolute accuracy of the values comes into question. Accuracy aside, it is clear that the Sb values are low, and a trend in the values can be distinguished. The upper levels of the GVZ appear to be higher in Sb relative to the deeper and northern portions (Figure 3.5.8).

**3.5.3.2 Metal Ratios**

Metal ratio analyses, both in individual mineral and in whole rock, can be very useful in determining fluid flow directions. Research has shown that fluid flow vectors in Mexican epithermal veins can be determined from the compositional variations of sulfosalt minerals using Sb/As and Ag/Cu ratios (Gemmell et al., 1989). Likewise, metal ratios derived from whole rock analyses (assays) have been used in the polymetallic mineralization of the Julcani Mining District.
in Peru, with Pb/Cu, Ag/Pb, and Ag/Cu being the most useful for determining fluid flow vectors (Goodell & Petersen, 1974). The basic premise behind the use of metal ratios in reconstructing paleohydrology is that certain elements precipitate from a hydrothermal solution at certain temperatures, salinities, pH's, etc. along the fluid flow path. In general, base metals such as Cu, Pb, and Zn precipitate first from a relatively hot fluid. As fluid flow continues up structure or laterally, the fluid cools (due to boiling, mixing, conduction, etc.) and Au and Ag are precipitated, followed by As, Sb, and Hg at shallow levels (Figure 3.5.1). By analyzing trends in the ratios between various elements, fluid flow directions may be postulated.

Metal ratio plots are presented in Figures 3.5.9 to 3.5.18. The significance of the results of these plots will be discussed in the relevant sections, categorized as follows:

1. Au values ratioed against Ag values
2. Au values ratioed against base metal values.
3. Ag values ratioed against base metal values.
4. Base metal values ratioed against other base metal values.
5. Sb values ratioed against As values.

- **Au/Ag**: Comparisons between the average Au grades (Figure 3.5.2) and the average Ag grades (Figure 3.5.3) along the Gosowong long section shows striking similarity in precious metal distribution. Analysis of the Au/Ag ratios along the GVZ shows that a distinct geochemical zoning is present (Figure 3.5.9). The highest Au/Ag ratios are associated with the shallow level QA style of mineralization, averaging around 1.7. With increasing depth, the relative Au values decrease, as indicated by average Au/Ag ratios of 0.5 and 0.15 within the deeper QC and more distal QS mineralization respectively. Within the GVZ, Au/Ag values appear to increase at shallower levels within the ore shoots, yet decrease distally from the highly mineralized ore shoots.
- **Au/base metals**: Base metal values (Cu, Pb, Zn) are characteristically very low at Gosowong (Table 3.5.2). Though significant amounts of Cu and Zn are associated with the QC style of mineralization, the levels remain relatively constant with the tendency to increase slightly with increasing depth (Figures 3.5.4, and 3.5.6). Very low values near the surface are likely due to supergene depletion. Pb, on the other hand, more closely mimics the distribution of Au values, and decreases to trace amounts with increasing depth (Figure 3.5.5).

Due to the extreme range of Au values and the relatively consistent distribution of base metal values, the ratios of Au to the various base metals are strongly influenced by the high Au values. Figures 3.5.10, 3.5.11, and 3.5.12 show the ratios between Au and the various base metals. Immediately apparent is the increase in the Au/base metal ratio at higher levels in the system, indicating higher relative base metal content at depth. A gentle southerly plunge to the contoured values is evident, outlined by the base of the high-Au zone, extending from around 10,600N, southward to 9500N.
Figure 3.5.11. Au/Pb contours with postulated fluid flow vectors within the GVZ.

Figure 3.5.12. Au/(Cu+Pb+Zn) contours with postulated fluid flow vectors within the GVZ.

- **Ag/base metals**: Analyses of the Ag/base metal ratios tell a very similar story to that of the Au/base metal ratios discussed in the previous section. Figures 3.5.13 and 3.5.14 show the contoured Ag/Cu and Ag/Pb values respectively. The most notable feature is the gentle southward plunge of the high-Ag horizon, as observed in the Au/Ag plot and the Au/base metal plots. Ag is concentrated within the upper part of the system with respect to base metals.
Figure 3.5.13. Ag/Cu contours with postulated fluid flow vectors within the GVZ.

Figure 3.5.14. Ag/Pb contours with postulated fluid flow vectors within the GVZ.

- **Base metal/base metal**: Base metal ratios are not often analyzed in low-sulfidation epithermal systems, as they are of generally low value and not an economic commodity. Figures 3.5.15, 3.5.16, and 3.5.17 illustrate Cu/Pb, Cu/Zn, and Zn/Pb respectively. Pb is the base metal most intimately associated with Au mineralization. Figures 3.5.15 and 3.5.17 show high levels of Cu and Zn in the deeper levels of the system, trending to more Pb-rich mineralization at shallow levels. Cu/Zn values show a dramatic increase within the shallow portions of the GVZ, particularly within the low-grade chalcedony zone between the QA and QC (Figure 3.6.16). The northern portion of the GVZ generally possesses base metal values very similar to those from deeper in the system.
Figure 3.5.15. Cu/(Cu+Pb) contours with postulated fluid flow vectors within the GVZ.

Figure 3.5.16. Cu/(Cu+Zn) contours with postulated fluid flow vectors within the GVZ.

Figure 3.5.17. Zn/(Zn+Pb) contours with postulated fluid flow vectors within the GVZ.

- Sb/As: Both Sb and As are known to be prominent at higher levels within the low sulfidation epithermal system, generally above the precious metal interval (Hedenquist et al., 1998; Clarke, 1989). Both Sb and As values in the GVZ are generally low (Table 3.5.2). In fact,
many of the Sb values were less than the detection limit for the XRF assaying technique (4 ppm) and have thus not been included in Figure 3.5.18. Even with the limited Sb assay data, a distinct trend is observed in the relative distribution of As and Sb in the GVZ. The shallow portion of the GVZ contains the highest Sb/(Sb+As) values, which gradually decrease with increasing depth. The low Sb/(Sb+As) values immediately to the south of the pit are associated with the advanced argillic altered cap.

![Figure 3.5.18. Sb/(Sb+As) contours with postulated fluid flow vectors within the GVZ.](image)

### 3.5.3.3 Vein Domain Scatter Plots

In order to better determine variations in the geochemical signatures of the three ore domains, trace element data were categorized into the vein domain type (QA, QC, or QS) and then plotted in X-Y scatter plots. The Au versus Ag plots (Figures 3.5.19 and 3.5.20) show three distinct groupings of values though this may be affected to some extent by the relative levels within the system. The Au versus total base metal plot (Figure 3.5.21) again shows a three-way grouping of the data points, with the QA showing lower base metal values than the QC. Again, some of this variation may be due to relative level in the system. The Pb versus Zn and the Cu versus Zn plots (Figures 3.5.22 and 3.5.23) clearly illustrate the variation in relative base metal values between the QA and QC. Au/Ag values are much lower in the deeper portion of the GVZ, giving way to higher Au/Ag values at shallower levels (Figure 3.5.24).
Figure 3.5.19. Au vs. Ag. Three distinct groupings are observed.

Figure 3.5.20. Au vs. Ag, log-log plot to better illustrate the distribution of the low-grade data points. The same distinct groupings are again observed.

Figure 3.5.21. Au (log) vs. total base metals. Three overlapping groupings are observed.

Figure 3.5.22. Pb vs. Zn, showing the distinct partitioning between the QA and QC.

Figure 3.5.23. Cu vs. Zn, showing the distinct partitioning between the QA and QC.

Figure 3.5.24. Au/Ag vs. RL, showing a distinct decrease in the Au/Ag ratio with increasing depth.
3.5.4 Discussion

- **Au/Ag**: Au/Ag values are often touted as being one of the most useful indicators of fluid flow direction in low-sulfidation epithermal systems, though research by various authors has shown that general agreement has not been reached on this matter. Buchanan (1981) states that Au/Ag ratios tend to be greater higher in the vein system, which is largely agreed to by Clarke (1989), Silberman & Berger (1985), and Hedenquist, et al (1996) who indicate that Au mineralization is dominant over Ag mineralization at shallow levels (Figure 3.5.25). Both Corbett & Leach (1998) and Lawless & White (1995) concluded that Au/Ag ratios are lower in shallow and distal portions of the epithermal system (Figure 3.5.26). Thus, it appears that sufficient uncertainty exists about the meaning of Au/Ag ratios in epithermal systems to cast doubt on any broad, generalizing statements. The Gosowong mineralization appears to conform to the former model, with Au mineralization dominant over Ag mineralization at shallow depth (Figure 3.5.24). High Au/Ag ratios in the near surface QA may be due, in part, to supergene leaching of the more mobile Ag ions (Leach, 1998).

![Figure 3.5.25. Schematic section showing typical variation of indicator elements as function of depth below paleosurface. This model indicates increasing Au:Ag values with decreasing depth. (After Hedenquist et al, 1996).](image-url)
The Au and Ag contoured long sections (Figures 3.5.2 & 3.5.3) show striking similarity in metal distribution. It is generally accepted that Ag and Au are transported mainly as bisulfide complexes under dilute, low-temperature conditions. Therefore, Ag mineralization generally mimics Au mineralization in the low sulfidation epithermal environment (Corbett & Leach, 1998).

The important features to note on the Au/Ag contoured long section (Figure 3.5.9) are the elevated Au/Ag values in the extreme southern GVZ (9600N) and at depth between 10,000N and 10,200N. In the first case, the Au/Ag geochemistry is strikingly similar to that of the QC. In fact, by projecting the QC ore-shoot down-plunge to the south, a broad, linear zone of elevated Au/Ag values can be traced out, from line 10,600N, south to line 9600N, and likely continuing to the south past the edge of the Gosowong long section. This is considered to be a positive indication for the prospectivity of the deep southern GVZ. The zone of elevated Au/Ag values at depth between 10,000N and 10,200N may indicate a broad zone of fluid upflow with a small lateral component to the flow vector. This correlates well with a zone of increased dilation as observed in Figure 3.1.10 (Chapter 3.1).

- **Au/base metals**: Base metal values (Cu, Pb, Zn) are characteristically very low at Gosowong (Table 3.5.2), likely reflecting the low temperatures and dilute fluid conditions in the GVZ. Base metals are generally transported as chloride complexes under most hydrothermal conditions and their deposition results from decreases in temperatures, salinities, and pressures (Barnes, 1979; Henley, 1985). Therefore, base metals are generally deposited in the deeper, hotter levels of the system, whereas Au (+Ag-As-Sb), transported as a bisulfide...
complex, will be deposited in the cooler, shallower levels of the system (Figure 3.5.27). However, it has been postulated that Cu may be preferentially transported as a bisulfide complex in low temperature epithermal environments under dilute and near neutral conditions (Barnes, 1979; Henley, 1985). Thus, low-grade but significant Cu mineralization is commonly associated with low-sulfidation epithermal veins (Corbett & Leach, 1998).

The gentle southerly plunge to the contoured values in the Au/base metal plots (Figures 3.5.10, 3.5.11 and 3.5.12), extending from around 10,600N, southward to 9500N, closely resembles that indicated by the Au/Ag plot, and likewise, the possible continuance of this horizon to the south indicates increased prospectivity of the deep southern GVZ. Fluid flow direction may be postulated by drawing flow vectors perpendicular to the contours, indicating primarily vertical flow with a minor north to south horizontal flow component.

Figure 3.5.27. Mechanisms for metal zonation in low-sulfidation hydrothermal systems (Corbett & Leach, 1998). Base metals (chloride complexes) are deposited due to cooling and dilution relatively deep in the system, while Ag-Au-As-Sb (bisulfide complexes) are deposited at shallower levels in response to boiling and oxidation. Both Ag and Cu can cross over from chloride complex transport at high temperatures to bisulfide complex transport at low temperatures.

- **Ag/base metal**: At Gosowong, Ag is concentrated within the upper part of the system with respect to base metals (Figures 3.5.13 and 3.5.14). Ag/Cu ratios in tetrahedrite in Mexican epithermal Ag systems show a similar pattern, with the ratio increasing upward to shallow levels (Gemmell et al, 1989). A similar pattern has been observed in the Peruvian Juicani mining district, where the Ag/Cu & Ag/Pb ratios increase dramatically up-structure, from deep (Pb & Cu-rich) to shallow (Ag-rich) levels (Goodell & Petersen, 1974). The gently

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south-plunging orientation of the high-Ag horizon may indicate that mineralizing fluids flowed mainly vertically up the structure with a minor north to south horizontal component. The elevated Ag/Pb values in the deep southern GVZ may indicate that the south-plunging precious metal horizon continues at depth to the south of the Gosowong long section.

- **Base metal/base metal**: Base metal ratios, particularly Pb/Cu, have been very useful in outlining fluid flow vectors in polymetallic vein systems in the Peruvian Jucali mining district (Goodele & Petersen, 1974). In this example, Pb/Cu ratios have been shown to systematically increase along the fluid flow path producing vectors to the fluid source and outflow areas. This appears to be the case at Gosowong, where Pb is more dominant in the shallow portion of the system. Pb appears to precipitate out of solution at much lower temperatures than do Cu or Zn. Thus, by analyzing the ratios Cu/Pb and Zn/Pb, fluid flow vectors can be determined. Figures 3.5.15 and 3.5.17 show high levels of Cu and Zn in the deeper levels of the system, trending to more Pb-rich mineralization at shallow levels. This metal zoning implies generally hotter conditions at depth and to the north, indicating a mainly vertical fluid flow direction.

- **Sb/As**: Acidification is the most effective mechanism for the deposition of As and Sb minerals from solution, with Sb preferentially precipitating at lower temperatures (Corbett & Leach, 1998). This is illustrated in Figures 3.5.1 and 3.5.27; both Sb and As are deposited in the upper portion of the epithermal system but there is a distinct zonation between the two elements, with Sb precipitating from solution at shallower levels than As. By analyzing the Sb and As variations in polybasite in epithermal Ag veins, Germell et al (1989) have concluded that Sb/As values increase along the fluid flow path, with low values in the deeper levels to high values at shallow levels. The Sb/As distribution along the GVZ appears to conform with this model, with Sb/As values generally increasing with RL, indicating generally cooler conditions near surface (Figure 3.5.18).

- **Supergene effects**: Evidence for supergene depletion is outlined in Figures 3.5.15 and 3.5.17. Pb is one of the least mobile of the metal ions while Cu and especially Zn are easily remobilized. In these figures, a low-Cu, low-Zn (high relative Pb) blanket extends over most of the deposit area. Though this phenomenon can be explained in part by the Au-Pb association in the ore itself and the normal metal zoning, it appears that supergene weathering has played a role in the redistribution of metal values near the surface.
- **Vein domain scatter plots:** These plots appear to indicate fundamental differences in the trace element geochemistry of the mineralizing fluids between the individual vein domains, implying there may have been separate and distinct mineralizing episodes. Though some of the trace element variation between the zones can be attributed to relative level within the system, it is thought that the main reason for the geochemical variation is due to variation in the primary composition of the fluid. This variation in the trace element geochemistry, in addition to geological relationships described in Chapter 2 and significant differences in vein mineralogy, has lead to the hypothesis that the QA and QC likely formed during separate and distinct hydrothermal events. The QS is interpreted to pre-date both the QA and QC with the QC being the latest mineralizing event.

### 3.5.5 Conclusions

Both the vertical and lateral zonation of trace elements are common features in low sulfidation epithermal Au-Ag vein systems and may be used as guide to the location of additional ore-grade mineralization. In this environment, the characteristics of the hydrothermal fluids change significantly over short depth intervals, which is reflected in the metal contents, grading upward from base metals to precious metals to surficial toxic elements (Corbett & Leach, 1998). Most models of epithermal deposits suggest that there may be a generalized metal zoning pattern that may be applied to all epithermal ore deposits. Unfortunately, this is not thought to be likely, as metal zoning patterns appear to be specific to individual mineral systems. A unique, widely applicable model of element zoning to delineate ore in all districts will probably not be achieved (Silberman & Berger, 1985). In any particular system, regular metal zoning patterns can be established and applied to exploration only after their relationships to ore-grade mineralization are known (Silberman & Berger, 1985).

Using this knowledge, the level of exposure of an epithermal system such as Gosowong can be postulated and further exploration can be planned by targeting the most productive parts of the system. Based on the trace element analyses, interpretations and conclusions can be made as to the paleohydrology and, more importantly, the prospectivity of the GVZ.
The GVZ appears to display most of the typical vertical metal zoning common in low sulfidation epithermal Au-Ag vein systems: base metals dominant deep in the system, precious metals dominant at shallow levels.

Ag distribution closely mimics that of Au, as both are likely transported and precipitated under similar physio-chemical conditions at shallow epithermal levels.

Au/Ag ratios decrease with depth, a common trend in low sulfidation epithermal systems. On the Gosowong long section, Au/Ag contours display a gentle southerly plunge.

Base metal values are generally very low in the GVZ, averaging 125 ppm for Cu, 53 ppm for Pb, and 83 ppm for Zn. Cu values are significantly higher then Pb and Zn.

Au/base metal and Ag/base metal ratios decrease with depth, indicating the transition from shallow, precious metal dominant conditions to deep, base metal dominant conditions. The distribution of the high Au and Ag values indicates a gentle southerly plunge to the precious metal-rich horizon.

Pb is the base metal most closely associated with Au mineralization. While Cu and Zn values show a slight increase with depth, Pb values are highest near surface and decrease with depth.

Base metal/base metal ratios illustrate the effect of supergene weathering on near surface vein material. Elements such as Cu and especially Zn are easily remobilized while the less mobile elements such as Pb remain at near original concentrations, forming a Pb-rich, Cu-Zn-depleted blanket along the surficial vein exposure.

Sb/As ratios indicate that Sb is dominant over As in the shallow portion of the system, correlating well with published metal zoning models.

A significant variation in trace element values and ratios is observed between the three vein domains (QA, QC, QS). This variation in the trace element geochemistry, in addition to geological relationships and significant differences in vein mineralogy, supports the hypothesis that the QA and QC probably formed during separate and distinct hydrothermal events. The majority of the QS is believed to have formed immediately prior to the QA, with the QC being the latest major mineralization event in the GVZ.

A summary of the metal ratio analyses implies a dominantly vertically upward direction of fluid flow with a small southward flow component.

The base of a broad zone of Au-Ag mineralization extends from surface at approximately 10,700N, plunging gently to the south, to 9500N and beyond. This horizon is thought to represent the base of the paleo-boiling zone that was responsible for most of the GVZ mineralization.
Based on metal ratios, the most prospective area appears to be a small zone in the deep southern GVZ (9500N, 9600N) that possesses a geochemical signature very similar to the Gosowong deposit (elevated: Au/base metals, Ag/base metals, Au/Ag, Cu/Zn), indicating shallow level, potentially ore-grade mineralization. This zone may extend past the boundary of the current drilling and thus is prospective for the discovery of further ore-grade mineralization.

Another prospective area lies deep in the GVZ between 9900N and 10,200N. This area possesses a geochemical signature similar to the shallow peripheral stockwork veining around the Gosowong ore shoots (elevated: Au/base metals, Ag/base metals, Au/Ag, Cu/Zn).

The northern GVZ and the area immediately beneath the Gosowong pit do not appear to be prospective for the discovery of additional ore-grade Au-Ag mineralization. Metal ratios indicate that these areas are generally very deep in the system, and likely dominated by base metal deposition.
4. DISCUSSION

4.1 INTRODUCTION

The primary aim of this study is to identify additional high-grade ore-shoots along the structure that hosts the Gosowong deposit. To this end, a number of detailed analyses of the stratigraphy, structure, textures, mineralogy, geochemistry, and paleohydrology of the Gosowong Vein Zone (GVZ) have been carried out. The various facets of this study have been integrated into a system model and will be discussed in the following sections. The ultimate outcome of this modeling will be to allow the predictive targeting of high-grade mineralization along the GVZ. Additional exploration work will be carried out along the GVZ based on the conclusions and recommendations put forward in this study.

4.2 INTEGRATED GOSOWONG MODEL

The interplay between stratigraphy and structure is thought to provide the main control on mineralization in the GVZ (Olberg et al, 1999). Much of what has been learned of the mineral distribution, alteration zoning, and paleohydrology of the GVZ can be attributed to this stratigraphy-structure relationship. The gentle southerly plunge of the volcanic and volcanioclastic strata along the GVZ is mimicked by the metal distribution, alteration mineralogy, quartz vein texture distribution, and paleo-thermal gradients. It has been interpreted that hydrothermal fluids have ascended the Gosowong fault and have dispersed out into the more permeable Gosowong Volcanioclastic unit. A similar model has been put forward by Hedenquist et al (2000), that illustrates the lithologic control on ascending hydrothermal fluids (Figure 4.1).

It appears that the southerly plunge of the ore-shoots, paleo-isotherms, alteration zoning, etc. may be in part due to the post-mineral tilting of the GVZ. It is clear that major deformation events in the late Miocene to early Pliocene have rotated the strata into a generally E-W striking, gently south-dipping orientation. It is likely that this southward rotation has continued throughout the mid to late Pliocene and possibly into the Quaternary, further rotating the strata to its current moderately south-dipping position. Thus, much of what has been interpreted as minor southward horizontal fluid flow may, in fact be purely vertical flow patterns which have been rotated southward, post deposition of the veining. Pre-mineralization deformation has rotated the strata
approximately 25-30° to the south, while post-mineralization deformation has added an additional 10-15° to the overall rotation of the strata. Thus, deeper levels of the system are exposed closer to the surface on the north end of the GVZ. Evidence for post-mineralization tilting is perhaps best illustrated in Chapter 3.5 in the metal distribution and metal ratio plots. The Au/Ag, Au/base metal, and Ag/base metal plots (Figures 3.5.9 to 3.5.14) best show the gently south plunging orientation of the high-grade ore-shoots. These gently south plunging ore shoots are interpreted to have formed within a paleo-boiling horizon. Linear, south-plunging zones of biayed calcite pseudomorphs indicate a paleo-boiling zone that was likely horizontal during vein deposition (Figure 3.2.8). A schematic interpretation of this ore genesis model is illustrated in Figure 4.2.

Figure 4.1. Schematic section that generalizes patterns of alteration in low-sulfidation systems, showing how a permeable rock unit affects the alteration zoning and vein distribution (Hedenquist et al., 2000).

The coincidence of the N-S striking fault and the Gosowong Volcaniclastics package appears to be the critical factor in the development of ore-grade mineralization along the GVZ, as most of the significant mineralization at Gosowong occurs within this stratigraphic package. Due to the great rheological and competency contrasts (brittle versus ductile) within this package, the faulting that has occurred here has produced an irregular array of dilational traps ideal for mineral deposition. During normal fault movement, the net effect is that steeper portions of the fault zone receive maximum dilation and thus maximum mineralization. This is well illustrated in Figure 3.1.12 which shows the positive correlation between steep vein dips and high gold grades. Furthermore, by comparing vein zone dip and total dilation (Figure 3.1.10), the relationship of increased dilation occurring within the steeper portions of the vein zone can be observed. Areas of steep vein dips and maximum dilation produce the most prospective targets.
Alteration and fluid inclusion isotherms show similar patterns in both magnitude and distribution. Hotter, deeper levels of the system appear to be better exposed on the north end of the GVZ, while cooler, shallow levels are exposed in the south (Figure 4.3). The general agreement between fluid inclusion isotherms (a snapshot in time) and alteration isotherms (the average fluid conditions over time) provides a higher level of confidence in the modeling of the system than would otherwise be provided by either of these facets alone.

Structural dilation along the GVZ exhibits complicated patterns due to the rheological variability inherent within the Gosowong Volcaniclastic unit. Plotting of the total dilation of the GVZ, as measured by the amount of vein infill within the drill hole intercepts, shows that the QC ore-shoot has been deposited along a gently south plunging dilatant zone (Figure 3.1.10). Due to the high degree of dilation, it is interpreted that fluids have flowed dominantly horizontally along this structure from south to north. The feeder structure is thought to be a wide vertical corridor centered between 10,000N and 10,100N deep in the system. This feeder structure is indicated by a zone of increased vein zone thickness and dilation (Figure 3.1.10) as well as high Au/Ag values (Figure 3.5.9), and high Au/base metal and Ag/base metal values (Figures 3.5.11 to 3.5.14).
Though this feeder structure may have been one of the main flow conduits it is likely that fluids ascended all along the GVZ structure but were concentrated in certain structurally favorable zones. A paleo-hydrological model for the GVZ has been constructed based on the results of the various parts of this study. Though there is some minor disagreement in the final conclusions of the individual facets of this study regarding paleo-hydrology, it is far outweighed by the similarities between each of the various aspects. The construction of the model first involves analyzing the basic foundation of the structure and stratigraphy, identifying zones of enhanced permeability, paths where fluids are likely to have flowed. Incorporated in to this are the paleo-isotherms provided by both alteration zoning and fluid inclusions. In addition, fluid flow vectors as determined by trace element geochemistry have been introduced to further refine the model. The model illustrates hydrothermal fluids vertically ascended the GVZ structure vertically (disregarding the post-mineral rotation) (Figure 4.4). Upon reaching the Gosowong Volcaniclastics - a unit of both lithological and structural permeability - the dominantly vertical path of ascent was altered, and increased amounts of sub-horizontal fluid flow ensued. The
majority of this sub-horizontal fluid flow followed wide dilatent zones northward through the Gosowong Volcaniclastics, where most of the boiling and mineral precipitation occurred. A smaller component of hydrothermal fluid flow permeated southward along the elasic units where minor boiling and vein deposition occurred but very little precious metal was precipitated.

![Diagram](image)

**Figure 4.4.** Postulated fluid flow vectors of the Gosowong Vein Zone superimposed on stratigraphy, fluid inclusion isotherms, ore-shoots, and alteration.

During boiling, exsolved volatiles such as H₂S ascended the structure and condensed into cool groundwater. The H₂S then oxidized to form sulfuric acid, resulting in a blanket of steam-heated acid-sulfate alteration overlaying the deposit. Due to significant uplift and erosion during the life of the system, the acid-sulfate alteration overprinted the shallow veining.

### 4.3 PROSPECTIVITY

The main reason for undertaking this detailed study was to assess the exploration prospectivity of the Gosowong Vein Zone. It was hoped that the final outcome would result in the successful targeting of drill holes into the most prospective portions of the GVZ. To accomplish
this aim, the results from each of the facets of this study have been incorporated into a “prospectivity matrix”, the net result of which will serve to illustrate the overall prospectivity of the Gosowong Vein Zone, providing target zones for further exploration activities.

The prospectivity matrix is the sum total of the prospectivities of each individual geological and geochemical parameter studied. The basic foundation of the prospectivity matrix is a 50 m x 50 m grid placed over the Gosowong long section, extending from 9100N in the south to 11,900N in the north and to a depth of –650 m down the dip of the vein. The results from each of the chapters have been interpreted and extrapolated onto the prospectivity matrix. A weighted points system has been used to score each of the individual parameters. Thus, each 50 m x 50 m block of the matrix receives a prospectivity score for each of the studied parameters. The sum total of the scores for each individual block of the matrix for each parameter indicates that blocks’ total prospectivity. These values were then contoured on long section, producing zones of prospectivity and zones of non-prospectivity. (See Appendix VI for more details).

The parameters used in this prospectivity matrix include (in order of importance):

1. **Stratigraphy**: 10 points for Gosowong Volcaniclastics, 5 points for ductile mudstone beds within competent lithologies
2. **Au grades**: 10 points for grades of >5 g/t Au, 7 points for grades of 1-5 g/t Au.
3. **Total dilation**: 7 points for fault dilation >8 m, 4 points for fault dilation from 4-8 m.
4. **Vein zone dip**: 7 points for vein zone dip >60°, 4 points for vein zone dip from 45-60°.
5. **Vein texture**: 7 points for poly-compositional colloform/crustiform/cockade banding, 5 points for banded chalcedony, 1 point for bladed calcite pseudomorphs.
6. **Alteration**: 4 points for illite±chlorite altered zones, 2 points for illite-smectite and smectite-chlorite altered zones.
7. **Fluid inclusions**: 4 points for $T_h$ of 200-225°C, 2 points for $T_h$ of 225-250°C.
8. **Au/Ag ratio**: 2 points for values >1, 1 point for values between 0.25 – 1.0.
9. **Cu/(Cu+Zn) ratio**: 2 points for values >73, 1 point for values between 60-73.

The final result of the prospectivity matrix is illustrated in Figure 4.5. Drill hole locations have been superimposed over the prospectivity contours to show the limits of the current drill pattern. The most striking feature of the prospectivity matrix is the red colored zone within the confines of the current pit boundary. Data from the Gosowong deposit was included in the matrix
to show how the matrix performs with known highly mineralized areas. The Gosowong deposit scored very highly (maximum 53/53) on the prospectivity matrix, as was expected, since the parameters for the matrix are based on the Gosowong mineralization.

![Prospectivity Rating](image)

**Prospectivity Rating**
- 40-53 Extremely prospective
- 30-40
- 20-30 Moderately prospective
- 10-20
- 5-10
- 0-5 Not prospective

**Figure 4.5.** Contoured results of the GVZ prospectivity matrix showing a south plunging zone of moderate to high prospectivity. Drill hole locations are indicated.

Another notable feature of the matrix is the gentle southerly plunge of the green and yellow contours, mimicking the stratigraphy. The orange colored area on the far south end of this southerly plunging zone has been extrapolated down plunge from data from the southernmost drill holes. The prospectivity scores received here are very similar in magnitude to those surrounding the high-grade ore-shoots in the Gosowong deposit.

Three other zones lower prospectivity but still of interest are 1) the green colored area around 10,200N, deep beneath the keel of the Gosowong deposit, 2) the green/yellow colored area around 10,900N and 50mRL, and 3) the far northern end of the long section, around 11,800N. The significance of these areas will be discussed further in the Recommendations section (Chapter 6).
5. CONCLUSIONS

The following bullet points summarize the conclusions of the Gosowong Vein Zone investigation.

Stratigraphy & Structure

- The preferential host rocks to faulting and subsequent quartz veining are the Gosowong Volcaniclastics: re-deposited volcaniclastic rocks of intermediate to mafic composition. Only rarely does significantly mineralized veining occur within rheologically competent units such as andesite and welded ignimbrite.
- The N-S striking, east-dipping Gosowong fault can be traced along the length of the GVZ and is the main control on vein emplacement. Normal dilational fault movement is indicated.
- The amount of dilation along the GVZ structure is strongly related to the dip of the vein zone. During normal fault movement, steeper portions of the GVZ show greater dilation than the flatter portions.
- With respect to structure and stratigraphy, the southern GVZ appears to be the most prospective area to explore for ore-grade mineralization. The preferred host rock package in the deposit, the Gosowong Volcaniclastics, plunges to the south beneath the Ridge Volcanics. In addition, an abrupt increase in both vein envelope thickness and structural dilation adds to the prospectivity of the far southern GVZ.
- With respect to structure and stratigraphy, the northern GVZ and the area deep beneath the deposit do not appear to be prospective. The competent, impermeable nature of the Tobobo Sandstone formation combined with the structural feathering out and eventual termination of the Gosowong fault do not suggest mineral prospectivity in these areas.

Quartz Vein Textures

- The quartz vein texture most commonly associated with ore-grade mineralization is crustiform/colloform banding, but it is the composition of the banding that is the determining factor. Poly-compositional alternating bands of quartz, chalcedony, adularia, chlorite, and sulfides generally contain high-grade mineralization. Mono-compositional quartz or chalcedony bands are generally low-grade or barren.
- The presence of bladed calcite pseudomorphs within and beneath the precious metal horizon does not conform to earlier textural models, but recent studies have produced new data
contradicting the old models, placing the bladed calcite zone within and subjacent to the ore horizon.

- Chalcedony and phreatic breccia deep in the system is enigmatic, perhaps representing an unrelated phase of mineralization. It is thought that this veining represents the top of a much deeper, blind epithermal system.
- Quartz vein textures show great variation over short distances both horizontally and vertically. Fluctuating fluid conditions and boiling levels may produce a large amount of textural overprinting.
- With respect to quartz vein textures, the portion of the GVZ north of the Gosowong pit does not appear prospective. Dominantly crystalline textures likely indicate static hydrothermal fluid conditions common at deep levels and areas peripheral to mineralization.

**Alteration Zoning**

- The GVZ exhibits typical low-sulfidation epithermal alteration patterns. Comparison between the Gosowong model and various published models shows striking similarities.
- Alteration distal to the vein zones and at depth is dominated by a propylitic assemblage of chlorite-epidote-carbonate, indicating low water to rock ratios and near-neutral pH fluids. This style of alteration is not an accurate indicator of fluid temperatures.
- Illite-group minerals and chlorite display a distinct zoning along the fluid pathway within the GVZ: illite-chlorite $\Rightarrow$ illite $\Rightarrow$ illite-smectite $\Rightarrow$ smectite-illite with decreasing depth. This zoning is related to decreasing fluid temperature along the fluid flow pathway.
- Most significant Au mineralization is associated with illite-smectite, illite, and illite-chlorite alteration, indicating fluid temperatures of 150-220°C within the QA zone and 220-270°C in the QC zone.
- Steam-heated alteration, consisting of kaolinite-dickite-talonite and vuggy quartz, overprints shallow ore and ore-related alteration in the southern end of the GVZ. This is interpreted to indicate rapid erosion of the system and a lowering of the water table, resulting in a telescoping of the alteration styles.
- Additional steam-heated alteration occurs to the north of the GVZ (north of 11,600N), past the limit of current drilling, perhaps indicating a subsurface boiling zone.
Fluid Inclusions

- Fluid inclusion analyses indicate mineralizing fluids to have a typical epithermal signature: dilute (generally less than 1.0 eq. wt. % NaCl) and low temperature (generally 175-265°C).
- The ubiquitous presence of coexisting vapor-rich and liquid-rich primary fluid inclusions indicate that boiling processes have taken place in the GVZ.
- The optimal temperature for the deposition of ore-grade mineralization ranges from 175-225°C.
- With respect to fluid inclusions, the most prospective area appears to be the southern zone of the GVZ. The paleo-hydrothermal conditions in the south appear to be most similar to those of the Gosowong deposit ($T_h = 175-225°C$).

Metal Zoning

- The GVZ appears to display most of the typical vertical metal zoning common in low sulfidation epithermal Au-Ag vein systems: base metals dominant deep in the system, precious metals dominant at shallow levels.
- Au/Ag ratios decrease with depth, a common trend in low sulfidation epithermal systems. On the Gosowong long section, Au/Ag contours display a gentle southerly plunge.
- Base metal values are generally very low in the GVZ, averaging 125 ppm for Cu, 53 ppm for Pb, and 83 ppm for Zn. Cu values are significantly higher than Pb and Zn.
- Au/base metal and Ag/base metal ratios decrease with depth, indicating the transition from shallow, precious metal dominant conditions to deep, base metal dominant conditions. The distribution of the high Au and Ag values indicate a gentle southerly plunge to the precious metal-rich horizon.
- A significant variation in trace element values and ratios is observed between the three vein domains (QA, QC, QS). This variation in the trace element geochemistry, in addition to geological relationships and significant differences in vein mineralogy, supports the hypothesis that the QA and QC probably formed during separate and distinct hydrothermal events. The majority of the QS is believed to have formed immediately prior to the QA, with the QC being the latest major mineralization event in the GVZ.
- Based on metal ratios, the most prospective area appears to be a small zone in the deep southern GVZ (9500N, 9600N) that possesses a geochemical signature very similar to the Gosowong deposit (elevated: Au/base metals, Ag/base metals, Au/Ag, Cu/Zn), indicating shallow level, potentially ore-grade mineralization. This zone may extend past the boundary
of the current drilling and thus is prospective for the discovery of further ore-grade mineralization.

- Based on metal ratios, the northern GVZ and the area immediately beneath the Gosowong pit do not appear to be prospective for the discovery of additional ore-grade mineralization. Metal ratios indicate that these areas are generally very deep in the system, dominated by base metal mineralization.

**Genetic Model & Prospectivity**

- Hydrothermal fluids are believed to have ascended near vertically up the GVZ structure. Upon reaching the Gosowong Volcaniclastics - a unit of both lithological and structural permeability - the dominantly vertical path of ascent was altered, and increased amounts of sub-horizontal fluid flow ensued. The majority of this sub-horizontal fluid flow followed wide dilatent zones northward through the Gosowong Volcaniclastics, where most of the boiling and mineral precipitation occurred. A smaller component of hydrothermal fluid flow permeated southward through the clastic units.

- It appears that the southerly plunge of the ore-shoots, paleo-isotherms, alteration zoning, etc. may be in part due to the post-mineral tilting of the GVZ. Thus, much of what has been interpreted as minor southward horizontal fluid flow may in fact be purely vertical flow patterns which have been rotated southward, post deposition of the veining. It is believed that pre-mineralization deformation has rotated the strata approximately 25-30° to the south, while post-mineralization deformation has added an additional 10-15° to the overall rotation of the strata. Thus, deeper levels of the system are exposed closer to the surface on the north end of the GVZ.

- Paleo-hydrothermal fluid temperatures and thermal gradients, as indicated from both fluid inclusions and alteration mineralogy, are in general agreement.

- A Gosowong specific "prospectivity matrix" indicates that the most prospective area of the GVZ (outside of the Gosowong deposit area) is the area deep and to the south of the deposit (9000N – 9600N). Additional areas of low to moderate prospectivity are 1) an area deep beneath the keel of the Gosowong deposit (10,200N and ~600m down dip) 2) an area several hundred meters to the north of the pit (10,900N and 50m down dip) and 3) the far northern end of the long section at shallow levels (11,900N).
6. RECOMMENDATIONS

The primary objective of this study, as stated in the introduction, is to identify additional high-grade mineralization along the structure that hosts the GVZ. In order for this to be accomplished, additional exploration work, namely diamond drilling, is essential. A number of prioritized drill holes will be proposed in this chapter based on the final conclusions of the investigation. Supporting data for the interpreted prospectivity will be provided for each of the proposed drill holes.

Some of the prospective areas outlined by the prospectivity matrix can be immediately dismissed due to the current density of the drill pattern in those areas. The Gosowong deposit for obvious reasons may be immediately discounted. The area outlined in the yellow contour immediately south of the Gosowong deposit has a drill hole density of around 100 m x 100 m. This density of drilling has been deemed sufficient for exploration purposes as it is extremely unlikely that a high-grade ore-shoot of any significance has remained undetected with this drill pattern. Likewise, the drill hole density north of the pit to 10,800N is sufficient for similar reasons.

The following five prioritized drill holes have been proposed to test the conclusions of this study (Figure 6.1).
Holes A & B (Figures 6.2 and 6.3): The purpose of these two holes is to test the south plunging zone of moderate prospectivity in the deep southern portion of the GVZ (underground mining target). This is the highest priority drill target identified in this study, but still a high-risk venture nonetheless. Each of the proposed holes exceed 400 m in depth meaning that, at current diamond drilling costs, the minimum cost for each hole would be approximately US$40,000. This zone has been identified as moderately prospective for the following reasons:

- **Stratigraphy**: Predicted down dip extent of the Gosowong Volcaniclastics.
- **Au**: >1 g/t Au intercepts in drill holes DSD001 and GSD168 on section 9600N.
- **Structural dilation**: Increased dilation in holes GSD182 (9500N), DSD001 (9600N), and GSD154 (9700N).
- **Vein dip**: Steepening of vein dip in deep southern holes.
- **Alteration**: Alteration assemblages (illite-smectite, illite-chlorite) indicate favorable conditions for ore formation.
- **Fluid inclusions**: Fluid inclusions indicate favorable temperatures for ore formation.
- **Metal zoning**: Geochemical signatures possibly indicating proximity to ore.
Figure 6.2. Section 9400N, proposed drill hole location (Hole A).

Figure 6.3. Section 9200N, proposed drill hole location (Hole B).

**Hole C** (Figure 6.4): The purpose of hole C is to test a deep zone of apparently shallow level quartz vein textures deep beneath the Gosowong deposit (underground mining target). The hole is targeted to intersect the vein zone approximately 100 m down dip from the DFD-009 intercept. This proposed hole, if drilled, will become the deepest hole in the Gosowong district at 600 m. Again, as with the first two proposed holes, drilling this hole would be a very high-risk venture. The minimum cost of this hole is estimated at around US$60,000. This zone has been identified as moderately prospective for the following reasons:
- **Quartz vein textures:** Apparently shallow level quartz vein textures (banded chalcedony, phreatic breccia, silicified sediments) found deep in the system in hole DFD009. Could be the top of another, likely temporally unrelated, epithermal system.

- **Structural dilation:** Slight increase in vein dilation seen in hole DFD009.

- **Vein dip:** Increase in vein dip seen in hole DFD009 and surrounding holes.

- **Au:** Anomalous Au, between 0.1 – 1.0 g/t Au.

- **Au/Ag ratio:** Similar to the Au/Ag ratio on the periphery of the ore-shoots.

- **Sb:** Slightly elevated Sb (6 ppm).

![Figure 6.4. Section 10,200N, proposed drill hole location (Hole C).](image)

**Hole D** (Figure 6.5): The purpose of hole D is to test the area immediately beneath the advanced argillic altered zone in the far northern end of the GVZ. This relatively short 200 m hole does not involve much risk, though the potential for a major discovery is thought to be much lower than that for holes A, B, and C. This zone has been identified as slightly prospective for the following reasons:
**Structure:** Along the strike of the GVZ, past the limits of current drilling. Though it appears that the GVZ structure is feathering out to the north, data is scant north of the Ruwait termination due to the extensive advanced argillic cover.

**Alteration:** Advanced argillic altered zone (kaolinite-alunite-dickite), similar to that overlying the south end of the deposit. May be related to an underlying boiling zone.

![Diagram](image)

**Figure 6.5.** Section 11,900N, proposed drill hole location (Hole D).

**Hole E** (Figure 6.6): The purpose of hole E is to test the area near the intersection of the GVZ and the Anggrek splay 300 m to the north of the Gosowong pit (open-pit mining target). This is another low risk hole, though the potential for a discovery is thought to be lower than for the other proposed drill holes. This zone has been identified as slightly prospective for the following reasons:

- **Stratigraphy:** Interbedded brittle and ductile volcanioclastic units.
- **Structural dilation:** Increased dilation seen in GSD208 (10,850N) and GSD209 (11,050N).
- **Vein dip:** Vein dip of greater than 45°.
- **Structural intersection:** Intersection between the GVZ and the SW trending Anggrek splay.
The total meterage for this proposed drilling program is 1760 m. At current drilling costs, the total cost to conduct this program would be around US$180,000, excluding salaries and wages. Most of the proposed holes are high-risk but with reasonable potential for a significant discovery. The perceived chances of success of this program must be weighed against the perceived prospectivities of satellite targets elsewhere in the Gosowong district.

One of the negative aspects of the proposed drill targets are that most of them are very deep and thus underground mining targets. This presents a whole new set of hurdles to overcome, the most important of which is the high cost of underground exploitation. The grades and tonnage must be sufficiently high, as high or higher than currently being mined, to justify the construction of an underground operation. The second negative aspect is the high cost, high risk nature of the proposed exploration. Deep drilling in this environment is a costly undertaking, and drilling budgets must be generous in order to support the ongoing program. It is hoped that the impetus and opportunity will arise in the current budget year to test these proposed targets, as it is believed the chances of success are reasonable.