Hydrothermal vein distribution in skarn type alteration zone of area X at PT. Freeport Indonesia

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Abstract. Kucing Liar is an economic skarn altered deposit located in Tembagapura, Papua. This deposit was found on Late Cretaceous to Miocene sedimentary rocks of Kembelangan Group and Papua New Guinea Limestone Group. The alteration from this deposit can be divided into groundmass alteration, named penetrative alteration, and selvage alteration forming hydrothermal veins. The penetrative alteration is divided into 9 zones, meanwhile the hydrothermal veins are classified by its mineral composition into 5 types of anhydrite veins, calcite, quartz, sulphide, and gypsum veins. Each vein type will associate the most with different penetrative alteration zone due to its protolith composition and on what stage the vein formed. The anhydrite and quartz veins are found to be associated the most with calc-silicate hornfels zone with the anhydrite sources came from calcite and quartz sources came from the surrounding rocks which the alteration fluid passed through. The sulphide and calcite veins are found to associate the most with dolomitization zone with calcite sources came from the surrounding rock and sulphide deposited filling the open spaces, such as fracture, in crystalline dolostone. Gypsum veins are found to associate the most with fault zone because it formed from the alteration of calcite by faulting process.

Keywords: Penetrative alteration, selvage alteration, vein, alteration zone, mineral association

1. Introduction
Kucing Liar is a skarn deposit associated with intermediate intrusion of Grassberg Igneous Complex (GIC) located in Tembagapura mining area of Papua (figure 1). The alteration of mineral in this area is resulted from the hydrothermal process of magma emplacement carried by hydrothermal fluid passing through the host rock [1]. The alteration in Kucing Liar can divided into penetrative alteration that altering the host rock groundmass and selvage alteration which means the alteration requires a fluid conduit and resulted in the formation of hydrothermal vein [2]. Each hydrothermal vein is composed by specific mineral creating a distinct physical appearance like color, hardness, and thickness [3].

The purpose of this research is to identify the distribution of hydrothermal vein according to the alteration zone. The distribution of hydrothermal vein type can be associated with penetrative alteration zone due to the dynamic alteration process, even though the reason still cannot be defined. Therefore, this research will identify in what penetrative alteration zone each type of hydrothermal vein associated the most.

The research activity took place in Eksplorasi Nusa Jaya Coreshed in Timika, Papua. The Kucing Liar deposit is classified as skarn deposit altering from carbonates sediment resulted from
the intrusion of magma. The protolith of this system is constructed by Cretaceous to Miocene rocks of Kembelangan Group and Papua New Guinea Limestone Group [4] (figure 2). Kembelangan Group is divided into 3 formation which are Ekmai Sandstone (Kkes), Ekmai Limestone (Kkel), and Ekmai Shale (Kkeh), meanwhile Papua New Guinea Limestone Group is divided into 4 formation which are Waripi Limestone (Ttw), Faumai Limetone (Tf), Sirga Sandstone (Ts), and Kais Limestone (Tk). The Waripi Limestone can furtherly be divided into 3 subformation, which are Waripi 3 (Ttw3), Waripi 2 (Ttw2), and Waripi 1 (Ttw1). The alteration system is then cut by a thrust fault, named Idenberg Fault No.1, with relatively west – east strike and dipping at 75° [4]. This fault uplifted the Waripi and older stratigraphy to be deposited on younger stratigraphy of Kais, Sirga, and Faumai.

2. Materials and method
The data for this research was generated from detail logging and core orienting activity of 6 representative boreholes of ± 500 meter each. The vein type was defined from the detail logging and confirmed by petrography analysis, meanwhile the vein was calculated from the core orienting data.

3. Results and discussion

3.1. Stratigraphy
The research area stratigraphically is constructed by carbonates sedimentary rocks and limestone that were deposited from Late Cretaceous to Miocene. The stratigraphy can be divided into 2 groups, Kembelangan Group that can be divided into 3 formations and New Guinea Limestone Group that can be divided into 4 formations.

Kembelangan group can be divided into 3 formations with different lithology composition. First is Ekmai Sandstone Formation (Kkes) that is classified as light grey sub-rounded to sub-angular medium sand and good sortation quartz arenite (figure 3i). Second is Ekmai Limestone Formation (Kkel) that is composed by light grey metamorphosed silty limestone (figure 3h). Third is Ekmai Shale Formation with brown strongly altered black calcareous shale (figure 3g), altered dominantly by orthoclase (K-feldspar).
New Guinea Limestone Group can be divided into 4 formations with limestone as its dominant lithology. Waripi Formation is the oldest formation from this group and can be subdivided into 3 subformation (sequentially older) of Waripi 3 (Tw3), Waripi 2 (Tw2), and Waripi 1 (Tw1). This formation is complex because it is constructed by alternating layers of homogenous dolostone (figure 3f), thin arkose wacke (figure 3e), and micritic limestone with spotted fossiliferous limestone (figure 3d). This formation is then overlaid by micritic and localized Milliolida fossiliferous limestone of Faumai Formation (figure 3c). On top of Faumai Formation, is found layer of brownish light grey sub-angular medium sand quartz wacke of Sirga Formation (figure 3b). Lastly, the youngest rock formation on the research area is constructed by Lacazinella fossiliferous limestone of Kais Formation (figure 3a).
3.2. Alteration and diagenesis
The research area is divided into 9 penetrative alteration and diagenesis zones as the result of its lithological control and altered mineral association. The alteration and diagenesis zones are grouped into 3 groups, which are skarn main alteration encompasses 2 zones, margin zone alteration and diagenesis encompasses 6 zones, and one post-fault alteration encompassed 1 zone only. Each zone has its own characteristic texture and mineral associations. Table 1 and figure 4 (a) to figure (i) summarize and illustrate the 9 penetrative alteration and diagenesis zones on the research area.

Figure 3. Hand specimen pictures of rock formations constructing Kucing Liar stratigraphy: (a) Kais fossiliferous limestone or Tk; (b) Sirga medium sand sandstone or Ts; (c) Faumai micritic limestone or Tf; (d) Waripi fossiliferous limestone member; (e) Waripi dolomitic sandstone member; (f) Waripi cryptocrystalline dolostone member; (g) k-feldspar altered after Ekmai black calcareous shale protolith or Kkeh; (h) Ekmai silty limestone or Kkel; (i) Ekmai medium sand sandstone or Kkes.
Figure 3 (continued). Hand specimen pictures of rock formations constructing Kucing Liar stratigraphy: (a) Kais fossiliferous limestone or Tk; (b) Sirga medium sand sandstone or Ts; (c) Faumai micritic limestone or Tf; (d) Waripi fossiliferous limestone member; (e) Waripi dolomitic sandstone member; (f) Waripi cryptocrystalline dolostone member; (g) k-feldspar altered after Ekmai black calcareous shale protolith or Kkeh; (h) Ekmai silty limestone or Kkel; (i) Ekmai medium sand sandstone or Kkes.

3.3. Hydrothermal vein appearance

Each hydrothermal vein has different physical characteristics such as the color, hardness, shape, and others. On this research, there are 5 hydrothermal veins types that are being analyzed, namely anhydrite, calcite, gypsum, quartz, and sulphide vein. All these 5 types have different physical appearance that can be described megascopically and confirmed petrographically. Sulphide vein is the easiest to defined type because it has yellowish gold color, which is different from the rest vein types that has lighter white color.

Non-sulphide hydrothermal veins have similar light color appearance with different transparency, thickness, continuity, and hardness. Quartz and anhydrite veins are the most similar veins because both are white colored, but we can differentiate these two veins from their hardness and appearances. Quartz veins are generally harder than waxy-textured anhydrite veins, therefore quartz veins cannot be scratched by scratcher. Quartz veins are also more opaque with white dove color compared to more transparent pinkish white anhydrite veins. Quartz veins are generally found thicker with continually consistent thickness and defined border with their surrounding rock, meanwhile anhydrite veins have more wavy shape (inconsistent thickness) and thin haloes-like border. Quartz veins have 1 to exceed 10 centimeters thickness, meanwhile anhydrite veins averagely have 0.5 to 2 centimeter thickness but thicker anhydrite veins can also be found.
Table 1. Penetrative alteration zone of research area.

| Group                        | Alteration zones | Altered mineral association | Protolith formation (lithology)          |
|------------------------------|------------------|------------------------------|------------------------------------------|
| Skarn main alteration        | Calcic skarn     | Dio + Grt ± Mt ± Trm-Act ± Ep| Waripi (dolomitic limestone)             |
| Magnesian skarn              |                  | Mt + Dio + Fo + Trm + Srp ± Grt| Waripi (limey dolostone)                 |
| Margin zone alteration and   | Marbleized       | Cal                          | Kais, Faumai, Waripi 3                   |
| diagenesis                   | Dolomitization   | Dol                          | Waripi (limestone)                       |
| Calc-silicate hornfels       |                  | Kfs + Qz vein ± Dio-Pl       | Ekmai (shale and limestone)              |
| Waripi silicification        | Dol ± Tlc        | Waripi (sandstone)           |
| Sirga silicification         | Met + Kfs ± Cal ± Qz| Sirga (sandstone)            |
| Ekmai silicification         | Met + Kfs + Dio ± Ep ± Chl | Ekmai (sandstone)          |
| Post-fault alteration        | Fault zone       | Mt ± Py ± Cp                 | Kais, Faumai (limestone)                 |

Act: Actinolite; Cal: Calcite; Chl: Chlore; Cp: Chalcopyrite; Dio: Diopside; Dol: Dolomite; Ep: Epidote; Fo: Forsterite; Grt: Garnet; Kfs: K-feldspar; Met: Metamorphism; Mt: Magnetite; Pl: Plagioclase; Py: Pyrite; Srp: Serpentine; Tlc: Talc; Trm: Tremolite; Qz vein: Quartz Vein; Qz: Quartz; ±: major mineral; ±: companion minerals (might be found, might not); the sequent shows the concentration.

Figure 4. Hand specimen pictures of alteration and diagenesis zones constructing Kucing Liar study area: (a) calcic skarn, (b) magnesian skarn, (c) marbleized, (d) hydrothermal dolomite, (e) calc-silicate hornfels, (f) fault zone, (g) Sirga silicification, (h) Waripi silicification and (i) Ekmai silicification.
Figure 4 (continued). Hand specimen pictures of alteration and diagenesis zones constructing Kucing Liar study area: (a) calcic skarn, (b) magnesian skarn, (c) marbleized, (d) hydrothermal dolomite, (e) calc-silicate hornfels, (f) fault zone, (g) Sirga silicification, (h) Waripi silicification and (i) Ekmai silicification.
Calcite, dolomite, and gypsum veins are also similar because they are white and relatively thin. The easiest way to differentiate calcite and dolomite veins are that calcite will react vigorously with hydrochloric acid (HCl). Calcite veins are predominantly more wavy and thinner with 0.4 centimeter of thickness compared to thicker 0.4 to maximum 1 centimeter dolomite veins. Meanwhile gypsum veins are the easiest type to differentiate of 3 because their very low hardness (easily scratched by human nail) and they have sheeted transparent habit. Gypsum vein’s appearances are similar to quartz veins because they both have defined border, but these two have very different hardness and also different habit. Therefore, to differentiate gypsum and quartz veins, we have to use scratcher.

3.4. Hydrothermal vein zonation

3.4.1. Anhydrite vein. Anhydrite veins are most often deposited in the calc-silicate hornfels zone, then calcic skarn, then dolomitization-Ekmai silicification, then magnesian skarn-reaction skarn, and lastly in marbleized zone. The anhydrite veins associate closely with calc-silicate hornfels zones because, according to writer’s interpretation, anhydrite mineral in this zone formed from the alteration of calcite that initially composing the silty limestone protolith of Ekmai Limestone. This argument is supported by the finding of high number of anhydrite veins in the alteration zones that initially composed of calcite mineral in their protolith, such as the calcic skarn and marbleized zones or in the carbonate sandstone of Ekmai Sandstone. From the six analyzed boreholes, there are total 31 anhydrite veins were found with the highest vein distribution was found on T-1 borehole. The average density for anhydrite veins are 2 vein per 1 meter interval with an angle of 75° to core axis (figure 5).

3.4.2. Calcite vein. Calcite veins are most often deposited in the dolomitization zone, then calcic-skarn-marble zone, Waripi silicification-reaction skarn zone, and lastly in magnesian skarn zone. The calcite residue that is not altered to dolomite or other mineral is interpreted to be trapped in the open space, such as in fractured, or weak zone and forming calcite veins. Calcite veins are found mostly in dolomitization zone because it altered from pure limestone with calcite as its main forming-mineral. From the six analyzed boreholes, there are a total of 55 calcite veins with the highest vein distribution was found on T-2 borehole. The average density is 1 vein per 1 meter interval (figure 6) with varying angles to the core axis but found dominantly at 45°. Calcite veins have very thin wavy of 0.1-centimetre thickness appearance so they can be hard to identify (figure 7).
3.4.3. Quartz vein. Quartz veins are most often deposited in the calc-silicate hornfels zone, then magnesian-skarn, and lastly in dolomitization-magnesian skarn zone. Quartz veins are interpreted to formed during retrograde phase or the late phase of alteration. The silicon (Si) for quartz veins was derived from magma carried in primary hydrothermal fluid and was added from the surrounding rocks which the fluid passed. The excess Si was then deposited as quartz vein filling the open spaces in host rock. From the six analyzed boreholes, there are a total of 88 quartz veins with the highest vein distribution was found on T-3 borehole. The average density is 3 vein per 1 meter interval but it decreases to 1 vein per 1 meter interval as it gets deeper. Quartz veins are generally deposited with an angle of 75° to core axis (figure 8). Quartz veins have 1 centimetre or more thickness and opaquely white.

3.4.4. Sulphide vein. Sulphide veins are most often deposited in the dolomitization zone, then magnesian-skarn, then calc-silicate hornfels-Waripi silicification, then calcic skarn, and lastly in reaction skarn-Ekmai silicification. From the six analyzed boreholes, there are a total of 35 sulphide veins and generally deposited with an angle of 45° to core axis. Sulphide veins have low density in dolomitization zone but higher in magnesian skarn zone. Sulphide veins have less than 0.2-centimetre thickness with yellowish gold or semi-sparkling black color.

3.4.5. Gypsum vein. Gypsum veins are most often deposited in the fault zone, then calc-silicate hornfels, and lastly in dolomitization-calcic and magnesian skarn zone-Ekmai silicification. The gypsum veins are found mostly in the fault zone because it is strongly believed that the gypsum formed from the alteration of calcite and anhydrite. The fault zone protolith is constructed from pure limestone of Kais and Faumai Formation, therefore it is believed that the gypsum derived from the alteration of calcite caused by the heat and pressure from faulting process.
Figure 9. Gypsum vein appearance on core.

Table 2. Hydrothermal vein distribution

| Alteration zone                                      | An | Ca | Gp | Qz | Sul |
|------------------------------------------------------|----|----|----|----|-----|
| Marble (metamorphosed limestone)                     | 1  | 8  | 0  | 0  | 0   |
| Dolomitization                                       | 4  | 22 | 1  | 2  | 12  |
| Waripi silicification                                | 0  | 6  | 0  | 0  | 3   |
| Reaction skarn                                        | 2  | 6  | 0  | 0  | 1   |
| Calcic skarn                                          | 6  | 8  | 1  | 2  | 3   |
| Magnesian skarn                                       | 2  | 5  | 1  | 14 | 10  |
| Calc-silicate hornfels                                | 12 | 0  | 5  | 70 | 7   |
| Ekmai silicification                                  | 4  | 0  | 1  | 0  | 1   |
| Fault zone                                            | 0  | 0  | 7  | 0  | 0   |
| Sirga silicification                                  | 0  | 0  | 0  | 0  | 0   |
| Total per vein type                                   | 31 | 55 | 16 | 88 | 37  |
| All analyzed vein                                     | 227|     |    |    |     |

From the six analyzed boreholes, there are a total of 16 gypsum veins with the highest vein distribution was found on L-2 borehole. The average density is 1 vein per 1 meter interval and generally deposited with an angle of 60° to core axis. Gypsum veins are 0.3 centimeter thick and very transparent (figure 9).

The hydrothermal vein distribution is shown in table 2.

4. Conclusion

The Kucing Liar Deposit is constructed from Late Cretaceous to Miocene rocks of Kembelangan Group and Papua New Guinea Limestone Group dominated by carbonates sedimentary rocks. This deposit is classified as skarn type and can be divided into 9 penetrative alteration zones based on their altered mineral association and into 5 selvage alteration type forming veins classified based on its mineral composition. Each vein type associated the most with different penetrative alteration zone. Anhydrite veins and quartz veins are associated the most with calc-silicate hornfels zone, calcite and sulphide veins are associated the most with dolomitization zone, meanwhile gypsum vein associated the most with fault zone. Based on the writer’s interpretation, the different association of each vein type and penetrative alteration zones controlled by the protolith composition and in what stage the vein formed.
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