

GEOPHYSICAL MODEL OF MT. LABO GEOTHERMAL FIELD, SOUTHEASTERN LUZON, PHILIPPINES

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Abstract

The geophysical model of Mt. Labo geothermal field, based on the results of the regional gravity and magnetotelluric (MT) surveys, indicates a geothermal reservoir centered beneath the Mabahong Labo thermal ground. The heat source of the present hydrothermal system is provided by a cooling intrusive body, mapped as a gravity high, associated with the Mt. Labo volcanic activity. The geothermal fluids circulate along fractures within the low-density reservoir rocks of the Susung Dalaga Formation. This reservoir rock shows relatively high resistivity values of 30 to 40 ohm-m. Directly overlying the resistive reservoir, occurring between -1000 m to -1500 m, is a thick alteration halo formed within the basal unit of the Labo Volcanics (Lbu). The predominantly hydrous, low-temperature clay minerals which compose the alteration halo give low resistivity values of 1 to 4 ohm-m. Outflow of hot fluids to the south-southwest, which possibly feeds the thermal springs at Kilbay and Alawihaw, may be channeled along the thinning low resistivity Lbu. The geophysical model also shows a possible separate hydrothermal system in the west associated with a relatively shallower intrusive body, also defined by positive gravity values. This intrusion, which could be related to the cluster of volcanic domes located south of Bakilid Fault, may provide the heat that drives the hot springs at Kilbay and Alawihaw. It could also be possible that the Kilbay and Alawihaw springs originate from both systems.

Based on the interpretation of the gravity and MT data, wells LB-ID and LB-5D lie closest to the intrusive, LB-3D and LB-4D are located in the center of the resource, while LB-2D and LB-6D lie along the margin or outside of the resource. The size of this resource, as defined by the 5 ohm-m MT low resistivity anomaly, is about 10 sq. km.

1.0 INTRODUCTION

Mt. Labo has been the object of geothermal exploration since the early 1980's. Total Exploration, in a joint venture with the Philippine Oil and Geothermal, Inc. (POGEL), conducted extensive studies in the area in 1982. These studies included geophysical surveys such as dipole-dipole and regional gravity. In 1987, PNOC Energy Development Corporation (PNOC-EDC) completed an integrated geoscientific exploration program consisting of geological, geochemical and geophysical surveys to assess the geothermal potential of Mt. Labo (Delfin, et al., 1988). The geophysical measurements consisted of DC Schlumberger resistivity traversing (SRT) and vertical electrical sounding (VES) in 337 and 39 stations, respectively (Layugan et al., 1988). These resistivity surveys defined a large 10 ohm-m anomaly located in the west-southwestern region of Mt. Labo. Results of the integrated study led to the drilling of two exploratory wells between 1990 and 1991. Four more wells were drilled from 1992 to 1994 - all were sited in the eastern half of the 10 ohm-m low resistivity anomaly. Of the six wells, only one discharged high-temperature neutral fluids, three have acid waters, one is relatively cold and one was prematurely abandoned during drilling. Pre-drilling and post-drilling hydrogeological model of Mt. Labo postulates a single large hydrothermal system upwelling in the vicinity of the Mabahong Labo acid SO₄-Cl springs, and predominantly outflowing towards the west-southwest, feeding the chloride springs of Kilbay and Alawihaw (Geoscientific Staff, 1991 and 1995).

In mid-1995, additional geophysical surveys were conducted consisting of Bouguer gravity, magnetotelluric (MT) resistivity soundings and mise-a-la-masse (MAM) profiling. The purpose of the gravity survey was to determine the overall subsurface geological structures. The MT measurements were

aimed at defining the deeper (1000 to 3000 m) resistivity structure beyond the depths (≤ 500 m) penetrated by the SRT and VES methods. The MAM profiling was undertaken to map local fault structures near the drilled area: due to its very limited coverage, the MAM results will not be discussed.

This paper will focus mainly on the results of the regional gravity and MT surveys. In conjunction with other available geoscientific data, a geophysical model of Mt. Labo geothermal field is proposed which has implications on the siting of future delineation wells.

2.0 GEOLOGY

Mt. Labo is the northernmost volcano in the Bicol Volcanic belt, a 200 km long chain of stratovolcanoes in southeastern Luzon. The regional basement consists of Pre-Cretaceous metamorphics and Cretaceous ultramafics found north and west of Mt. Labo (Fig. 1). Unconformably overlying this basement at various places are Tertiary sediments and volcanic rocks. These are then intruded by Paleogene granodiorite and Middle Miocene diorite intrusives.

The geologic map of Mt. Labo geothermal field is presented in Figure 2. The oldest rocks are the weathered and moderately altered Upper Miocene Susung Dalaga Formation found west of Mt. Labo. It consists of andesitic lava flows, agglomerates, and tuffs with intercalated sandstone, siltstone and claystones. Unconformably overlying these volcanics is a Pliocene sequence of shallow-marine sedimentary rocks belonging to the Viñas Formation. Outcrops of this formation in the study area consist of sandstone, poorly to highly fossiliferous air-fall tuffs, calcisiltite, and metamorphosed limestone. This unit is exposed northwest of Mt. Labo. The Labo Volcanics, products of the Pleistocene Mt. Labo volcano, constitute the youngest and most widespread rock unit in the area. These volcanic deposits, which were erupted from 0.6 to 0.08 Ma, are likely associated with the present thermal activity of Mt. Labo. The Labo Volcanics are subdivided into four informal members (Delfin and Alincastré, 1988). The oldest and most widespread member is the basal unit (Lbu) consisting of weathered and variably altered andesite, dacite, and basalt lavas and lahars. Erupted on the surface of the basal unit are numerous lava domes, hornblende dacite (Ldd) and hornblende andesite (Lda) in composition. These are distributed throughout the field with the largest number found southwest of Mt. Labo. The central cone (Lcc) of Mt. Labo overlies the basal unit and possibly some lava domes. It is largely made up of andesite and dacite lavas and laharic breccia. Pyroclastic flows (Lpf) blanketing the main edifice and partly burying some domes, is the youngest unit. They consist of non-bedded, poorly sorted and poorly consolidated to well compacted andesite and dacite block and ash-flows erupted about 80,000 ybp.

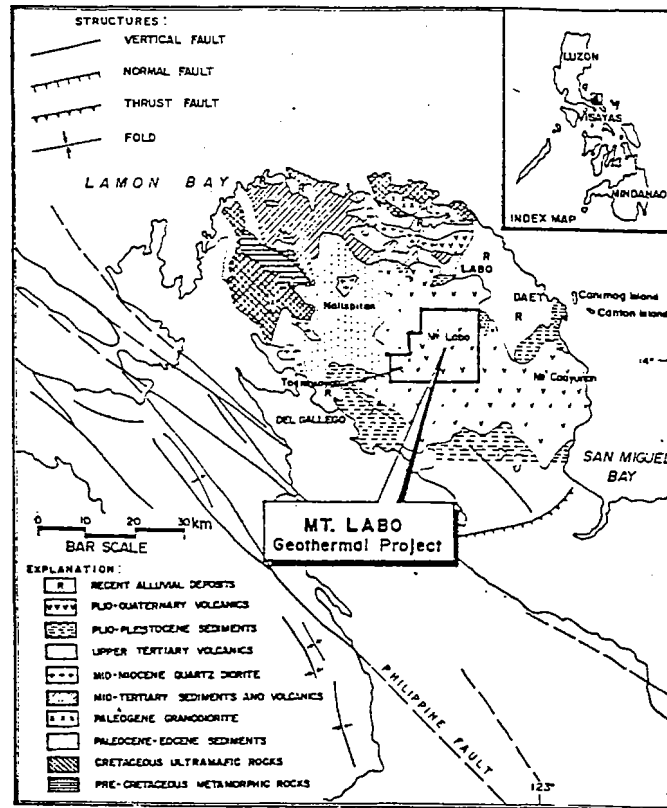


Figure 1. Regional geology of Northern Bicol Peninsula (modified from the Philippine Bureau of Mines and Geosciences, 1981)

This unit is exposed northwest of Mt. Labo. The Labo Volcanics, products of the Pleistocene Mt. Labo volcano, constitute the youngest and most widespread rock unit in the area. These volcanic deposits, which were erupted from 0.6 to 0.08 Ma, are likely associated with the present thermal activity of Mt. Labo. The Labo Volcanics are subdivided into four informal members (Delfin and Alincastré, 1988). The oldest and most widespread member is the basal unit (Lbu) consisting of weathered and variably altered andesite, dacite, and basalt lavas and lahars. Erupted on the surface of the basal unit are numerous lava domes, hornblende dacite (Ldd) and hornblende andesite (Lda) in composition. These are distributed throughout the field with the largest number found southwest of Mt. Labo. The central cone (Lcc) of Mt. Labo overlies the basal unit and possibly some lava domes. It is largely made up of andesite and dacite lavas and laharic breccia. Pyroclastic flows (Lpf) blanketing the main edifice and partly burying some domes, is the youngest unit. They consist of non-bedded, poorly sorted and poorly consolidated to well compacted andesite and dacite block and ash-flows erupted about 80,000 ybp.

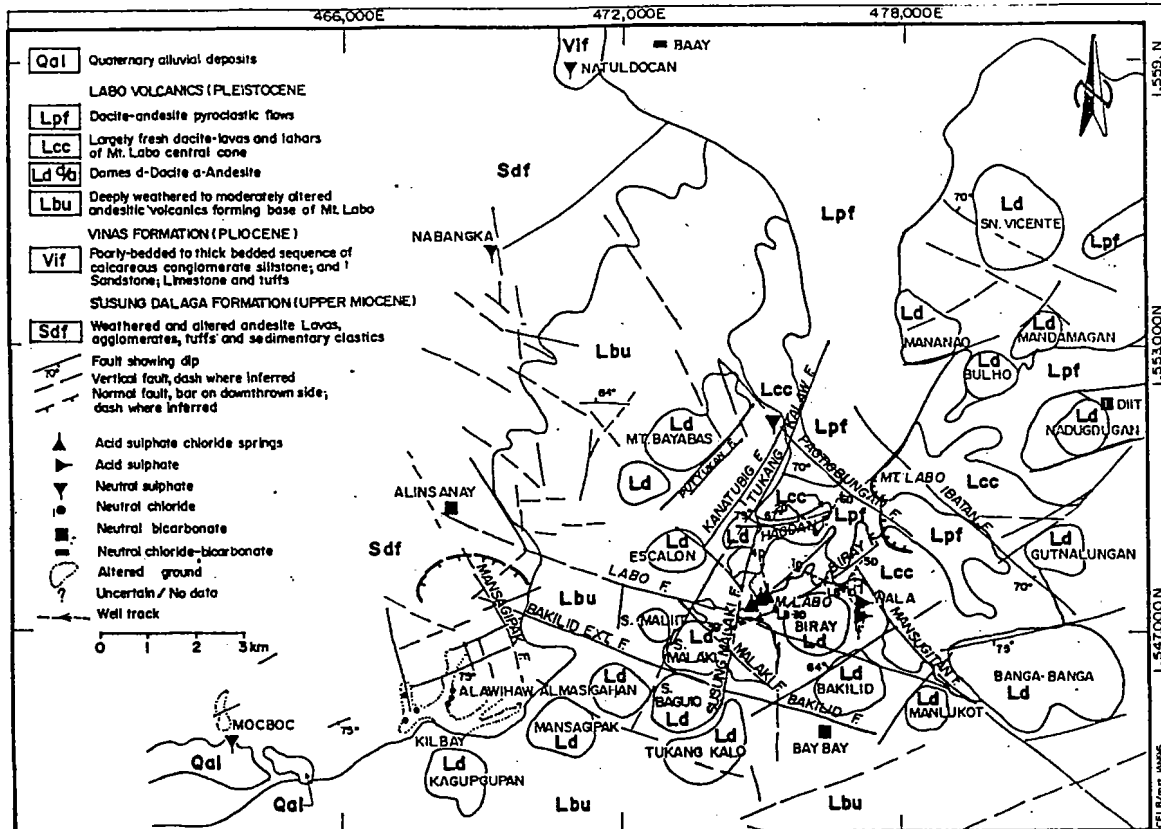


Figure 2. Geologic map of Mt. Labo (after Delfin and Alincastre, 1988; modified by Panem, 1995)

The Mt. Labo geothermal field is cut by northwest and northeast-trending dip-slip faults. **Three** major northwest-striking faults, the Ibatan, Pagtigbungan, and Labo Faults, define a pair of adjoining host and graben-like blocks in the summit and southern flank of Mt. Labo (Fig. 2). The eastern half of this 2.5 to 5 km wide graben is **transected** by several closely-spaced northeast striking faults such as Kanatubig, Tukang Kalaw, Hagdan, Mabahong Labo, and Biray Faults. The resulting configuration is a series of **narrow**, northeast-trending fault **blocks** within, and occasionally **cutting** through, the northwest-trending graben.

3.0 REGIONAL GRAVITY SURVEY

A regional gravity survey **was** conducted in Mt. Labo geothermal project from March to April, **1995** and from July to August, **1995** (Los Baiios and Maneja, **1996**). A total of **169** stations were occupied using a LaCoste and Romberg **G-526** gravity meter. These stations were tied to a Bureau of Coast and Geodetic Survey (BCGS) gravity station in Naga City some **52 km** southeast of Mt. Labo. Station elevations were measured using the single base altimetry method utilizing **two** BAROMEK microbarometers. Station coordinates were read from 1:50,000 topographic maps. The gravity field **data** were corrected for **drift** and **earth** tides and converted to observed gravity values using a **GREUDUC** software. The effect of free-air, latitude, Bouguer and terrain were corrected using **GEOLINK** software to produce the **final** Bouguer anomaly map. The inner terrain corrections (0 to 20 m) were estimated in the field while the intermediate zone (**20 to 100 m**) were read from the topographic maps using a hammer zone graticule. The outer terrain corrections (**100 m to 167 km**) were obtained **from** the digitized topographic map of the project area using the GEOSOFT terrain package.

3.1 Results

The Bouguer gravity values were calculated using a density of 2.3 g/cm^3 (a reasonable value considering the area is underlain predominantly by altered rocks and thick sedimentary formations) producing the Bouguer anomaly map (Fig. 3). This map indicates a huge gravity low of < -1 mgal west of Mt. Labo. Gravity highs with values ranging from 23 to > 29 mgals are concentrated in north-northeast towards the towns of Labo and Daet. The residual Bouguer anomaly map (Fig. 4) was obtained by removing a second order polynomial regional gravity field which indicates a decreasing gradient towards the west-southwest area near Kilbay and Alawihaw hot springs.

The residual gravity contours reveal a pronounced gravity low of -2 to < -6 mgals west of Mt. Labo. Four zones of gravity highs with values ranging from 2 to > 7 mgals are observed: 1) between Tulay na Lupa and Labo town in the north, 2) near Daet in the northeast, 3) to the south beneath LB-ID and LB-5D, and 4) in the southwest within the Kilbay-Alawihaw area:

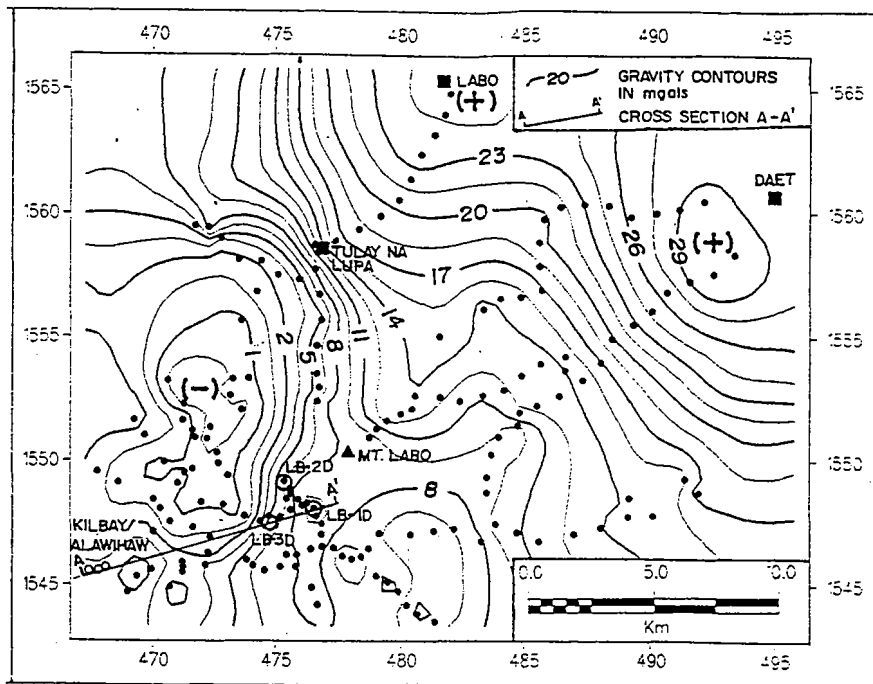


Figure 3. Bouguer anomaly map

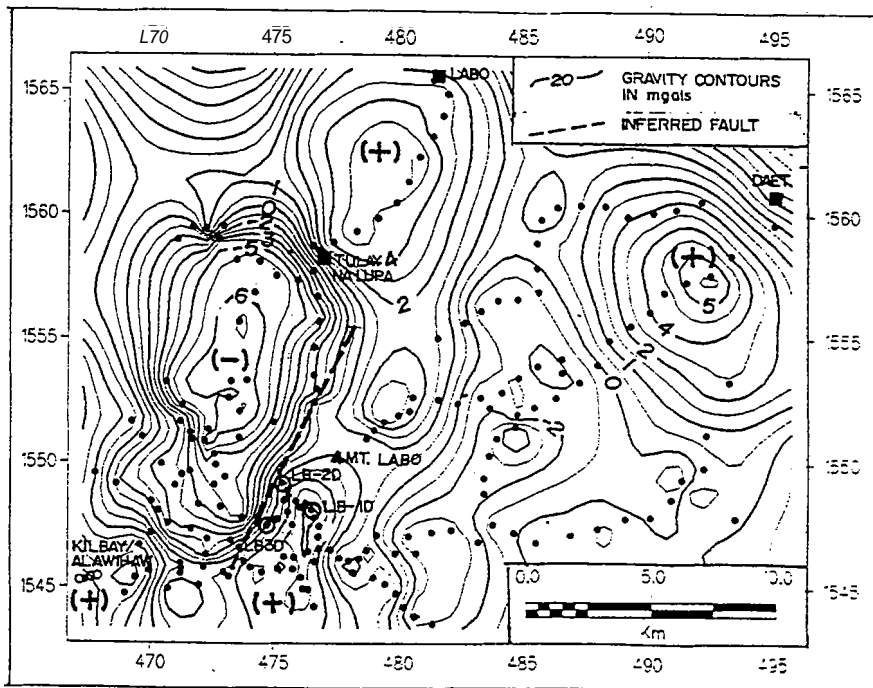


Figure 4. Residual Bouguer anomaly map

A 2.5-D model using the **GEOLINK** software was created for cross-section A-A' (Fig. 5). This section runs west-southwest to east-northeast traversing the Kilbay-Alawihaw area towards wells LB-3D and LB-

ID. The Bouguer anomaly map was used during modelling with the reduction density of 2.3 g/cm^3 as the background density. The boundaries between each polygon adheres to the surface geology while the depths of the different lithologies were constrained by borehole data of LB-ID and LB-3D. The densities used during modelling were based from the rock density of the surface and core samples measured in the laboratory using the volume displacement method. The half-strike lengths and density values of the different bodies are indicated below the model (Fig. 5).

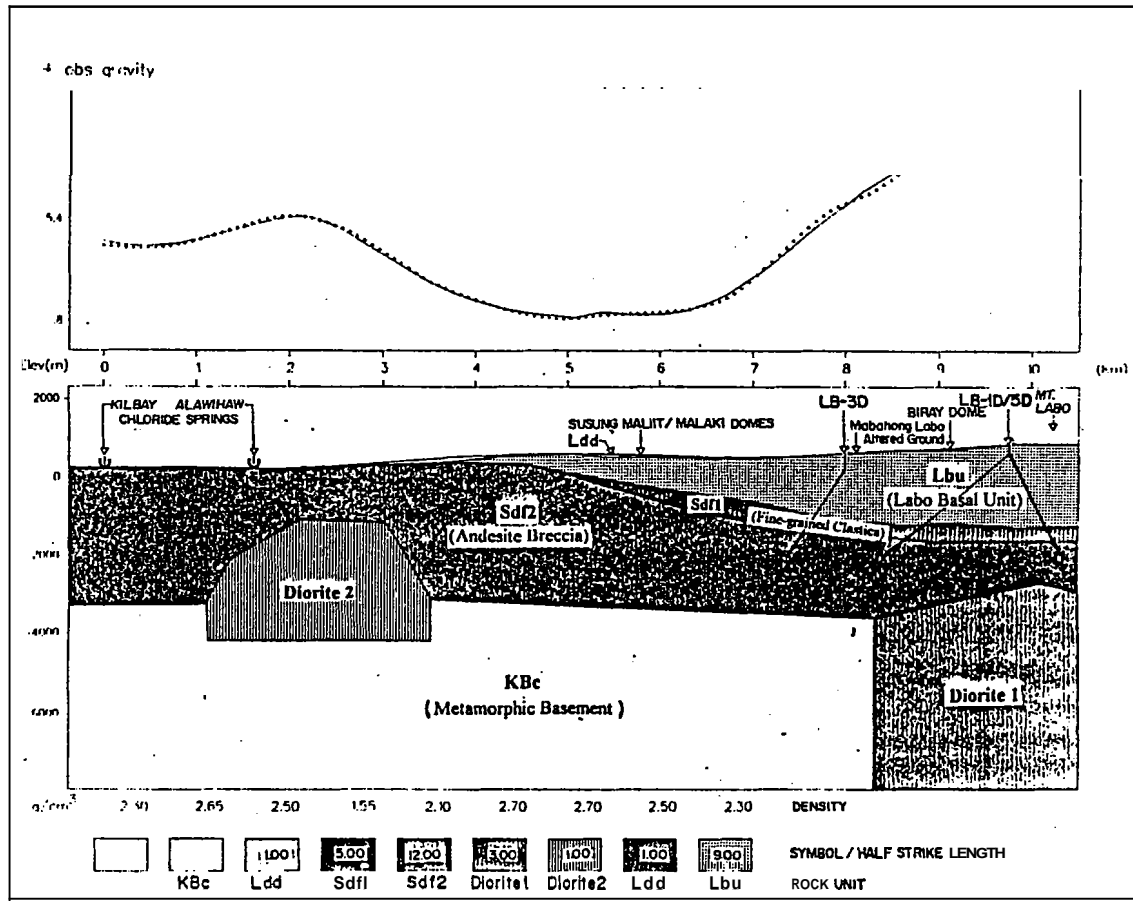


Figure 5. Gravity profile along cross-section A-A'

In cross-section A-A', the Susung Dalaga Formation was modelled to consist of two components. **Sdfl** is the he-grained clastic member composed primarily of claystones, siltstones and sandstones ($\rho=1.55 \text{ g/cm}^3$) intersected by wells LB-ID and LB-3D at depths between 1740 mMD and 1935 mMD, respectively (Panem et al., 1990; Ramos et al., 1992). The **Sdfl** is about 400 m thick and is displaced upward by an inferred fault towards Kilbay-Alawihaw. **Sdf2** is the andesite breccia member ($\rho=2.1 \text{ g/cm}^3$), underlying the he-grained elastics. The **Sdf2** outcrops near the Kilbay-Alawihaw area and extends to depths up to about 2.3 km beneath LB-ID. The Labo volcanics basal unit (**Lbu**) has a density of 2.3 g/cm^3 and is thickest (-1800 m) below LB-ID, reaching a bottom depth of about 1700 m. It eventually thins out towards the southwest. Two diorite bodies namely, Diorite 1 and Diorite 2, were modelled. Diorite 1 is located directly beneath LB-SD at depth of about 4 km while Diorite 2 is found beneath the Kilbay-Alawihaw area at depth of about 1.3 km. Both diorites were modelled to have a density of 2.7 g/cm^3 similar to the density of diorite obtained in Tongonan (Ignacio and Bromley, 19829). The dacitic lava domes of Biray and Susung Maliit/Malaki ($\rho=2.5 \text{ g/cm}^3$) are represented by **Ldd** which attains a maximum thickness of 100 m. Lastly, the depth to the metamorphic basement complex (**KBc**) ranges from 3.1 to 4.1 km from the surface. It is

assumed to have the same density (2.65 g/cm^3) as the one sampled in Mt. Parker area (Apuada and Hallinan, 1995).

3.2 Interpretation

The low gravity zone, elongated in a north-south direction and recognized in the western region of Mt. Labo, correlates with the thick sedimentary rocks of the Susung Dalaga Formation. This formation thickens from east to west and is displaced by a major north-northeast to south-southwest fault structure. This structure is inferred from the steep gradient separating the negative and the positive gravity values as shown in the residual Bouguer gravity maps (Fig. 4). This major structure may coincide with the Tukang Kalaw and Susung Malaki located near wells LB-3D and LB-4D (Fig. 2).

The gravity high within Mt. Labo is associated with the diorite intrusion beneath LB-5D. Likewise, the gravity high observed from the residual Bouguer map is interpreted as a shallower and smaller diorite intrusion in the Kilbay-Alawihaw area in the southwest. This diorite could be associated with the cluster of volcanic domes such as Small Baguio, Almasigahan, Tukang Kalo, Mansagipak and Kagupgupan located south of Bakilid Fault (Panem, 1996 pers. comm.) (Fig. 2). The gravity highs observed near the toms of Daet and Labo are due to a shallow metamorphic basement rock. This interpretation is in close agreement with the increasing gravity gradient towards the north-northeast direction as observed in the regional, Bouguer and residual anomaly maps. The metamorphic basement consisting of Pre-Cretaceous schist and quartzites are exposed in Canimog and Canton Islands (Fig. 1) about 5 km northeast of Daet (Philippine Bureau of Mines and Geosciences, 1981).

4.0 MAGNETOTELLURIC (MT) SOUNDING MEASUREMENTS

A magnetotelluric (MT) sounding survey was carried out at Mt. Labo geothermal project from May to June, 1995. Thirty-two (32) MT soundings were measured in sites located largely west and south of Mt. Labo (Fig. 6). A far-remote reference technique was employed to reduce noise during measurements. This involved a reference site remaining stationary during the entire duration of the survey and two measurement sites occupied simultaneously and later transferred to two new sites the following day. Three sets of Phoenix V-5/SPV-5 MT system were used to record the time-series electromagnetic data. This system allowed data acquisition at 40 different frequencies ranging from 384 Hz (0.003 sec) to 0.00055 Hz (18.18 sec). At high frequency range (384 to 9 Hz) the depth of investigation is roughly a few hundred meters while penetration to depths of 30 to 40 km is afforded by the low frequency range (6 to 0.00055 Hz). High frequency electromagnetic signals were observed for three hours (5 to 8 PM) while the low frequency signals were recorded for 11 hours (8 PM to 8 AM). All the TE modes of the MT field curves were processed using a one-dimensional program in GEOLINK software (Layugan, D.B., 1996).

4.1 Results

The results of the MT data are presented in the form of isoresistivity map at depth of about 1000 m (Fig. 6) and MT resistivity profile cutting across the geothermal field (Fig. 7). The most prominent feature in the isoresistivity map is the 5 ohm-m low resistivity anomaly centered at Mabahong Labo thermal ground. Steep gradient of increasing resistivity values of 5 to 20 ohm-m surrounds the northern half of the anomaly. Generally, diffused contours are found in the south and southeast. Relatively high values of > 50 ohm-m were recorded by three MT stations east of the thermal springs at Kilbay and Alawihaw. The resistivity model running west-southwest to east-northeast in cross-section A-A' (Fig. 7) shows the vertical distribution of resistivity from a high elevation of about 900 m to a depth of -2000 m. The most obvious features of the profile are the zones of low resistivity (< 5 ohm-m) and the relatively higher values (> 15 to 110 ohm-m) occurring as second and third layers, respectively. The low resistivity zone is thickest (-1600 m) below station MT-1 and thinnest (~ 600 to 800 m) below MT-10, MT-15 and MT-16. Relatively higher resistivity values of 16 to 22 ohm-m mapped below MT-3 provide a sharp boundary for the conductive zone to the east.

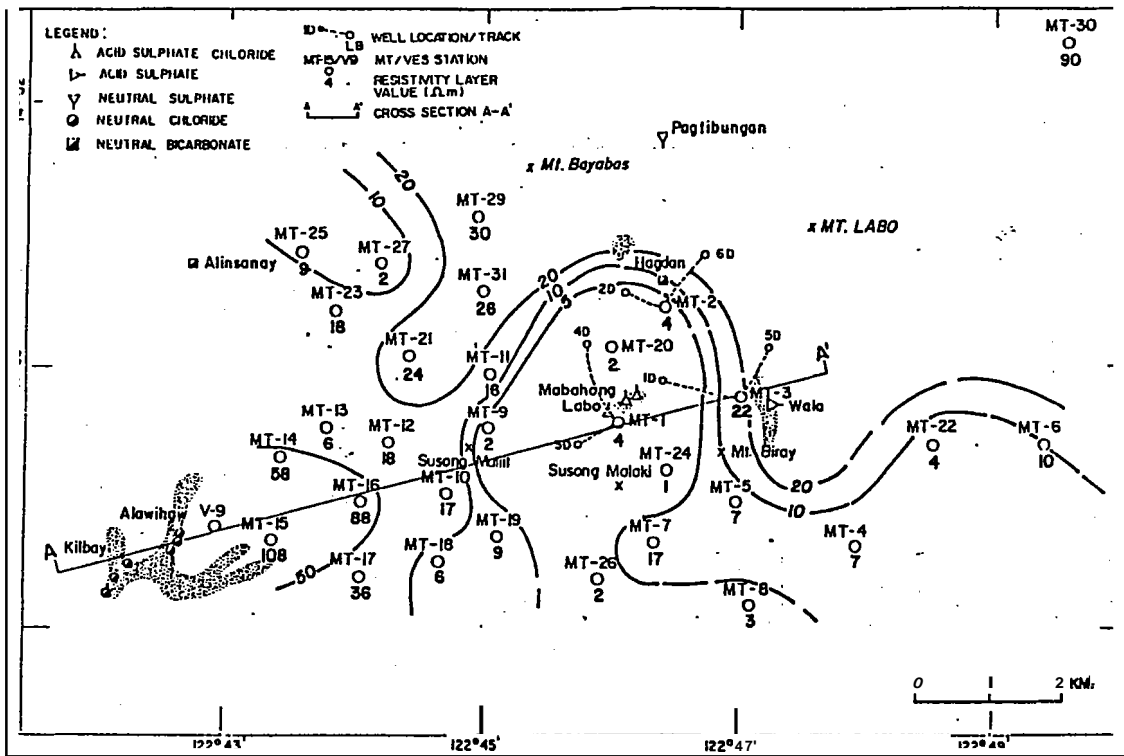


Figure 6. Isoresistivity map at about 1000 m depth based on MT data

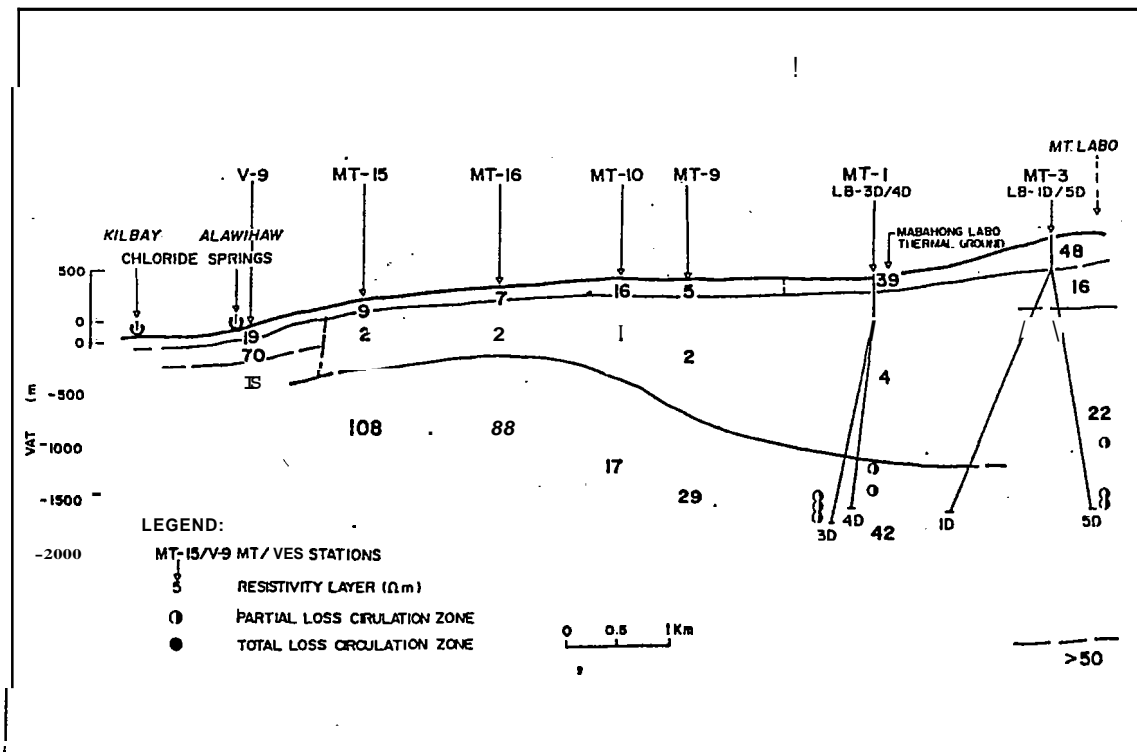


Figure 7. MT resistivity model along section line A-A'

4.2 Interpretation

The low resistivity zone of $< 5 \text{ ohm-m}$ defined by the iso-resistivity map at about 1000 m depth and the resistivity profile in cross-section A-A' probably outlines the size and extent of the geothermal system found in Mt. Labo. This conductive body coincides with the thick alteration halo developed directly above the geothermal reservoir where hydrothermal activity is more intense and active. This alteration halo represents the hydrous low-temperature clay minerals, primarily smectite, which were encountered in the drilled wells at Mt. Labo. The resistive bottom layer located directly below the thick conductive zone exhibits higher resistivity values of 30 ohm-m in MT-9 and 40 ohm-m in MT-1. This resistive basement were also mapped below MT-2, MT-20 and MT-24 (not shown) which have bottom resistivity values between 20 and 60 ohm-m. This resistive basement hosts the production zones in wells LB-ID, LB-3D and LB-4D (Fig. 7). The rise in resistivity values in the resistive basement could be due to replacement of the clay minerals by higher temperature and anhydrous minerals such as epidote. This resistivity structure modelled by the MT data is a deviation from the previously thought signature of low resistivity horizons associated with the production zones as mapped by shallow-penetrating Schlumberger resistivity traversing (SRT) and vertical electrical sounding (VES) methods. Thus, the low resistivity zone is not directly caused by saline fluids but rather by intense rock alteration consisting predominantly of low-temperature clay minerals. The relationship between the MT resistivity data and alteration zones at Mt. Labo were also observed at the geothermal fields of Hatchobaru and Sumikawa in Japan (Ushijima et al., 1986; Uchida, 1995) and Northern Negros in the Philippines (Rigor et al., 1995). The low resistivity zone and the generally high resistive basement hosting the production zones were validated by the results of the resistivity logging measurements in some of the wells in Hatchobaru and Sumikawa where MT and logging data are generally in good agreement.

5.0 GEOPHYSICAL MODEL OF MT. LABO GEOTHERMAL FIELD

The geophysical model of Mt. Labo geothermal field was based primarily on the results of the magnetotelluric (MT) and the regional gravity (Fig. 8). The model indicates that the geothermal resource is centered beneath Mabuhong Labo thermal ground (Fig. 9). The margin of the resource is best represented by the outline of the 5 ohm-m MT low resistivity anomaly at about 1000 m depth (Fig. 6). Based on the extent of this anomaly, the size of the resource is about 10 sq. km.

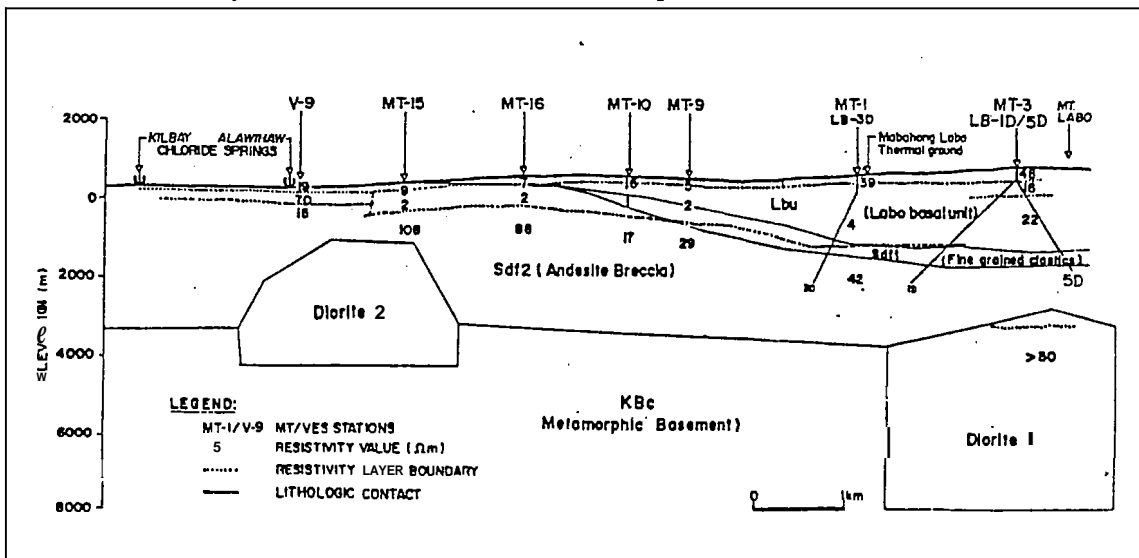


Figure 8. Correlation between gravity and MT data

The heat source of the present hydrothermal system is provided by the intrusive body mapped as a gravity high associated with the Quaternary volcanic activity of Mt. Labo. The geothermal fluids circulate

along fractures within the low density reservoir rocks belonging to the Susung Dalaga Formation. This reservoir rock shows relatively high resistivity values of 30 to 40 ohm-m. Overlying the resistive reservoir, occurring between -1000 m to -1500 m, is a thick alteration halo formed within the basal unit of the Labo Volcanics (Lbu). The predominantly hydrous, low-temperature clay minerals which compose the alteration halo yield low resistivity values of 1 to 4 ohm-m. Outflow of hot fluids to the south-southwest could be channeled along the thinning low resistivity Lbu and possibly feeding the chloride springs at Kilbay and Alawihaw.

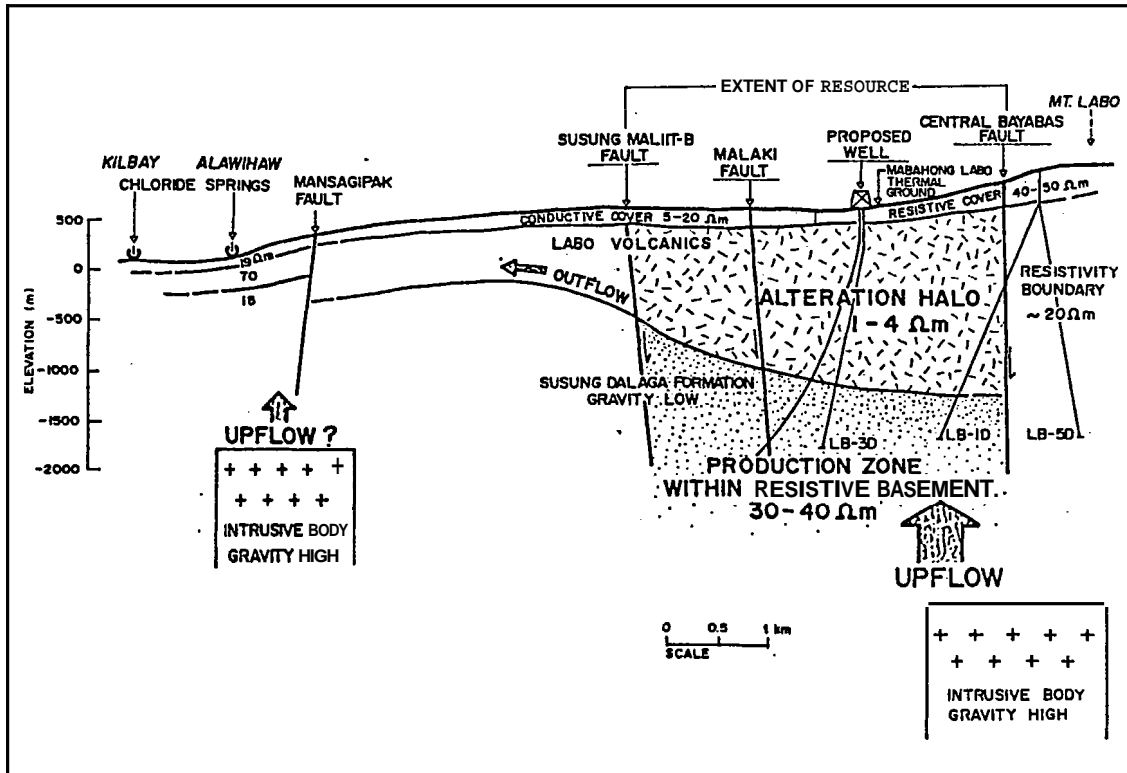


Figure 9. Geophysical model of Mt. Labo geothermal field

The geophysical model (Fig. 9) also shows a possible separate system associated with an intrusive body defined by positive gravity values. This body could be related to a group of volcanic domes such as Small Baguio, Almasigahan, Tukang Kalo, Mansagipak and Kagupgupan located south of Bakilid Fault (Fig. 2). The chloride springs of Kilbay and Alawihaw could be associated with this intrusive. The different resistivity signature (-15 ohm-m) based on the VES data (Figs. 7 and 8) near Kilbay and Alawihaw with that of the low resistivity (1 to 4 ohm-m) at Mabahong Labo thermal ground supports the idea of two separate systems. In addition, the northwest trend of the major structures in Mt. Labo such as Labo, Pagtigbungan and Ibatan Faults (Fig. 2) argues against a west-southwest outflow. However, it could also be postulated that the Kilbay and Alawihaw hot springs have been derived from both the Mabahong Labo and Kilbay-Alawihaw hydrothermal systems.

Based on the interpretation of the MT and gravity data, wells LB-ID and LB-5D lie closest to the diorite intrusive, LB-3D and LB-ID are located in the center of the reservoir while the wells LB-2D and 6D lie along the margin or outside of the reservoir (Figs. 6 and 9). A well west of LB-3D is proposed to be drilled to intersect the Malaki Fault within the resistive basement and further test the western extent of the reservoir (Fig. 9).

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REFERENCES

- Apuada, N.A. and Hallinan, S.E. (1995). Gravity Models of the Mt. Parker Geothermal Prospect, Mindanao. PNOC-EDC Internal Report.
- Delfin, F.G., Villaseñor, L.B. and Layugan, D.B. (1988). Exploration and Evaluation of the **Del Gallego** (Mt. **Labo**) Geothermal Prospect. PNOC-EDC Internal Report.
- Delfin**, F.G. and Alincastre, R.S. (1988). Geology of the Del Gallego (Mt. Labo) Geothermal Prospect. PNOC-EDC Internal Report.
- Geoscientific **Staff** (1991). Post-drilling Geoscientific Evaluation of the Mt. Labo Geothermal Project, Camarines Norte Vol. 1. PNOC-EDC Internal Report
- Geoscientific **Staff** (1995). Mt. Labo Geothermal Project Resource Assessment Update. PNOC-EDC Internal Report.
- Ignacio** C.P. and Bromley C.J. (1982). Interpretation of Gravity Surveys at Tongonan Geothermal Field, Northern Leyte, Philippines. PNOC Technical Bulletin Vol.1, No.1, pp. 1-20
- Layugan, D.B., Maneja, F.C. and Fragata, J.J. (1988). Resistivity Measurements at Del Gallego (Mt. **Labo**) Geothermal Prospect. PNOC-EDC Internal Report.
- Layugan, D.B. (1996). Interpretation of Magnetotelluric (MT) Data of Mt. **Labo** Geothermal Project. In press.
- Los Baños C.F. and Maneja F.C. (1996). Regional Gravity Survey of Mt **Labo** Geothermal Project. In press.
- Panem C.C., Maturgo, O.O. and Villarosa H.G.A. (1990). Geology and Petrology of Well LB-ID. PNOC-EDC Internal Report.
- Panem, C.C. (1995). 120,000 Geologic Map of Mt. Labo Geothermal Project.
- Panem**, C.C. (1995). Notes on the Structural Features of Mt. **Labo** Geothermal **Area**. PNOC-EDC Internal Report.
- Philippine **Bureau** of Mines and **Geosciences** (1981). Geology and **Mineral** Resources of the Philippines, Vol. 1 pp 70-71.
- Ramos, S.G., Malixi, L.V. and Espiridion, J. A. (1992). Geology and Petrology of Well LB-3D. PNOC-EDC Internal Report.
- Rigor, D.M., Apuada, N.A., Layugan, D.B., Los Baños, C.F., Maneja, F.C. and Delfin, F.G. (1995). Interpretation of Magnetotelluric Data of the Northern Negros Geothermal Project, Central Philippines. PNOC-EDC Internal Report.
- Uchida, T. (1995). Resistivity Structure of Sumikawa Geothermal Field, Northeastern Japan, **Obtained** from Magnetotelluric Data, Proceeding of the World Geothermal Congress, pp 921-925.
- Ushijima, K., Noritomi, K., Tagomori, K., Kinoshita, Y. (1986). Joint Inversion of MT and DC resistivity **Data** at Hatchobaru **Area**. Geothermal Resources Council, Transactions, Vol.10, pp. 243-246.