APPLICATION OF Cl, B TRACERS AND GEOINDICATORS TO DELINEATE SOME PRODUCTION CHARACTERISTICS OF MT. LABO GEOTHERMAL SYSTEM, PHILIPPINES

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ABSTRACT

This report focuses on interpretation on water chemistry in the Mt. Labo area with respect to delineating the characteristics of its waters. The types of waters in the area are: a) dilute neutral pH warm springs, b) alkaline Cl hot springs, c) acid to neutral pH SO_4-Cl warm springs, d) slightly acid (pH of 5.1 at 270°C) Cl well waters, with relatively high SO_4.

The source of supply of Cl and B in the warm springs is the rock, with these waters react. On the other hand, the main source of supply of Cl in the other types of water is considered to be the magma heat source to geothermal system. In these latter water types, however, most of the B is derived from the dissolving rock. The SO_4-Cl warm springs are considered to form by mixing of magmatic gases with surface waters, whereas, the alkaline Cl hot spring waters and well fluids are formed by mixing of magmatic gases at depth.

The acid to neutral pH SO_4-Cl waters are relatively far from equilibrium for secondary minerals, geothermometry results for these waters are not considered to be reliable. Quartz equilibrium temperatures (266 to 270 °C) for the well discharges match accurately with the measured temperatures (270°C), indicating that equilibrium is attained with respect to quartz in the reservoir.

1.0 Introduction

In the present study, the behavior of the Cl and B tracers and geoindicators is assessed and subsequently applied to delineate the chemical characteristics of the recently drilled geothermal field at Mt. Labo in the Philippines. The field is located in the province of Camarines Norte at the Northern tip of the Bicol Peninsula in the southeastern Luzon (Figure 1).

The database on water composition selected to answer the above questions are from the data by Clemente (1990), Gerardo (1993), and Sanchez (1993). In all 43 analyses from rivers and springs are used and 23 from wells, both downhole and discharge samples. The two exploration wells have only one dominant feed zone. Downhole measurements have been used to obtain the aquifer temperature.

2.0 Chloride and Boron

The contribution of Cl and B to natural waters at Mt. Labo from degassing magma (Cl_m and B_m) and rock dissolution (Cl_r and B_r) can be calculated from the Cl/B ratios of these sources and the measured Cl (Cl_w) and B (B_w) concentrations in water samples. These could be calculated as:

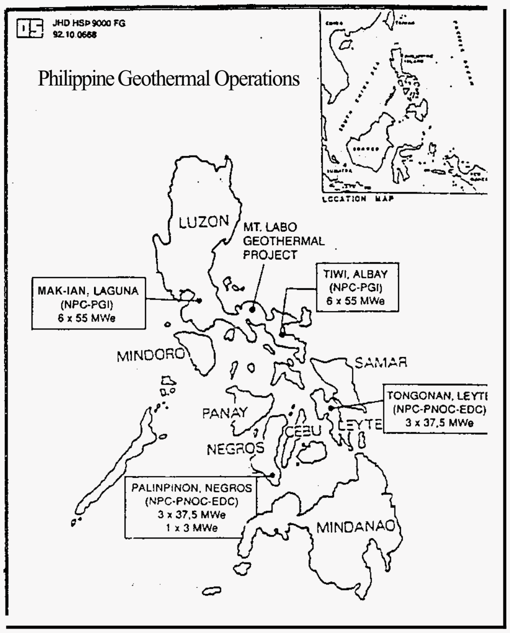


FIGURE 1: Location of Mt. Labo geothermal project and present geothermal production operations in the Philippines

$$B_w = B_r + B_m \qquad (1)$$

$$Cl_w = Cl_r + Cl_m \qquad (2)$$

$$Cl_m = (Cl_w - R \times B_w) \times P \qquad (3)$$

$$\text{where } P = \frac{M}{M-R},\ P > 0$$

where R and M are the Cl/B mass ratios of rock dissolution and the degassing magma, respectively.

The closer the selected value of M is to that of R, the greater the magmatic contribution to the hydrothermal system for a given aqueous Cl/B ratio. This becomes evident by using the Cl/B_m ratio of 671 (Le Guern and Bernard, 1982; Symonds et al., 1987) instead of the larger value of 4276 (Symonds, 1992), though both values are derived from the data on gases from andesitic magma. If R is fixed at a value of 10, P becomes equal to 1.015 and 1.0023, respectively. It is apparent that the difference between the P values from the two andesitic Cl/B_m ratios is small (about 1.23%), and the variation in the calculated Cl_m is governed by the Cl and B concentrations of the geothermal waters and not by the selected Cl/B ratio of the magma source. Therefore, Eq. 3 gives almost similar results for different andesitic magma heat

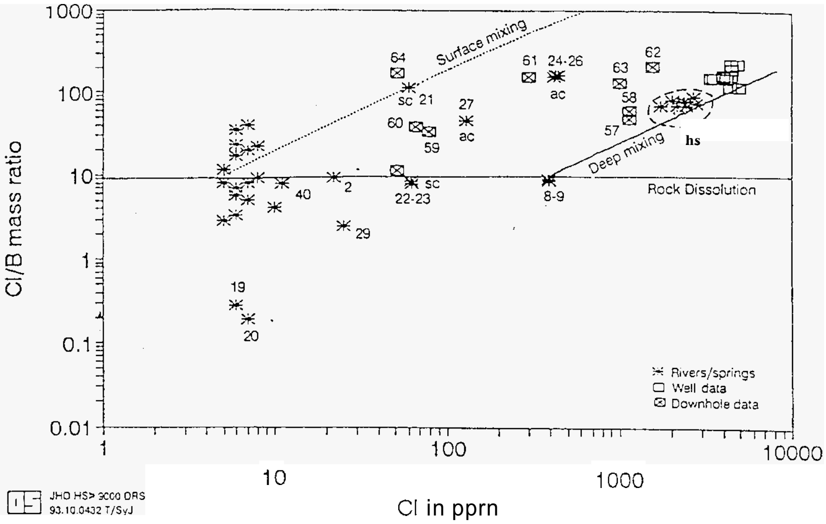


FIGURE 2: Distribution of Cl/B of Mt. Labo waters vs. Cl. The Cl and B in these waters is assumed to have originated from rock dissolution and degassing of the magma heat source. Rock dissolution is delineated at Cl/B equal to 10. The effect of the magmatic gas contribution on the Cl/B-Cl relationship in surface and deep waters is also shown. A Cl/B ratio of 4276 was assumed for the magmatic gases. The magmatic gases may mix with surface water or deep waters. (Spring waters that have significantly reacted with the rock and the degassing magma are labelled by a number code and **ac** (for acid pH SO_4- Cl spring), **sc** (for neutral pH SO_4-Cl spring), or **hs** (tor neutral pH alkali-Cl hot spring); downhole samples are also labelled by a number code.)

sources. In this report we used the M value of 4276 to estimate the minimum contribution of the degassing andesitic magma in geothermal waters.

Figures 2 and 3 show the relation between Cl and B in samples from rivers/springs and well fluids where Cl/B and B plotted against Cl, respectively. The andesitic rock dissolution is delineated at a Cl/B ratio of 10. Similarly, the mixing lines from the degassing magma are also delineated. Two types of mixing were considered:

1. Mixing of magmatic gases with surface waters
2. Mixing of magmatic gases with deep waters

Magmatic gases mixing with surface waters

There are five springs that could be considered products of magmatic gases being mixed with surface waters. They are U. Mabahong Labo springs, coded as 21 and 24-27; all are sulfate Cl springs. Spring 21 has a neutral pH while there have a pH of 3.1 to 3.5. Clemente (1990) considered their sulfates a product of near surface oxidation of H_2S (i.e. by atmospheric O_2), and the high Cl contribution from a neutral-pH Cl reservoir, channelled by the Mabahong Labo fault. In view of recent welldata, however, this seems an unlikely source for the Cl, because the springs are located at high elevation (550 to 650 masl) the groundwater level is at least 100 m below the springs (Biniza, 1990) and the geothermal waters at depth have a low pH (5.1).

The surface mixing curves indicated in Figures 2 and 3 correspond to the addition of Cl and B from the magma source to surface waters containing approximately 5 ppm of Cl with Cl/B ratio of 10. The line is generated using Eq. 4:

$$Cl/B = Cl_w/B_w = \frac{Cl_m + Cl_r}{Br + \frac{Cl_m}{4276}} \qquad (4)$$

The waters of the acid to neutral-pH SO_4-Cl springs at U. Mabahong Labo (21, 24-27) are considered to be products of the mixing of magmatic gases with the surface waters. The Cl content of spring No. 21, in particular, is a direct result of mixing of Cl from the magma with surface waters, but the neutral pH of this spring is caused by water rock interaction subsequent to mixing. The dissolution of the magmatic gases SO, and HCl has turned the waters of springs 24-27 acid, causing considerable rock dissolution, which has raised the concentration of Cl. This explains why the data points for samples 24-27 fall below the surface mixing curve.

Magmatic gases mixing with deep waters

The well fluids (44-56) and the Kilbay-Alawihaw hot springs (5-7, and 11-15) could be considered products of the mixing of magmatic gases with deep waters. The low pH (5.1) of the well fluids is due to the dissolution of SO, and HCl gases that are channelled along the Mabahong Labo fault to the deep water. The mixing curve for the deep waters and the magmatic gases is generated from Eq. 4. The initial values of Cl_r and B_r set at 390 and 39 ppm, respectively. These are the Cl and B concentrations of Baay springs (8,9), respectively.

The amount of Cl and B in the geothermal waters derived from magmatic gases

The degree of mixing of magmatic gases with surface and deep waters can be evaluated with the aid of Figures 2 and 3. In Figure 2, Cl/B is plotted against Cl, while B is plotted against Cl in Figure 3. Although Figure 2 could also be used to explain B in the fluids, the letter figure was presented to illustrate, in detail, the behavior of B in these mixing processes.

The amount of Cl_m in the geothermal waters is computed by expressing Eq. 4 in terms of Cl_m and Cl_w, where U is calculated Cl_w/B_w mass ratio. of the sample, and M (equal to 4276) and R (equal to 10) are the Cl/B mass ratios of andesitic magma gas and the andesitic rock. respectively:

$$Cl_m = Cl_w \times \frac{M \times (R-U)}{U \times (R-M)} \qquad (5)$$

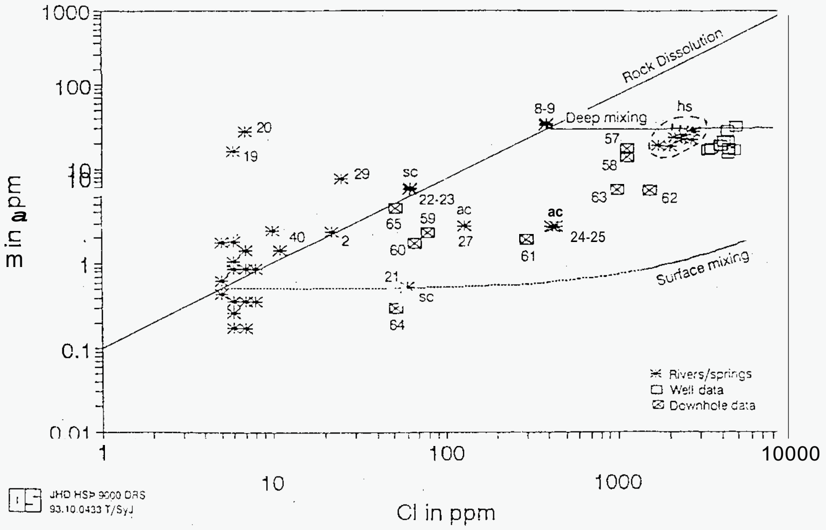


FIGURE3 : Distribution of B in hlt. Labo waters vs. Cl; the same assumptions are made as in Figure 6. The B originating from the dissolving rock and degassing magma is evaluated from the Cl/B ratios of 10 and 4276, respectively. (The symbols and the codes are the same as in Figure 2)

TABLE 1: Summary of the calculated amount of Cl and **B** in natural waters at Mt. Labo deriving from **a)** the dissolving rock, and b) degassing magma

Source	*No.* Code	Cl_w	B_w	$U = Cl_w/B_w$	Cl_m	B_m	Cl_r	8,	$\%Cl_m$	$\%B_r$
U. Mabahong Labo	21	60	0.52	115.4	55	0.013	51	0.51	82	98
U. Mabahong Lsbo	24	446	2.68	1664	420	0.098	25.8	258	94	96
U. Mabahong Lqbo	25	427	2.59	1649	402	0.094	25.0	250	94	96
U. Mabahong Labo	25	420	2.68	156.7	394	0.092	25.9	2.59	94	97
U. Mabahong Labo	21	128	2.73	469	101	0.024	21.1	2.71	79	99
Kilbay-Alawihaw	5 to 7 &									
hot springs (avg)	11 to 15	2312	2955	78.2	2021	0.473	290.8	29.08	87	98
Wells (avg)	44 to 56	4240	2 6 W	163 1	3989	0.933	250.7	25.07	94.	96
Downhole	57	1142	22.50	50P	919	0.215	222.9	2229	80	99
Downhole	58	1142	18.20	62 7	962	0.225	179.7	17.97	84	99
Downhole	59	79	2.30	343	56	0.013	22.9	2.29	71	99
Downhole	60	66	1.70	38 8	49	0.011	16.9	1.69	74	99
Downhole	61	299	1.93	157.4	281	0.066	18.3	1.83	94	97
Downhole	62	1547	7.30	211 9	1477	0.346	69.5	6.95	96	95
Downhole	63	1000	r.40	135.1	928	0.217	71.8	7.18	93	97
Downhole	64	52	0.30	1733	49	0.011	2.9	0.29	94	96
Downhole	65	52	4.50	11.6	7	0.002	45.0	4.50	13	100

Note:
1. Cl_m and B_m are Cl and B from degassing magma.
2. Cl_r and 8, are Cl and B from rock dissolution.
3. Cl_w and 8 are Cl and 8 as analyzed.

B_m is computed by expressing Eq. 4 in terms of B_m and B_w

$$B_m = B_w \times \frac{U-R}{M-R} \qquad (6)$$

Subsequently, Cl_r and B_r are computed using Eqs. 1 and 2. A summary of computed percentage of Cl and B in the Mt. Labo waters derived from rock dissolution and magmatic gases is presented in Table 1.

3.0 Geoindicator (SiO_2)

Various studies indicate that rock dissolution, rather than mineral-solution equilibria, is the principal process affecting the composition of natural surface waters and cold groundwaters. As these water seep into the ground and develop into geothermal water by gaining heat they attain saturation with respect to various hydrothermal minerals. Through precipitation of these minerals water tend to equilibrate with them. Crossplots of specific geoindicators against a tracer for thermal and non-thermal water in a particular area can help assessing the state of evolution of the water and in this way aid geothermometry interpretation. **A** line of assumed "incompatible behavior", i.e. following stoichiometric dissolution, for SiO_2 geoindicator, is delineated in the figure to illustrate the behavior during rock dissolution stage.

Rock dissolution diagram

From Figure 4, it can be seen that all warm springs that have reacted significantly with the rock and the magmatic gases as deduced from their Cl and B content (springs 2,8,9,21,22-27,29,40), as well as the hot spring and well fluids, are shifted away from the dissolution line. On the other hand, surface waters (unlabelled asterisk) align approximately along the dissolution lines, indicating that the activities of the geoindicators in surface waters are not controlled by mineral-solution equilibria, but their dissolution from the rock.

The lateral shift of the warm springs (labelled asterisk) and the well fluids away from the dissolution line could be due to: a) precipitation of the respective geoindicator species from solution to form secondary minerals, or, b) the addition of Cl to the water from the magma source, or any combination of the two processes. The dissolution diagrams cannot differentiate or identify which process or processes are involved. However, certain salient features could be deduced using these diagrams.

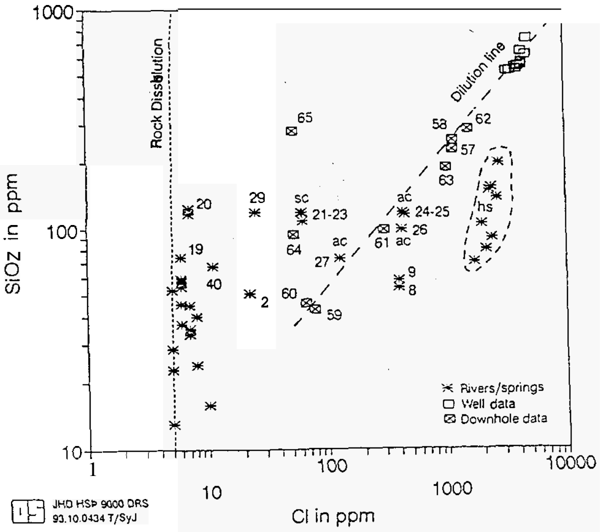
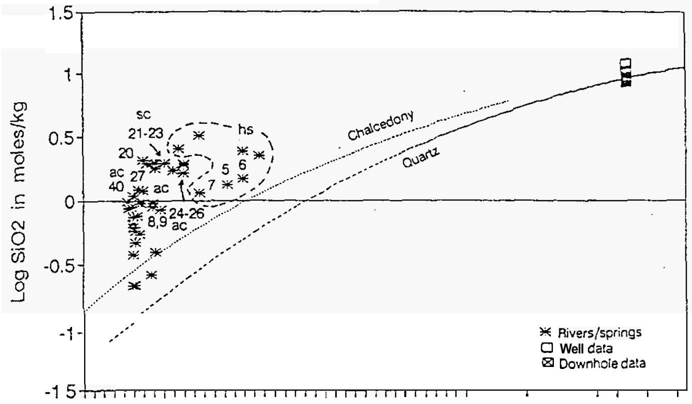


FIGURE **4** : The distribution of SiO_2 vs. total Cl in natural waters at Mt. Labo; the slope of the line (3020) represents the ratio of SiO_2/Cl in andesitic rock. It is drawn through a value of 5 ppm Cl at zero SiO_2, the estimated Cl concentration in local precipitation



In Figure **4**, the data points for neutral pH alkali-Cl hot springs (hs group) do not align along the dilution line of the well fluids and downhole samples. This indicates that SiO_2 of the hot springs could either br controlled by a different SiO_2 mineral, or which seems more likely, the hot spring waters have lost silica in the upflow through precipitation. Therefore, quartz equilibrium temperatures for the hot springs will be low in relation to actual aquifer temperatures.

In Figure 5 the data points for the hot springs are above the saturation line, indicating that the water in these hot springs are supersaturated relative to quartz. However, the well fluids plot close to quartz solubility curve, indicating that the water at depth is close to equilibrium with quartz. The close alignment of some of the hot springs (5-7) with the chalcedony saturation line indicates that these waters have attained equilibrium with chalcedony saturation line indicates that these waters have attained equilibrium with chalcedony at the prevailing discharge temperatures. If these waters have attained the temperature observed at depth in the wells, the hot spring waters must have lost a considerable amount of silica in the upflow through precipitation, yet not sufficient to attain equilibrium with quartz at the spring discharge temperatures, and generally not with chalcedony either.

On the basis of the quartz solubility data of Fournier and Potter (1982), the last equilibration temperature of the hot springs (5-7) are found to range from 120 to 130°C, the last equilibration temperatures of the hot springs (5-7) are found to range from 120 to 130°C, while for the wells the measured temperature (270°C) is almost equal to the quartz equilibrium temperatures, ranging from 266 to 270°C.

4.0 Conclusions

The types of waters in Mt. Labo Geothermal system are a) dilute neutral pH warm springs, b) alkaline Cl hot springs, c) cid to neutral, pH SO_4- I warm springs, d) slightly acid (pH of 5.1 at 270°C) Cl well waters, relatively high SO,

The source of supply of Cl and B in the warm spring water is the rock, with these waters react. On the other hand, the main source of supply of Cl in the other types of water is considered to be the magma heat source to the geothermal system. In these latter water types, however, most of the **B** is derived from the dissolving rock. the SO_4-Cl warm springs, are considered to form by mixing of magmatic gases with surface waters, whereas, the alkaline Cl hot springs waters and well fluids are formed by mixing of magmatic gases at depth.

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