

A PETROLOGIC EVALUATION OF THE LAGUNAO SECTOR OF THE SOUTHERN NEGROS GEOTHERMAL PROJECT

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Abstract

Petrologic studies of Lagunao wells show that hydrothermal alteration in the sector is mainly produced by recent neutral-pH fluids. The characteristic alteration assemblage consists of smectite, illitic clays, epidotes associated with chlorite, calcite and quartz. The sulfide mineral phases, on the other hand, are mainly pyrite and chalcopyrite with minor covellite/chalcocite, bornite, mackinawite (?), sphalerite and galena.

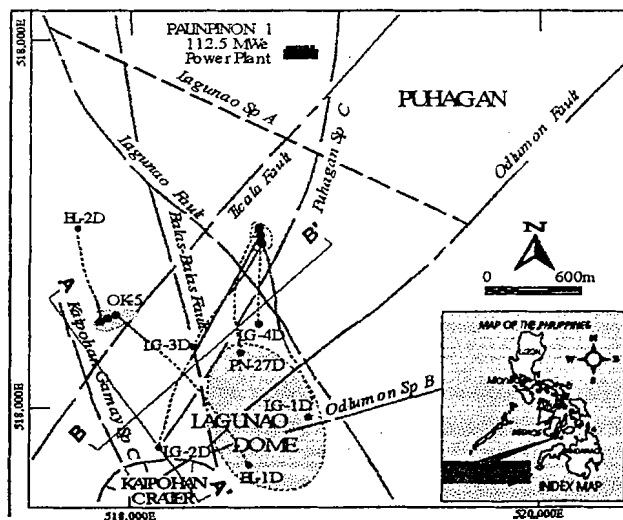
Based on the existence of stable hydrothermal alteration, the upflow of hot, neutral-chloride brine in Lagunao is postulated to occur beneath the area bounded by Ticala Fault in the northwest and Lagunao Fault in the northeast. The outflow regions, on the other hand, are the areas northeast of Lagunao Fault and northwest of Ticala Fault where fluid flow is mainly horizontal and deep such that relict alteration at shallow levels remains extant. The southwestern boundary of the upflow is inferred to be the Kaipohan Canyon Splay C based on the decreasing trend of isotherms towards LG-2D. Towards the southeast, the Odlumon Fault likely acts as the margin of the neutral upflow since all the aquifers of wells drilled southeast of this structure proved to be acidic.

Acid fluids in Lagunao tapped by wells BL-1D and LG-1D are believed to have deep-seated origins based on a comparison with the results of the petrologic evaluation of Cawayan sector of the Bacon-Manito Geothermal Project, and on the results of sulfur isotope analysis in Palinpinon. The acidity of the fluids can be attributed to the presence of acidic gases such as SO_2 and H_2S exsolved from the cooling magmatic source of the Lagunao dome.

1.0 INTRODUCTION

The Lagunao sector is situated within the Southern Negros Geothermal Project (SNGP) which lies at the southeastern tip of the Negros Island (Fig. 1). Seven geothermal bores, OK-5, LG-ID, LG-2D, LG-3D, LG-4D, BL-1D and BL-2D, have so far been drilled in Lagunao.

Among the Lagunao wells, BL-ID was drilled deepest at -2419 mVD (-1490 mRL), and BL-2D shallowest at 1598 mVD (459 mRL). All the wells were not sampled completely due to blind drilling which is encountered as shallow as about -200 mRL in OK-5 and LG-4D. Cores were cut within the blind-drilled depths only at OK-5, BL-ID and LG-ID. Wells BL-1D and LG-1D have acid discharges; OK-5, BL-2D and

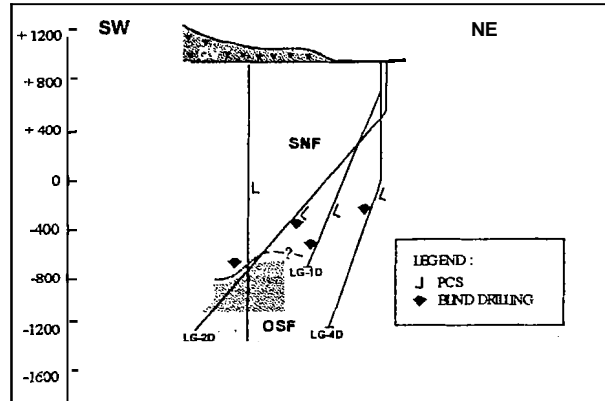


OK-5 and BL-ID are supplying **steam** to the 20 MWe Balas-Balas modular power plant with BL-2D programed to contribute additional capacity. LG-3D and LG-4D are presently hooked to the 112.5 MWe Palinpinon I power plant. Both LG-ID and LG-2D have been cemented and have never been utilized.

This petrologic **study** aims to: 1) describe the distribution of hydrothermal alteration, both silicate and sulfide phases, in Lagunao; 2) postulate a petrologic model of the Lagunao sector; and 3) recommend targets for future replacement wells.

20 GENERAL STRATIGRAPHY

The Lagunao wells encountered three stratigraphic units, namely: 1) Cuernos Volcanics (CV), 2) Southern Negros Formation (SNF), and 3) Okoy Sedimentary Formation (OSF) (Fig. 2). The CV is the youngest unit and **has** a thickness of ~ 20 m in LG-ID. It is composed of unaltered to slightly weathered biotite-, hornblende-, and two pyroxene-bearing andesite lavas. The SNF, the thickest formation intersected **within** the sampled depths, consists mainly of moderately to intensely altered andesite lavas, **tuff** breccias, tuffs, andesite hyaloclastites, and completely altered rocks. **The** SNF **till** **mRL**



3.0 DISTRIBUTION OF HYDROTHERMAL ALTERATION

3.1 Neutral-pH Alteration

The **rocks** in the Lagunao wells are generally altered to a neutral-pH suite characterized **by** smectite, illitic clays and epidotes which is associated with chlorite, calcite and **quartz**. These minerals **occur as**: 1) replacement of phenocrystic plagioclases and ferromagnesian clasts, matrices of lavas and breccias, and 2) veins and vug-fill.

Illitic Clays. Replacement illite-smectite is first noted as shallow as +600 mRL in BL-2D, +400 mRL in OK-5, but +300 mRL in LG-1D and LG-4D, and around +200 mRL in LG-2D, LG-3D and BL-ID (Figs. 3 and 4). In most of these wells, it exists in generally weak amounts in variably altered clasts of the **SNF** breccias and is associated with smectite, chlorite, anhydrite, and incipient to anhedral epidote. At +200 mRL in BL-1D, replacement illite-smectite is present in relatively weak to moderate quantities together with chlorite, **quartz**, and incipient epidote.

On the other hand, replacement illite initially **occurs** at +300 mRL in BL-2D and OK-5 (Fig. 3) in **weak** amounts as clast alteration of the **SNF** breccias. It exists alongside **with** smectite, illite-smectite, **quartz**, and anhedral epidote. In LG-ID, LG-2D, LG-3D, and LG-4D, weak to moderate quantities of replacement illite are found **from** +70 to +100 mRL (Fig. 4) altering detrital clasts of the **SNF** breccias. It is generally associated with smectite, illite-smectite, and incipient to anhedral epidote. At +50 mRL in BL-ID, replacement illite exists in moderate quantities together with calcite and **quartz**. Below 0 mRL, replacement illite increases in abundance and usually occurs **as** whole-rock alteration in the **SNF** breccias and is **most** likely recent at these depths.

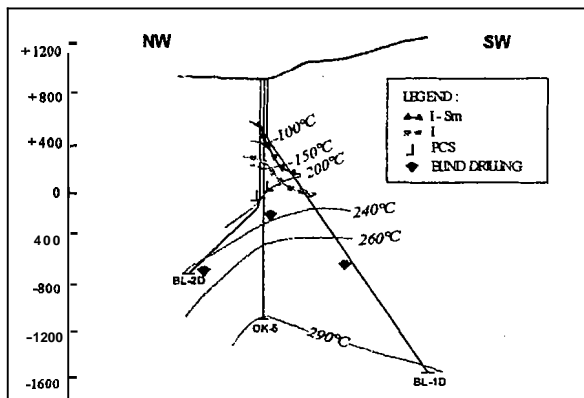


Figure 3. First appearance of illitic clays in Laguna wells along section A-A'.

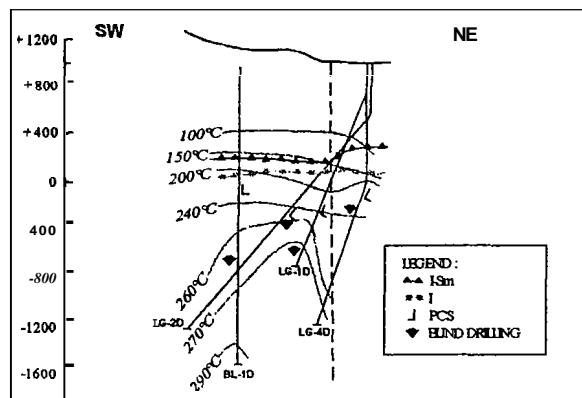


Figure 4. First appearance of illitic clay in Laguna wells along section B-B'.

Epidote. In general, most of the replacement epidote forms are initially present at shallow levels, equal to or above 0 mRL, in OK-5 and BL-2D (Fig. 5). On the other hand, only incipient to anhedral crystals of replacement epidote are first noted above 0 mRL in LG-1D, LG-2D, LG-3D, LG-4D and BL-1D (Figs. 5 and 6). At these depths, they often occur sporadically in rare to weak quantities altering the fragments of the SNF breccias and are associated with smectite and illite-smectite. Moderately to well-crystalline replacement epidotes in BL-2D and OK-5 are also partially altered to calcite, sphene or leucosene.

The observed retrogradation of replacement epidote in OK-5 and BL-2D, and its existence as clast alteration of the SNF breccias above 0 mRL in LG-1D, LG-2D, LG-3D and LG-4D strongly suggest that these minerals are either detrital or relict phases at shallow depths in Laguna, except in BL-1D.

Below 0 mRL, subhedral and euhedral replacement epidotes appear in LG-1D, LG-2D, LG-3D, LG-4D, and BL-1D (Fig. 6). Generally, these minerals occur in weak to moderate amounts as whole-rock alteration in the SNF breccias alongside with illite, chlorite, calcite and quartz. Moreover, most of the epidote grains do not exhibit retrograde features at these depths. This implies that like replacement illite, subhedral to euhedral replacement epidote is likely recent, in-situ alteration at deeper levels in Laguna.

Subhedral and euhedral epidote is likewise found as vein deposits in almost all Laguna wells. Subhedral epidote occurs from 0 mRL in BL-1D, BL-2D and OK-5 till -200 mRL in LG-1D and LG-3D. Euhedral veins, on the other hand, were only observed at the sampled depths of LG-1D and BL-2D at -500 mRL, and near the bottomhole of BL-1D at -1490 mRL. The epidote veins are relatively fresh and are often associated with quartz, calcite, wairakite and anhydrite.

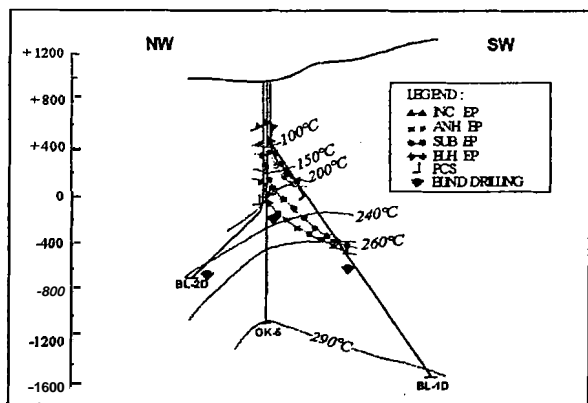


Figure 5. First appearance of replacement epidotes in Laguna wells along section A-A'.

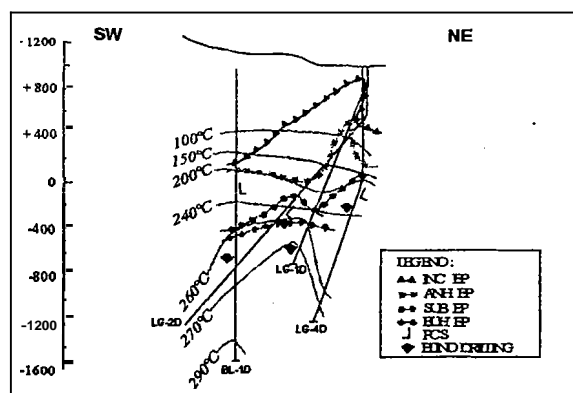


Figure 6. First appearance of replacement epidotes in Laguna wells along section B-B'.

3.2 Acid Alteration

In most Lagunao wells, the acid alteration minerals are mainly diaspore, pyrophyllite and kaolinite/dickite. They usually occur in weak to moderate amounts, and in thin, discrete zones (≤ 20 m). At sampled depths, these thin acid horizons exist from around +900 mRL in OK-5 down to about -600 mRL in LG-3D, BL-1D, BL-2D and LG-1D (Fig. 7). Alunite is only observed in wells OK-5 and LG-3D, and in LG-4D (Fig. 7) above +0 mRL in weak to moderate amounts.

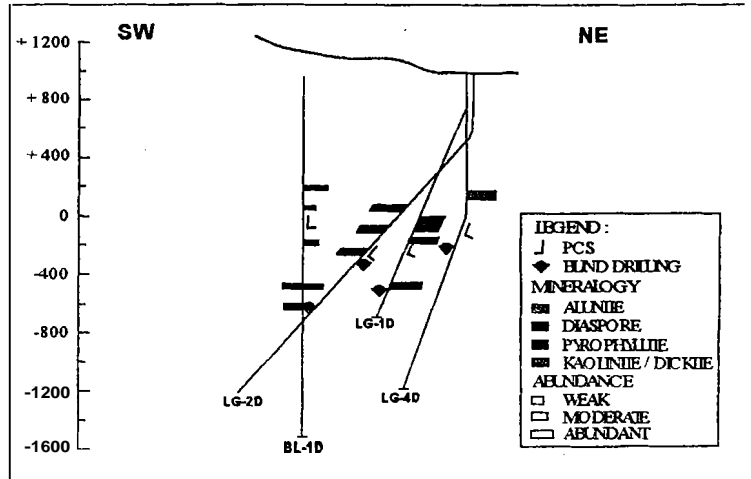


Figure 7. Acid occurrences in Lagunao wells along section B-B'.

In general, the acid mineral phases occur as replacement of completely altered clasts of the SNF breccias, alongside with volcanic fragments which are moderately to intensely altered to a neutral-pH suite consisting of chlorite, calcite, illitic clays, and epidote. Most of the diaspore grains are pitted and corroded while some are partially replaced by smectite-like clays.

Their observed association with neutral-pH alteration phases, and retrogradational textures indicate the detrital and/or relict nature of acid alteration in all the Lagunao wells. No recent acid alteration minerals are observed in any of the Lagunao wells within the sampled depths.

3.3 Hydrothermal Sulfide Minerals

The hydrothermal sulfide phases in Lagunao wells consist mainly of pyrite and chalcopyrite. The minor sulfide minerals include covellite/chalcocite, bornite, mackinawite (?), sphalerite and galena. These sulfide phases occur as disseminations, as alteration of magnetite and hematite, and as veins/veinlets. One very noticeable opaque mineral is native copper which exists in rare quantities above 0 mRL in all the wells studied in Lagunao, except in BL-2D.

- a) *Pyrite* (FeS_2) generally occurs as fine to coarse, anhedral to subhedral grains in all wells (Fig. 8). It exists as disseminations, as alteration of magnetite and hematite, and as veins/veinlets. It is present in moderate to abundant amounts ($\geq 10\%$) in BL-1D and LG-1D, and in weak to moderate quantities (between 1% and $> 10\%$) in wells LG-2D, LG-3D, LG-4D, BL-2D and OK-5. Pyrite veins are common in all the Lagunao wells but are present in relatively greater quantities in BL-1D and LG-1D.

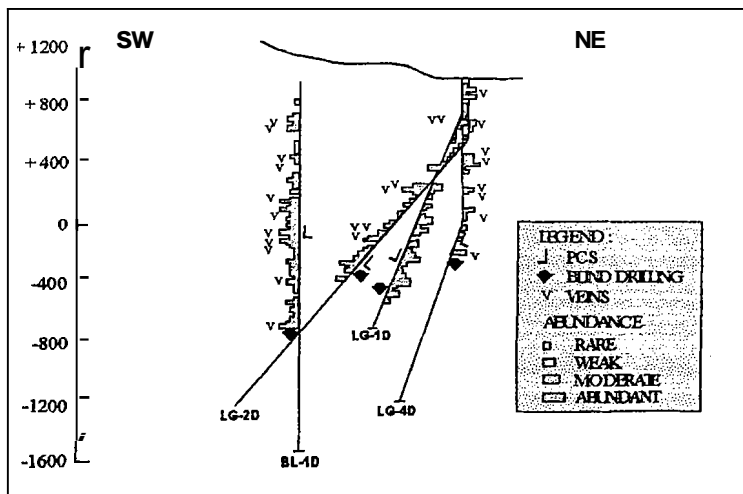


Figure 8. Distribution of pyrite in Lagunao wells along section B-B'.

- b) **Chalcopyrite** (CuFeS_2) is the second major sulfide (Fig. 9). It usually occurs as fine to very fine anhedral often associated with pyrite, bornite, and covellite/chalcosite. **Medium** to coarse chalcopyrite grains are generally more common in BL-1D and LG-1D. Chalcopyrite exists as disseminations, and occasionally as alteration rims of pyrite. It is present in weak to moderate quantities in BL-1D and LG-1D, and in rare to weak amounts in LG-1D, LG-2D, LG-3D, LG-4D, **OK-5** and BL-2D. Chalcopyrite veins in rare amounts were observed only in BL-1D and LG-1D.

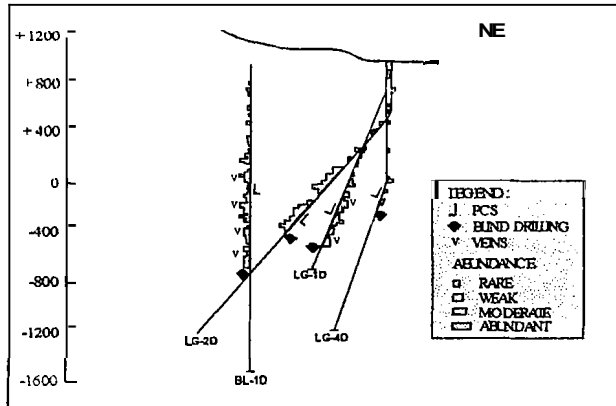


Figure 9. Distribution of chalcopyrite in Lagunao wells along section B-B'.

- c) The copper sulfides **covellite/chalcosite** ($\text{CuS}/\text{Cu}_2\text{S}$) are sporadically present in rare to weak amounts ($\leq 1\%$) in all the Lagunao wells. Moderate quantities ($\sim 10\%$) of covellite/chalcosite were even observed at 360 mRL in **OK-5**. They occur as very fine to coarse, subhedral to anhedral isolated grains or as alteration of bornite and sphalerite. Their usual mineral association includes chalcopyrite, bornite and magnetite.
- d) **Bornite** (Cu_5FeS_4) comprises $\sim 1\%$ of the total polished section area. Like the copper sulfides, bornite occurs sporadically in Lagunao wells. Very fine to coarse, anhedral to subhedral bornite grains exist either as isolated grains, or associated with chalcopyrite, covellite/chalcosite, pyrite, sphalerite and magnetite. It occasionally shows alteration to covellite/chalcosite or chalcopyrite.
- e) **Sphalerite** (ZnS) was only found in rare quantities ($< 1\%$) in **OK-5**, **LG-3D**, and **LG-1D**. It occurs as fine to coarse isolated grains characteristically containing chalcopyrite inclusions.
- f) **Mackinawite** (?) (FeS) was only seen in rare to weak quantities in **LG-2D** and **BL-2D**. Fine to medium mackinawite (?) grains exist as disseminations, or as replacement of pyrite. It shows alteration to chalcopyrite.
- g) **Galena** (PbS) is a rare sulfide found at two depths in **LG-3D**. It occurs as fine isolated subhedras.
- h) **Native copper** (Cu) is conspicuously present as pink, tarnished, scratched grains above 0 mRL in all the wells studied. Fine to medium anhedral and subhedras of native copper comprise $< 1\%$ of the total polished section area. It is mainly associated with hematite and pyrite.

4.0 CORRELATION WITH ISOTHERMS, STRUCTURES AND FLUID CHEMISTRY

In most Philippine geothermal fields, the distribution of clays and epidote is commonly used to estimate formation temperatures due to their sensitivity to temperature changes in the reservoir. Hydrothermal clays are mainly composed of smectite at temperatures lower than 150°C . Interstratified illite-smectite starts to appear at about $150\text{--}180^\circ\text{C}$, while illite dominates at depths where hotter ($\geq 220^\circ\text{C}$) temperatures exist. In addition to clays, the morphology of epidote is another useful geothermometer. At temperatures of $\sim 180\text{--}200^\circ\text{C}$, epidote crystals tend to be incipient to poorly crystalline, while at $\sim 200\text{--}230^\circ\text{C}$, epidote grains turn subhedral. Finally, euhedral epidote crystals develop at temperatures equal to or greater than $240\text{--}250^\circ\text{C}$.

In Lagunao, the occurrences of clays and epidotes in **BL-1D**, and below 0 mRL in **LG-1D**, **LG-2D**, **LG-3D**, **OK-5** and **BL-2D** agree with present reservoir temperatures. For instance, in **BL-1D**, illite-smectite appeared at $\sim 150^\circ\text{C}$, while illite first occurred at +50 mRL where temperatures are close to 220°C (Fig. 3).

The epidotes in BL-ID are likewise in equilibrium with present-day conditions with incipient epidotes existing at ~200° C, and then prograding to euhedral epidotes at temperatures greater than 260° C (Fig. 5). Similarly, the presence of clays and epidotes below +200 mRL in LG-2D and below 0 mRL in LG-ID, LG-3D, **OK-5** and BL-2D all agree with reservoir temperatures (Figs. 3, 4, 5, and 6). The compatibility of these mineral geothermometers with present temperatures confirms that neutral-pH hydrothermal alteration in BL-ID, and at deep levels in LG-1D, LG-2D, LG-3D, **OK-5** and BL-2D are all deposited by current neutral brine as earlier suggested by their abundance and occurrence. Likewise, the hydrothermal sulfides in BL-ID and below 0 mRL in LG-ID, LG-2D, **LG-3D**, **OK-5** and BL-2D are interpreted to be produced by recent neutral-pH fluids based on their association with stable neutral-pH alteration.

depths in Lagunao. The hydrothermal sulfides above 0 mRL in LG-1D, 2D, 3D, 4D, BL-2D and **OK-5** are likewise inferred to be either relict or detrital based mainly on their association with relict and/or detrital neutral-pH minerals..

Based on its coincidence with stable neutral-pH alteration minerals in **OK-5**, Ticala Fault' likely conducts neutral waters in this well along the minor aquifer at +35 mRL to -165 mRL (Fig. 10). Due to blind drilling, no rock samples were collected in OK-5 below -200 mRL. Nonetheless, the neutral discharge

-515 to -615 mRL and the minor feed at -965 to -1015 mRL (Fig. 10).

In BL-2D, its stable neutral-pH alteration below 0 mRL, and its neutral discharge fluids both indicate that neutral fluids are currently flowing along Okoy D, Sogongon Splay A and Balas-Balas Splay A (Fig. 10). On the other hand, in LG-2D, no rock samples were collected within its fault intercepts due to blind drilling. Thus, only its neutral-pH discharge chemistry is used to conclude that neutral brine flows along Balas-Balas, Puhagan Splay C and Odlumon (Fig. 11). In LG-3D, Balas-Balas and Puhagan Splay C also conduct neutral-pH fluids based on their association with stable neutral-pH alteration.

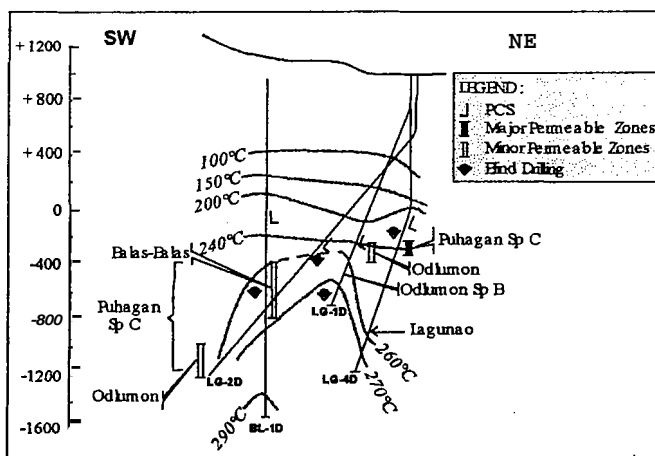
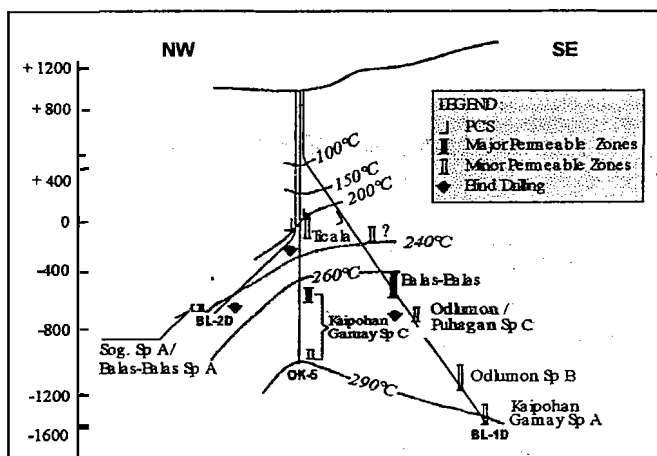


Figure 11. Structures and permeable zones of Lagunao wells along section B-B'.

¹All structural data taken from Camit and Villarosa, 1996.

Balas-Balas Fault also channels neutral-pH fluids in BL-ID as implied by the presence of stable neutral-pH alteration along its intersection at -395 to -570 mRL, the well's major aquifer (Fig. 10). Odlumon and Puhagan Splay C, on the other hand, are correlative to the minor production zone of BL-1D at -650 to -730 mRL which lies within the blind-drilled section. Thus, the hydrothermal alteration at this interval cannot be determined. However, based on the neutral discharge of LG-2D which intersected these faults, neutral-pH fluids are believed to be also flowing along the intercepts of Odlumon and Puhagan Splay C in BL-ID. Hence, this well likely intersected neutral-pH fluids at its main aquifer related to Balas-Balas, and its minor feed associated with Odlumon and Puhagan Splay C. Its acid inflow, which became evident in its later discharge, more likely coincides with its **two** minor aquifers near bottom (-1065 to -1230 and -1360 to -1450 mRL). Again, hydrothermal alteration within this interval cannot be assessed due to the absence of rock samples. Based on downhole fluid sampling, however, acid waters exist near bottom of BL-ID (Ramos-Candelaria, 1992). Among the mapped structures, the bottom aquifer at -1360 to -1450 mRL *can* be correlated to Kaipohan Gamay Splay **A**, while that at -1065 to -1230 mRL can be associated to Odlumon Splay B. Thus, these two faults probably conduct acid fluids in BL-ID.

Odlumon Fault possibly channels neutral-pH fluids in LG-ID as suggested by its association with stable neutral-pH alteration at -150 to -350 mRL where it is almost cased-off (Fig. 11). This fault also conducts neutral brine in LG-2D and probably in BL-ID. The **main** production zone in LG-1D lies at -467 mRL, marking the start of blind drilling. Results of downhole fluid sampling suggest that acid waters are likely inflowing through this major aquifer (Ramos-Candelaria, 1992). Odlumon Splay B can be correlated **to the** probable acid feed in LG-ID. This same fault probably conducts acid waters in BL-ID.

Based on **correlation** with hydrothermal alteration and results of discharge and downhole fluid sampling, the following **structures** are **believed** to be channeling neutral-pH fluids in the Lagunao sector – Ticala, Kaipohan Gamay Splay C, Okoy D, Sogongon Splay **A**, Balas-Balas Splay **A**, Puhagan Splay C, Balas-Balas and Odlumon (Fig. 12). The probable acid conduits are Kaipohan Gamay Splay A and Odlumon Splay B.

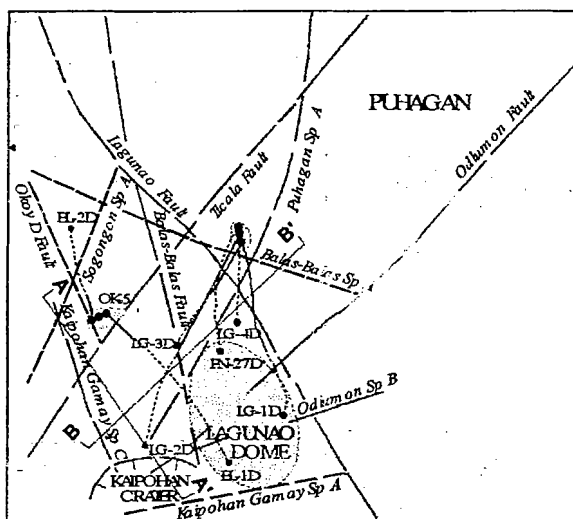


Figure 12. Structural map of the Lagunao sector:

5.0 PETROLOGIC MODEL

The hydrothermal alteration in Lagunao is mainly produced by recent neutral-pH fluids based on its abundance and Occurrence as whole-rock alteration below 0 mRL. Comparisons with stable isotherms further confirm that **most** of these neutral-pH alteration minerals, especially below 0 mRL, are indeed formed by present-day neutral brine. Due to early onset of blind drilling, hydrothermal alteration within many production zones cannot be assessed. Nonetheless, the chemistry of their discharge fluids proved that neutral-pH fluids were **tapped** by OK-5, BL-2D and LG-2D. Although both LG-3D and LG-4D are **dry**, neutral brine likely exists beneath these two wells based on their proximity with neutral brine producers.

The presence of stable neutral-pH alteration minerals in BL-ID from surface down to its bottom, and below 0 mRL in OK-5, LG-ID, LG-2D and LG-3D, suggests that these wells penetrated a sector where extensive circulation of massive **amounts** of hot, neutral-pH fluids is presently occurring. In particular, the disappearance of shallow relict alteration in BL-ID implies prolonged and intense rock-water interaction even at shallow levels. In contrast, relict mineral phases still exist at shallow depths (above 0 mRL) in LG-ID, LG-2D, LG-3D, LG-4D, OK-5 and BL-2D. The persistence of shallow relict alteration indicates less extensive fluid-rock interaction at shallow levels in these wells.

Correlation with mapped structures showed that two faults apparently act as boundaries between stable and relict hydrothermal alteration – Ticala and Lagunao. All the shallow relict alteration in LG-1D, LG-2D, LG-3D and LG-4D occur northeast of Lagunao Fault, while only recent alteration minerals exist southeast of this structure (Fig. 13). On the other hand, shallow relict alteration in OK-5 and BL-2D lie northwest of Ticala Fault, while stable minerals in BL-1D and OK-5 occur southeast of this fault (Fig. 13).

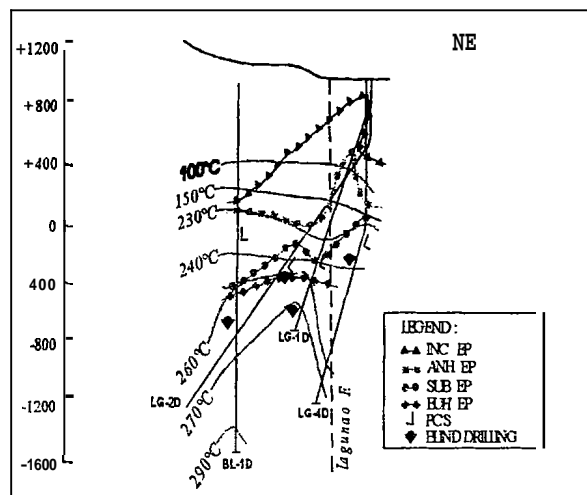


Figure 13. Intersection of Lagunao wells with Lagunaofault.

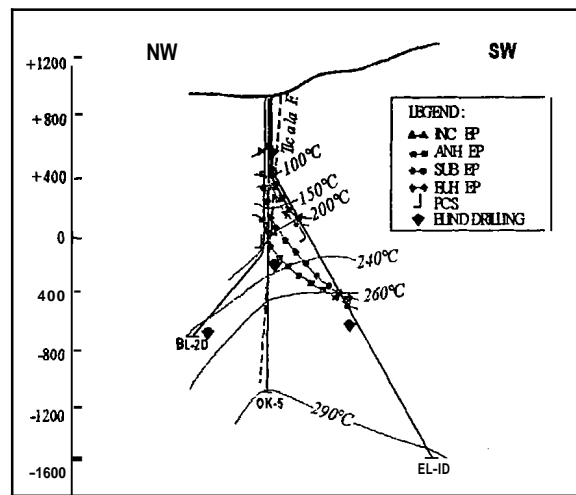


Figure 14. Intersection of Lagunao wells with Ticalafault.

Based on the existence of stable neutral-pH hydrothermal alteration, the block bounded by Ticala and Lagunao Faults is postulated as the upflow region of neutral brine (Fig. 15 and 16). In this area, extensive fluid convection apparently occurs both at deep and shallow levels of the reservoir such that full rock-water equilibrium has been attained all throughout this region. On the other hand, the areas northeast of Lagunao Fault and northwest of Ticala Fault (Fig. 15) are interpreted to be outflow regions where flow of hot neutral brine is mainly horizontal and deep (below 0 mRL) such that neutral-pH alteration at deep levels are all stable while at shallow levels, relict alteration remained extant. The decline of stable isotherms towards BL-2D and towards LG-4D confirms that Ticala and Lagunao Faults are the likely boundaries of the neutral upflow region in Lagunao.

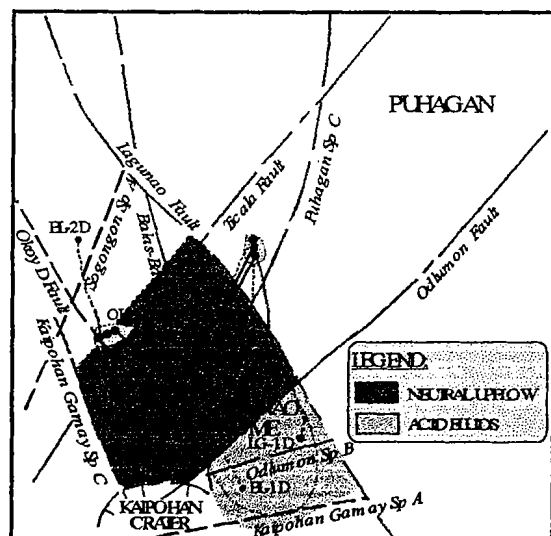


Figure 15. Plan view of the conceptual model of the Lagunao hydrothermal system.

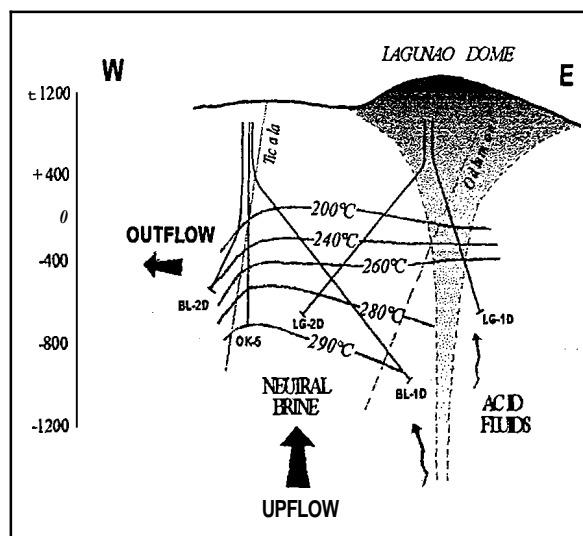


Figure 16. Conceptual model of the Lagunao hydrothermal system.

On the southwestern region, there is no petrologic data to define the boundary of the upflow. However, based on the decreasing trend of isotherms towards LG-2D, the Kaipohan Gamay Splay C is inferred to be the probable southwestern margin of the neutral upflow. Towards the southeast, the Odlumon Fault likely acts as the boundary of the neutral upflow since all aquifers located southeast of this structure proved to be acidic. Thus, though BL-ID and LG-1D intersected neutral brine at their shallow feeds, their deeper aquifers located southeast of Odlumon Fault are producing acidic fluids (Fig. 15). The plunge of the 290° C stable isotherm from OK-5 towards BL-ID (Fig. 16) confirmed that the bottom of BL-ID did not tap the upflow region.

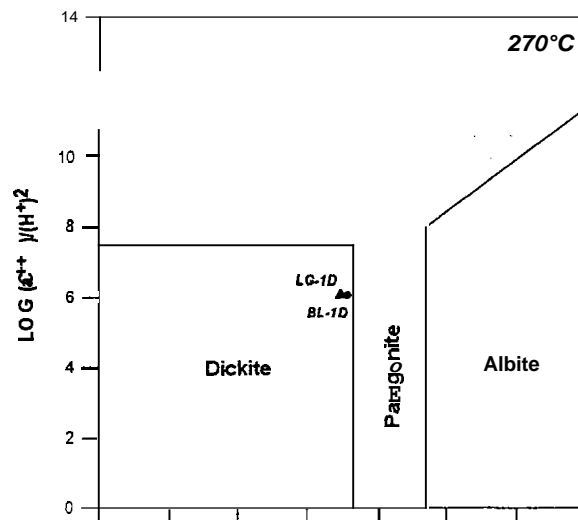
Thus, the postulated upflow of hot, neutral brine in Lagunaos is likely bounded by Ticala Fault in the northwest, Lagunaos Fault in the northeast, Kaipohan Gamay Splay C (?) in the southwest, and Odlumon Fault in the southeast. This model is consistent with stable isotherms and chemistry data which indicate that the upflow of the Palinpinon hydrothermal system is located beneath OK-5, and that Puhagan, Nasuji and Sogongon are outflow regions. The heat source presently driving the Palinpinon hydrothermal system could be a huge, magmatic body related to the Pleistocene Cuernos de Negros Volcano.

6.0 ORIGIN OF ACID FLUIDS IN LAGUNAO

Among the seven wells in Lagunaos, only two wells encountered acid-sulfate fluids based on their

postulated acid feeds in these two wells all lie within their blind-drilled sections. Thus, no rock samples were collected along these acid zones. Silicate stability diagrams showed that their reservoir fluids plot within the dickite stability region (Fig. 17). Hence, rocks within these acid zones are likely altered to the acid clay, dickite, probably in association with other high-temperature acid alteration minerals such as diaspore and pyrophyllite.

Due to the lack of rock samples within the acid feeds, no direct petrologic evidence can be used to determine the nature of acid fluids in Lagunaos. In



been

In the absence of direct petrologic data, results of petrologic evaluation of the shallow acid fluids in Cawayan (Rosell and Ramos, pers. comm., 1997) will be applied in Lagunaos. In the Cawayan sector of the Bacon-Manit0 Geothermal Project (BMGP), a thick zone of fresh acid alteration overlies the deep, neutral hydrothermal system. The acid alteration cap is widespread from a c e (+700 mRL) down to about 0 mRL. Below 0 mRL, fresh acid alteration no longer abounds. Instead, neutral-pH alteration predominates and the acid minerals exist only in thin, discrete zones correlative to faults. Thus, the shallow acid fluids which produced the thick acid alteration cap likely migrated down along vertical structures, and eventually became neutralized through interaction with surrounding rocks. In the production sector, the maximum depth of acid fluid penetration is -600 mRL, and its maximum temperature of occurrence is -240° C. Thus, below -600 mRL in the Cawayan production sector, no more acid fluids exist. Only neutral brine is circulating at the deeper portions of the Cawayan reservoir where temperatures are $\geq 280^\circ$ C. In the reinjection sector, shallow acid fluids were able to percolate down to greater depths (-1000 mRL) probably due to colder temperatures (-240° C) in comparison to the production area.

Based on these observations in Cawayan, the acid fluids in Lagunao therefore are not likely surficial in origin. Their level of Occurrence is too deep (-1200 mRL), and their associated temperature is much too high (270°-310° C) for descending shallow fluids to remain acidic. **At** these great depths and high temperatures, surficial acid waters will most likely be already neutralized through interaction with country rocks as **they** flow down along structural channels.

No direct petrologic evidence likewise exists to support a deep origin of acidity in Lagunao. In Mt. Labo, the association of pneumatolytic minerals such as topaz and fluorite with deep acid alteration was **used** to infer that the deep fluids were rendered acidic **by** exsolved gases from a cooling intrusive **body** beneath Mt. Labo (PNOC-EDC, **1995**). Due to the lack of rock samples within the acid feeds in BL-ID and LG-ID, the presence of high-temperature acid alteration minerals associated with pneumatolytic minerals cannot be verified.

Sulfur isotope data of Palinpinon wells, however, imply that the acid-sulfate waters in Lagunao have probably deep-seated origins (Bayon, 1996). In particular, BL-ID fluids yielded a **high** $\delta^{34}\text{S}$ value (~ 20 ‰) in dissolved sulfate which is too enriched to be derived from surficial oxidation of H_2S whose $\delta^{34}\text{S}$ is only 0 to - 3 ‰. **This** discrepancy in $\delta^{34}\text{S}$ values in H_2S and in dissolved sulfate in BL-ID suggests that sulfate waters in Lagunao are more likely derived from deep, magmatic sources, rather than from **near** surface oxidation of H_2S **gases**.

Thus, based on a comparison with Cawayan sector in BMGP, and the **results of sulfur** isotope analysis in **Palinpinon**, the acid fluids in Lagunao are postulated to have deep origins. The **proximity** of the bottomholes of the acid wells BL-ID and LG-ID **to** the possible neck of Lagunao dome suggests that the acid fluids are likely related to the deep-seated root of this dome. The acidity of the **fluids can** be attributed to the presence of acidic gases such as SO_2 and H_2S exsolved from the cooling magmatic **source** of the Lagunao dome, which is likely shallower and distinct **from** the deeper magmatic **body** presently, driving the Palinpinon neutral hydrothermal system.

7.0 IMPLICATIONS ON FUTURE DRILLING

Based on the conceptual model of Lagunao, the upflow of neutral chloride brine **with** temperatures of $\geq 300^\circ \text{C}$ occurs beneath the area bounded **by** faults Ticala, Lagunao, Kaipohan Gamay Splay C and Odlumon (Fig. 15). Hence, this region appears to be the most viable area for targeting future replacement wells in Lagunao. To definitely intersect hot, neutral fluids, wells which will be drilled from the pads of LG-ID and OK-5 should target the following structures – Balas-Balas, Puhagan Splay C, Ticala and Kaipohan Gamay Splay C.

Additional geothermal wells may likewise be targeted towards the area northwest of Ticala Fault from pad of **OK-5** where neutral chloride waters are still likely present but at reduced temperatures. **Based** on BL-2D, 220° C and 240° C fluids are flowing along structures at approximately -430 mRL and -520 mRL, respectively.

Deep acid fluids are believed to be present southeast of the Odlumon Fault, in the vicinity of the Lagunao dome. This region, therefore, should never be drilled to avoid the postulated deep acid waters.

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