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Multistage Gold Mineralization at The Wanagon Gold Prospect, Ertsberg District, Mimika Regency, Papua Province, Indonesia

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Abstract - The Wanagon Gold prospect area located in the Ertsberg District, Papua Province, the eastern part of Indonesia, is predominantly underlain by Upper Mesozoic to Cenozoic sedimentary rocks intruded by the Wanagon Sill monzodiorite-diorite and andesite intrusion (Wanagon Dike). The study by previous researchers at Wanagon Gold prospect was based on pre-2005 exploration data and did not contain extensive additional drillings in 2007-2011. This paper aims to elucidate the genesis of the Wanagon Gold deposits based on the latest exploration data. The mineralogy was determined by using thin section and polish section analyses, a scanning electron microscope with an energy dispersive spectrometer (SEM-EDS), X-ray diffraction (XRD), and Near-Infrared spectroscopy (NIR). The chemical composition of the rock was identified using an X-ray fluorescence spectrometer (XRF). Gold mineralization is associated with pyrite, of which there are three types of gold-bearing pyrite: (1) massive pyrite, (2) disseminated pyrite, and (3) fine-grained pyrite associated with clay minerals. Only massive pyrite contains visible gold-bearing minerals such as native gold, electrum, and gold-telluride minerals, while in nonmassive pyrite, gold is only detected by the assay. The deposit is interpreted as structurally controlled distal gold skarn. Instead, its local association of gold with arsenic also indicates a minor component of more-distal sediment-hosted type gold mineralization.

Keywords: Wanagon Gold, skarn, sedimentary host, pyrite, gold

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Introduction

Background

The Wanagon Gold prospect (WG) is situated in the Ertsberg District (Tembagapura District) in Mimika Regency, Papua Province, Indonesia (Figure 1) (Rusmana *et al*., 1995). The prospect lies ± 3 km lengthways to the strike northwest of the giant Grasberg copper-gold porphyry deposit (MacDonald and Arnold, 1994; Pollard and Taylor, 2002, 2005) with a similar distance at the southwest of the Big Gossan copper-gold skarn deposit (Meinert *et al*., 1997; Prendergast *et al*., 2005) and near Kucing Liar deep skarn deposit (New, 2006; Leys *et al*., 2012). Ertsberg District also contains several skarn bodies associated with the Ertsberg intrusion, including the now mined-out Ertsberg deposit (Gibbin, 2006;

Katchan, 1982), the actively mined Ertsberg East Skarn System (Rubin and Kyle, 1997; Couts *et al*., 1999; Leys *et al*., 2012; Sieber *et al*., 2020), and the Dom (Mertig *et al*., 1994; Gibbin, 2006). Skarn is the calc-silicate mineral-dominated-rock formed by replacing carbonate-bearing rocks throughout regional or contact metamorphism and metasomatism (Einaudi *et al*., 1981; Meinert *et al*., 1997; Idrus *et al*., 2011). Skarn can occur from various metasomatism processes involving fluids of magmatic, metamorphic, meteoric, and marine origin (Meinert *et al.*, 2005). Even though most skarns occurred adjacent to the plutons, skarn correspondingly can form alongside faults and main shear zones, on the seafloor, in deeply buried metamorphic terranes at lower crustal depths and shallow geothermal systems (Meinert *et al*., 2005). High-temperature (600°–800°C) early thermal metamorphism and subsequent metasomatism are often followed by lower temperature retrograde alteration (Meinert *et al*., 2003) as hydrothermal fluids, cool, and undergo phase separation.

Exploration of Wanagon Gold prospect started in 1973 when surface gossanous samples returned assays up to 121 g/t Au. Mapping and extensive channel sampling with follow-up drilling in 1981 -1993 showed that around 500 m of continuous mineralization extends along and up to 250 m away from the WNW-trending Wanagon Fault. Based on this drilling, the prospect estimated contains 950,000 ounces of gold (Malensek, 1997; PTFI, 1995, 2002, 2011). As well as exploring WG, drilling in 1993 intersected narrow Cu-Au mineralization at the contact of the nearby Wanagon Sill with sediments at depth. A further phase of prospect mapping and sampling in 2002 -2006 was followed by systematic drillings in 2007-2011.

Previously, researchers reported that WG mineralization dominantly comprises pyrite-sphalerite-arsenopyrite-gold with minor Bi-Te minerals and sulfosalts that all overprint older Cu-Au skarn mineralization and interpreted the deposit to be of epithermal type *(Prendergast et al*., 2005). Other authors (MacDonald and Arnold, 1994; Leys *et al*., 2012) interpreted the mineralization to be of a sediment-hosted gold type, a style that commonly occurs distal to porphyry deposits (Sillitoe, 2010). There were many different conclusions from previous researchers related to the deposit type of Wanagon Gold prospect. It is still not clear about the depth and distribution of the mineralization zone in this prospect. Mineralization studied by previous researchers (Meinert *et al*., 1997; Prendergast *et al*., 2005) was based on pre-2005 exploration data, and did not include results from extensive additional drilling completed in 2007-2 011 (a hundred and twenty drill holes). The more thorough investigation of Wanagon Gold mineralization based on the latest exploration data was the primary purpose of this study. This paper describes the mineralogy and geochemistry of Wanagon Gold mineralization, and investigates the genesis of the deposit as part of the geologic history of the Ertsberg District.

District Geology

The Ertsberg District consists of the Mesozoic and Cenozoic sedimentary rocks that intruded by various equigranular to porphyritic intrusions (Figure 1) (McMahon, 1994; Rusmana *et al*., 1995; McDowell *et al*., 1996; Ufford, 1996). The sediments comprise the clastic Jurassic to Cretaceous Kembelangan Group sediments in the southwestern part of the district that is overlain by the carbonate units of the Cenozoic New Guinea Limestone Group (NGLG), the rest of the district (McMahon, 1994; McDowell *et al*., 1996; Ufford, 1996).

The upper part of the Kembelangan Group contains the Ekmai Formation that has three members: the uppermost Ekmai Shale (~3-5 m), the underlying Ekmai Limestone-a calcareous mudstone (~100 m), and the Ekmai Sandstone (~600 m) (Leys *et al*., 2012). All three members are in places strongly altered and host significant mineralization, such as at Big Gossan and Wanagon Gold (Meinert *et al*., 1997; Prendergast *et al*., 2005). In and around these deposits, the Ekmai Shale is commonly hornfelsed and hosts fracture-controlled mineralization. The Ekmai

Limestone is hornfels, skarn-altered, and hosts both vein-style and skarn mineralization. On the other hand, the Ekmai Sandstone is silicified, or K-feldspar altered, and commonly hosted disseminated and fracture-controlled mineralization (Leys *et al*., 2012).

The dominant sediments within the Ertsberg District are carbonate rocks of the Lower to Middle Cenozoic NGLG, the youngest of which is the >1,200 m thick, in part highly fossiliferous, Kais Formation. The underlying 3−10 m thick, calcareous quartz sandstone Sirga Formation is the only NGLG clastic unit, and forms a regional stratigraphic marker horizon (Ufford, 1996; Leys *et al.*, 2012). Below this, there lies the massive-to-poorly bedded, clean limestones of the Faumai Formation. The lowermost NGLG unit is the Waripi Formation, an anhydrite nodule-bearing dolomitic limestone that contains thin but laterally continuous quartz sandstone beds. Micritic dissolution and bioclastic produce secondary vuggy and molding through deep-burial diagenesis in dolomitic limestone of Waripi Formation. This formation hosts the bulk of the skarn-hosted mineralization in the district (Leys *et al*., 2012). Quaternary and Recent deposits are found mainly in fluvial and glacial valleys and comprise alluvium, colluvium, and glacial till, and small glaciers still exist on some mountain peaks (Rusmana *et al*., 1995; Ufford, 1996; PTFI, 2001).

There were two main phases of deformation that have affected the Ertsberg District (Weiland and Cloos, 1996; Sapiie and Cloos, 2004; Sapiie, 2016). The first phase occurred between 12 and 4 Ma and was associated with regional shortening caused by the subduction of the northern edge of the Australian late below the Pacific Plate (Weiland and Cloos, 1996; Sapiie and Cloos, 2004). Kilometers-scale folds associated with thrust faults formed in this phase predominantly characterized by open synclines, such as the Yellow Valley syncline and tight anticlines (Sapiie and Cloos, 2004). The second deformation phase occurred from 4 to 2 Ma and occurred by up to kilometer-scale strike-slip movements on steepened, pre-existing thrust faults due to closure of the subduction zone and a change in the direction of shortening (Weiland and Cloos, 1996; Cloos *et al*., 2005; Sapiie, 2016). The largest strike-slip fault zones are a few tens of meters wide, containing many subparallel planar faults, and internally are highly brecciated (Cloos *et al*., 2005; Sapiie and Cloos, 2013; Sapiie, 2016). The timing and distribution of igneous emplacement are correlated with strike-slip faulting in the Ertsberg District, because this style of tectonic activity creates localized zones of an extension where magmas are intruded (McDowell *et al.*, 1996; Leys *et al*., 2012).

Ertsberg District intrusions span from 4.4 to 2.6 Ma (Wafforn, 2017), and consist of fine-to-medium grained porphyritic-to-equigranular monzonites and monzodiorites that are predominantly hosted by NGLG limestones at the surface. Grasberg Igneous Complex (GIC) and the Ertsberg Intrusive Complex (EIC) are the two major intrusive igneous complexes. However, there are also numerous smaller dikes, stocks, and sills, all of which were emplaced at depths of ± 2 km or less (McMahon, 1994; McDowell *et al.*, 1996). The more minor intrusions include the Wanagon Sill with a composite zircon U-Pb age of 3.56 ± 0.07 Ma (Wafforn, 2017) and are thus one of the older district intrusions. The intrusive and minor volcanic rocks of the GIC are slightly younger and have ages from 3.5 to 3.1 Ma, and the Ertsberg intrusion is younger still with ages from 3.1 to 2.6 Ma (Wafforn, 2017). The trace element features of the district intrusions are like those reported from several copper-gold deposits in Papua New Guinea, suggesting an arc-like magma source (McMahon, 1994; McDowell *et al*., 1996). However, more recent studies have shown that magmatism was directly related to an episode of asthenospheric upwelling produced by rupture of the subducting plate in an arc-continent collision setting and was not directly related to subduction (Leys *et al*., 2012).

Porphyry and skarn alteration and mineralization are in general, closely spatially and temporally related to intrusive activity, especially that of the Grasberg and Ertsberg complexes (Gibbin, 2006; Leys *et al*., 2012; MacDonald and Arnold, 1994; Pollard and Taylor, 2002; Sieber *et al*., 2020). Grasberg has well-developed porphyry-style alteration and mineralization comprising a central potassic (K-feldspar-quartz-anhydrite) alteration zone with associated quartz-magnetite stockwork overprinted by chalcopyrite-bornite-(covellite) veins and disseminated mineralization (MacDonald and Arnold, 1994). A less Cu-mineralized region of intense phyllic (quartz-sericite-pyrite) alteration through more concentrated covellite and molybdenite surrounds the potassic core, flanked by minor chlorite-epidote-carbonate (propylitic) alteration. Massive sulfide at the edge of the complex, a 5–30 m thick zone of pyrite with secondary chalcopyrite and minor bornite-covellite overprints the contact between igneous and country-rock limestones (Leys *et al*., 2012).

Most Ertsberg district skarns are linked with the Ertsberg intrusion, principally along its northern margin (Figure 1). Skarn mineralogy is strongly controlled by protolith carbonate composition, comprising Ca-dominated assemblages (grossular to andradite garnet-monticellite-vesuvianite) which were hosted by Kais or Faumai Formation limestones, and Mg-Ca skarns (pyrope to andradite garnet-diopside-forsterite) by Waripi Formation dolostones (Gibbin, 2006; Mertig *et al*., 1994). Massive magnetite skarn is found in both Ca- and Mg-Ca skarns and retrograde alteration of skarn to actinolite-tremolite, and serpentine-talc are commonly associated with mineralization. As with porphyry-style mineralization, chalcopyrite with lesser bornite is the dominant copper sulfide in skarns, and mineralization is paragenetically late (Leys *et al*., 2012).

Methods

Reconnaissance-type outcrop mapping and drill-core logging were carried out to determine the geology and types of WG alteration and mineralization, and to take samples for a further study. Thin sections and polished sections were analyzed using a NIKON ECLIPSE E600 POL polarizing microscope. Semiquantitative analysis was performed using a scanning electron microscope with an energy dispersive spectrometer (SEM-EDS). X-ray diffraction (XRD) analyses were performed using a Rigaku RINT 2100 X-ray diffractometer. Investigating rock sample chemical composition was using a Rigaku RIX 3100 X-ray fluorescence spectrometer (XRF). All analyses were conducted at the Mining Engineering Department, ITB, Bandung, Indonesia. In addition, Near-Infrared spectroscopy (NIR) analyses were conducted at the PT Eksplorasi Nusa Jaya (ENJ) core-shed

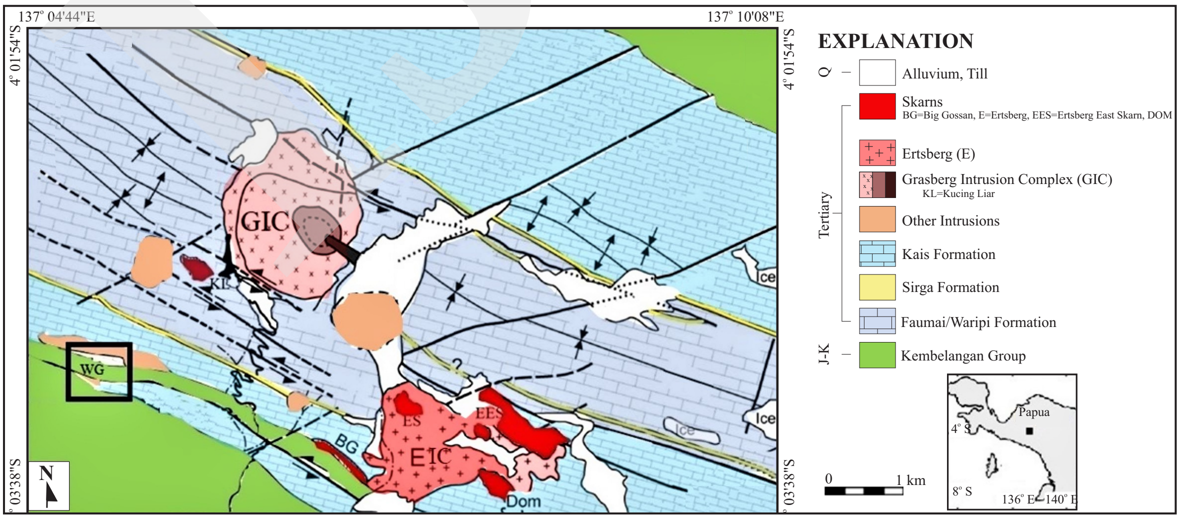

Figure 1. Geologic map of the Ertsberg District, Papua, Indonesia and Wanagon Gold Prospect (WG) within the district (New, 2006; simplified from Sapiie and Cloos, 2004, 2013; Leys *et al*., 2012).

in Timika, Papua. The thin section analysis was carried out on 120 samples, ore microscopy on 56 samples, XRD on 115 samples, XRF on 29 samples, NIR on 90 samples, and SEM-EDS analyses were completed on 21 samples.

Result and Analysis

Wanagon Gold Deposit Geology

In the centre of the deposit near the fault, Waripi Formation, dolomitic limestone and dolostones are replaced by massive pyrite that grades outward into silicified and marbleized carbonates containing pyrite veinlets and dissemination. Within the deposit, Ekmai Limestone units are strongly altered to hornfels and skarn, whereas Ekmai Sandstone units are silicified, and K-feldspar (adularia) are altered, both contain pyrite veinlets and dissemination. A few weakly altered andesitic dikes (Wanagon Dike) cut the altered and mineralized sediments and are thus of post-mineralization age at ~3,30 Ma (Wafforn, 2017) (Figure 2 a and b). However, the only significant intrusion in the WG area is the strike-parallel, up to two km long and two hundred meters thick, altered, and mineralized porphyritic monzodiorite-diorite Wanagon Sill (Figure 2c and d) that lies immediately north of the prospect.

Alteration and Mineralization

Four types of alteration (Figure 3) (Hartiningsih *et al.*, 2020; Hartiningsih, 2021) which affect the prospect area are: (a) garnet-clinopyroxene-wollastonite ± olivine prograde skarn in Ekmai Formation and Waripi Formation near the fault; (b) epidote-adularia-quartz-chlorite ± amphibole ± biotite ± sericite retrograde skarn; (c) calcite-quartz ± chalcedony ± kaolinite ± zeolite retrograde skarn, and (d) late-stage calcite-gypsum-smectite ± cristobalite ± tridymite in Ekmai Sandstone units and Waripi Formation dolomitic limestones.

In most skarn deposit, the retrograde skarn alteration predominantly overprints prograde skarn alteration (Einaudi *et al.*, 1981; Corbett and Leach, 1998; Meinert *et al.*, 2005). This situation occurred in the prospect area where the higher temperature calc-silicate alteration of carbonate rocks is overprinted by the lower temperature

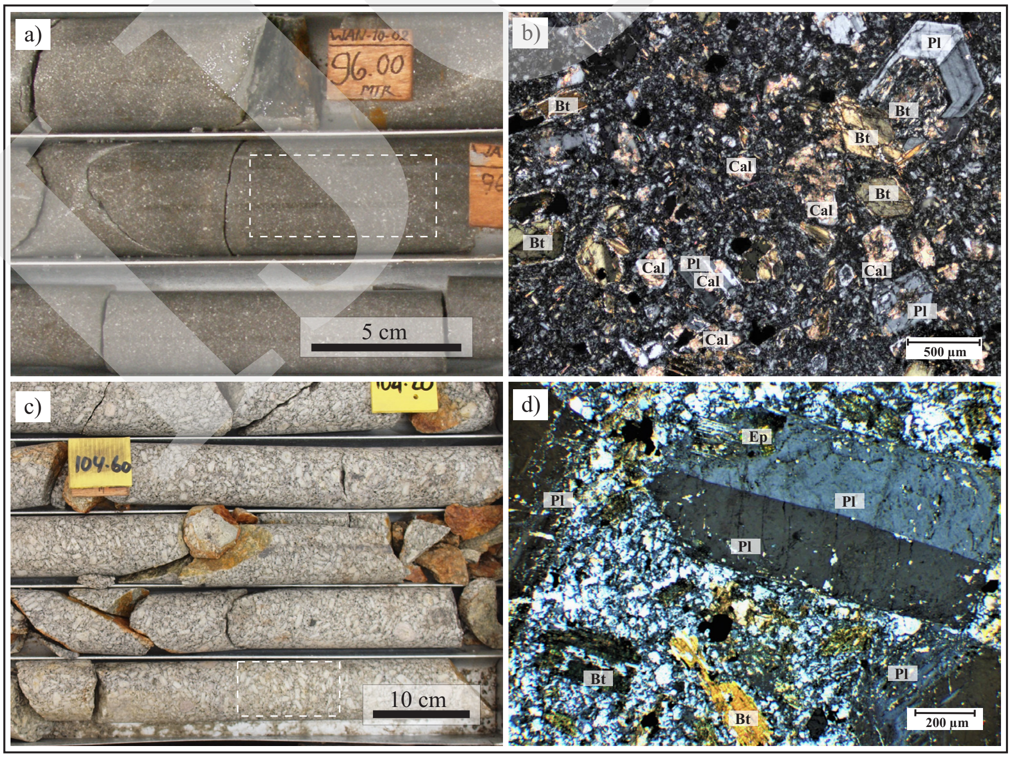

Figure 2. Core sample photographs and cross nicol photomicrograph of Wanagon Dike (a and b) and Wanagon Sill (c and d).

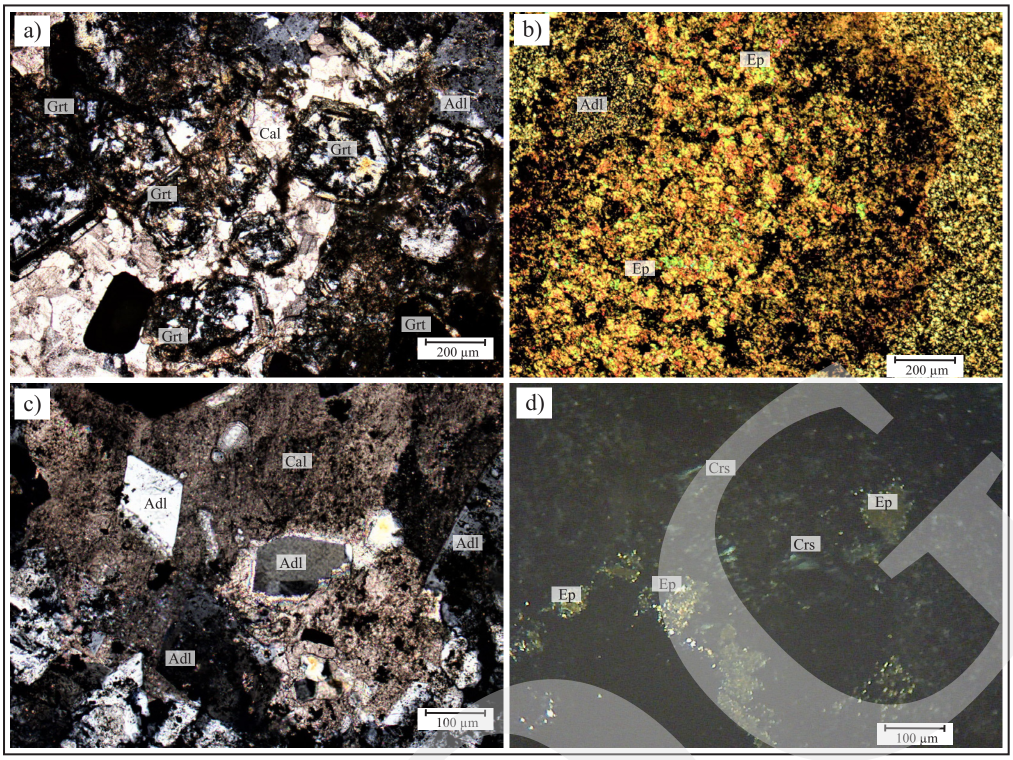

Figure 3. Cross Nicol photomicrographs of Wanagon Gold prograde and retrograde alteration in thin section: (a) garnet (Grt), and adularia (Adl) replace calcite in limestone; (b) epidote (Ep) and adularia (Adl) replace calcite in limestone; (c) adularia (Adl) replaces calcite in limestone; (d) cristobalite (Crs) and epidote (Ep) in dolomitic limestone.

of retrograde skarn and the late-stage alteration near the surface. The prograde skarn alteration is pervasive within limestones and shales of the Ekmai Formation, but even weakly developed as endoskarn in the southern edge of the Wanagon Sill. The late-stage alteration only developed near the surface within Ekmai Sandstone units and Waripi Formation dolomitic limestones.

Based on the geochemistry of >10,000 WG drill-core samples, gold mineralization has a strong correlation through Ag and moderate correlation with Pb, Zn, and As. The correlation also exhibits with individual core assay results where around 85% of high Au grades are associated with Pb-Zn and 15% with As. Gold mineralization predominantly is closely associated with pyrite (Figure 4). There are three types of pyrite present as the carrier of gold mineral: (1) massive pyrite, (2) disseminated pyrite, and (3) fine-grained framboidal pyrite associated with clay minerals. Only massive pyrite contains visible gold-bearing minerals (Figure 5) such as native gold, electrum,

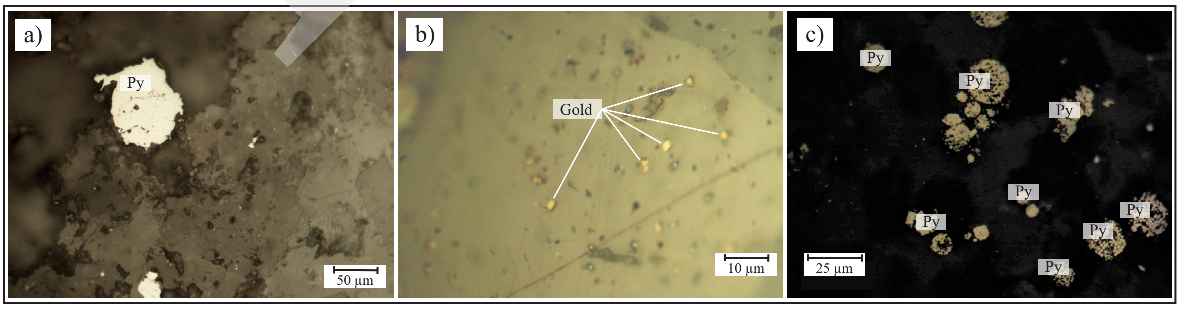

Figure 4. Photomicrographs of pyrite (Py) as the carrier of gold (Au) in polished section: (a) disseminated pyrite, (b) massive pyrite, (c) framboidal pyrite.

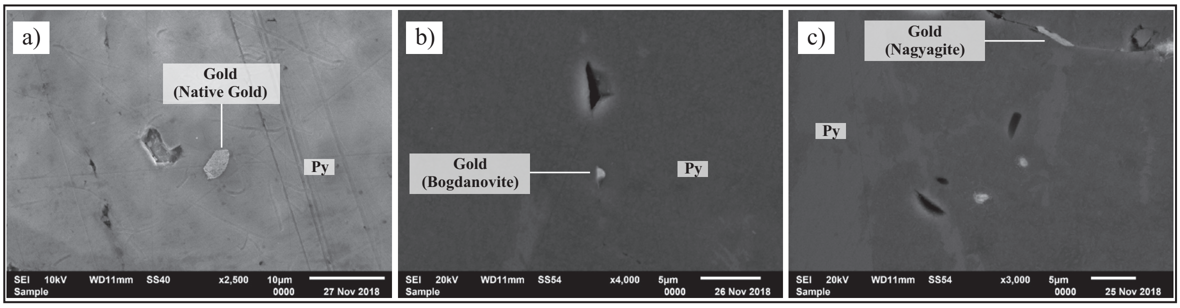

Figure 5. Photomicrographs SEM-EDS analysis of gold as inclusions in pyrite within shale. (a) sandstone (b) and dolomitic limestone (c).

and Au-Te minerals (bogdanovite, nagyagite, calaverite, krennerite, sylvanite). Gold-bearing minerals in massive sulfide exist as inclusions in pyrite and locally in galena, sphalerite, chalcopyrite, and host rock fragments enclosed within pyrite. The average massive sulfide Au grade is 7.7 ppm, and the highest-grade sample contains 80 ppm gold. No gold-bearing minerals were observed by microscopy or SEM in other types of pyrite, and the presence of gold is only indicated from assays.

Discussion

Thermal metamorphic alteration in WG contains the following mineral assemblages: (1) Ca-Mg silicates in dolomitic limestone of Waripi Formation; (b) Ca-silicate and wollastonite marble in the limestone of Ekmai Formation; (c) Hornfels/ Ca-Al silicates in calcareous shale of Ekmai Formation. Sulfide deposition, including massive pyrite and associated Pb, Zn, and minor Cu sulfide, commenced during the latter stages of metasomatic skarn formation. Retrograde alteration of prograde minerals is a typical process in skarn formation where earlier anhydrous (prograde) minerals were replaced by hydrous minerals (Einaudi *et al*., 1981; Meinert *et al*., 2005). Retrograde skarn mineralogy predominantly overprints the prograde zonation sequence and characteristically structurally controlled. Consequently, there frequently is a zone of rich hydrous minerals lengthways stratigraphic, intrusive or fault contacts. This superposition of later phases can be difficult to distinguish from a sequence of spatial zonation by a reason of a metasomatic fluid progressive reaction (Meinert *et al*., 2005). This process occurred at WG with the replacement of prograde garnet, wollastonite, clinopyroxene, and olivine by retrograde minerals, epidote, amphibole, chlorite, and minor other hydrous minerals, along fluid conduits that are typically structurally controlled. The irregularly distributed and incomplete replacement of earlier higher temperature minerals by later, lower temperature phases makes it challenging to identify mineral zoning patterns (Dick and Hodgson, 1982; Meinert *et al*., 2005). Both WG massive and disseminated sulfide deposition were interpreted to have occurred together with retrograde alteration due to declining hydrothermal fluid temperatures and their change to a reducing oxidation state (Corbett and Leach, 1998). Gold mineralization was also interpreted to have been deposited at the same time as pyrite and other sulfides. The paragenesis of minerals in Wanagon Gold is shown in Figure 6.

There is no correlation between gold mineralization and igneous intrusions in WG, as shown by very low to no Au grades within and close to the Wanagon Sill and the andesite dikes. The Wanagon Gold deposit is closely linked with the Wanagon Fault, a primary WNW-trending strike-slip structure, as well as a local subparallel structure called the North Wanagon Fault. Sediments host the deposit trend of WNW, dip NNE steeply, and comprise altered and mineralized Ekmai Formation sandstones and limestones together with Waripi Formation dolomitic limestones.

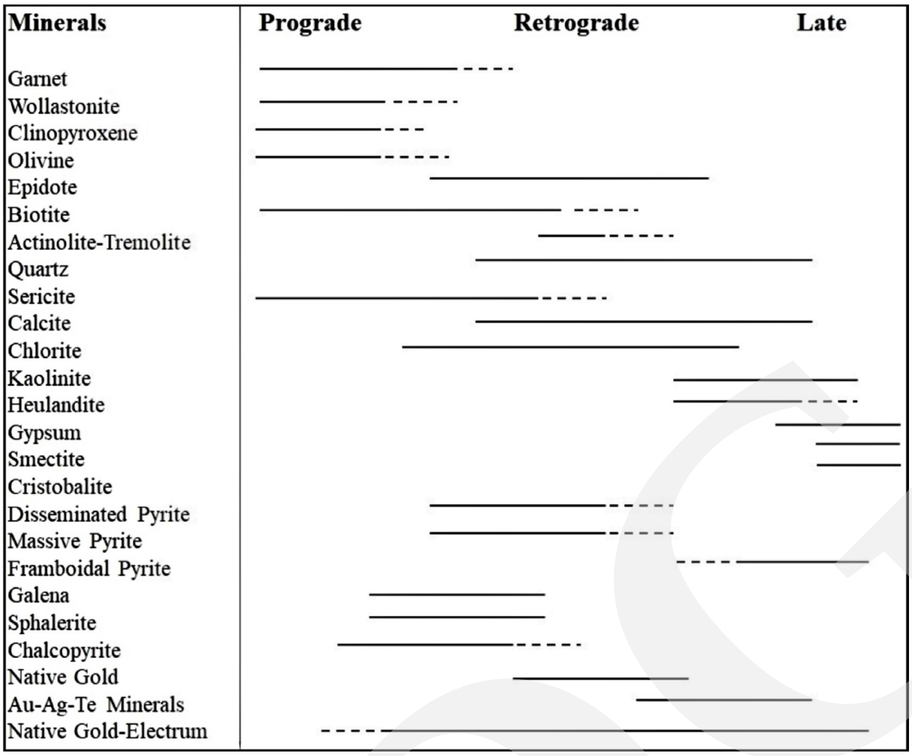

Figure 6. Wanagon Gold Prospect paragenesis.

Near the North Wanagon Fault zone, the Wanagon Dike (Andesite Intrusion) has apparently removed the gold mineralization zone within the sandstone and limestone unit of Ekmai Formation, probably due to overprinted by intense calcite-quartz alteration. The same situation also occurred in GIC, where the Gajah Tidur alteration system effectually removed preexisting mineralization from the Grasberg and Kucing Liar orebodies (Leys *et al*., 2012; Bensaman *et al*., 2015). In contrast, gold grades correlate strongly with the Wanagon and North Wanagon Faults, adjacent to which many massive sulfide lenses occur with high gold grades (Figure 7). Thus, skarn alteration at WG has been associated with these significant faults and, in general, shows no relationship to igneous intrusions, unlike the significant skarn body that occurs on the Ertsberg intrusion northern margin. However, WG was clearly formed by hydrothermal fluids associated with a porphyry system, and it is supposed that the Wanagon and North Wanagon faults provided conduits for such fluids from a porphyry source not yet intersected by drilling. This situation is somewhat like the Yilgarn Craton, Western Australia, where skarns and related gold mineralization formed adjacent to shear zones where these intersect favourable lithologies (Mueller, 1988; Mueller and Groves, 1991). At WG, hydrothermal fluids passed along major and associated minor faults and deposited prograde and later retrograde skarn minerals in all surrounding lithologies, including within Ekmai Formation sandstones (Figure 7).

It is considered that there were two populations of gold mineralization which are present in WG. The first population predominantly Au-Ag-Pb-Zn type associated with massive sulfide and skarn, and the second type is a minor Au-As type associated with the late-stage mineralization. Even though WG Cu grades are generally low, the assay statistics show a weak association of Cu with Mo. This association indicates that higher temperature hydrothermal fluids that formed prograde skarns were porphyry-related and contained minor amounts of Cu and Mo.

The association of gold mineralization at WG with skarn and massive Fe-Zn-Pb sulfides shows that mineralization is predominantly of distal

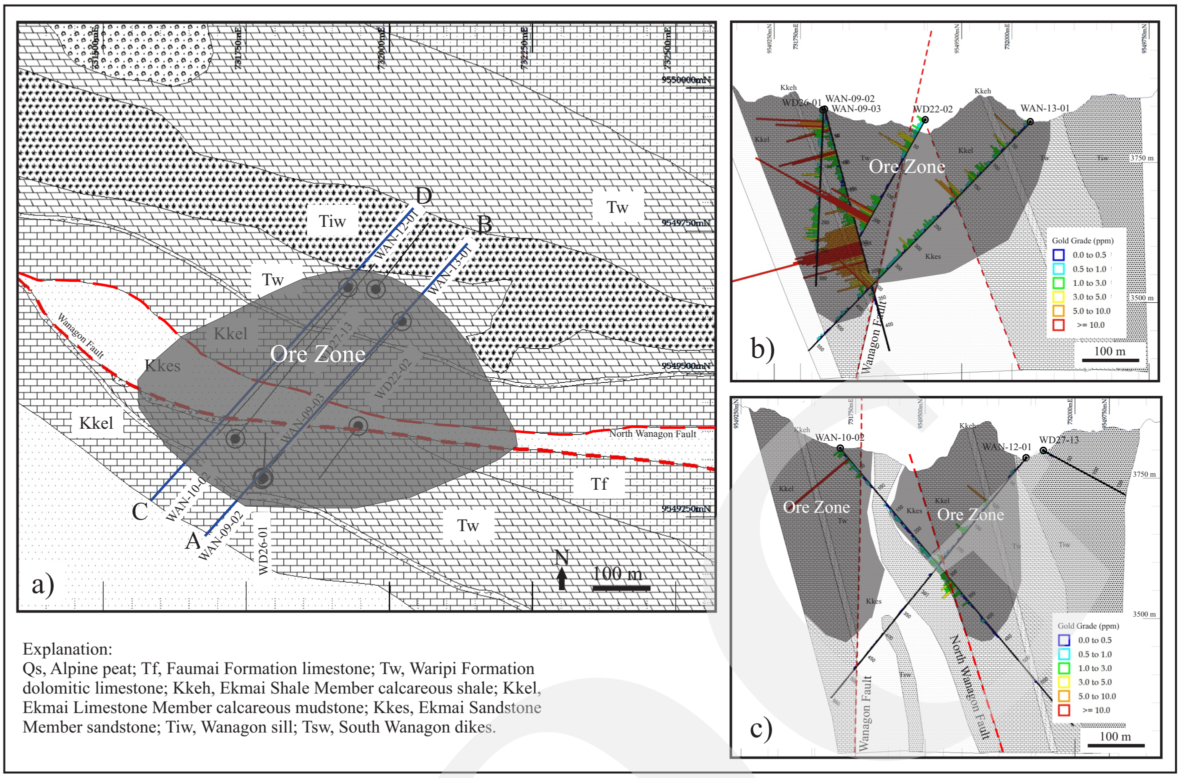

Figure 7. Geological map of Wanagon Gold Prospect (a) showing with AB (b) and CD (c) cross-sections indicated.

Au skarn type, as indicated in Sillitoe's 2010 porphyry copper system model (Sillitoe, 2010). However, the association of gold with arsenic is not normal in distal gold skarn type mineralization, and it is speculated that it instead represents a minor late-stage gold mineralizing event of very distal, sediment-hosted Au-As type. This type of mineralization, like the Mesel Gold deposit, is structurally and lithological controlled (Carlile and Mitchell, 1994; Corbett and Leach, 1998; Garwin *et al*., 1995). If so, the lack of Au-bearing minerals in WG samples with disseminated and framboidal pyrite may be because sediment-hosted type gold within pyrite is too fine-grained to detect even by electron microscopy, and thus 'invisible'.

Conclusions

Gold mineralization in the Wanagon Gold prospect shows no association with igneous intrusions (Wanagon Dike and Wanagon Sill) and is strongly structurally controlled (by the Wanagon Fault and North Wanagon Fault). The mineralization of gold is predominantly associated with pyrite and locally with sphalerite and galena. There are three types of gold-bearing pyrite: (a) Massive pyrite that hosts most of the high-grade gold which occurs as native Au, electrum or as Au-tellurides; (b) Disseminated pyrite which commonly contains lower gold grades but no Au-bearing minerals were found; (c) Fine-grained framboidal pyrite associated with clay minerals that have some low-grade gold but also lacks of any Au-bearing minerals. Assay results from >10,000 drill-core samples confirm the strong Au-Ag association, and show a moderate Au-Pb-Zn and Au-As association. Based on the strong structural control, prograde and retrograde skarn, lack of direct association with igneous intrusions, geochemistry, and mineralization style, the Wanagon Gold is mainly a distal gold skarn type. However, it also has a minor component of very distal, sediment-hosted Au-As type of mineralization, containing very fine-grained 'invisible' gold associated with disseminated and framboidal pyrite.

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References

Bensaman, B., Furqan, R.A., Rosana, M.F., and Yuningsih, E.T., 2015. Hydrothermal Alteration and Mineralization Characteristics of Gajah Tidur Prospect, Ertsberg Mining District, Papua, Indonesia. *The 2nd International Conference and 1 St Joint Conference*. Presented at the ICG, Bandung, p.9.

Carlile, J.C. and Mitchell, A.H.G., 1994. Magmatic arcs and associated gold and copper mineralization in Indonesia. *Journal of Geochemical Exploration,* 50, p.91-142. DOI: 10.1016/0375-6742(94)90022-1

Cloos, M., Sapiie, B., Ufford, A.Q., Weiland, R.J., Warren, P.Q., and McMahon, T., 2005. Collisional Delamination in New Guinea: The geotectonic of subducting slab breakoff. *Geological Society of America,* 400, p.1-51. DOI: 10.1130/2005.2400.

Corbett, G.J. and Leach, T.M., 1998. Southwest Pacific Rim Gold Copper System: Structure, Alteration, and Mineralization. *Society of Economic Geologists, Special Publication,* 6. DOI: 10.5382/SP.06

Couts, B.P., Susanto, H., Belluz, N., Flint, D., and Edwards, A., 1999. Geology of the Deep Ore Zone, Ertsberg Skarn System, Irian Jaya, Australian Institute of Mining and Metallurgy. Presented at *the Pacrim 99 Conggress, Bali, Indonesia*, p.539-547.

Dick, L. and Hodgson, C.J., 1982. The MacTung W-Cu(Zn) contact metasomatic and related deposits of the northeastern Canadian Cordillera. *Economic Geology,* 77, p.845-867. DOI: 10.2113/gsecongeo.77.4.845.

Einaudi, M.T., Meinert, L.D., and Newberry, R.J., 1981. Skarn Deposits. *Economic Geology,* 75, p.317-392. DOI: 10.5382/AV75.11.

Garwin, S.L., Hendri, D., and Lauricella, P.F., 1995. The geologyof the Mesel sedimen-hosted gold deposit, North Sulawesi, Indonesia. Presented at *the Pacrim Congress 95*, The Australasian Institute of Mining and Metallurgy, Carlton South, p.221-226.

Gibbin, S., 2006. *The Magmatic and Hydrothermal Evolution of The Ertsberg Intrusion in The Gunung Bijih (Ertsberg) Mining District, West Papua, Indonesia* (Ph.D. Dissertation). Department Of Geosciences, University of Arizona, USA.

Hartiningsih, E., 2021. *The Genetic Model of Wanagon Gold Prospect, Tembagapura District (Ertsberg District), Mimika Regency, Papua*, (Doctoral Dissertation). Bandung Institute of Technology, Bandung.

Hartiningsih, E., Syafrizal, Sucipta, I.G.B.E., and Notosiswoyo, S., 2020. Hydrothermal Alteration Characteristic of Wanagon Gold Prospect, Ertsberg District, Papua, Indonesia; determine by Petrographic Analysis, X-ray Diffraction (XRD) and Near-Infrared Spectroscopy (NIR), in: Geosciences and Earth Resources Engineering for Sustainable Future. Presented at *the The International Conference on Geoscience and Earth Resources (ICGERE), Bandung*.

Idrus, A., Setijadji, L.D., and Thamba, F., 2011. Geology and Characteristics of Pb-Zn-Cu-Ag Skarn Deposit at Ruwai, Lamandau Regency, Central Kalimantan. *Jurnal Geologi Indonesia,* 6 (4), p.191-201. DOI: 10.17014/ijog.v6i4.126

Katchan, G., 1982. *Mineralogy and geochemistry of the Ertsberg (Gunung Bijih) and Ertsberg East (Gunung Bijih Timur) skarns, Irian Jaya, Indonesia, and OK Tedi skarns, Papua New Guinea* (Ph.D Dissertation). University of Sydney, New South Wales, Australia.

Leys, C.A., Cloos, M., New, B.T.E., and MacDonald, G.D., 2012. Copper-Gold ± Molybdenum Deposits of the Ertsberg-Grasberg District, Papua, Indonesia. *Society of Economic Geolgists, Inc.,* 16, p.215-235. DOI: 10.5382/SP.16.10.

MacDonald, G.D. and Arnold, L.C., 1994. Geological and Geochemical Zoning of the Grasberg Igneous Complex, Irian Jaya, Indonesia. *Journal of Geochemical Exploration,* 50, p.143-178. DOI: SSDI 0375-6742(93)E0052-X

Malensek, G.A., 1997. *Economic evaluation of the Wanagon Gold deposit, Irian Jaya, Indonesia* (M.Sc Thesis). Colorado School of Mines, USA.

McDowell, F.W., McMahon, T.P., Warren, P.Q., and Cloos, M., 1996. Pliocene Cu-Au-bearing Igneous Instrusions of the Gunung Bijih (Ertsberg) District Irian Jaya, Indonesia: K-Ar Geochronology. *The Journal of Geology,* 104, p.327-340. DOI: 10.1086/629828

McMahon, T.P., 1994. Pliocene Intrusions in the Gunung Bijih (Ertsberg) Mining District, Irian Jaya, Indonesia: Petrography and Mineral Chemistry. *Ore Geology Reviews,* 36, p.925-946. DOI: 10.1080/00206819409465490.

Meinert, L.D., Dipple, G.M., and Nicolescu, S., 2005. World Skarn Deposits. *Society of Economic Geologist, Inc.,* 100, p.299-336. DOI: 10.5382/AV100.11.

Meinert, L.D., Hede, Satoh, H., and Matsuhisa, Y., 2003. Formation of Anhydrous and Hydrous Skarn in Cu-Au Ore Deposits by Magmatic Fluids. *Economic Geology,* 98, p.147-156. DOI: 10.2113/gsecongeo.98.1.147.

Meinert, L.D., Hefton, K.K., Mayes, D., and Tasiran, I., 1997. Geology, Zonation, and Fluid Evolution of the Big Gossan Cu-Au Skarn Deposit, Ertsberg District, Irian Jaya. *Economic Geology,* 92, p.509-534. DOI: 10.2113/gsecongeo.92.5.509.

Mertig, H.J., Rubin, J.N., and Kyle, J.R., 1994. Skarn Cu-Au orebodies of the Gunung Bijih (Ertsberg) district, Irian Jaya, Indonesia. *Journal of Geochemical Exploration,* 50, p.179-202. DOI: 10.1016/0375-6742(94)90024-8.

Mueller, A.G., 1988. Archaean gold–silver deposits with prominent calc-silicate alteration in the Southern Cross greenstone belt, Western Australia; analogues of Phanerozoic skarn deposits. *Publication*. Geology Department and University Extension, University of Western Australia, 12, p.141-163.

Mueller, A.G. and Groves, D.I., 1991. The classification of Western Australian greenstone-hosted gold deposits according to wallrock-alteration mineral assemblages. *Ore Geolgy Reviews,* 6, p.291-331. DOI: 10.1016/0169-1368(91)90008-u

New, B.T.E., 2006. *Control of copper and gold distribution in the Kucing Liar deposit, Ertsberg Mining District, West Papua, Indonesia* (Ph.D Dissertation). James Cook University, Queensland, Australia.

Pollard, P.J. and Taylor, R.G., 2005. Ages of Intrusion, Alteration, and Mineralization at the Grasberg Cu-Au Deposit, Papua, Indonesia. *Economic Geology,* 100, p.1005-1020. DOI: 0361-0128/05/3532/1005-16 $6.00.

Pollard, P.J. and Taylor, R.G., 2002. Paragenesis of the Grasberg Cu–Au deposit, Irian Jaya, Indonesia: results from logging section 13. Miner. *Deposita,* 37, p.117-136. DOI: 10.1007/s00126-001-0234-7

Prendergast, K., Clarke, G.W., Person, N.J., and Harris, K., 2005. Genesis of Pyrite-Au-As-Zn-Bi-Te Zones Associated with Cu-Au Skarns: Evidence from the Big Gossan and Wanagon Gold Deposits, Ertsberg District, Papua, Indonesia. *Economic Geology,* 100, p1021-1050. DOI: 10.2113/gsecongeo.100.5.1021

PTFI, 2011. Deportment of Gold in Freeport's Wanagon Feeds (Unpublished company report No. 11/38). PTFI.

PTFI, 2002. Wanagon Gold drill proposal (Unpublished company report No. Ri-824). PTFI.

PTFI, 2001. *COWA Geology Map*.

PTFI, 1995. Wanagon Gold Prospect Process Evaluation (Unpublished company report No. 3590). PTFI.

Rubin, J.N. and Kyle, J.R., 1997. Precious metal mineralogy in porphyryskarn- and replacement–type ore deposits of the Ertsberg (Gunung Bijih) district, Irian Jaya, Indonesia. *Economic Geology,* 92, p.535-550. DOI: 10.2113/gsecongeo.92.5.535

Rusmana, E., Parris, K., Sukanta, U., and Samodra, H., 1995. *Peta Geologi Lembar Timika, Irian Jaya skala 1: 250.000.* Geological Research and Depelopment Centre, Bandung.

Sapiie, B., 2016. Kinematic Analysis of Fault-Slip Data in the Central Range of Papua, Indonesia. Indones. *Indonesian Journal on Geoscience,* 3 (1), p.1-16. DOI: 10.17014/ijog.3.1.1-16.

Sapiie, B. and Cloos, M., 2013. Strike–slip faulting and veining in the Grasberg giant porphyry Cu-Au deposit, Ertsberg (Gunung Bijih) mining district, Papua, Indonesia. *International Geolgical Reviews, 55*, p.1-42. DOI: 10.1080/00206814.2012.728697.

Sapiie, B. and Cloos, M., 2004. Strike-slip faulting in the core of the Central Range of west New Guinea: Ertsberg Mining District, Indonesia. *Geological Society of America, Bulletin,* 16, p.277-293. DOI: 10.1130/B25319.1.

Sieber, M., Brink, F.J., Leys, C.A., King, P.L., and Henley, R.W., 2020. Prograde and retrograde metasomatic reactions in mineralised magnesium-silicate skarn in the Cu-Au Ertsberg East Skarn System, Ertsberg, Papua Province, Indonesia. *Ore Geology Reviews,* 125, 103697. DOI: 10.1016/j.oregeorev.2020.103697.

Sillitoe, R.H., 2010. Porphyry Copper Systems. *Economic Geology,* 105, p3-41. DOI: 0361-0128/10/3863/3-39.

Ufford, A.I., 1996. *Stratigraphy, structural geology and tectonics of a young forearc-continent collision, western Central Range, Irian Jaya (western New Guinea), Indonesia* (Ph.D. Dissertation). Texas Austin, USA.

Wafforn, S., 2017. *Geo- and Thermochronology of the Ertsberg-Grasberg Cu-Au Mining District, west New Guinea, Indonesia* (Ph.D Dissertation). The University of Texas, Austin, Texas, USA. DOI: 10.1130/abs/2018am-322684

Weiland, R.J. and Cloos, M., 1996. Pliocene-Pleistocene asymmetric unroofing of the Irian fold belt, Irian Jaya, Indonesia :Apatite fission-track thermochronology. *Geological Society of Australia, Bulletin,* 108, p.1438-1449.