SULFIDE MINERALS AS INDICATORS OF ACID $Cl-SO_4$ FLUIDS

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Abstract

Rocks altered by acid CI-SO, fluids exhibit similar silicate alteration as those affected by neutral-chloride waters. Silicates, therefore, are not suitable fluid pH indicators in geothermal areas like Mt. Apo and Mahanagdong where such acid fluids exist with neutral brine. In lieu of silicates, sulfide mineralogy is evaluated as a potential fluid pH index in these areas.

In Mt. Apo, the sulfide assemblage of acid wells within the Sandawa collapse resembles that of adjacent neutral producers. The suite consists mainly of pyrite (FeS_2) and rare chalcopyrite ($CuFeS_2$) with traces of bornite (Cu_5FeS_4), covellite (CuS)/chalcocite (Cu_2S) and/or sphalerite (ZnS). The abundance and occurrence of these sulfides are comparable in acid and neutral wells. Like silicates, therefore, sulfide minerals cannot be employed as index of discharge fluid pH among Sandawa wells.

The sulfide phases in Mahanagdong are the same as those in Mt. Apo. Acidic wells in Mahanagdong, however, contain relatively higher amounts of pyrite and chalcopyrite. Veins of pyrite are common, while chalcopyrite veins are present in these acid producers. In contrast, neutral wells in Mahanagdong encountered lesser quantities of pyrite and chalcopyrite. Veins of pyrite are also fewer, while veins of chalcopyrite are absent in these neutral wells. Thus, unlike in Mt. Apo, relative sulfide abundance and presence of sulfide veins can be used to derect the existence of acid $Cl-SO_4$ fluids in Mahanagdong.

1.0 INTRODUCTION

Geothermal wells which produce acid fluids are commonly encountered at or near the zone of upflow of geothermal systems. Petrologic studies of cores and cuttings from these wells failed to predict the presence of acid fluids mainly because of the predominance of neutral alteration minerals and the scarcity or corroded state of typical acid alteration minerals. These wells with acid fluid discharges were initially observed to contain more sulfide minerals compared with wells with neutral-pH discharges. Thus, this study aims to: (1) characterize the sulfide mineral assemblages in acid and neutral-pH wells; (2) compare these sulfide assemblages with those in a known active magmatic system; and (3) determine the use of sulfide minerals as indicators of acid fluids.

Fourteen production wells from the Mahanagdong Geothermal Field in Leyte, and ten production wells from the Mindanao 1 Geothermal Field (Mt. Apo) were analyzed for this study (Fig. 1). However, only five representative wells from Mahanagdong and four wells from Mt. Apo will be discussed in detail. The three wells drilled in Mt. Pinatubo were also included to characterize a known active magmatic system.

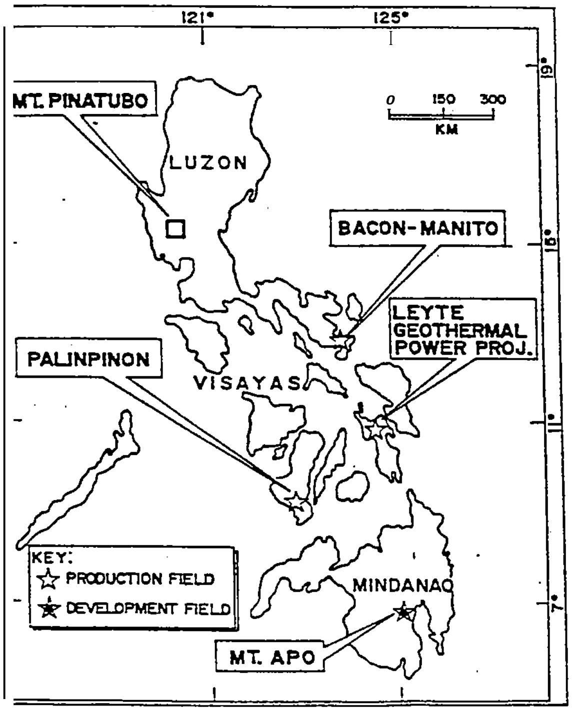


Fig. 1. Location map of PNOC-EDC geothermal areas.

2.0 SILICATE ALTERATION

2.1 Mahanagdong

Rocks in the Mahanagdong geothermal field exhibit widespread silicate alteration known to be produced by neutral-pH fluids (e.g. smectite, illitic clay, epidote). Though occurring as detrital alteration of clasts especially above -200 m RL, silicates primarily exist as phenocryst/matrix replacement and as veins. The same neutral silicate assemblage is observed in all acid (MG-9D, 15D) and neutral wells (MG-3D, 16D, 18D) in Mahanagdong (Fig. 2).

In contrast, silicates deposited by acid fluids such as pyrophyllite and dickite (in association with diaspore/alunite) are generally scarce, and are often relict or detrital. Thin zones of moderate amounts of acid alteration occur only in a few wells including acid (MG-9D/21D) and neutral producers (MG-3D/14D) (Fig. 3).

To determine the stable mineral phases in the various wells, their deep fluid chemistry were calculated using the WATCH speciation software (Amorrson, 1990) and were plotted in silicate stability diagrams constructed for 280°C and 300°C. The diagrams include silicates usually found in Mahanagdong such as clinozoisite (epidote), paragonite (illite) and dickite (Figs.4a/b).

Except for MG-9D, all wells plot within the paragonite stability field explaining the widespread Occurrence of illite in Mahanagdong (Figs. 4a/b). Furthermore, the proximity of MG-3D deep fluids to the triple point of paragonite-clinozoisite-dickite rationalizes the coexistence of these three mineral phases in the well (Fig. 4a). Apparently, the neutral-pH fluids of MG-3D are in equilibrium with both neutral (epidote, illite) and acid (dickite) silicates. Likewise, epidote can also be a stable mineral phase in acid well MG-15D whose deep fluids also plot close to the said triple point (Fig. 4b).

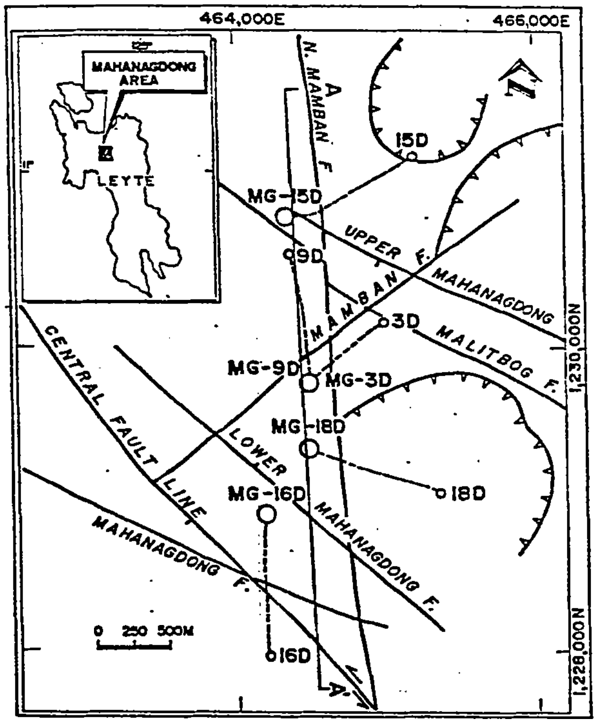


Fig. 2. Location map of Mahanagdong area.

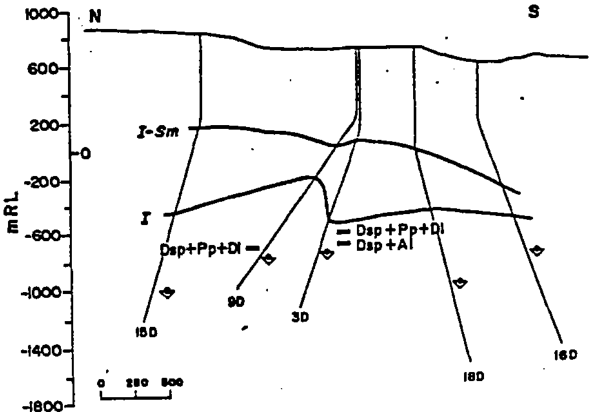
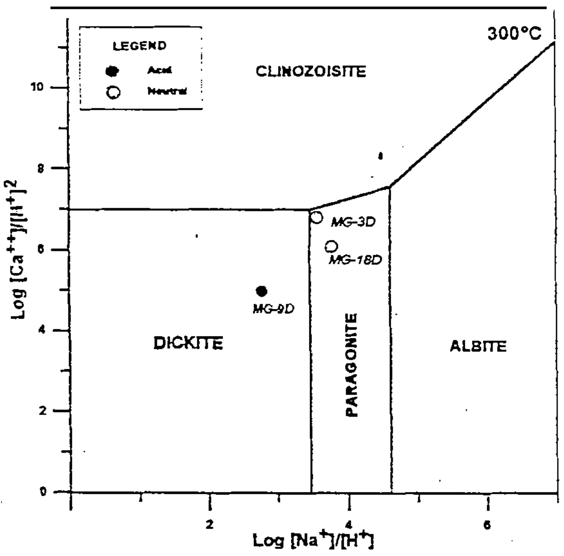


Fig. 3. Alteration zones and acid minerals in Mahanagdong.



4a. Mahanagdong wells in a stability diagram for minerals in the $CaO-Na_2O-Al_2O_3-SiO_2-H_2O$ system at 300°C.

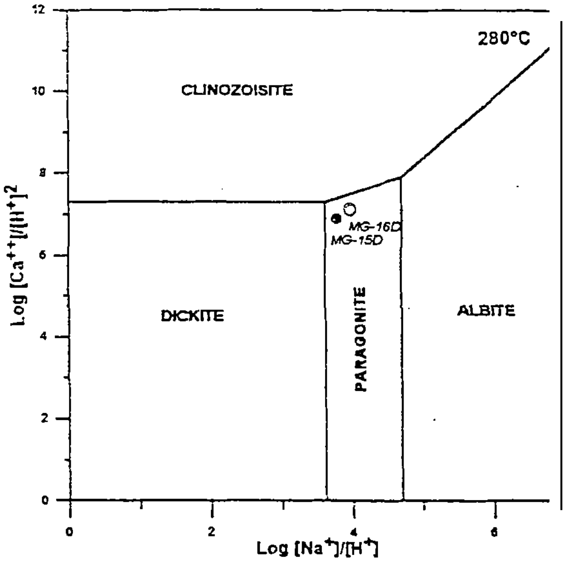


Fig. 4b. Mahanagdong wells in a stability diagram for minerals in the $CaO-Na_2O-Al_2O_3-SiO_2-H_2O$ system at 280°C.

2.2 Mt. Apo

Wells drilled within the western side of the Sandawa collapse in Mt. Apo (Fig. 5) exhibit a predominantly neutral type of silicate alteration including chlorite, smectite. illite, epidote. actinolite and secondary biotite (*Fig.* 6). Acid alteration minerals such as diaspore and pyrophyllite are scarce, and often relict based on retrogradational textures (Fig. 6). Most wells at the western side of Sandawa tapped neutral-chloride fluids except for three (KN-1D, KN-2D and KN-3) which discharged acid fluids.

Wells drilled at the eastern side of the Sandawa collapse. on the other hand encountered very thick zones of acid alteration minerals (TO-1D) (Fig. *6*). Abundant fresh alunite crystals and unaltered diaspore subhedras coexist with pyrophyllite and dickite. All of these wells invariably discharge acid fluids (PS-1D, TO-1D, TO-2D).

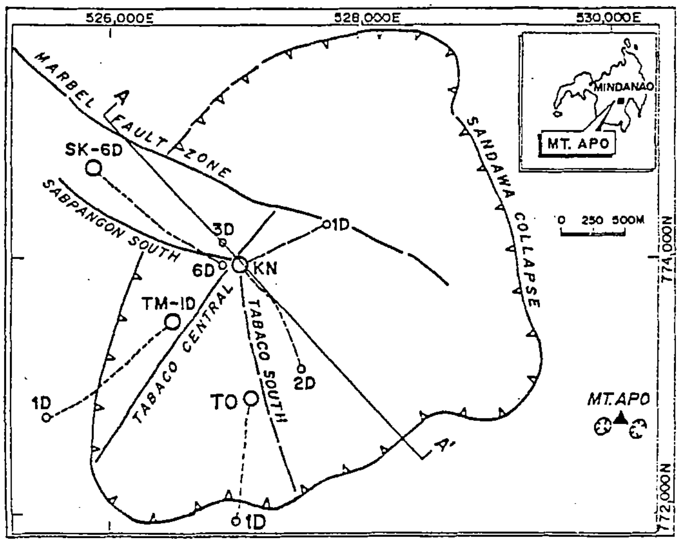


Fig. 5. Location map of Mt. Apo.

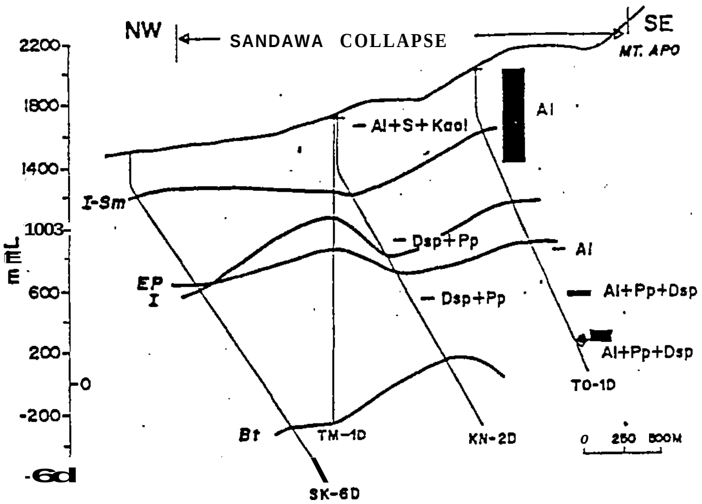


Fig. 6. Alteration zones and acid minerals in Mt. Apo.

The deep fluid chemistry of the wells were plotted in silicate stability diagrams at 280°C and 300°C (Figs. 7a/b). The locations of the data points are all consistent with the dominant mineral phases observed in the wells. For instance. the position of KN-1D and KN-3 near the boundary of clinozoisite and paragonite implies that abundant epidote and secondary biotite are stable minerals in these acid wells. The plots of acid KN-2D (Fig. 7a) and neutral SK-6D/TM-1D (Fig. 7b) within the clinozoisite stability region, on the other hand indicate that abundant epidote could be expected in both acid and neutral wells in Mt. Apo.

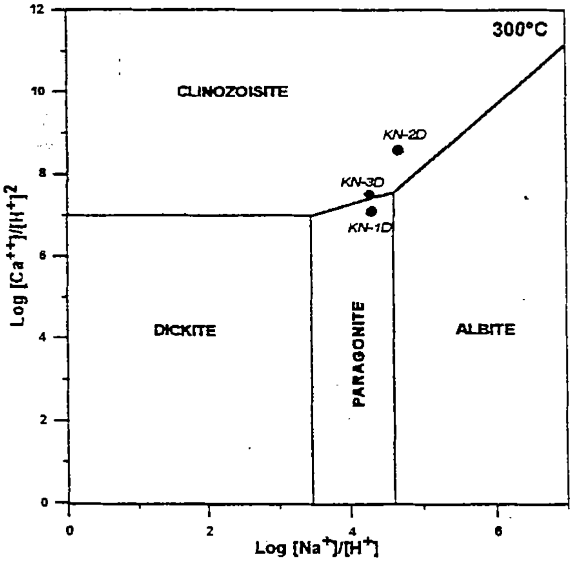


Fig. 7a. Mt. Apo wells in a stability diagram for minerals in the $CaO-Na_2O-Al_2O_3-SiO_2-H_2O$ system at 300°C.

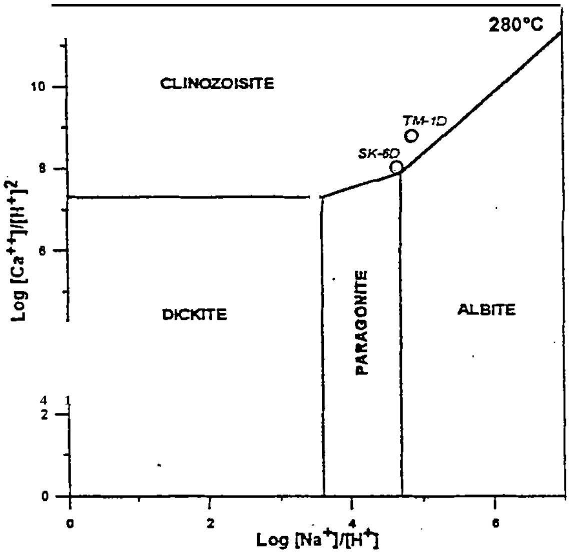


Fig. 7b. Mt. Apo wells in a stability diagram for minerals in the $CaO-Na_2O-Al_2O_3-SiO_2-H_2O$ system at 280°C.

Due to its lower resenoir temperature of 250°C. the deep fluids of TO-1D were plotted in a mineral stability diagram at 250°C. Its position within the diclate stability field agrees with the prevalence of dickite in TO-1D coexisting with abundant alunite. pyrophyllite and diaspore.

2.3 Pinatubo

Rocks in Pinatubo (Fig. 8) are characterized by a dominance of neutral-pH. alteration composed of smectite, illite, chlorite, epidote, actinolite and biotite (Fig. 9). These neutral silicate alteration minerals, especially in PIN-3D, are mainly relict based on their retrogradation features and their haphazard distribution. However, illite and secondary biotite, could be stable in PIN-1 and PIN-2D, respectively, based on their unaltered states and their agreement with stable measured temperatures.

Unexpectedly for wells in a known active magmatic system, the acid minerals in Pinatubo occur only in thin and discrete zones. The acid alteration assemblage consists of weak to moderate amounts of fresh diaspore, pyrophyllite: dickite, and minor quantities of alunite (PNOC-EDC, 1990).

The chemistry of the deep fluids of PIN-3D and PIN-2D were plotted in silicate stability diagrams for 270°C and 325°C (Figs. 10a/b). The location of PIN-3D in the dickite stability field confirms the recentness of its acid zones composed of dickite, diaspore and pyrophyllite (Fig. 10a). Other silicate minerals in PIN-3D are truly relict phases. PIN-2D fluids fall at the boundary between paragonite and clinozoisite, suggesting its equilibrium with these two mineral phases (Fig. 10a). The plot of PIN-1 fluids on the paragonite field (Fig. 10b), on the other hand, explains the predominant fresh illite in this well. Based on these plots, acid wells PIN-1 and PIN-2D can have neutral silicates (illite, biotite, epidote) as stable phases.

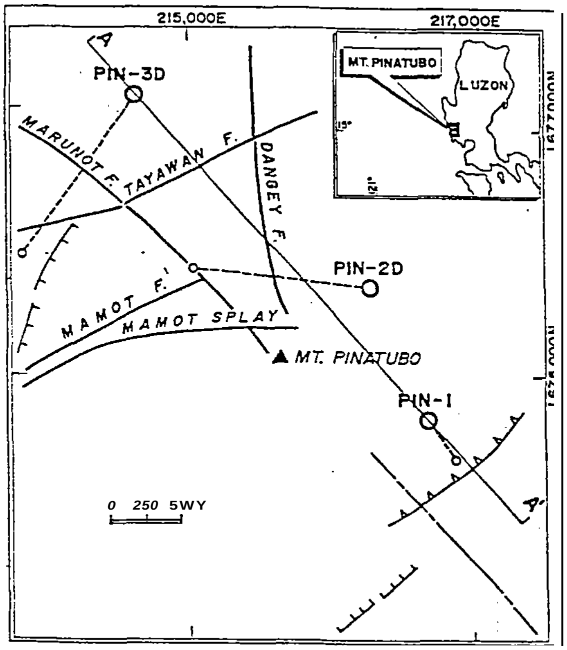


Fig. 8. Location map of Mt. Pinatubo area.

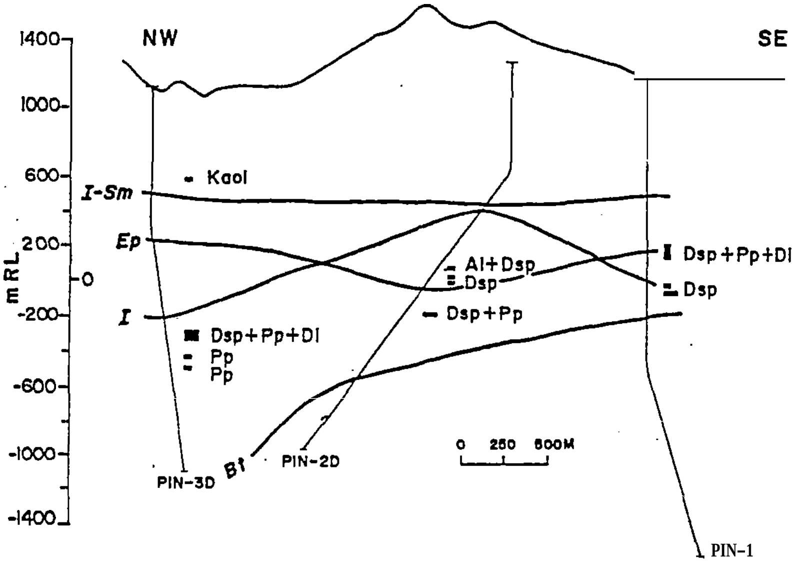


Fig. 9. Alteration zones and acid minerals in Mt. Pinatubo.

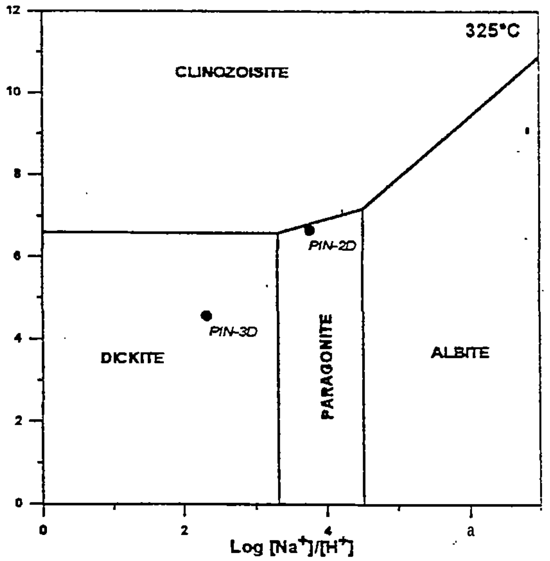


Fig. 10a. Pinatubo wells in a stability diagram for minerals in the $CaO-Na_2O-Al_2O_3-SiO_2-H_2O$ system at 325°C.

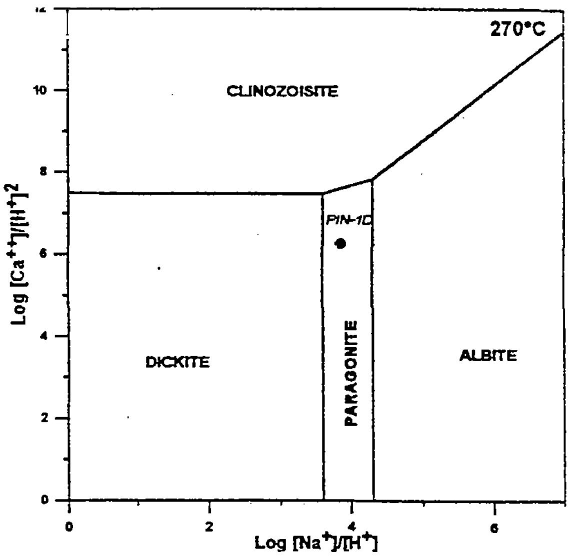


Fig. 10b. Pinatubo well in a stability diagram for minerals in the $CaO-Na_2O-Al_2O_3-SiO_2-H_2O$ system at 270°C.

2.4 Summary

Except for TO-ID which contains thick acid zones, wells which discharged acid fluids in Mt. Apo and Mahanagdong exhibit similar silicate alteration assemblages as those which produced neutral brine. In both acid and neutral producers, the predominant stable silicate replacement is classified as neutral, i.e. epidote, illite, secondary biotite. Typical acid silicates are Scarce and are often suspected to be relict phases.

The stability of neutral silicates such as epidote and secondary biotite in these acid producers is mainly due to the near neutral-pH (~5) of their fluids at reservoir conditions. The subsequent decrease in fluid pH occurs only upon discharge when H_2SO_4 further dissociates at lower temperatures (Sanchez, pers. comm., 1995). This type of fluids is termed acid $Cl-SO_4$ waters based on its acidic discharge fluid pH and its high chloride and sulfate concentrations (Salonga, 1995).

Based on silicate alteration therefore, wells in Mt. Apo and Mahanagdong which intersected these acid $Cl-SO_4$ fluids cannot possibly be **distinguished** from wells which encountered neutral brine.

In Pinatubo, acid silicates are likewise restricted in thin zones, but are distinctly fresh compared to the acid minerals in Mt. Apo and Mahanagdong. Surprisingly, even neutral silicates illite and secondary biotite *can* be in equilibrium with acid magmatic fluids as seen in PIN-1 and PN-2D.

3.0 SULFIDE MINERALOGY

3.1 Mahanagdong

In Mahanagdong, sulfides exist mainly as disseminations, as replacement *of* iron oxides, and as veins/veinlets. The sulfide minerals observed in the wells include pyrite (FeS_2), chalcopyite ($CuFeS_2$), bornite (Cu_5FeS_4), covellite (CuS), chalcocite (Cu_2S) and sphalerite (ZnS) (Fig. 11).

Pyrite (FeS_2) is the dominant sulfide in all the wells. It occurs mainly as euhedral to subhedral grains whose sizes range from fine (~0.1 mm) to coarse (~0.7 mm). Pyrite exists mainly as disseminations, as

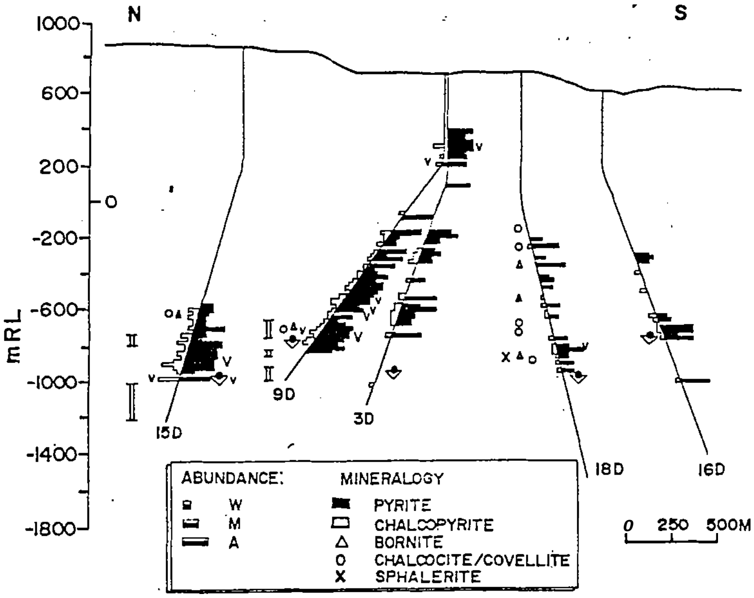


Fig. 11. Sulfide mineral distribution in Mahanagdong.

veins, and as replacement of primary magnetite and secondary hematite. Its common associations are chalcopyrite and magnetite. In general, pyrite abounds in acid wells comprising ≥20% of the polished section area. In comparison, pyrite exists in lesser amounts (~10-20%) in neutral wells. Furthermore, pyrite veins are common in acid wells, and are scarce in neutral wells (Fig. 11).

Like pyrite, ***chalcopyrite*** ($CuFeS_2$) is ubiquitous in Mahanagdong. However, it exists in lesser quantities than pyrite. Chalcopyrite is usually observed as very fine (0.07 to 0.1 mm) anhedral to subhedral grains associated with pyrite, and rarely with bornite, covellite: chalcocite and sphalerite. In acid wells, chalcopyrite exists as disseminations, as veins/veinlets, and as alteration rims in some pyrite grains. It consists ~1% of the polished section area. In contrast, chalcopyrite occurs only as disseminations in neutral wells. It does not exist as veins nor as alteration of pyrite. It is also found in lesser quantities (≤10 grains) in neutral wells.

Bornite (Cu_5FeS_4) occurs only in rare amounts (≤3 grains). It is present in all acid and in some neutral wells in Mahanagdong usually as fine- (~0.1 mm) to medium-grained (~0.5 mm) subhedras associated with chalcopyrite. In MG-9D, bornite apparently fills cracks within a coarse chalcopyrite grain (Fig. 12).

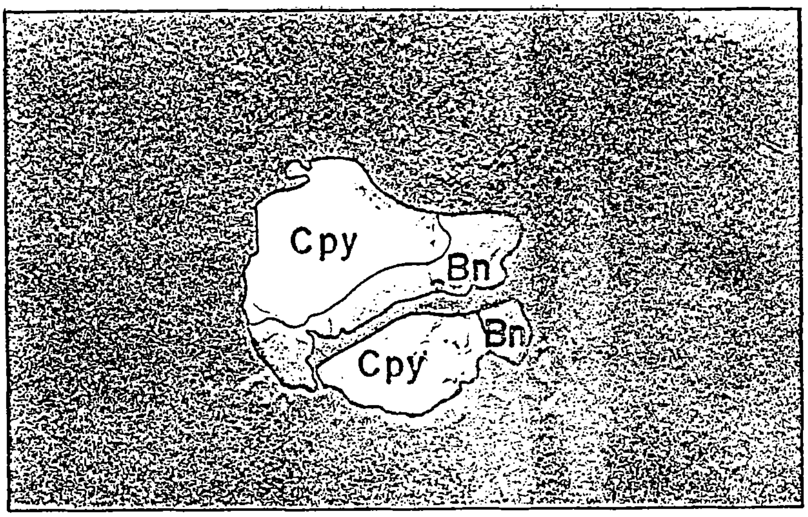


Fig. 12. Chalcopyrite crack filled with later generation bornite (from Well MG-9D). [Scale: Small side of photo ~0.10 mm]

Like bornite. the copper sulfides (*chalcocite*, Cu_2S: *coveflite,* CuS) occur only in rare quantities (≤3 gains) in all acid and in some neutral wells. They are present as isolated fine to medium gains. or as intergrowths with chalcopyrite ± bornite.

Sphalerite (ZnS) is the rarest sulfide mineral occurring in only four **wells** in Mahanagdong. It exists as an isolated grain in MG-21D, as host of chalcopnte inclusions in MG-3D and MG-17D, and as intergrowth with bornite in MG-18D.

3.2 Mt. Apo

The type, Occurrence and abundance of sulfides in the Sandawa wells in Mt. Apo are almost comparable to those of Mahanagdong wells (Fig. 13).

Pyrite (FeS_2) is the most abundant sulfide. occurring as subhedral to anhedral coarse to fine-grained disseminations. as veins and as replacement of **primary** magnetite. It consists ≥20% of the total **polished section area** in **both** acid and neutral wells.

Chalcopyrite ($CuFeS_2$) is always present comprising ≤ 1% of the total **polished section** area in most of the wells. It exists in larger quantities in acid KN-1D and in neutral TM-2D, reachmg up to –10% at some depths. Chalcopyrite occurs as fine to coarse anhedral grains often associated with pynte. It also replaces primary magnetite in some acid and neutral wells. Chalcopyrite veins are found in acid well KN-3D; and also in neutral well SK-6D where it occurs with sphalerite.

Bornite (Cu_5FeS_4) exists as fine anhedral grains often associated with chalcopyrite. It is present in rare amounts *(–5* grains) in acid wells KN-1D and TO-ID, and in still fewer amounts (–2 grains) in acid wells KN-2D, KN-3 and TO-2D, and in neutral well TM-1D.

The copper sulfides *(chalcocite,* Cu_2S: *covellite,* CuS) were seen in only two wells. both of which are acid (KN-3 and TO-1D). They occur as fine to medium gains in rare amounts **(–5 grains).**

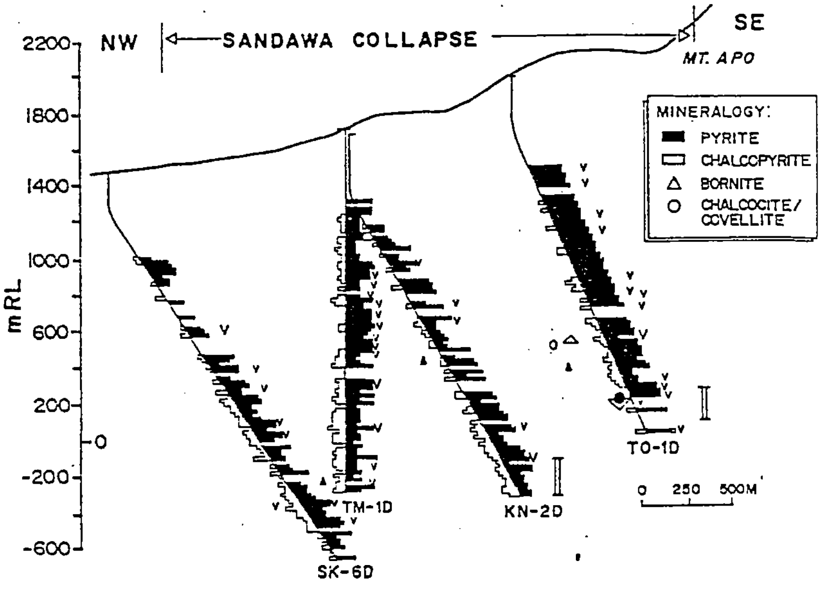


Fig. 13. Sulfide mineral distribution in Mt. Apo.

3.3 Pinatubo

The sulfide minerals in Pinatubo are more abundant and more diverse compared to those in Mahanagdong and Mt. Apo. The sulfide assemblage consists mainly of pyrite (FeS_2) and chalcopyrite ($CuFeS_2$), and fewer quantities of bornite (Cu_5FeS_4), covellite (CuS), chalcocite (Cu_2S), sphalerite (ZnS), cubanite ($CuFe_2S_3$) and bismuthinite (Bi_2S_3) (Fig. 14).

Pyrite (FeS_2) is present (≥20%) in all three Pinatubo wells. It is more abundant in PIN-I and PIN-2D at +100 mRL to -300 mRL. At deeper levels. it becomes more abundant in PIN-3D. Pyrite is generally present as medium to coarse subhedral to anhedral grains. It occurs mostly as disseminations, occasionally as veins and alteration products. Pyrite veins are most common in PIN-3D. but were also observed in PIN-1 and PIN-2D especially at shallower depths. It is usually associated with chalcopyrite, magnetite. bornite, covellite, chalcocite, and occasionally with sphalerite. Pyrite commonly occurs as rims around magnetite and as inclusions in chalcopyrite.

Chalcopyrite ($CuFeS_2$) is abundant (~10%) in all Pinatubo wells. It is generally present as fine to medium anhedral gains. It usually occurs as isolated grains, or associated with pyrite. bornite. magnetite. and occasionally with bismuthinite, sphalerite. or covellite/chalcocite. Chalcopyrite veins are more common in PIN-3D than in PIN-1 and PIN-2D.

Bornite (Cu_5FeS_4) is present in rare to moderate amounts (<1-10%) near the bottom of PIN-1 and PIN-3D. It occurs as fine to coarse subhedral crystals. Isolated grains of bornite, as well as in association with chalcopyrite and pyrite are common. It is occasionally associated with covellite/chalcocite, sphalerite and bismuthinite. Bornite also occurs as rims around pyrite and chalcopyrite, and as inclusions in chalcopyrite.

Cubanite ($CuFe_2S_3$) is present as very fine anhedral to subhedral grains only in PIN-1 and PIN-2D. It occurs singly as direct deposition products in rare quantities (<1%) in PIN-1. In PIN-2D, it was noted only at the bottom of the well as vein mineral in weak amount.

Covellite (CuS) was noted only in PIN-1 and PIN-3D. It occurs in very narrow, discrete zones near the bottom of PIN-I in generally rare amount (<1%), and in one instance reaching moderate quantity (10%). In PIN-3D, rare to moderate quantities of covellite are present. It is generally present as very fine to fine anhedral grains. It is usually found as rims around pyrite, and occasionally around magnetite, sphalerite. bornite, and bismuthinite. The mineral *chalcocite* (Cu_2S) is almost always associated with covellite as its alteration product.

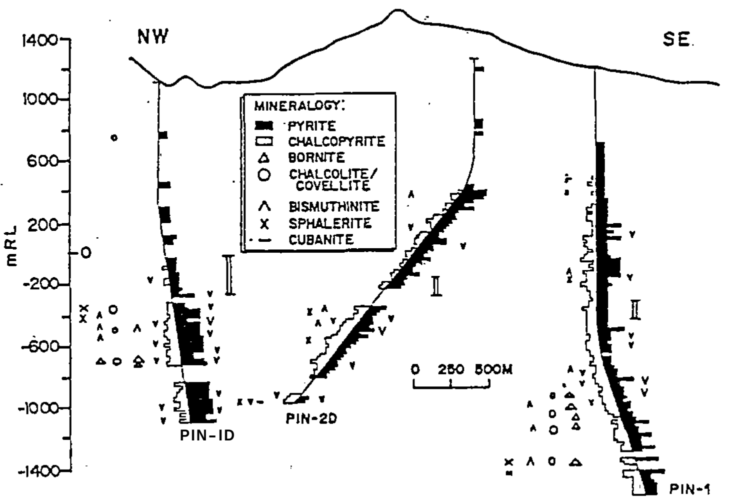


Fig. 14. Sulfide mineral distribution in Mt. Pinatubo.

Sphalerite (ZnS) is present in rare quantities (<1%) as fine to coarse subhedras in all the Pinatubo wells. This sulfide which often contains numerous minute chalcopyrite inclusions occurs as isolated grains, or rarely in association with chalcopyrite, pyrite, bismuthinite, bornite and cubanite.

Bismuthinite (Bi_2S_3) is found only in Pinatubo wells as fine to medium subhedral grains. It is generally present in rare amounts, usually as isolated crystals. It occasionally **occurs as** rims around pyrite and chalcopyrite, or attached to chalcopyrite, pyrite, bornite, sphalerite, or magnetite.

4.0 DISCUSSION

4.1 Stability of Sulfide Minerals

A stability diagram for sulfide and oxide phases at 300°C (Beane and Titley, 1981) is used to relate the fluid chemistry of the various wells to the observed sulfide mineral phases. The sulfur and oxygen activities of the reservoir **fluids** in each well were calculated using the following equations:

$$H_2S \Leftrightarrow H_2 + \tfrac{1}{2} S_2 \qquad (1)$$

$$\log K = \log a_{H_2} + \tfrac{1}{2}\log a_{S_2} - \log a_{H_2S} \qquad (2)$$

$$H_2O \Leftrightarrow H_2 + \tfrac{1}{2}O_2 \qquad (3)$$

$$\log K = \log a_{H_2} + \tfrac{1}{2}\log a_{O_2} - \log a_{H_2O} \qquad (4)$$

The values of log a_{S_2} and log a_{O_2} all lie within the chalcopyrite + pyrite stability region (Fig. 15) indicating that reservoir **fluids** of all wells are in equilibrium with these two sulfide minerals. These plots agree with the predominance of pyrite and chalcopyrite in Mahanagdong Mt. Apo and Pinatubo.

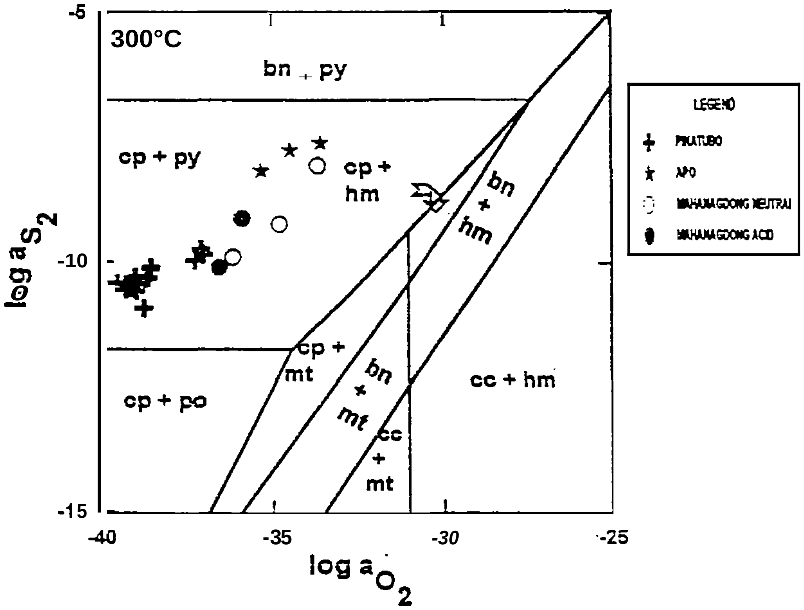


Fig. 15. Sulfide and oxide stability diagram (Beane and Titley, 1981).

Among the wells studied, Pinatubo fluids contain the highest concentrations of H_2S (~145 mmoles/100 moles H_2O), and H_2 (5-8 mmoles/100 moles H_2O) causing them to plot at the lower left corner of the chalcopyrite + pyrite field. On the other hand, the H_2S and H_2 concentrations of Mt. Apo and Mahanagdong **fluids** are relatively lower, ~10-14 mmoles H_2S/100 moles H_2O and ~0.1-0.4 mmoles H_2/100 moles H_2O.

be readily attributed to their high H_2S concentrations directly derived from the degassing magmatic body beneath Mt. Pinatubo. Apart from providing large amounts of H_2S, these magmatic vapors also transport abundant metals such as Cu, Fe, Zn and Bi leached from the country rocks.

4.2 Sulfide Minerals in Acid **vs.** Neutral Wells

Table 1 summarizes the distribution of major sulfide phases in acid and neutral wells in Mahanagdong and in Sandawa Collapse in Mt. Apo. For comparison, sulfide minerals of the three acid wells in Pinatubo are included. In terms of percentage area in polished section, the Pinatubo wells contain the highest amounts of sulfide minerals consisting –30%. In Mahanagdong and Mt. Apo, total sulfides make up only ~20%, or even lesser in some wells.

AREA	TOTAL PY	VEIN PY	TOTAL CPY	VEIN CPY	TOTAL BN
PINATUBO					
ACID	A	M	M	M	W
MAHANAGDONG					
ACID	A	M	W	R	R
NEUTRAL	A-M	R-ϕ	R	ϕ	R-ϕ
MT. APO					
ACID	A	M	W	R-ϕ	R-ϕ
NEUTRAL	A	M	W	R-ϕ	R-ϕ

LEGEND: **A** >10% W 1% ϕ absent
M 10% R <1%

Table 1. Major **sulfides in** acid vs. neutral **wells.**

The dominant sulfide, pyrite, is equally abundant (–20%) in all Pinatubo and Mt. Apo wells. In addition, veins of pyrite are common in **all** of these wells. In Mahanagdong, however, pyrite generally occurs in higher amounts (~20%) in acid **than** in neutral wells (–10-20%). Moreover, pyrite often exists **as** veins in acid wells, but seldom in neutral wells.

Chalcopyrite is the second most common sulfide phase in all the wells studied. In comparison to Mahanagdong and Mt. Apo, it is distinctly higher in **amounts** in Pinatubo wells where it consists –10% and usually deposits **as** veins. In Mt. Apo, on the other hand, chalcopyrite comprises only –1% of the polished section area in both acid and neutral wells. It occurs **as** disseminations, **as** replacement of magnetite. and **as** veins. In Mahanagdong, chalcopyite consists –1% of the total polished section area in acid wells. Veins **of** chalcopyrite are present in these acid wells. ***On*** the other hand: it occurs in rarer **amounts,** usually less than 10 grains, in neutral wells. No veins of chalcopyite were observed among these neutral wells in Mahanagdong.

Bornite is most abundant in Pinatubo where it occurs **as** fine to coarse subhedral grains comprising –1% of the total polished section **area.** In Mahanagdong, it is present only in rare **amounts** (≤5 **grains)** in all acid wells, and in some neutral wells. Bornite is likewise rare in Mt. Apo, existing in some acid and in some neutral wells.

Zinc and copper sulfides are the minor sulfide phases occurring in rare amounts (<10 grains) in all the areas studied. Sphalerite occurs in all Pinatubo wells, in some acid and neutral wells in Mahanagdong. and in some neutral wells in Mt. Apo. Covellite/chalcocite. on the other hand. exist in PIN-I and PIN-3D only. They occur in all acid, and some neutral wells in Mahanagdong. and in some acid wells in Mt. Apo.

Bismuthinite and cubanite are two rare sulfide phases found only in Pinatubo. The former exists as fine to medium-grained subhedras in all three Pinatubo wells. while the latter occurs as fine anhedral to subhedral grains in PIN-I and PIN-2D only. Neither of these sulfides were seen in Mahanagdong nor in Mt. Apo.

In summary, all major sulfide minerals are most abundant in the three acid wells in Pinatubo. Pyrite, chalcopyrite and bornite all exist in larger quantities in the three Pinatubo wells in comparison to Mahanagdong and Mt. Apo. Furthermore, minor sulfide phases are more diverse in Pinatubo.

In Mt. Apo, the assemblage and distribution of sulfide minerals are comparable in both acid and neutral wells. There is also no marked difference in occurrence of the major sulfides between acid and neutral producers. Like silicates, therefore, sulfide mineralogy *cannot* be used as a reliable indicator of discharge fluid pH in Mt. Apo.

Acid wells in Mahanagdong, on the other hand contain higher amounts of the major sulfides. pynte and chalcopyrite, in contrast to neutral wells. Moreover. pyrite veins are more common and chalcopyrite veins are only present among acidic wells. Thus, unlike in Mt. Apo, there is a discernible contrast in sulfide mineralogy between acid and neutral producers in Mahanagdong. Apparently, acid Cl-SO_4 fluids in Mahanagdong are depositing higher amounts of pyrite and chalcopyrite in comparison to neutral chloride waters. During the course of well drilling in Mahanagdong, therefore, the presence of (1) relatively abundant total pyrite and total chalcopyite, (2) abundant pyrite veins and (3) chalcopyrite veins in the drill cuttings can already be used to predict an acidic fluid discharge for that well.

5.0 CONCLUSIONS

Acid Cl-SO_4 fluids in Mt. Apo and Mahanagdong produce similar silicate alteration as neutral-chloride waters. Even acid-magmatic fluids in Pinatubo are apparently in equilibrium with neutral silicates like secondary biotite and illite. Silicate minerals therefore are often ambiguous indicators of fluid pH. especially in areas where acid fluids exist nith neutral brine.

Instead of silicates, sulfide mineralogy is evaluated as a potential fluid pH index in Mt. Apo and Mahanagdong. Rocks altered by acid Cl-SO_4 fluids in Mt. Apo exhibit similar sulfide mineralogy as those rocks affected by neutral chloride fluids. Like silicates, therefore. sulfide minerals cannot be employed as an indicator of discharge fluid pH in Mt. Apo.

The sulfide phases in Mahanagdong resemble those in Mt. Apo. Unlike in Mt. Apo, however. there is a discernible contrast in sulfide abundance and occurrence between acid and neutral producers in Mahanagdong. Wells which discharged acid fluids contain higher amounts of total sulfides and sulfide veins in comparison to neutral wells. In Mahanagdong. therefore, sulfides can be used to detect the presence of acid Cl-SO_4 fluids.

In an active magmatic-hydrothermal field like Pinatubo, sulfides are more abundant and more diverse in comparison to geothermal areas like Mt. Apo and Mahanagdong. This abundance and diversity of sulfides can be directly attributed to the presence of a degassing magmatic body which supplies high concentrations of H_2S gases as well as abundant metals Like Cu, Fe. Zn and Bi.

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