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PORPHYRY-STYLE MINERALISATION IN THE ERTSBERG DIORITE, GUNUNG BIJIH (ERTSBERG/GRASBERG) DISTRICT, WEST PAPUA, INDONESIA

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Abstract - Newly-recognised porphyry-style mineralisation within the Ertsberg intrusion displays significant differences from porphyry mineralisation at the Grasberg porphyry Cu-Au deposit. Stockwork mineralisation in the Ertsberg occurs near the giant East Ertsberg Skarn System, close to the northern margin of the intrusion. Stockwork mineralisation in the diorite is spatially associated with 5-15 m wide, E-striking, dykes of porphyritic hornblende monzonite that cut equigranular Ertsberg diorite. The porphyry dykes strike parallel to major district structures and occur where those structures project into the Ertsberg intrusion. Hornblende abundance greater than biotite, the much greater content of sphene, a paucity of broken phenocrysts, and the aplitic groundmass distinguish the porphyry dykes in the Ertsberg Stockwork Zone from the finer-grained groundmass Kali dykes of the Grasberg deposit.

Hydrothermal alteration in the Ertsberg Stockwork Zone proceeded through three main stages with little repetition: i) early feldspar-stable alteration, ii) transitional stage characterised by green sericite veins and endoskarn development, and iii) a late stage quartz-sericite-pyrite alteration. Feldspar-stable mineralisation pre-dates the Ertsberg porphyry dykes, but feldspar-destructive alteration post-dates the porphyry. Although economically-important, early, hairline bornite veinlets and zones of pervasive shreddy biotite alteration of mafic minerals cut equigranular diorite, but not adjacent porphyry, while garnet-bearing endoskarn and sericitic alteration types both cut the porphyry dykes, suggesting the dykes intruded during mineralisation. Transitional stage bornite-chalcopyrite and chalcopyrite-pyrite-green sericite veinlets which are important contributors to both copper and gold grades, have magnetite-bearing halos where they cut endoskarn, and quartz-green sericite selvages in diorite. Late-stage veins contribute little to no grade, contain quartz-sericite-pyrite ±chalcopyrite filling and have white sericite selvages.

Compared with rocks from the nearby Grasberg orebody, the Ertsberg porphyry deposit has a coarser grained groundmass in the porphyritic phases, a much weaker development of hydrolytic alteration styles, an absence of very high sulphidation state mineralisation / advanced argillic alteration, and an absence of breccias in igneous rocks, suggesting the physiochemical conditions of mineralisation for the two deposits differed significantly.

The calcic nature of the endoskarn veins, their spatial relationship with regional structures and the porphyry dykes, and their coincidence with a change in mineralisation style from feldspar-stable to feldspar-destructive hydrolytic assemblages suggests porphyry dyke and endoskarn formation correspond to a major shift in mineralising conditions in the Ertsberg Stockwork Zone.

Introduction

The Gunung Bijih mining district is well known for the giant Grasberg porphyry deposit (MacDonald and Arnold, 1994; McMahon, 1994 a, b; Harrison, 1999; Penniston-Dorland, 1997, 2001; Pollard and Taylor, 2002) and associated copper-gold skarn deposits (Widodo *et al.,* 1998, 1999; New *et al.,* 1999; Gibbins, 2000; Gibbins *et al.,* 2000). The large Ertsberg diorite pluton, located approximately 1.5 km to the southeast of the Grasberg deposit, is known primarily for several large Cu-Au skarn deposits, including the original Ertsberg orebody, Dom (Mertig *et al.,* 1994; Mertig, 1995), Big Gossan (Meinert *et al.,* 1997; Prendergast, 2002), and the East Ertsberg Skarn System (EESS), which includes the GBT, IOZ, DOZ, and MLZ skarn deposits (Rubin and Kyle, 1997, 1998; Coutts *et al.,* 1999, Clarke, 2002 - Fig. 1). The total reserve and resource estimates for the Ertsberg skarns alone are over 450 Mt (P.T. Freeport Indonesia, 2003 - Table 1).

Exploration within diorite along the northern margins of the Ertsberg pluton near the EESS, identified a body of

Table 1: *Summary of Production and Reserve Data*

Source: P.T. Freeport Indonesia (Ertsberg only, Grasberg not included)

Aggregate Proved & Probable Reserves, Dec. 31, 2002

	Million Tonnes	Copper (%)	Gold ppm	Silver ppm
Mill Level Zone (MLZ)	50	1.40	1.04	4.88
Deep Ore Zone (DOZ)	184	0.96	0.65	5.11
Intermediate Ore Zone (IOZ)	2	1.14	0.15	9.45
Ertsberg Stockwork Zone	121	0.54	0.90	1.64
Big Gossan	33	2.81	1.00	16.85
Dom	71	1.37	0.36	7.33
Total Reserves	461	1.09	0.74	5.38

Aggregate Geologic Resources, Dec. 31, 2002

	Million Tonnes	Copper (%)	Gold ppm	Silver ppm
Mill Level Zone (MLZ)	139	0.58	0.65	3.30
Deep Ore Zone (DOZ)	58	0.48	0.53	2.29
Intermediate Ore Zone (IOZ)				
Gunung Bijih (GB)	3	1.67	0.47	7.87
Ertsberg Stockwork Zone	122	0.44	0.58	1.22
Big Gossan	14	1.72	0.90	11.28
Dom	21	1.11	0.29	10.01
Total Geological Resources	357	0.60	0.59	3.17

Total Reserves & Resources

Million Tonnes	Copper (%)	Gold ppm	Silver ppm
818	**0.88**	**0.67**	**4.41**

stockwork-type ore roughly centred on the access ramps to the EESS skarn deposits (Pennington, 1993). The disseminated ore in the Ertsberg diorite, called the Ertsberg Stockwork Zone deposit, is part of a classic porphyry copper system that is quite distinct from the Grasberg porphyry deposit both spatially, temporally, and geologically. As of December 2002, the Ertsberg Stockwork Zone contains 121 Mt of proven and probable ore reserves averaging over 1% copper equivalent with a high Au:Cu ratio (>1.5) plus an additional 122 Mt resource with similar copper, but lower gold grades (P.T. Freeport Indonesia, 2003). This paper reports on our studies of this mineralised zone based on underground mapping, examination of drill core, and petrographic analysis during the period 1999-2002.

District setting

Intermediate composition magmas began intruding the tightly-folded Mesozoic and Cenozoic strata in the Ertsberg mining district - the siliciclastic Kembelangan Group and Tertiary New Guinea Carbonate Group - at roughly 4 Ma, peaking between 3.2 and 2.6 Ma (McDowell *et al.,* 1996).

Major district faults and the axial planes of folds in the sedimentary rocks strike 110º, with fold limbs typically dipping between 50º and 80º to the north and south. Although reverse faults dominate the 110º set, Sapie and Cloos (1995) report evidence of significant strike-slip offsets. Porphyry dykes intruded the 110º fault set and zones of mineralisation follow this trend.

Although not mapped within the intrusions of the district, zones of poor drill core recovery and leaching of anhydrite-filled veins in the Ertsberg diorite roughly align with the large 110º fault set, suggesting at least minor post-intrusive movement. A second set of generally northeast-oriented left-lateral strike-slip faults offset the 110º faults. In contrast to the 110º fault set, the NE-striking faults only locally affected skarn formation (Glover, 2001) and do not appear to direct dyke emplacement.

Rock Types

Equigranular Diorite Phases

Two main phases of equigranular diorite occur within the Ertsberg pluton: the main clinopyroxene-dominant- and a biotite-clinopyroxene-diorite (Table 2).

Most of the Ertsberg pluton consists of the "Main Diorite," a quartz monzodiorite that contains 13-18% 2-6 mm clinopyroxene and < 1% biotite set in a sea of plagioclase that commonly exhibits flow foliation (Fig. 2). The Main Diorite constitutes most of the Ertsberg intrusion and is relatively homogeneous.

The biotite-clinopyroxene diorite, hereafter referred to as the Biotite-CPX Diorite, occurs as a large body of uncertain dimensions within the Main Diorite and contains only 10-13% mafic minerals, with 1-4 mm biotite and clinopyroxene in approximately equal proportions (Fig. 2). Clinopyroxene locally exceeds biotite abundance and develops a sieve-like texture in some biotite-rich samples. In contrast to the Main Diorite, the Biotite-CPX Diorite lacks magmatic foliation. Contacts between Main Diorite and Biotite-CPX Diorite are generally sharp, occurring over a 0-5 cm transition zone.

Titanite, magnetite, and zircon occur as common accessory minerals in both equigranular phases. Titanite commonly clusters near mafic sites, suggesting some titanite may have formed as a by-product of propylitic alteration of mafic minerals. Widespread partial alteration of clinopyroxene to actinolite is common throughout the entire pluton.

Porphyry Dykes

Porphyry-style mineralisation in the Ertsberg pluton is spatially associated with 5-15 metre wide, east-striking dykes of porphyritic quartz-monzonite that cut both the Main Diorite and the Biotite-CPX Diorite (Fig. 3). Three types of porphyritic dykes have been mapped to date in underground exposures, namely: two "porphyry" phases with sugary, aplitic groundmass, and one porphyritic diorite dyke with an aphanitic groundmass. Several variants of porphyry dykes also occur in the southern part of the Ertsberg intrusion near the Dom deposit. The porphyry most closely related spatially and temporally to mineralisation contains phenocrysts of 40% 1.5-3 mm plagioclase, 3-5% 1-3 mm hornblende, and 1% 1.5 mm biotite set in a sugary, aplitic groundmass (Fig. 2). Although titanite also occurs in the equigranular Ertsberg phases, titanite is conspicuous in the porphyry dykes in hand specimen due to the fine-grained nature of the groundmass.

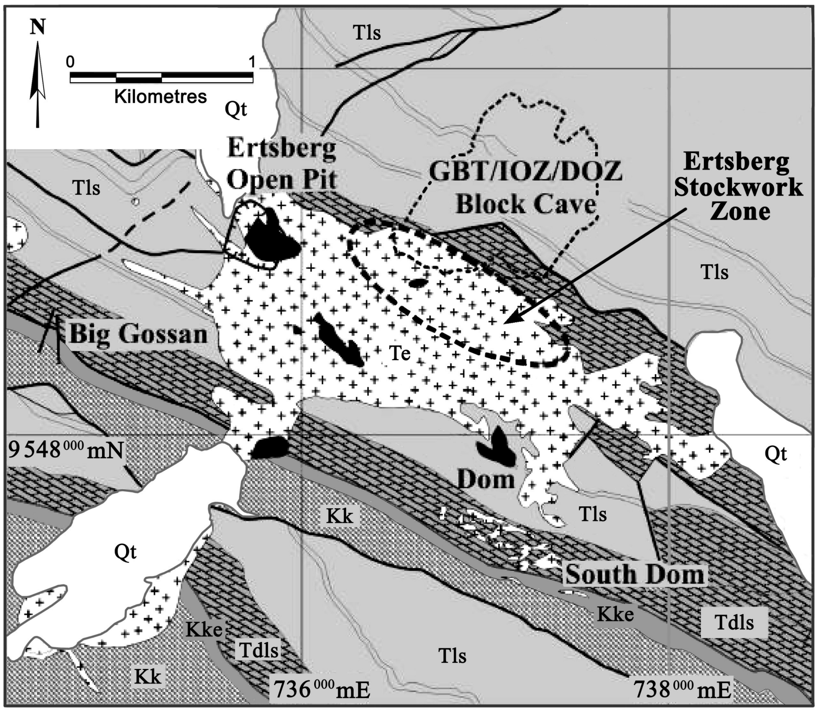
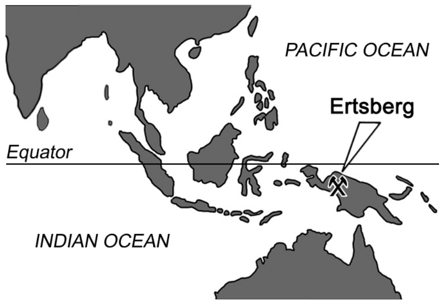


Figure 1: ***Geologic map of the Ertsberg pluton and adjacent sedimentary rocks*** showing the locations of major skarn deposits and the general location of diorite-hosted Ertsberg Stockwork Zone mineralisation (outlined in dashed line). Skarn outcrops shown in black. Bold lines indicate faults. Qt = glacial till, Te = Tertiary Ertsberg intrusion, Tls = Tertiary limestones, Tdls = Tertiary dolomitic limestones, Kk = Cretaceous Kembelangan Fm., and Kke = Cretaceous Ekmai sandy limestone.



Geochemically, porphyry rocks plot in the trachyte-trachy andesite field.

Porphyry dykes differ significantly from the equigranular phases of the Ertsberg intrusion in that the porphyry dykes contain hornblende as the dominant mafic mineral rather than clinopyroxene. The occurrence of hornblende rather than clinopyroxene-biotite suggests a temporal change in the water saturation state in the magma.

Most of the porphyry dykes observed by these authors occur within the Ertsberg Stockwork Zone, along-strike with one of the major 110º-striking district faults. As noted above, evidence exists for post-mineral movement along these faults. The majority of offset along the 110º fault set, however, predates intrusion of the Ertsberg pluton. The coincidence of the dykes with these major faults both spatially and in strike orientation suggests either the faults remained active during mineralisation or at least focused stress on the main body of crystallised Ertsberg diorite along their strike, thereby controlling dyke emplacement. No dykes are known to intrude the younger northeast-striking fault set.

Comparison of Igneous Rocks at Ertsberg & Grasberg

The Kali dykes of the Grasberg Igneous Complex intruded in multiple stages, with some dykes being affected by weak, very late stage alteration and pyrite mineralisation and others clearly post-dating all mineralisation. The Kali dyke samples we studied for this comparison are of part of the earlier set, being sericite-chlorite altered and having disseminated pyrite. The Ertsberg porphyry dykes differ petrographically from the Kali dykes of the Grasberg deposit in several ways. Ertsberg porphyry dykes have hornblende abundance greater than biotite, a much greater abundance of sphene, and a coarser-grained aplitic (sugary) groundmass compared to the Kali dykes samples studied by these authors (Fig. 4). The Kali samples have approximately equal biotite and hornblende phenocryst populations, a paucity of sphene, abundant broken phenocrysts, and a distinctly finer-grained groundmass. Of all of the Kali dyke samples observed by these authors, none closely resemble the porphyry dykes in the Ertsberg.

The abundance of sphene in the Ertsberg porphyry dykes, though, is also characteristic of the main equigranular Ertsberg diorite phases, suggesting the equigranular phases and the porphyry dykes may be genetically related. The temporal transition from the Main Diorite to Biotite-CPX Diorite to hornblende-biotite porphyries may reflect a progressive saturation of the underlying magma chamber with respect to water that culminated in the hydrothermal event responsible for mineralisation.

Alteration/Mineralisation

Hydrothermal alteration in the Ertsberg Stockwork Zone appears to be relatively simple compared to many porphyry deposits. Feldspar-stable mineralisation pre-dates intrusion of the Ertsberg porphyry dykes, whereas feldspar-destructive alteration types dominate alteration that post-dates the porphyry intrusions (Table 3). Broadly, alteration and mineralisation proceeded through three stages: i) early feldspar-stable alteration, ii) transitional stage characterised by green sericite veins and endoskarn development, and iii) late stage quartz-sericite-pyrite alteration.

Early magnetite veins associated with actinolite alteration of clinopyroxene and white, albitic alteration of feldspar (Fig. 5) predate all other vein types. These veins contribute no copper or gold to the ore and probably reflect the earliest prograde development of the hydrothermal system that was later overprinted by the mineralising fluids.

Hairline bornite veinlets with selvages of biotitised clinopyroxene and zones of pervasive shreddy biotite

	Phase	Texture	Magmatic minerals: Ino-silicate %	Ino-silicate Size (mm)	Biotite %	Biotite Size (mm)	Mafics Align ?	Feldspar phenocrysts	Key recognition features	Shape
1.	Main CPX- equigranular diorite	equigranular	10	2-3	< 1	2	Common	No	Equigranular, magmatic biotite books rare, slightly more mafic than equigranular biotite-hornblende	Irregular stock
2.	Biotite = CPX equigranular diorite	equigranular	8	2	4	3	No	No	Big magmatic biotite books, equigranular	Irregular stock within the CPX-dominant phase
3a.	Hornblende porphyry diorite	porphyritic	3-5	2-3	0	0	Common	3-4 mm	Low mafic content, feldspar phenocryst cleavage glints, sphene	E-striking 10 m thick dykes
3b.	"Mafic" hornblende diorite porphyry	porphyritic	5-8	2-3	0	0	Common	3-4 mm	Mafic variant of 3a	E-striking 10 m thick dykes
3c.	"White" hornblende diorite porphyry	porphyritic	1-2	2	0	0	No	3-4 mm	Mafic-poor variant of 3a	E-striking 10 m thick dykes
4.	Fine-grained porphyritic biotite diorite	porphyritic	0	0	3-5	2	No	No	Finer grain size, darker mafic groundmass, conspicuous biotite phenocrysts	1 m dyke of uncertain orientation

After Friehauf and Soebari, 1999

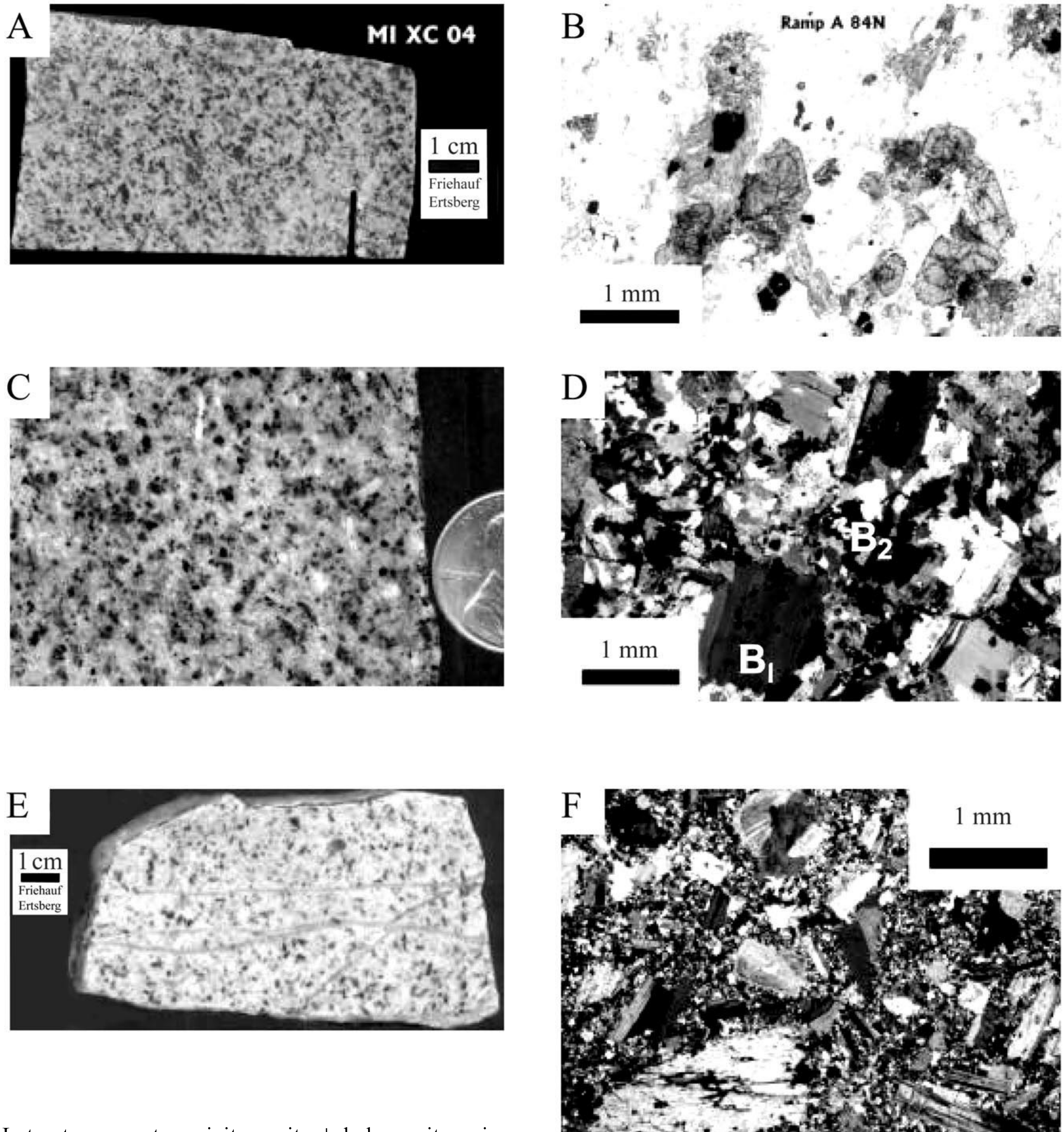
Table 2: *Ertsberg Diorite Phases*

alteration of mafic sites cut and offset early magnetite-actinolite-albite veins. The early, hairline veins are not strictly planar, commonly curving over their cm-scale strike lengths. Vein filling in early hairline veins ranges from simple biotite-only types to bornite-chalcopyrite-magnetite-anhydrite ±quartz types. Total sulphide content is very low, with bornite and chalcopyrite grains occurring only as sporadically distributed, isolated blebs on an otherwise inconspicuous fracture. Anhydrite fills thicker veins, but sulphide content is low, regardless of vein thickness. Within the ore zone, mafic minerals are completely altered to shreddy hydrothermal biotite, but secondary biotite alteration grades laterally to isolated one-cm wide vein selvages peripheral to ore zones. Alteration of plagioclase to hard, pink K-feldspar is restricted to deeper, central portions of the ore zone where the quartz content of veins increases, locally forming quartz veins up to one centimetre in width. Bornite in thicker, quartz-rich veins associated with potassic alteration typically occurs as large, isolated blebs in addition to the finer disseminated grains and gold grades are typically high (>2 ppm) in intervals cut by these veins. Although no vein truncations by dykes have yet been documented, these early, hairline veins cut equigranular diorite, but only extremely rarely cut adjacent porphyry, and pervasive alteration of mafic minerals to shreddy hydrothermal biotite does not affect the dykes, indicating the dykes post-date most potassic alteration.

Both equigranular diorite and porphyry dykes were altered to garnet-bearing endoskarn, commonly, but not exclusively along the margins of the porphyry dykes. Endoskarn veins are texture-destructive near the centre, but have texture-preservative replacement zones interior to the sharp contact with feldspar-bearing rock. Massive brown garnet near the centres of endoskarn veins locally contains voids that are completely filled with anhydrite ±bornite, suggesting endoskarn-forming fluids transported some copper. Most endoskarn, however, is very low-grade to barren.

Transitional-stage green sericite veins crosscut endoskarn, developing magnetite-bearing halos where they cut endoskarn and green sericite selvages in diorite. The green sericite veins are important contributors of both copper and gold grade in the Ertsberg Stockwork Zone, especially those containing bornite. Transitional green sericite veins show a systematic variation in mineralogy from bornite-chalcopyrite-anhydrite-quartz filled veins with magnetite-stable dark green sericite selvages to pyrite-anhydrite-quartz ±chalcopyrite or bornite with lighter green, magnetite-destructive green sericite selvages. The bornite-bearing, magnetite-stable type of green sericite vein correlates best with copper and gold grades. The transition from bornite-chalcopyrite to chalcopyrite-pyrite assemblages certainly constitutes a change in the Cu:Fe ratio of the sulphide mineralogy and coincides with sulphidation of magnetite to pyrite in vein selvages. In the absence of bornite-pyrite assemblage, however, this transition does not necessarily indicate an increase in sulphidation state because chalcopyrite is stable in both end members of the transition. Temporally, magnetite-destructive pyrite-chalcopyrite-bearing green sericite veins crosscut magnetite-stable, bornite-bearing green sericite veins.

Figure 2: ***Main Diorite*** in **A)** ***hand specimen,*** and **B)** ***plane-polars photomicrograph*** (CPX partially altered to actinolite). ***Bio-CPX Diorite*** in **C)** ***hand specimen,*** and **D)** ***crossed-polars photomicrograph*** (CPX altered to shreddy biotite). ***Ertsberg porphyry*** dyke rock in **E)** ***hand specimen*** (cut by anhydrite veins), and **F)** ***crossed-polars photomicrograph*** (hornblende bottom left). Note there are significantly fewer mafic mineral sites, zoned phenocrysts, and sugary groundmass in the Ertsberg porphyry compared to the Ertsberg equigranular phases.



Late stage quartz-sericite-pyrite ±chalcopyrite veins crosscut all green sericite veins. Sericite is characteristically a bleached white colour and disseminated magmatic magnetite in the selvages is sulphidised to pyrite. These late-stage veins are straight, continuous, and typical of "QSP" ("phyllic") veins in many other porphyry copper deposits.

Very late-stage anhydrite veins and chlorite veins (Table 3) crosscut all other vein types. These generally lack sulphides or contain only minor amounts of pyrite. Chlorite veins represent classic propylitic alteration in many porphyry districts, occurring in rocks with epidote, actinolite, and calcite alteration. These veins probably represent cooler, propylitic remobilisation of sulphate from earlier veins.

Preliminary SEM studies of early potassic-, transitional-, and late-stage veins demonstrate gold occurs in all three stages (Cook *et al.,* 2003). Gold occurs both as electrum and telluride, most closely associated with bornite grains in bornite-bearing veins and with chalcopyrite where bornite was not present.

		Vein type	Vein filling	Alteration halo in diorite	Diorite phases that host vein
Feldspar-stable	1.	Magnetite-actinolite	Magnetite	CPX altered to actinolite + feldspar altered to albite	Equigranular phases only
	2.	Biotite	Biotite	Pervasive shreddy biotite	Equigranular phases only
	3.	Hairline bornite-biotite	Quartz-biotite-bornite-chalcopyrite	Slight pinkening of feldspar on fracture surface, CPX within 1 cm of veins altered to shreddy biotite	Equigranular phases only
	X*.	Molybdenite	Molybdenite-pyrite-anhydrite	None, *or* 1 cm bleached zone with sericitic wash	Equigranular phases only
Feldspar-destructive	4.	Endoskarn	Garnet ± anhydrite	Inner zone of texture-destructive dark brown garnet + anhydrite ± epidote ± pyroxene Outer zone of texture-preserving light brown garnet with pyroxene pseudomorphs of mafic minerals Minor epidote-chlorite alteration of feldspar	Equigranular phases and porphyry
	5.	Bornite-anhydrite-green sericite	Quartz-anhydrite-bornite-chalcopyrite	1 cm thick magnetite-stable green sericite zone with disseminated bornite-chalcopyrite; locally develops inner halo of magnetite-destructive tan sericite with disseminated sulphides	Equigranular phases and porphyry (?)
	6.	Pyrite-chalcopyrite-sericite	Quartz-pyrite-chalcopyrite ± anhydrite	1 cm pale green to white sericite, magnetite-destructive <5 mm chloritic outer halo	Equigranular phases and porphyry (?)
	7.	Quartz-sericite-pyrite	Quartz-pyrite	1 cm tan to white sericite, magnetite-destructive <5 mm green sericite outer halo	Equigranular phases and porphyry (?)
	8.	Purple anhydrite-pyrite	Quartz-pyrite	1 cm tan to white sericite, magnetite-destructive	All
Very late	9a.	Chlorite	Chlorite ± pyrite	None	All
	9b.	Anhydrite	Purple / white anhydrite	None	All

* These veins not noted by number since relative timing inconclusive at present (i.e., no cross-cutting relationships *with offset of vein*).

Table 3: ***Summary of Vein Types in the Ertsberg Stockwork Zone***

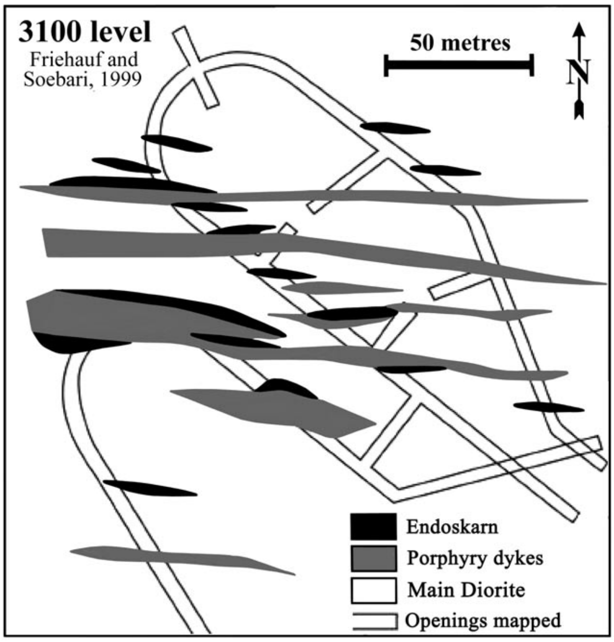


Figure 3: ***Geologic map showing relationship between porphyry dykes and endoskarn*** exposed in the access ramps to the EESS deposits based on mapping by Friehauf and Soebari, 1999.

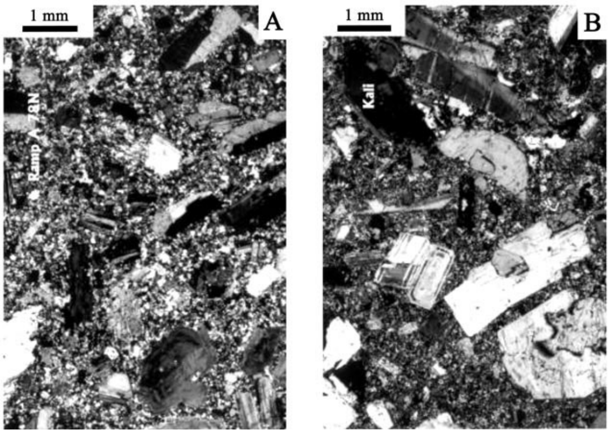


Figure 4: ***Comparison of* A) *Ertsberg porphyry dyke,*** and **B) *Kali dyke from Grasberg*** (shown at the same scale). Note how the Grasberg Kali sample contains strongly-zoned, broken phenocrysts set in an aphanitic groundmass.

Discussion

The observation that the porphyry dykes post-date early bornite mineralisation, but predate later mineralisation styles is important for two reasons. From a production perspective, dykes commonly constitute slightly lower grade intercepts in drill core because they post-date some copper mineralisation. The implication of this is that dyke-parallel drilling may not provide an accurate representation of grade as a whole. The geological evidence that the dykes were coeval with mineralisation, and their broad spatial coincidence with porphyry-type mineralisation, suggests the dykes may have been sourced from the magma chamber that was genetically related to mineralisation.

The coincidence of porphyry dyke emplacement with the change in mineralisation style suggests a major change in the geological/geochemical environment. Mineralisation prior to dyke emplacement occurred as discontinuous hairline veins that one would expect to form in a hot, approximately isotropic stress environment and/or under slow strain rate conditions. A change to more through-going rock fracture is suggested by the introduction of dyke-shaped intrusions, formation of laterally continuous vein types, initiation of long-distance chemical transport of components from sedimentary wall rocks into the pluton (forming endoskarn), and more efficient cooling of hydrothermal solutions that produce hydrolytic alteration styles.

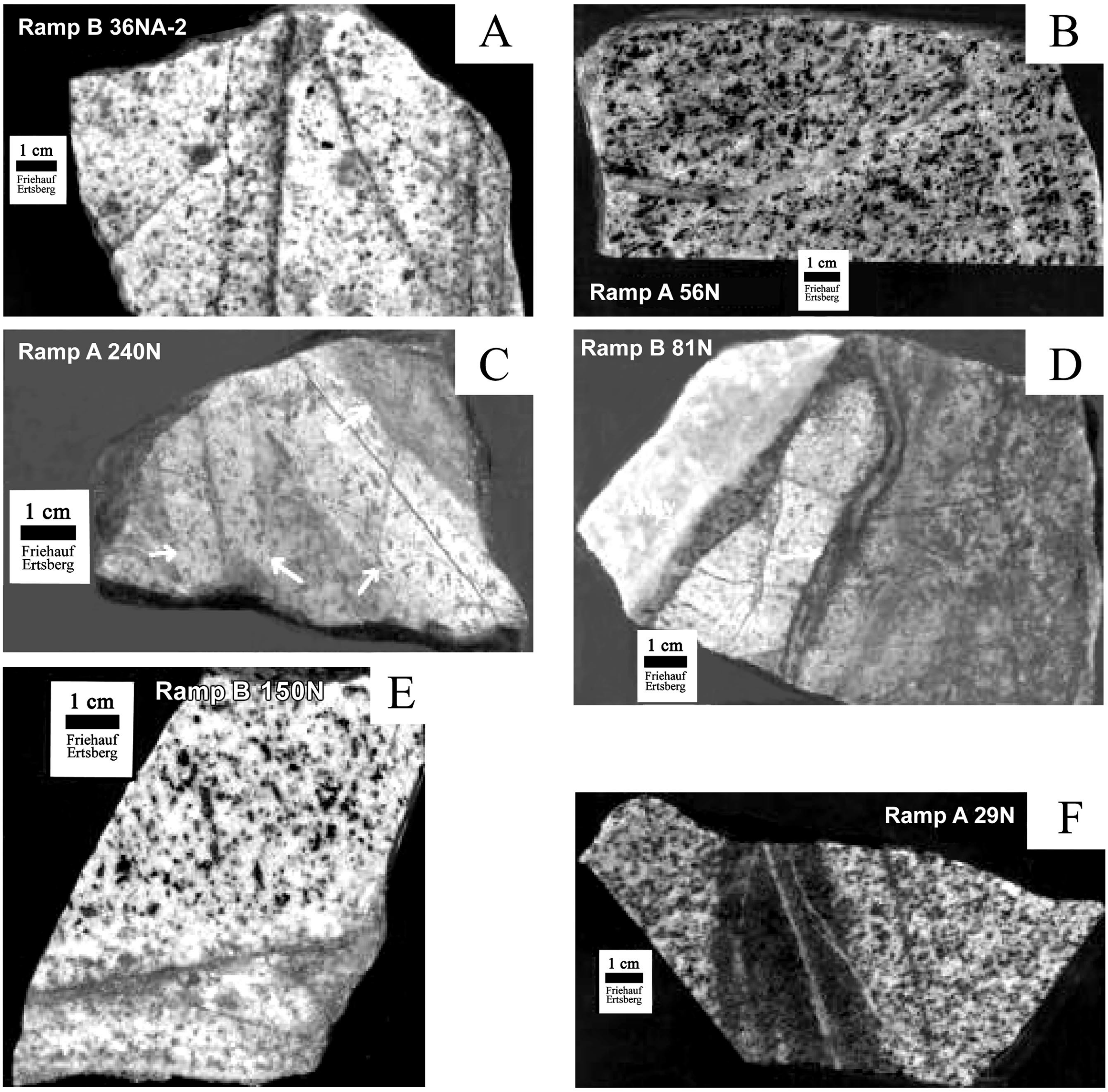
Finally, the calcic nature of the vein endoskarn in the porphyry suggests that vertical and/or E-W lateral fluid flow interacting with calcic limestones characteristic of the upper part of the carbonate section may have dominated, rather than N-S lateral fluid flow from the nearby dolomitic carbonate wall rocks to the north where the highly magnesian forsterite-monticellite skarns of the GBT/IOZ/DOZ deposits (EESS) occur. An investigation into the relationship between igneous- and sedimentary-hosted ores of the Ertsberg complex is underway in which we are focusing on documenting fluid flow paths between the porphyry-hosted ores and the circum-Ertsberg skarns and how those flow paths might have affected skarn mineralogy in the EESS, Original Ertsberg, Dom, and other skarns.

Although world-class when one considers the combined diorite- and skarn-hosted ores of the Ertsberg Stockwork Zone porphyry deposit, the Ertsberg Stockwork Zone is none-the-less smaller than the adjacent Grasberg deposit. The reasons for this disparity in size and the styles of mineralisation remain unproven.

Compared with porphyritic rocks from the nearby Grasberg deposit (Kali dykes), the dykes in the Ertsberg Stockwork Zone have: a) a coarser grained groundmass in the porphyritic phases (Fig. 4), b) a much weaker development of hydrolytic alteration styles, c) an absence of high sulphidation state mineralisation / advanced argillic alteration, and d) an absence of breccias. These differences would seem to suggest that the Ertsberg porphyry deposit might have formed at a greater depth than the Grasberg ores. This certainly would have affected the physio-chemical factors that control exsolution of hydrothermal fluids from the magma, the cooling rates of hydrothermal fluids, and the extents of fluid flow and may be the root cause of some of the differences in mineralisation style between the Ertsberg and Grasberg deposits.

Geochronological evidence suggests, however, that the Ertsberg intrusion is actually slightly younger than the Grasberg intrusions. Given the currently similar elevations of the Grasberg and Ertsberg deposits, and the occurrence of volcanic rocks in the tuff ring at the Grasberg deposit that suggest Grasberg mineralisation occurred very near the surface, any model calling on depth of emplacement as the key difference in mineralising styles would need to somehow submerge the district in the few tens of thousands of years following the formation of the Grasberg deposit and then exhume the district while preserving the Grasberg volcanic rocks. There are no known major faults separating the two deposits.

Figure 5: **A)** ***Early-stage magnetite-albite-actinolite veins***, **B)** ***early-stage potassic alteration veins with secondary biotite selvages,*** **C)** ***texture-preserving garnet endoskarn veins*** (arrows indicate edge of garnet, balled arrow indicates edge of texture-destructive alteration), **D)** ***retrograde magnetite alteration of garnet endoskarn veins*** (arrow indicates magnetite selvage), **E)** ***late-stage, magnetite-destructive, white sericite veins with pyrite ± chalcopyrite filling***, and **F)** ***transitional-stage magnetite-stable green sericite veins with bornite vein filling.***



Finally, mineralisation within the Ertsberg intrusion appears to lack the multiple, overprinting and repeating stages characteristic of Grasberg and many other large, high-grade porphyry deposits. This simplicity could reflect a one cycle-only hydrothermal system. Alternatively, in view of the size of the skarn orebodies to the north, multiple cycles may have mineralised the deposit, but focused on slightly different centres.

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