PROCEEDING, Twenty-Third Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California. January 26-28, 1998
SGP-TR-158

HYDROTHERMAL PETROLOGY OF THE LAGUNA0 SECTOR OF THE SOUTHERN NEGROS GEOTHERMAL PROJECT

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ABSTRACT

Petrologc 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 chalcopynte with minor covellite/chalcocite, bornite, maclanawite (?), 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 Gamay Splay C based on the decreasing trend of isotherms towards LG-2D. Towards the southeast, the Odlumon Fault llkely acts as the margin of the neutral upflow since all the aquifers of wells dnlled southeast of this structure proved to be acidlc.

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 petrologc evaluation of Cawayan sector of the Bacon-Manit0 Geothermal Project, and on the results of sulfur isotope analysis in Palinpinon. The acidity of the fluids can be attributed to the presence of acidlc gases such as SO_2 and H_2S exsolved from the cooling magmatic source of the Lagunao dome.

INTRODUCTION

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

Among the Lagunao wells, BL-1D was drilled deepest at –2419 mVD (-1490 mRL), and BL-2D shallowest at 1598 mVD (-659 mRL) All the wells were not sampled completely due to blind dnlling 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-1D and LG-1D. Wells BL-1D and LG-ID have acid discharges; OK-5, BL-2D and LG-2D produced neutral-pH fluids, whle LG-3D and LG-4D have dry discharges

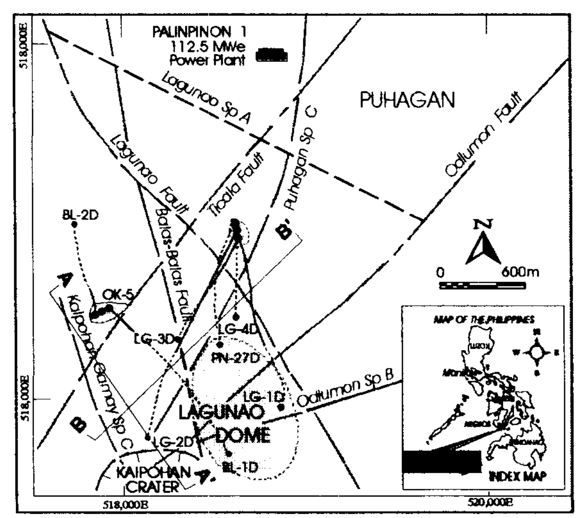


Figure I. Location map of the Lagunao wells in the Southern Negros geothermal project.

OK-5 and BL-1D are supplying steam to the 20 MWe Balas-Balas modular power plant with BL-2D programmed to contribute additional capacity. LG-3D and LG-4D are presently hooked to the 112.5 MWe Palinpinon I power plant. Both LG-1D 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.

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-1D. 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 exists till depths of about -750 mRL in BL-ID.

The oldest formation in the wells is the OSF, whch was sampled only in OK-5, BL-1D and BL-2D. It is made up of fossiliferous, calcareous siltstones and sandstones, and sedimentary breccias. The OSF is interpreted to have been deposited in a bathyal environment during Early Pliocene (Villarosa et al., 1988).

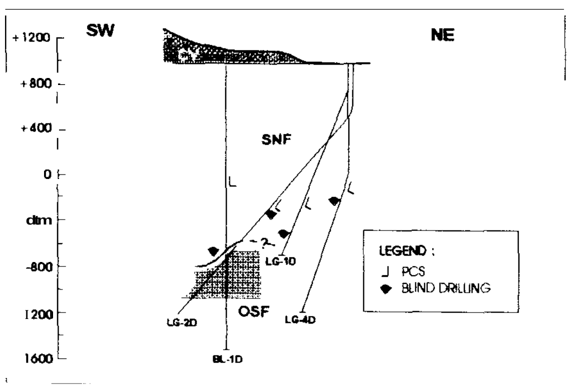


Figure 2 Generalized stratigraphy of Lagunao wells along section B-B'

DISTRIBUTION OF HYDROTHERMAL ALTERATION

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 ferromagnesians, 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, about + 300 mRL in LG-1D and LG-4D, and around +200 mRL in LG-2D, LG-3D and BL-1D (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-1D, 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.

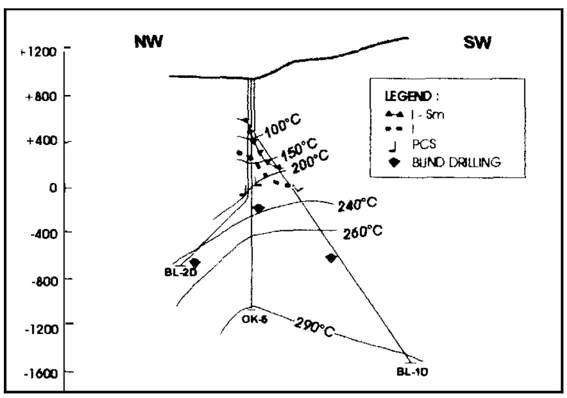


Figure 3. First appearance of illitic clays in Lagunao wells along section A-A'.

Below 0 mRL, replacement illite increases in abundance and usually occurs as whole-rock alteration in the SNF breccias and is most llkely recent at these depths.

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 leucoxene.

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-ID, LG-2D, LG-3D and LG-4D strongly suggest that these minerals are either detrital or relict phases at shallow depths in Lagunao, 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 Lagunao.

Subhedral and euhedral epidote is likewise found as vein deposits in almost all Lagunao 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 anhydnte.

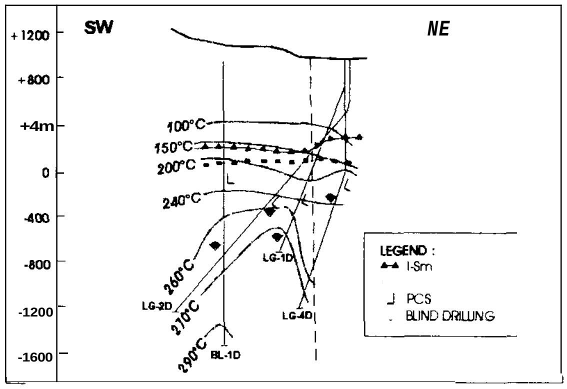


Figure 4. First appearance of illitic clays in Lagunao wells along section B-B'.

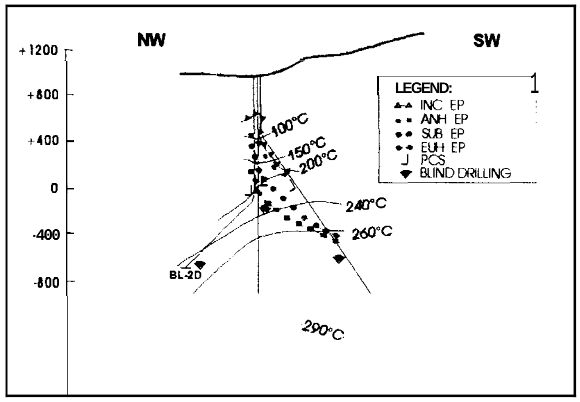


Figure 5. First appearance of replacement epidotes in Lagunao wells along section A-A'.

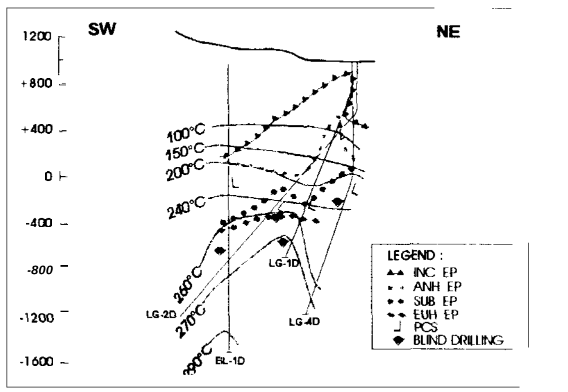


Figure 6. First appearance of replacement epidotes in Lagunao wells along section B-B'.

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.

In general, the acid mineral phases occur as replacement of completely altered clasts of the **SNF** breccias, alongside with volcanic fragments whch 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.

<u>**Hydrothermal Sulfide Minerals**</u>

The hydrothermal sulfide phases in Lagunao wells consist mainly of pynte and chalcopyrite. The minor sulfide minerals include covellite/chalcocite, bornite, maclunawite (?), 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.

b) ***Chalcopyrite*** ($CuFeS_2$) is the second major sulfide (Fig. 9). It usually occurs as fine to very fine anhedras often associated with pyrite, bornite, and covellite/chalcocite. Medium to coarse chalcopyrite grains are generally more common in BL-1D and LG-ID. Chalcopyrite exists as disseminations, and occasionally as

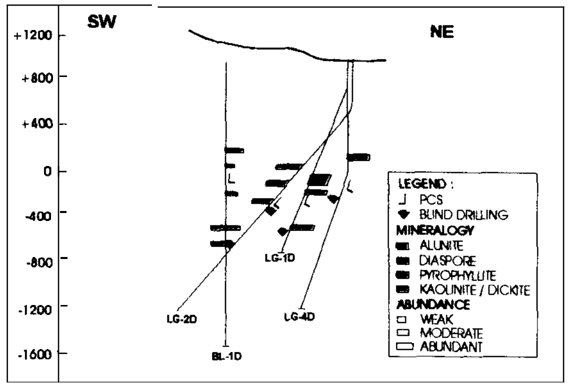


***Figure** 7. **Acid occurrences in Lagunao wells along section** B-B'*

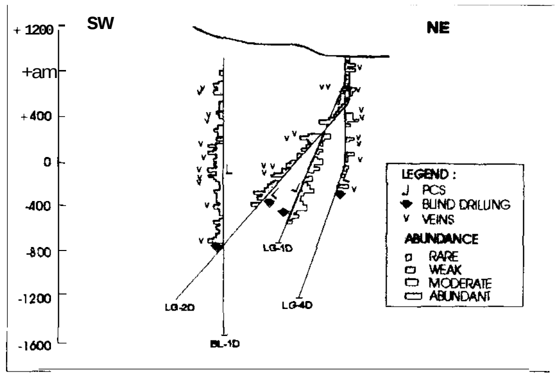


***Figure 8. Distribution of pyrite in Lagunao wells along section** B-B'.*

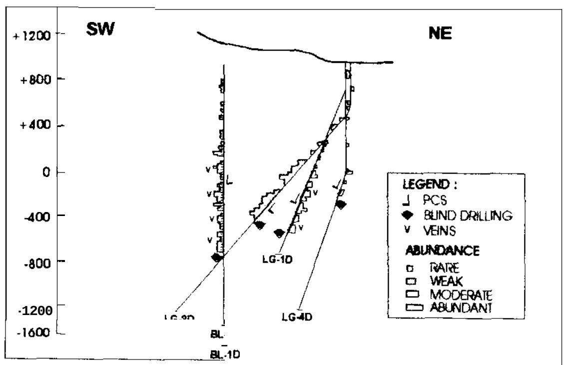


***Figure** 9. **Distribution of chalcopyrite in Lagunao wells along section** B-B'.*

c) alteration rims of pyrite. It is present in weak to moderate quantities in BL-ID and LG-1D, and in rare to weak amounts in LG-ID, **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.

d) The copper sulfides *covellite/chalcocite* (CuS/Cu_2S) are sporadically present in rare to weak amounts (≤ 1%) in all the Lagunao wells. Moderate quantities (–10%) of covellite/ chalcocite were even observed at -460 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.

e) ***Bornite*** (Cu_5FeS_4) comprises **≤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/ chalcocite, pynte, sphalerite and magnetite. It occasionally shows alteration to covellite/ chalcocite or chalcopyrite.

f) ***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 chalcopynte inclusions.

g) *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 pynte. It shows alteration to chalcopynte.

h) ***Galena*** **(PbS)** is a rare sulfide found at two depths in LG-3D. It occurs as fine isolated subhedras.

i) ***Native copper*** (Cu) is conspicuously present as pink, tarnished, scratched grains above 0 mRL in all the wells studied. Fine to medium anhedras and subhedras of native copper comprise < 1 % of the total polished section area. It is mainly associated with hematite and pynte.

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 150-180°C, while illite dominates at depths where hotter (≥ 220°C) temperatures exist. In addition to clays, the morphology of epidote is another useful geothermometer. At temperatures of ~180-200°C, epidote crystals tend to be incipient to poorly crystalline, while at ~200-230°C, epidote grains turn subhedral. Finally, euhedral epidote crystals develop at temperatures equal to or greater than 240-250°C.

In Lagunao, the occurrences of clays and epidotes in BL-ID, and below 0 mRL in LG-ID, LG-2D, **LG-3D**, OK-5 and BL-2D agree with present reservoir temperatures. For instance, in BL-ID, illite-smectite appeared at –150°C, wlule illite first occurred at +50 mRL where temperatures are close to 220°C (Fig. 3). The epidotes in BL-1D 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-1D, LG-3D, OK-5 and BL-2D all agree with reservoir temperatures (Figs. 3, 4, 5, and 6). The compatibility of these mineral geothennometers with present temperatures confirms that neutral-pH hydrothermal alteration in BL-1D, 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-1D 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.

On the other hand, at shallow levels (above *0* mRL) in LG-1D, 2D, 3D, 4D, BL-2D and **OK-5,** epidote and clays occur at depths where temperatures are much lower than their formation temperatures (Figs. 3, 4, **5** and 6). For example, incipient epidote already exists at +640 mRL in OK-5 where temperatures are less than 100°C, while anhedral epidote is already observed at + 400 mRL where temperatures are only 100°C. The discrepancy of these shallow mineral occurrences with present reservoir conditions indicates that these minerals are relict phases which are not deposited **by** present neutral-pH fluids. Moreover, their observed retrogradation and their existence as clast alteration suggest that these minerals are truly relict at shallow

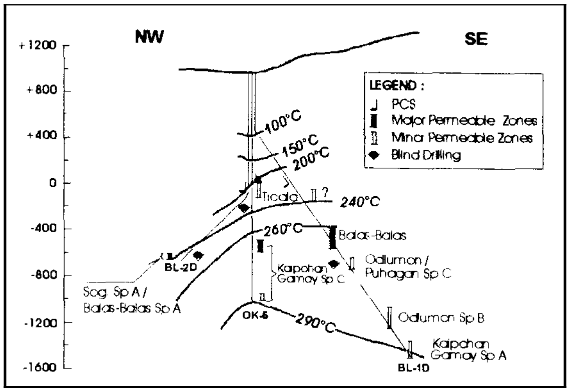


Figure 10. Structures and permeable zones of Lagunao wells along section A-A'.

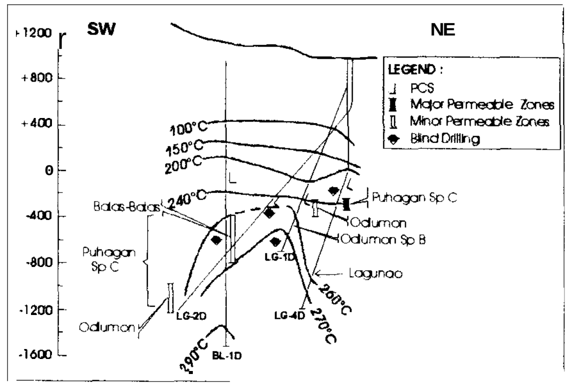


Figure 11. Structures and permeable zones of Lagunao wells along section B-B'.

depths in Lagunao. The hydrothermal sulfides above 0 mRL in LG-ID, 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 dnlling, no **rock** samples were collected in OK-5 below -200 mRL. Nonetheless, the neutral Qscharge fluids of this well implies that neutral brine is also flowing along Kaipohan Gamay Splay C, the structure associated with the major feed at -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 Qscharge 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 Qscharge 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.

Balas-Balas Fault also channels neutral-pH fluids in BL-1D 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-ID at *-650* to -730 mRL whch lies within the blind-drilled section. Thus, the hydrothermal alteration at this interval cannot be determined. However, based on the neutral Qscharge of LG-2D whch intersected these faults, neutral-pH fluids are believed to be also flowing along the intercepts of Odlumon and Puhagan Splay C in BL-1D. 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 Qscharge, 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-1D (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-ID 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

All structural data taken from Camit and Villarosa, 1996.

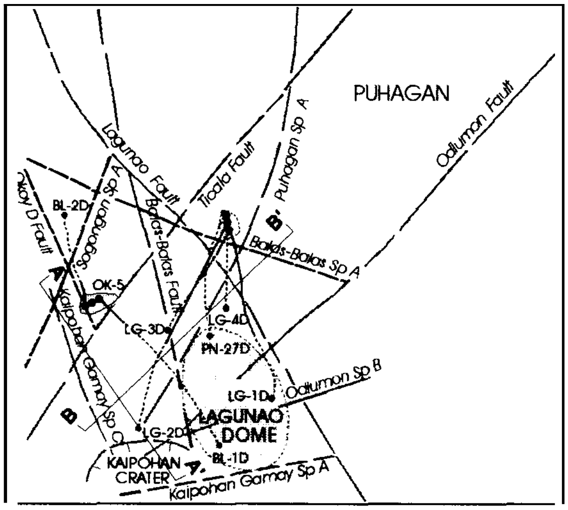


Figure 12. Structural map of the Lagunao sector.

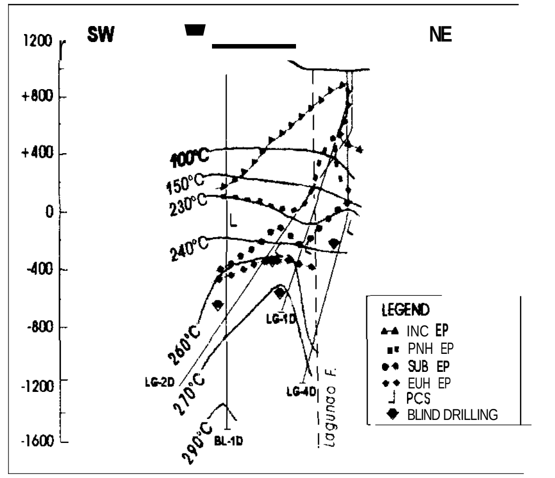


Figure 13. Intersection of Lagunao wells with Lagunao fault.

(Ramos-Candelaria, 1992). Odlumon Splay B can be correlated to the probable acid feed in LG-1D. This same fault probably conducts acid waters in BL-1D.

Based on correlation with hydrothermal alteration and results of Qscharge 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.

ROLOGIC 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 dnlling, hydrothermal alteration within many production zones cannot be assessed. Nonetheless, the chemistry of their Qscharge 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-1D, 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-1D 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-1D, **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-ID, **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. 14)

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 regons 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 llkely boundaries of the neutral upflow region in Lagunao.

On the southwestern regon, 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 margn 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 acidlc. Thus, though BL-1D and LG-1D intersected neutral brine at their shallow feeds, their deeper aquifers located southeast of Odlumon Fault are producing acidlc fluids (Fig. 15). The plunge of the 290° C stable isotherm from OK-5 towards BL-1D (Fig. 16) confirmed that the bottom of BL-1D did not tap the upflow region.

Thus. the postulated upflow of hot, neutral brine in Lagunao is llkely bounded **by** Ticala Fault in the northwest, Lagunao 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 hhagan, Nasuji and Sogongon are outflow regons. The heat source presently driving the Palinpinon hydrothermal system could be a huge, magmatic ***body*** related to the Pleistocene Cuernos de Negros Volcano.

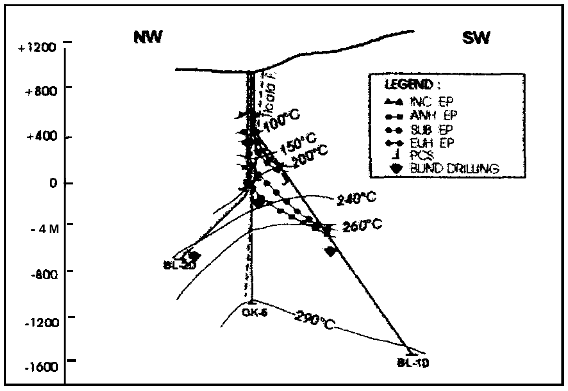


Figure 14. Intersection of Lagunao wells with Ticalafault.

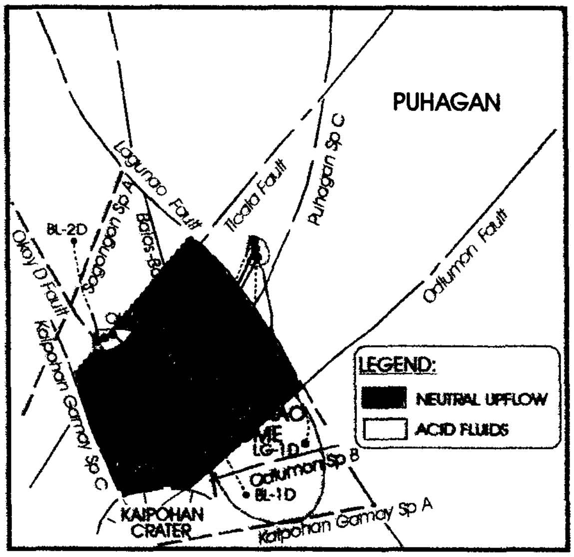
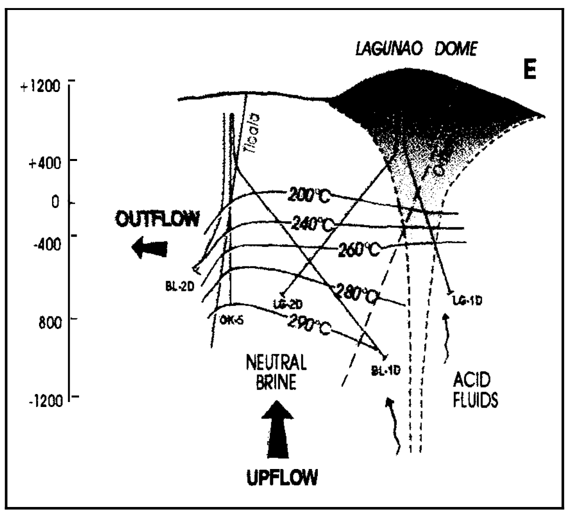


Figure 15. Plan view of the conceptual model of the Lagunao hydrothermal system.



igure 16. Conceptual model of the Lagunao hydrothermal system.

ORIGIN OF ACID FLUIDS IN LAGUNA0

Among the seven wells in Lagunao, **only** two wells encountered acid-sulfate fluids based on their discharge chemistry - LG-1D and BL-1D. The 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).

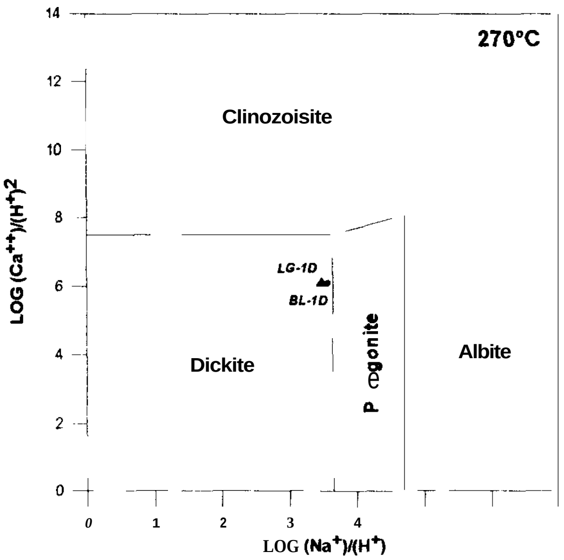


*Figure 17. Stability diagram **for** minerals in **the** CaO-Na_2O-Al_2O_3-SiO_2-H_2O system at 270°C.*

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 dlrect petrologic evidence can be used to determine the nature of acid fluids in Lagunao. In addltion, no wells were spudded near the Kaipohan acid altered grounds to confirm whether a thick shallow acid alteration zone has indeed been formed **by** descending surficial acid waters as postulated **by** Seastres and Hermoso (pers. comm., 1995).

In the absence of dlrect petrologic **data,** results of petrologic evaluation of the shallow acid fluids in Cawayan (Rosell and Ramos, pers. comm., 1997) will be applied in Lagunao. 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 surface (+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 whch 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 ≥ 280°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 acidlc. At these great depths and high temperatures, surficial acid waters will most llkely be already neutralized through interaction with country rocks as they flow down along structural channels.

No dlrect 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-1D, 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-1D fluids yielded a high $\delta^{34}S$ value (~ 20 ‰) in dissolved sulfate which is too enriched to be derived from surficial oxidation of H_2S whose $\delta^{34}S$ is only 0 to -3 ‰. This discrepancy in $\delta^{34}S$ 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 **tha** bottomholes of the acid wells BL-1D and LG-1D to the possible neck of Lagunao dome suggests that the acid fluids are ldcely related to the deep-seated root of this dome. The acidity of the fluids can be attributed to the presence of acidlc gases such as SO_2 and H_2S exsolved from the cooling magmatic source of the Lagunao dome, whch is llkely shallower and distinct **from** the deeper magmatic **body** presently driving the Palinpinon neutral hydrothermal system.

IMPLI(ON FUTURE DRILL

Based on the conceptual model of Lagunao, the upflow of neutral chloride brine with temperatures of ≥ 300°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 whch 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 ldcely 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 dnlled to avoid the postulated **deep** acid waters.

ACKNOWLEDGMENTS

The authors wish to thank Maribel Zaide-Delfin for her critical review of our paper. We also thank **Dennis** Sanchez for helping with the WATCH software. To **Manny** Teoxon and Teddy Amper who drafted the figures, and Menchie Melo who prepared the final lay-out of our manuscript, our gratitude is extended.

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