Host Rock Packaging in the Big Gossan - Kucing Liar Cu-Au Mineralization type in the Grasberg-Ertsberg District, Papua

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Big Gossan and Kucing Liar are two known economics Cu-Au Skarn ore deposits that are occurs in the sedimentary rock units. These ore deposits represent about 14 % of the current PT. Freeport Indonesia's 2.5 billion mineable ore reserve. The concept of examining the host-rock packaging in skarn exploration is extremely useful. This involves examining the stratigraphic package containing the carbonate rocks in terms of anticipated mechanical properties and probable permeability. Permeability is normally a subsidiary control which only becomes effective after the fluids have gained entry from a distant source.

Introduction

The Grasberg-Ertsberg Mining District is located in the highlands of the central range Jayawijaya Mountains of Papua (Irian Jaya) province Indonesia. The Grasberg-Ertsberg District is one of the richest mining districts in the world. The district contains six known skarn and porphyry copper deposits with mineable reserves. Total 1999 proven and probable reserves in the district are 2.5 billion tonnes at 1.13% Cu and 1.05 g/t Au, dominated by the Grasberg super-giant porphyry copper-gold deposit (1.9 bt @ 1.04% Cu, 1.04 g/t Au).

Kucing Liar and Big Gossan deposits occur in the stratigraphy contact of New Guinea Group and Kembelangan Group. The other skarn system occurs associated with the contact of New Guinea group and Ertsberg Diorite. This paper presents a review of the copper-gold mineralization appears in the sedimentary units and/or stratigraphic controls and its potential around the Grasberg-Ertsberg district related to this mineralization type.

Location

The Grasberg-Ertsberg district is located in Irian Jaya, the easternmost province of Indonesia and the western half of the island of New Guinea (Figure 1). The district is on the crest of the Jayawijaya mountain range at elevations of 2,900 to 4,300 meters. Within a few kilometers of the mines are equatorial glaciers and the highest peak in the region, Puncak Jaya, at about 4,970 meters elevation.

The area is characterized by extreme topography, with dense jungle vegetation in the lower elevations giving way to grassy vegetation above treeline in the upper portions of the district. Annual rainfall exceeds four meters per year.

General Geology

The deposits are located within the Tertiary Papuan mobile belt, where major mineral deposits such as Grasberg (Indonesia), Ok Tedi and Porgera (PNG) are associated with late Miocene to Pliocene igneous intrusions. The deposits are localized along and around a major WNW-ESE strike-parallel reverse fault, the Idenberg Number 1 Fault, which dips northeast at 50° - 70°. The Idenberg Fault has been mapped over a length of 10 km. and is one of a number of important WNW-ESE strike-parallel faults within the Ertzberg district, which have associated skarn and sediment-replacement deposits (Widodo et al., 1998).

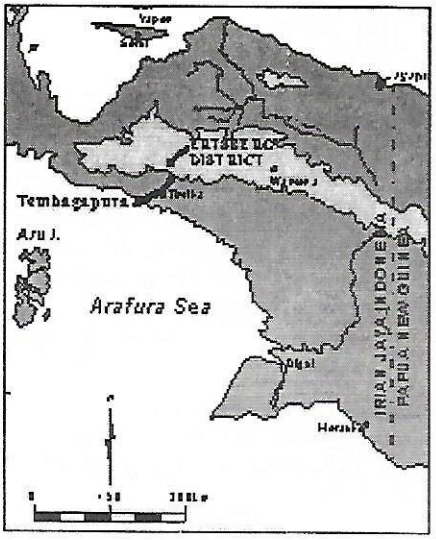

Fig 1: Location map of the study area

Although the Idenberg Fault appears to represent the feeder to some mineralization zones, there is a strong lithological control on the replacement-style deposit. The main stratigraphic units, which host the mineralization, are the Paleocene Lower Waripi Formation dolostones, and the underlying Cretaceous Kembelangan Limestone and Ekmai Sandstone Units of the Kembelangan Group. The Upper Cretaceous Kembelangan Shale unit, which lies between the Waripi and the Kembelangan Limestone Unit, is largely unmineralized but extensively hornfelsed within the Kucing Liar and Big Gossan deposits, and forms an important stratigraphic marker (Widodo et al., 1998).

Stratigraphy

The oldest rocks exposed on the property consist of Jurassic Cretaceous sandstones, shales and limestones of the Kembelangan Group. The Kembelangan group is about 2000 m thick within the concession. The most important host lithologies for skarn mineralization from this group appear to be the Ekmai sandstone, the Kembelangan limestone and the Kembelangan shale, which form the three uppermost units. The Ekmai sandstone and the Kembelangan limestone are altered and mineralized in the Kucing Liar and Big Gossan deposits, while the Kembelangan shale, which is hornfelsed and mineralized in these deposits, forms an important stratigraphic marker.

The Jurassic -Cretaceous section is overlain by Miocene age limestones and dolomites of the New Guinea Limestone Group. This total section is about 1600 m thick. The lowest unit of this section is composed of the Paleocene Waripi Formation. Its varies up to 290 m in thickness and is composed mainly of bedded dolomite with several interbeds of fine grained quartz sandstone near the top of the unit, followed by a distinct evaporite unit at the top of the formation. The Waripi Formation is the main mineralized unit in the Kucing Liar deposit.

The Waripi Formation is overlain by the Eocene - Oligocene Faumai Formation, which is about 200 to 220 m thick and composed of massive to thickly bedded fossiliferous limestone beds. The Faumai Formation is overlain by the Oligocene Sirga Formation, a coarse-grained sandstone unit that is about 30m thick, and forms an important marker bed in the district. This unit, in turn, is overlain by the Kais Formation, a > 1000 m sequence of fossiliferous carbonates, shales, coal beds and siliciclastics.

The Waripi and Kembalangan Formations are mineralized in the Kucing Liar and the Big Gossan ore bodies. The Kembelangan limestone, Waripi Formation, and Faumai Formation are mineralized in the East Ertsberg skarn system (EESS), but ore is restricted to the Waripi and Faumai formations. The Faumai Formation is the host for the DOM ore body.

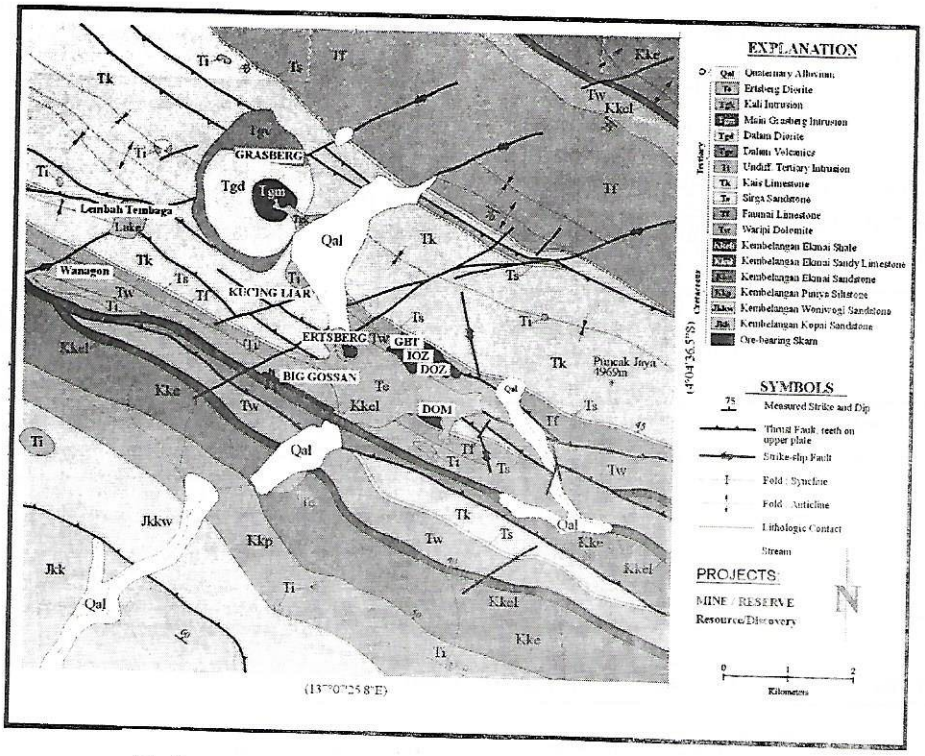

Fig 2: Generalized geological map of the Grasberg-Ertsberg district

Structure

The district lays in the crest of a synclinorium whose axis trends west-northwest to east-southeast (110^0). Within the center of the synclinorium are tightly folded New Guinea Limestone Group rocks. Moderately dipping Kembelangan Group rocks are exposed on the north and south flanks of the broad fold feature. Imbricate thrust faults subparallel the bedding and have apparent vertical offsets of at least hundreds of meters. These faults can have large (100+m) breccia/fracture zones associated with them. A series of cross structures at 500 to 700 and at 3500 postdate the 1100 structures. The intersection of these structures appears to be a control for the location of the main igneous intrusions of the district (Brannon, 2000).

Magmatic Activity

The New Guinea Group is the host for two major hypabyssal intrusions, the Grasberg Complex and the Ertsberg Intrusion, and numerous other smaller stocks, dikes, and sills (McMahon, 1994). Compositions range from quartz monzodiorite to quartz monzonite and granodiorite, alkalic-calcic to calc-alkaline. The intrusive activity is Pliocene in age, ranging from 2.4 to 4.4 Ma, postdating the major structural deformation. Both of the major stocks have outcrop areas of roughly three square kilometers, and have associated copper-gold ore bodies. The other minor intrusions are variably altered and mineralized but as yet are not known to host economic ore bodies (Brannon, 2000).

All of the observed intrusive rocks in the district are porphyritic or have associated porphyritic phases. Most of the economic skarn deposits in the district are proximal to the Ertsberg Intrusion or related dikes. The Grasberg Complex, host to the Grasberg deposit, is a multistage intrusive complex with associated vestiges of volcanoclastic and pyroclastic rocks occurring at the surface.

Ore Deposits

In the Grasberg-Ertsberg mining district area, there are two main types of ore deposits, namely porphyry copper-gold and copper-gold skarn/carbonate replacement. They consist of at least six copper-gold-silver ore bodies and several other subeconomic deposits, most centered on the Grasberg and Ertsberg intrusive complexes (Table 1). In addition to the proven and probable reserves in Table 1, about 1.4 billion tonnes are present in the geological resource category.

The Grasberg super giant porphyry copper-gold deposit possesses the world's largest gold deposit and among the five largest copper deposits in an operating mine. Grasberg's current reserves are 1.9 billion tonnes at an average grade of 1.04 % Cu, 1.04 g/t Au, and 3.1 g/t Ag. Other porphyry-style mineralization is present within the district (Lembah Tembaga, Kay, Ertsberg Intrusion) though these are either subeconomic or, perhaps more importantly, not yet completely drill-tested (Brannon, 2000).

Kucing Liar, Ertzberg, Big Gossan and EESS (East Ertsberg Skarn System) present as Copper-gold Skarn/ carbonate replacement deposit style. This deposits represent about 24.2 % of total reserve. Wanagon is considered as subeconomic or not yet completely appraised. The recent exploration work to the south of this district area has identified a numerous of a potential of copper-gold Skarn/ carbonate replacement deposit style hosted in the older sedimentary unit in Kopai sandstone member. Further investigation and drill test are crucial to define their potential.

	Average Ore grade Per Tonne				Recoverable Reserves		
	Tonnes (mm)	Cu %	Au G/t	Ag g/t	Cu x bil. lbs.	Au x mil. ozs.	Ag x mil ozs.
Grasberg : Open Pit	1,186	1.02	1.19	3.0	21.9	34.8	57.1
Underground	691	1.08	0.77	3.2	14.0	13.6	36.3
Kucing Liar (Skarn)	320	1.41	1.41	5.3	8.2	10.3	25.5
DOZ (Skarn)	181	1.15	0.87	5.2	4.0	4.1	15.9
Big Gossan (Skarn)	37	2.69	1.02	16.4	1.8	0.9	9.9
DOM (Skarn)	31	1.67	0.42	9.6	0.9	0.3	4.7
IOZ (Skarn)	29	1.09	0.43	7.6	0.6	0.3	3.7
Total Reserves	2,475	1.13	1.06	3.8	51.3	64.4	153.1

Table 1: Proven and probable reserve of PT. Freeport Indonesia (per Dec 31, 1998)

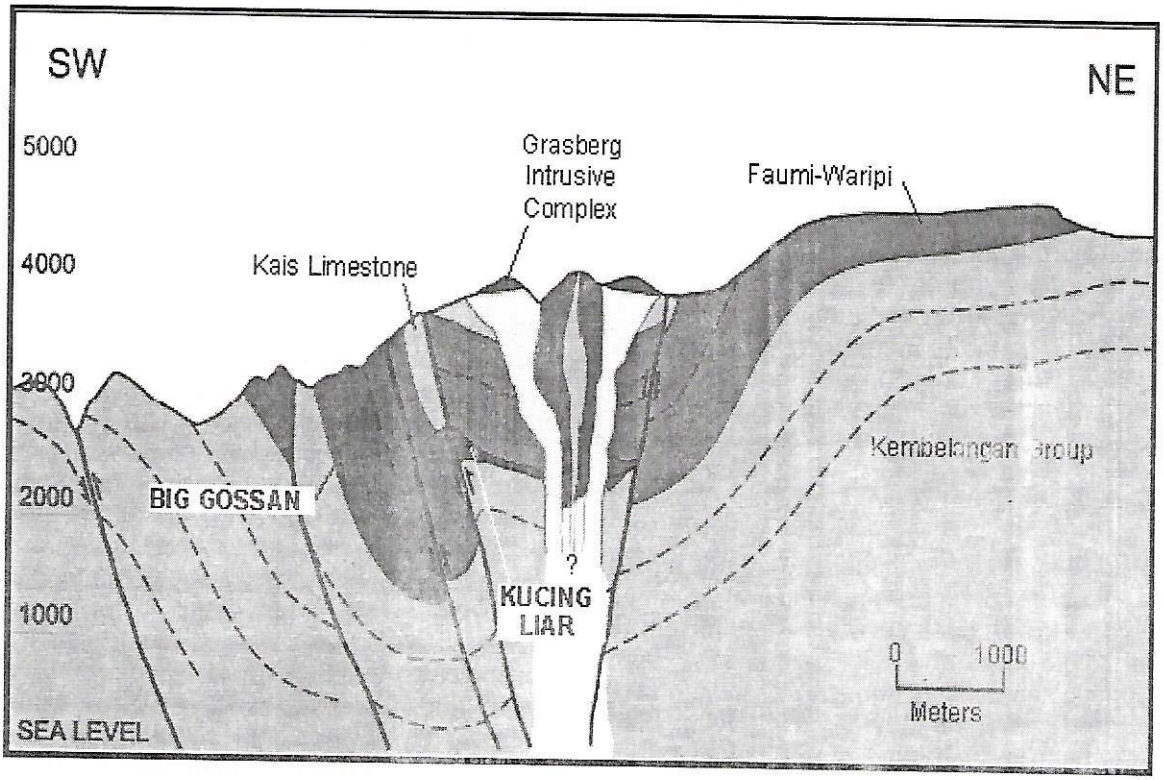

Fig 3: Cross-section across Grasberg showing the Big Gossan and Kucing Liar deposits in relation with the Grasberg prophyry deposit (Brannon, 2000)

Kucing Liar

Kucing Liar is the most recent discovery within the district; it is a complex ore body comprising magnetite-copper-gold replacement and skarn-hosted mineralization. The deposit is hosted by the lower Waripi and upper Ekmai Formations. Alteration in the Waripi is typically pyroxene-potassium feldspar-quartz. The extensive mineralization in the Ekmai Formation is unusual in the district and includes quartz stockwork veining, potassium feldspar flooding, and covellite. The deposit has a defined strike length of about 2,000 meters, is 400-600 meters wide, and has an average thickness of about 250 meters. The thickest and strongest mineralization at Kucing Liar is adjacent to the Idenberg #1 Fault, a WNW-striking reverse fault with apparent vertical offset of at least 800 meters and unknown horizontal offset. Kucing Liar is adjacent to the southern margin of the Grasberg Intrusive Complex, but appears to be the product of a hydrothermal event separate from the main-stage Grasberg mineralization.

Big Gossan

The Big Gossan copper-gold skarn deposit is the highest-grade copper deposit in the district (Table 1). Big Gossan is hosted largely in the lower Waripi formation and is associated with a series of 3-4 Ma granodioritic dikes (Meinert, Hefton, Mayes, and Tasiran, 1997). Big Gossan is a vertically oriented, tabular ore body, which is parallel to the faulted contact between the Cretaceous Ekmai shale member and the Paleocene Waripi formation. The deposit extends for about 1,500 meters along strike, over 1,000 meters vertically, and has an average width of fifty meters. Hydrothermal alteration and mineralization is controlled by favorable stratigraphy, bedding planes, and faults. Prograde skarn alteration is dominantly pyroxene-garnet (2:1 ratio), with garnet dominating proximally and pyroxene distally. Calcic, coarse-grained prograde pyroxene-garnet-magnetite skarn and retrograde amphibole-chlorite skarn host the ore, which has chalcopyrite as the dominant copper-bearing sulphide.

Host-Rock Packaging

The host rock packaging factor of Big Gossan deposits was studied, examined and well documented by Prof. Roger Taylor from James Cook University, Australia (1999).
The concept of examining the host-rock packaging in skarn exploration involves examining the stratigraphic package containing the carbonate rocks in terms of predicting mechanical properties and probable permeability. It should be stated at the outset that all available evidence from both skarn and carbonate replacement styles indicates that, from a chemical perspective, the fluids involved have no inherent preference for either dolomite or limestone.

The end result will be influenced by the amount of magnesium- or calcium-rich minerals that have been developed, but it seems the key factors are initial fluid access and local permeability. Some diagenetic processes remove aragonite from shells and carbonate matrices and thus increase the permeability. Features of this nature can be important from a ground preparation perspective, but ultimately skarn formation is more closely related to initial entry points for fluids, and the fact that carbonate rocks alter with relative ease. The physical characteristics and the package of the host rock units, which often assist the deformation, are:

- likely fracturing or faulting either cross cutting, or more commonly running parallel to, layering (this can vary from very minor crack style to complete brecciation);
- major to minor slippage along layering in response to folding and/or nearby igneous intrusion;
- interaction of both of the above situations.

Sedimentary and sedimentary/ igneous packaging varies enormously, but failure in response to tectonic forces will usually seek out the weak points such as contacts between units of contrasting strength and massive versus weaker layered rocks.
Thus, in skarn systems and many other hydrothermal systems, fracturing, slippage and faulting are commonly found:

- at junctions between massive consolidated sandstone units and less competent shaly layers;
- at junctions between igneous sills/dykes and the carbonate host rocks;
- at many bedding parallel planes where a relatively well-bedded sequence of narrow carbonate layers is interlayered with more sandy or shaly materials;
- at very fine scales, bedding plane slip may occur within almost any well-bedded unit. This is especially important in carbonate-rich shales.

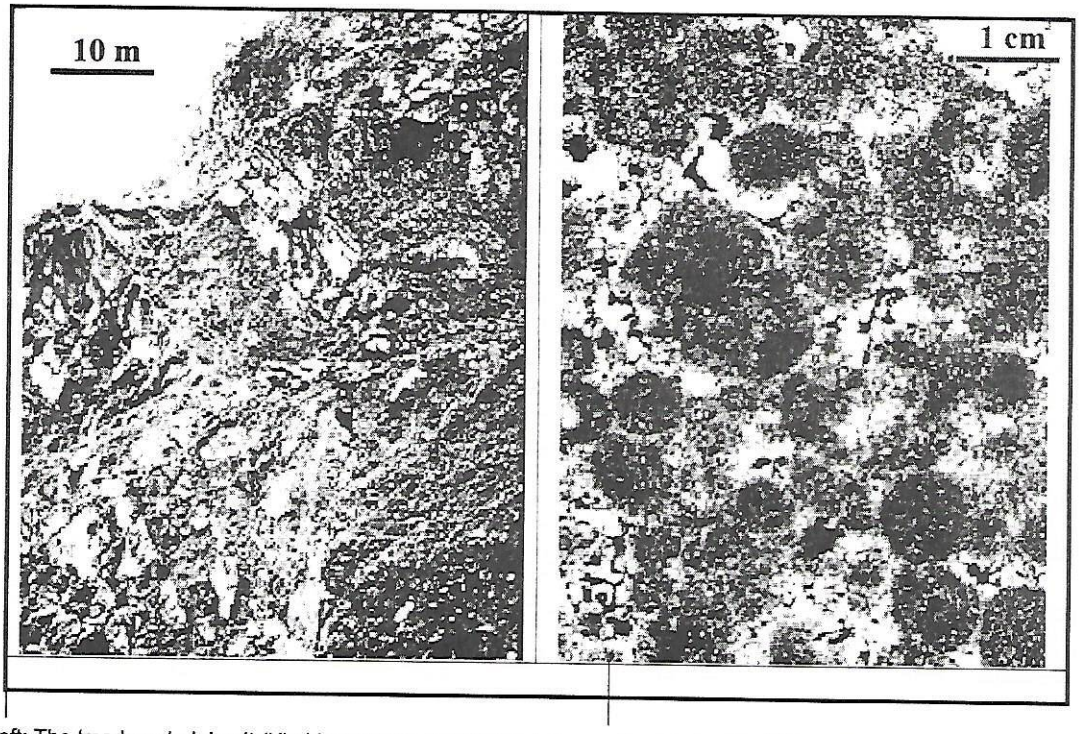

Fig 4: Left: The 'marker shale' unit (Kkeh) at centre, is situated between the interbedded Waripi Formation (Tw) to the right, and the limestone member (Kkel) of the Ekmai Formation to the left. The competency contrasts are reflected in the weathering effects, and it is not difficult to imagine that stress relief would focus in and around the weaker 'shale' horizon. The layered Waripi Formation is also a favoured site for mechanical disruption (Taylor, 1999). Right: A thin section illustrating the presence of numerous small holes (black) developed around grain boundaries in the white matrix of the Waripi Formation (Tw). This is a less dramatic example than the fossil cavities of Faumai limestone, and illustrates a more common situation which can occur at even smaller scales to provide permeability for incoming ore fluids. A major structure is usually required to effect initial fluid entry to the unit (Taylor, 1999).

These are a wide variety of combinations where any or all of the above combine to relieve the stress induced by combinations of folding, intrusion and faulting. It should be noted that permeability produced by dislocation along numerous small-scale, layer-parallel structures is commonly far more effective in channeling skarn-producing fluids into a large mass of host-rocks than is very localized major faulting.

A quick field or drill core check will add confirmation, as it quickly becomes apparent where recent fracturing/faulting is inclined to focus. Commonly, the activity of drilling causes the core to fracture at these natural points, and is signaled via the initial engineering core logging and/or photography of core trays. The natural porosity/permeability of likely host units also merits consideration. Massive limestone or marble is relatively impermeable, with meteoric water being restricted to joints and fractures/faults. However, carbonate rocks vary widely, and most of them display a long history of diagenetic and later changes.

Broad and Local Scale Rock Packaging Perspectives

The Big Gossan skarn system straddles the junction between the lower Waripi and the Upper Ekmai limestone with the Ekmai shale occurring within but along the southern edge of the main area of mineralized skarn development. The stratigraphic package dips steeply NE at 80°. Meinert et al. (1997) indicated the possibility of faulted contacts between the Cretaceous Ekmai Formation shale marker, and the Paleocene Waripi formation.

A large, regional-scale fault structure, called the Big Gossan Fault, is marked on the plan, and occurs approximately 100 metres south of the ore zone. However there is no obvious reason in terms of rock packaging for breaking along this point, and the fault is apparently not associated with channeling skarn-forming fluids. Given that a major skarn occurs within 100 metres, there are some unanswered questions concerning the timing and/or existence of this structure.

Given that the early stages of skarn systems commonly overprint and effectively conceal the controlling structures, an investigation of underground exposures was made peripheral to the skarn. A recent review of the stratigraphic column has been conducted by Brian New, and the logging of two relatively unaltered drill holes has provided considerable detail concerning the packaging of units, their grain sizes, and the relative amounts of calcite versus dolomite. The dolomite component occurs as an alteration of pre-existing calcite, and is of uncertain origin. A considerable diagenetic effect is suspected. The drill holes are well away from the Big Gossan deposit and hence do not allow detailed comparison. However it is useful to inspect the new data from a rock breaking perspective.

Intuitively, many mechanical weak points could be expected, with the shaly Upper Ekmai and Lower Waripi contact looking particularly vulnerable. The multi-layered, compositionally variable Waripi Formation is another prime candidate, as is the Faumai/Waripi contact zone, and possibly sections of the Upper Faumai. Interestingly, fluid flow as marked by pyroxene development in KLS 3.1 indicates concentration within the limestone that comprises the Upper Ekmai Formation. In this particular instance it is possible that contact disruption is not the prime feature exploited by the pyroxene-producing fluids. The remaining pyroxene locations are within selected segments of the Waripi, and the Waripi sector of the Faumai/Waripi contact. The fluids appear to have moved within the predicted zones, but the occurrence of relatively minor skarn suggests that secondary permeability may have been the major control, and that the region may have been distal to the major fluid channel ways (structures).

Kucing Liar deposits occur in same stratigraphic position with the Big Gossan deposits. Figure 6, some polished drill cores, shows a similarity of altered rock texture and structure with the Big Gossan deposit. The lithogeochemical study suggested that this ore deposit has similar stratigraphy control, lithological packaging factor and ore deposit occurrence model. Although they have same stratigraphic position, the correlation and the historical deposition of those mineral deposits are not well explained.

A detailed study of the metal zoning indicates that lithological contacts and fault system play a major role as fluid channel ways for the mineralization. The Kucing Liar mineralization commonly occurs in the lower part of Waripi formation that comprises gray dolomite unit. The general stratigraphic section (Figure 5) shows that the mineralization is zoned away from the Ekmai-Waripi contact. Au-Cu-Mo (Se) mineralization occurs in the contact zone and decreases away from it with a simultaneous increase in Pb-Zn-As- (Ag) as a halo.

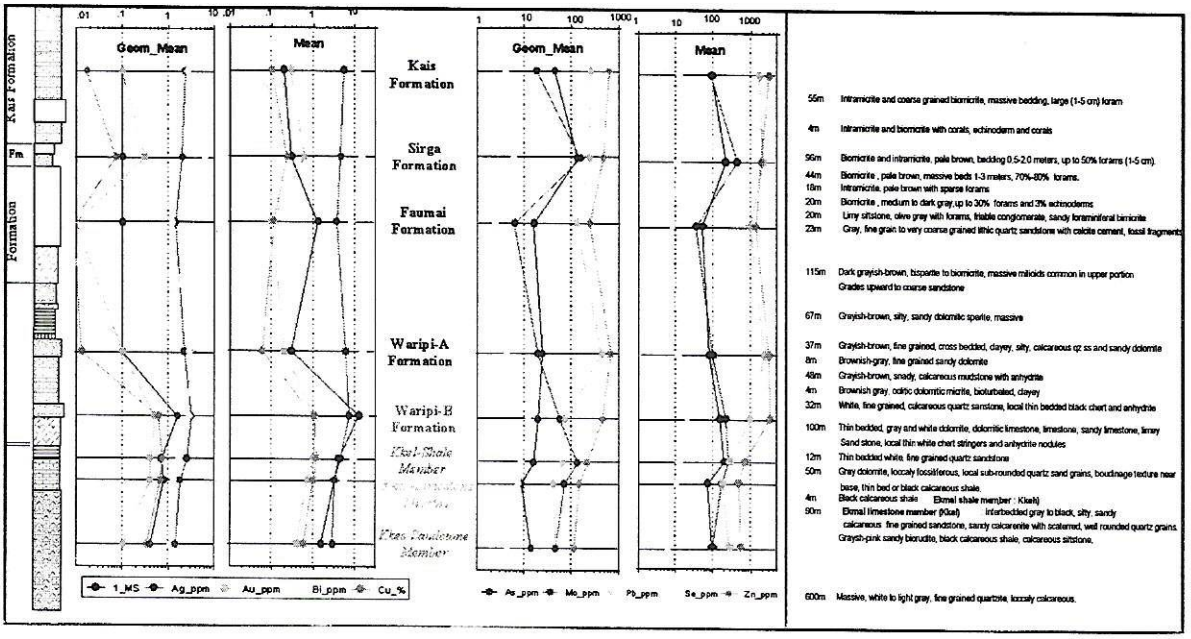

Fig 5: Vertical geochemical signature of all sedimentary formations, including skarn from Kucing Liar drill-core (Setyadi, 1999)

The mineralizing fluids are thought to have been mainly channeled along and around the lithological contact zone. Narrow zones of minor mineralization are also noted along other stratigraphic contacts, but these are not well developed perhaps due to lower permeability conditions. The zonation of metals within Kucing Liar (Figure 5) shows a decrease in Cu and an increase in Pb and Zn away from the contact of the Ekmai and Waripi formations. The metal zoning suggests that this contact zone was the main channel-way for mineralizing fluids. However, the bulk of the mineralization occurs in the hanging wall of the Idenberg #1 Fault and must be related to it in some ways (Setyadi, 1999).

Mineral Exploration Implication

The concept of examining the host-rock packaging in skarn exploration is extremely useful. A detailed stratigraphic measured-section and also the study of the physical rock properties should be warranted to predict the favorable lithological sequence. A prudent cross section should be significant to reconstruct and identify a possible favorable zone at the deep. The fluid source distance (intrusive), structure and surface multi-element geochemical anomaly must be used in the data integration to define the potential of area.

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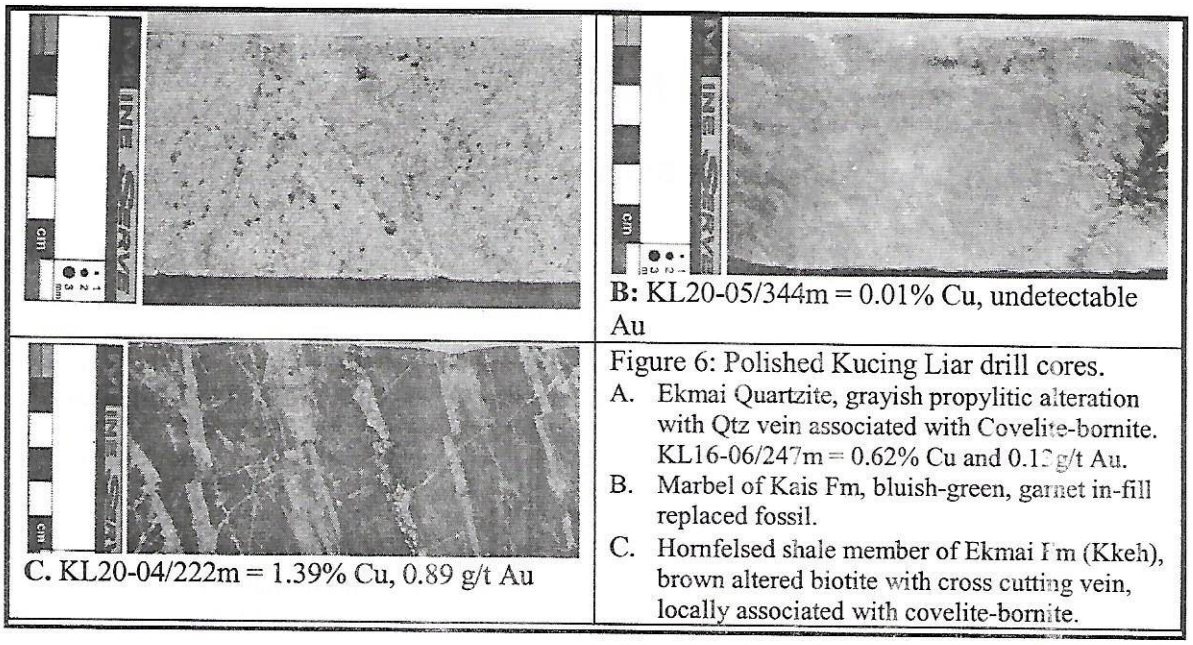

B: KL20-05/344m = 0.01% Cu, undetectable Au

C. KL20-04/222m = 1.39% Cu, 0.89 g/t Au

Figure 6: Polished Kucing Liar drill cores.

A. Ekmai Quartzite, grayish propylitic alteration with Qtz vein associated with Covelite-bornite. KL16-06/247m = 0.62% Cu and 0.1? g/t Au.
B. Marbel of Kais Fm, bluish-green, garnet in-fill replaced fossil.
C. Hornfelsed shale member of Ekmai Fm (Kkeh), brown altered biotite with cross cutting vein, locally associated with covelite-bornite.

Continuation from p. 5 (Sumardiman et al.)

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