RESOURCE CHARACTERIZATION, RESERVES ESTIMATION AND DEVELOPMENT SCHEME OF MAIBARARA GEOTHERMAL FIELD, PHILIPPINES

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ABSTRACT

The Maibarara Geothermal Field is one of the newest fields to be developed in the Philippines. Exploration of the field was started by PGI (Philippine Geothermal Inc.) in the 1970's and this led to the drilling of 12 wells from 1977-1983. The potential of the field was realized after testing of these wells; however due to various reasons, development of the field did not materialize. Only after the Philippines' Renewable Energy Law was enacted in 2008 that field development was initiated by Petroenergy Resources Corp. when it won the bid for the service contract. Maibarara Geothermal Inc (MGI) was subsequently established to develop the field. To date, preparations are underway for the construction of the steamfield and the 20 MW power plant for 2013-3rd Qtr commissioning.

The Maibarara Geothermal Field is within a northeast-trending zone of active faulting and intense and young volcanism in South-Central Luzon. The field is associated with Mt. Makiling, as it lies just northwest of the volcano's flank. The permeability of the reservoir is correlated with structures and lithologic contacts. The wells which delineated the center of the resource indicate neutral-pH fluid residing in the reservoir with temperatures as high as 320^{o}C. A highly two-phase zone occurs at mean sea level down to ~-1200 mrsl. Based on stored heat calculation and Monte Carlo estimates, the field has the potential to produce 12-51 MW (P90-P10) in 25 years.

Development plan for the field is compact, as both the fluid conveyance system and the power plant lie approximately 100 meters apart. The power plant is designed and optimized for a single-flash, condensing steam power cycle based on the enthalpy and fluid flow characteristics of the production wells. Three production wells will be utilized for steam production while two wells will be used for injection of hot brine and cold power plant condensates.

Measures are in place to minimize the environmental impacts of development and future production. Strict adherence to environmental regulations is being followed. Steps are also undertaken to partner with the project stakeholders in our corporate social responsibility and community assistance programs.

Keywords: Maibarara Geothermal Field, resource characterization, development scheme, environmental issues

1. INTRODUCTION

The Maibarara Geothermal Field (MGF) is situated at the western flank of the andesitic cone of Mt. Makiling in Luzon Island, Philippines (Figure 1). It is approximately 70 kms southeast of the capital city Manila and straddles the provinces of Laguna and Batangas. Maibarara Geothermal Field is one of two geothermal fields associated with Mt. Makiling. The other field is Makiling-Banahaw Geothermal Field (Mak-ban) currently operated by CHEVRON and is situated to the southeast of Mt. Makiling.

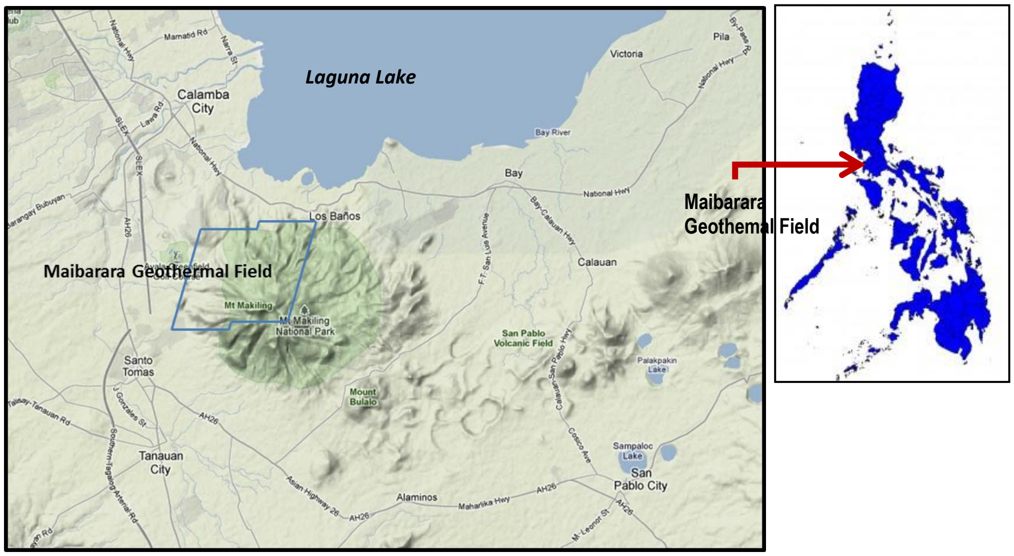

Figure 1. Location of Maibarara Geothermal Field.

Exploration History

The earliest exploration activities in Mt. Makiling and vicinity consist of geologic mapping and conduct of electrical surveys in the early 1970's (PERC, 2009). Philippine Geothermal Inc. (PGI) subsequently drilled in the area and started the development of the Bulalo Geothermal Field (currently known as Mak-Ban Geothermal Field). Exploration efforts in the western flank of Makiling were also conducted by PGI which comprise of electrical surveys, gravity survey, magneto-telluric (MT) survey, and shallow (60-150m) temperature gradient drilling towards the late 1970s (Buban et al., 1994). Geophysical survey revealed a north-trending dumbbell-shaped MT low-resistivity anomaly (6.8 km x 2.6 km) on the western flank of Mt. Makiling (Abrigo, et.al., 1994). Subsequent drilling of twelve wells proved the presence of Maibarara geothermal system in the middle of the geophysical anomaly. However, the south-southwest extent remains unclear to date.

Table 1 lists the wells drilled in the Maibarara Geothermal Field showing the date of drilling, total depth reached, date tested and status of the wells.

Well No.	Completion Date of Drilling	Total Depth		Fluid collection	Remarks
		m MD	m VD		
Mai-1	8/13/1977	1022	1022	Downhole	Non-commercial, cement plugged
Mai-2	5/14/1979	1676	1676	Downhole	Non-commercial, cement plugged
Mai-3D	7/20/1980	2980	2805	discharge	Commercial, relined, cement plugged
Mai-4	9/5/1981	3062	3062	Downhole	Non-commercial, idle
Mai-5D	2/16/1981	2563	2475	discharge	Commercial, relined, cement plugged
Mai-6D	4/9/1981	1981	1792	discharge	Commercial, cement plugged
Mai-7D	7/6/1981	2429	2179	-	Non-commercial, cement plugged
Mai-8D	8/15/1981	2195	2071	Downhole	Non-commercial, idle
Mai-9D	5/24/1981	1679	1482	discharge	Commercial, idle
Mai-10D	6/7/1982	2980	2704	Downhole	Non-commercial, cement plugged
Mai-11D	2/19/1983	2701	2701	discharge	Commercial, cement plugged
79-11 SH	10/18/1979	1608	1608	downhole	Non-commercial, cement plugged

Maibarara Geothermal Renewable Energy Service Contract

With the enactment of the Renewable Energy Law in 2008, the Department of Energy launched a competitive bidding for renewable energy service contracts in 2009. One of the areas offered was the Maibarara Concession Area, covering an area of 1600 hectares (Figure 2). PetroEnergy Resources Corporation (PERC) was awarded the Geothermal Service Contract last February 2010 to develop Maibarara Geothermal Field. Several milestones have already been reached towards the end of 2010 and will continue towards the completion and commissioning of the planned 20-MWe power plant targeted on 2013 (***Appendix 1***). Out of the twelve wells drilled circa 1970s-1980s, only five attained commerciality during their initial testing.

Two of the five wells will be used for production (Mai-6D and Mai-9D) while Mai-11D will be used as a start-up injector well. Work-over of these wells have been an important aspect since there is the need to re-evaluate and verify the power output of the field. Mai-6D, Mai-9D and Mai-11D were worked-over during the 1st quarter of 2011, and were flow-tested from March to May 2011.

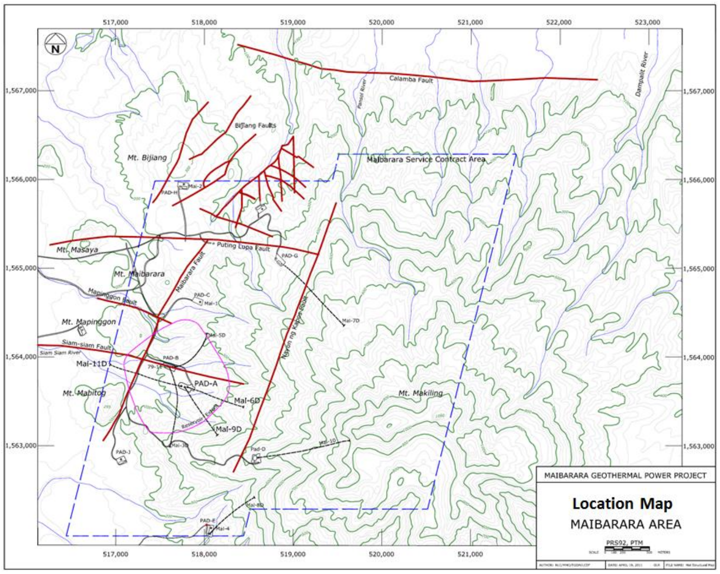

Figure 2: Map showing Maibarara Service Contract Area, showing pads and welltracks

The report will discuss the conceptual model of the Maibarara Geothermal Field; the reserves estimates based on the results of the surveys, drilling and testing of the wells; and the development scheme for the whole project.

2. RESOURCE CHARACTERIZATION

Geology

The Maibarara Geothemal Field is situated at the western flanks of the extinct andesite stratovolcano Mt. Makiling. Mt. Makiling belongs to a cluster of volcanoes and domes associated with the Macolod Corridor, a 40-80 km wide northeast-trending zone of active faulting and intense and young explosive volcanism.

Wells drilled indicate that the Maibarara Geothermal Field is underlain by two formations, namely: Makiling Volcanics and Pre-Makiling Volcanics. Both formations consist of intercalations of tuff and andesite. Towards the center of the geothermal resource, a hornblende-quartz diorite pluton intersects the Pre-Makiling Volcanics at depths of ~2.5 km from the surface. The reservoir is hosted by Pre-Makiling Volcanics. (Figure 3)

Based on the presence of secondary amphibole in wells Mai-5D, Mai-6D, Mai-11D and Mai-3D, a temperature of >280^{o}C is indicated in the central part of the resource. The co-existence of interlayered clays (180-220^{o}C) and wairakite (>220^{o}C) in Mai-2 to the north as well as in Mai-8D and Mai-4 to the south suggest cooling of the reservoir (Figure 4). Moreover, the plunging of the illite and wairakite zones in Mai-4 and Mai-8D already suggests the southern boundary of the resource.

At the surface, there were identified structures cutting across the field (Figure 2). The most prominent structures identified are the almost N-S trending Nayon ng Kapos Fault in the east and the Maibarara Fault in the west. An E-W trending Puting Lupa Fault is defined at the northernmost area of the field. Several E-W structures were identified running across the field.

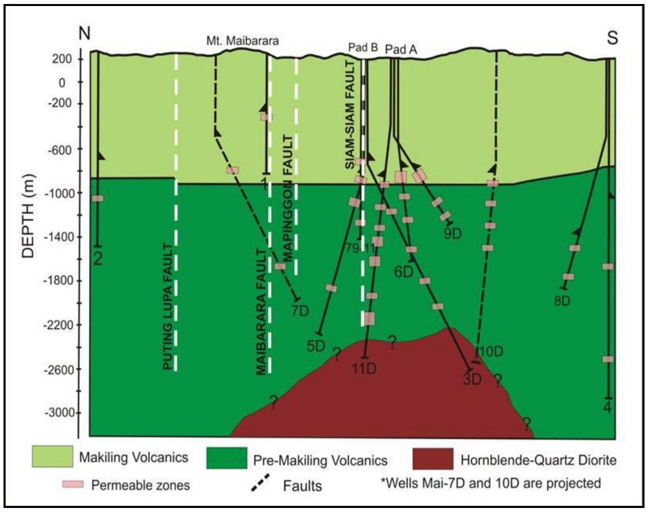

Figure 3: : Cross-section of the Maibarara Geothermal Field showing wel profiles, formation encountered and permeable horizons in each well.

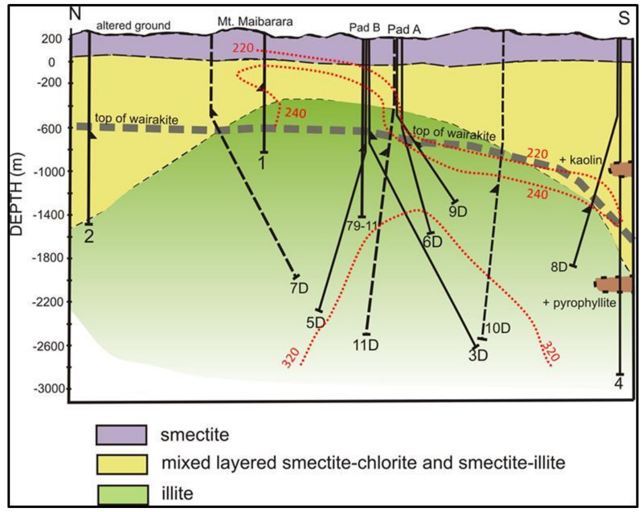

Figure 4: Clay mineralogy across the field. Indicated in dashed line is the approximate depth of first appearance of wairakite. Also shown are the discreet acid minerals in the southern portion of the field. Isotherms based on well measurements are indicated as well.

Subsurface correlation of these faults to identified permeable zones in the wells, indicate that Nayon ng Kapos Fault and Maibarara Faults extend deep in the reservoir and serves as a conduit of hot geothermal fluids. In fact, Maibarara and Nayon ng Kapos Fault form the western and eastern boundary of the resource, respectively. Aside from these structures at subsurface, the wells' identified permeable zones are correlated to the contacts between tuff and andesite layers within the Pre-Makiling Volcanics, and the contact between Makiling Volcanics and Pre-Makiling Volcanics. Correlation of the permeable horizons in the wells indicates a general lateral permeable horizon from -800 mrsl to –1600 mrsl in Maibarara reservoir (shown in Figure 3).

Geochemistry of Fluids

The discharge data from the wells indicate that the Maibarara reservoir can be generally grouped into two types based on Schoeller diagram (Figure 5). Mai-3D, Mai-5D, Mai-6Dand Mai-11D can be grouped as one having similar chemistry; while Mai-1 and Mai-9D are differentiated from the other wells by their lower chemistry concentration. All the wells discharged neutral-pH fluids.

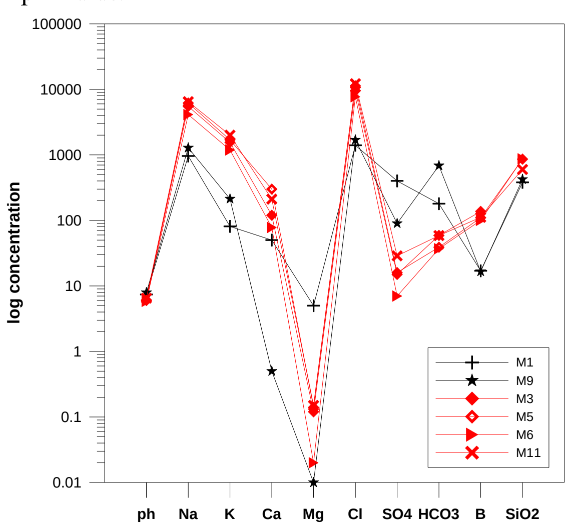

Figure 5: Schoeller diagram of Maibarara discharge fluids

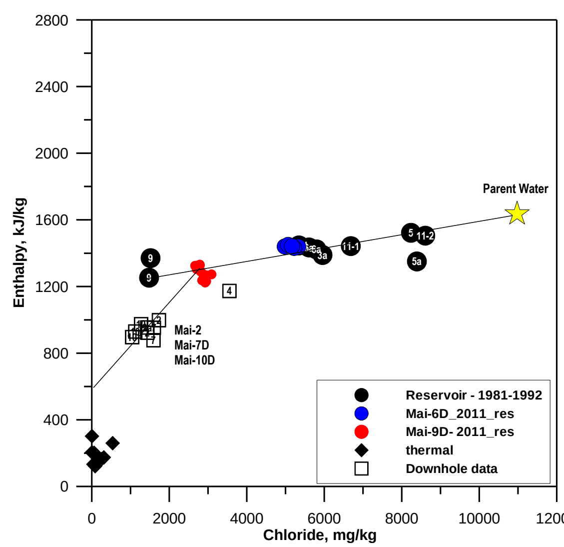

Figure 6: Chloride vs Enthalpy diagram showing the differentiation of fluids in the reservoir

The fluids of the Maibarara resource have temperatures ranging from 300-320°C. The center of the resource is defined by wells Mai-3D, Mai-6D, Mai-5D, and Mai-11D. Mai-5D has the highest fluid temperature at 320°C and the most enriched with chloride content of ~8000 mg/kg (Figure 6). The fluids of Mai-6D, Mai3D, Mai-11D and Mai-9D were formed thru dilution of the parent or source water. Mai-9D gives the most diluted waters in the reservoir. The down-hole chemistry of the peripheral wells, Mai-7D, Mai-10D, and Mai-2 have similar chemistry but is distinct from the central wells. These wells may have targeted already the boundary of the resource.

Figure 7 shows the comparison between discharge chemistry (in squares) and reservoir chemistry (in circles) of the wells. The diluted nature of the discharged fluids indicates the presence of a perched highly-two phase or steam zone in the reservoir. The presence of this steam zone contributed to the gases in steam with NCG ranging from 0.4% to a maximum of 1.8% (Figure 8).

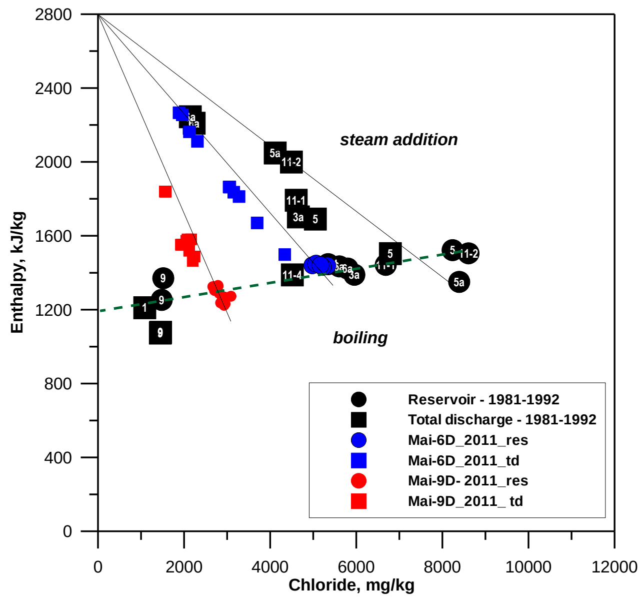

Figure 7: Comparison between discharge chemistry (in squares) and reservoir chemistry (in circles). Numbers inside symbols denote well nomenclature.

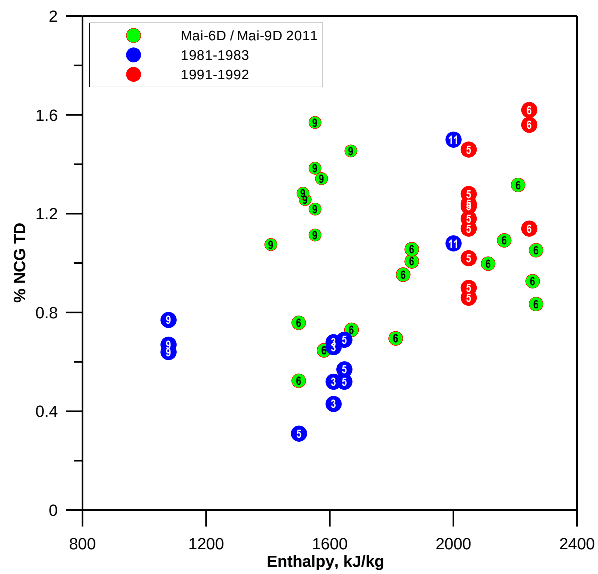

Figure 8: NCG content of wells. Numbers inside symbols indicate well nomenclature.

Reservoir Measured Pressure and Temperature

The pressure vs. depth profile shows a nearly hydrostatic condition typical of a liquid-dominated reservoir. Reservoir pressures of Mai-3D, Mai-6D and Mai-11D lie above the fields' reservoir profile which is typical for wells located in the upflow zone (Figure 9). Mai-5D's reservoir pressure is slightly below the pressure gradient suggesting slightly two-phase conditions of the well. The lower PCP of 79-11 suggests two-phase condition at the well. The water level is at 38 m MSL with a pressure gradient of 0.816MPa/100 m.

Based on temperature contours at -1220 msl (Figure 10) and -1830 msl (Figure 11), the highest temperatures are in the vicinity of wells Mai 3D, Mai 5D, and Mai 6D. The aerial coverage of the hot system at the bottom extends towards Mai4 and Mai8D where measured temperatures are > 280 °C. The contours at -610 m MSL (Figure 12) indicate that the hot outflow is towards the northwest following the northeast-southwest trending faults of Maibarara and Nayon ng Kapos Faults. There seems to be a small outflow towards the west as suggested by the contours at -1220 m MSL and to the south as indicated by the -1830 m MSL temperature contours.

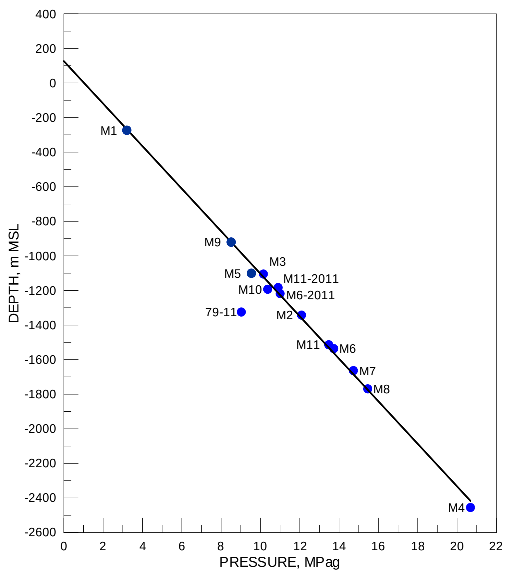

Figure 9: Pressure Profile of Maibarara wells

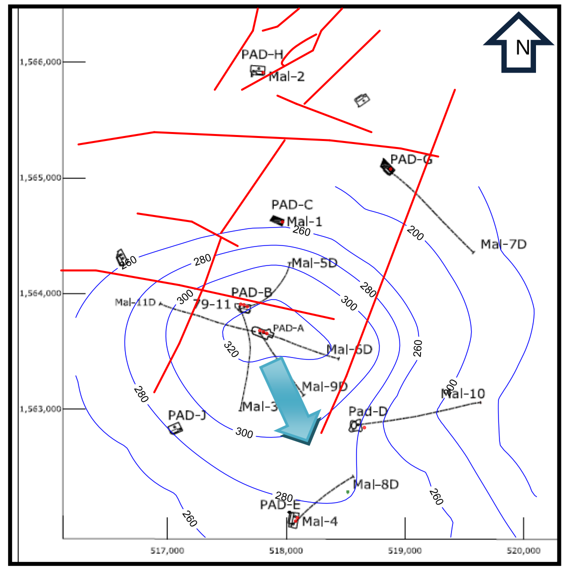

Figure 10: Temperature contours at -1220 mrsl

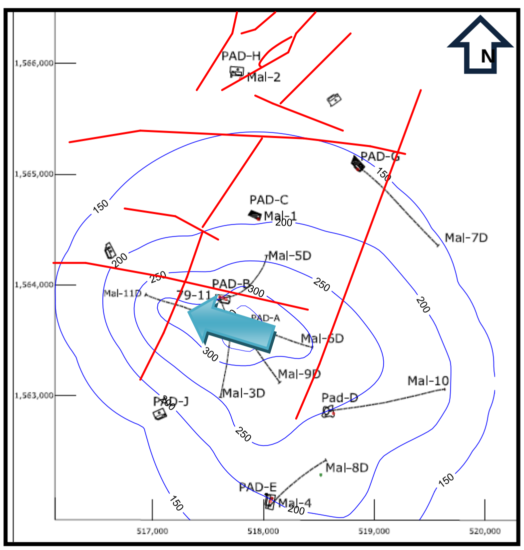

Figure 11: Temperature contours at -1830 mrsl

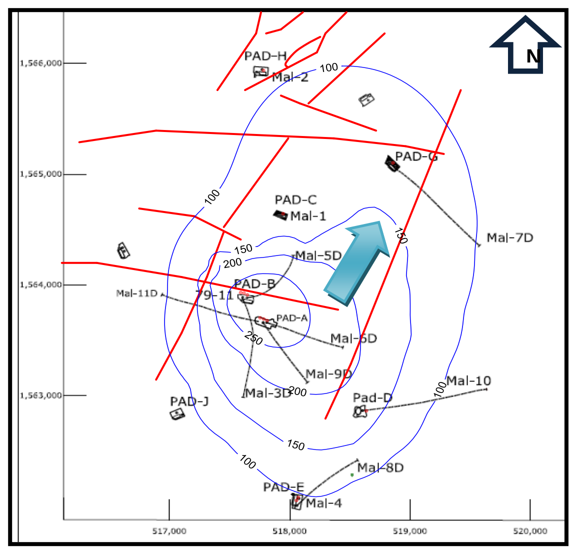

Figure 12: Temperature contours at -610 mrsl

Conceptual Model

Figure 13 below illustrates the Maibarara reservoir. A hot fluid of 320°C temperature upflows beneath the vicinity of Mai-6D and Mai-5D. Mai-6D encountered this hot fluid the shallowest. The ascending hot fluids follow approximately the trend of the Hornblende-Quartz Diorite body at the center of the resource. The fluids outflow towards the north, south and western part of the resource as tapped by Mai-3D, Mai-9D and Mai-11D. The outflow to the south seems to be deeper than that of the center of the resource. A highly two-phase horizon exists from o msl to-1200 msl tapped by wells Mai-5D, Mai-6D, Mai-3D and Mai-9D. Peripheral waters were encountered by wells Mai-2, Mai-7D and Mai-10D, which defines the boundary to the north, NE and SE, respectively.

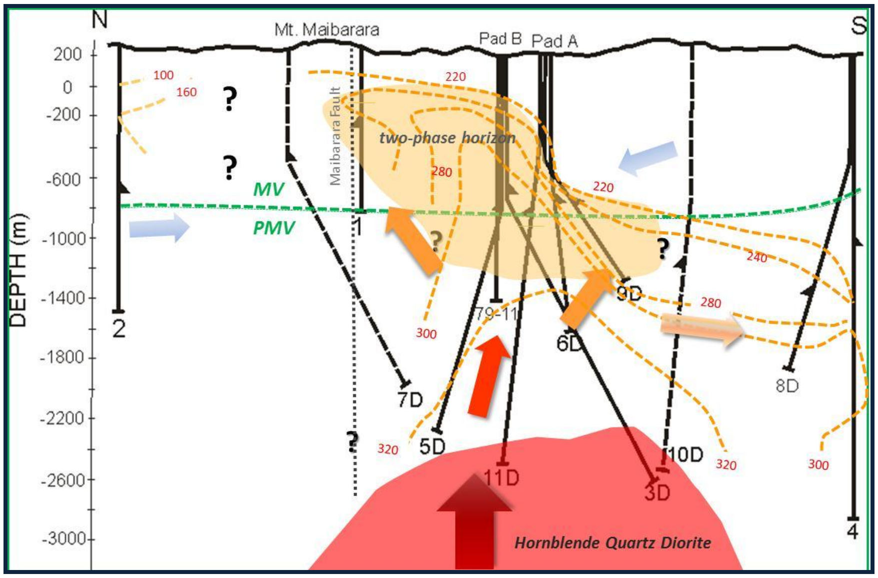

Figure 13: Conceptual diagram of Maibarara Geothermal Reservoir

3. Reserves Estimates

The Monte Carlo simulation results show that the expected mean reserve for the proven resource area of Maibarara is 27.9 MW for 25 years. The probability distribution shows there is a 90% probability that the proven reserves range between 12 MW and 50 MW for 25 years (Figure 14). This estimate provides confidence that the proven resource at Maibarara can support a 20 MW power plant for a 25 year operating period.

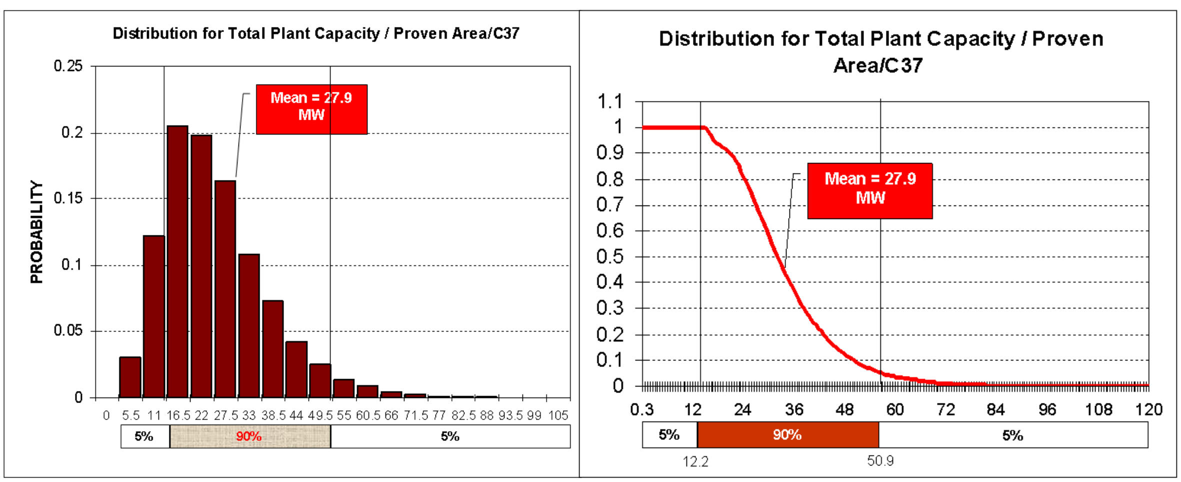

Figure 14 Probability distribution of power potential from stored heat calculation

The estimated steam reserve is conservative since it does not consider any fluid and heat recharge which would extend the sustainable life of the geothermal power plants.

4. DEVELOPMENT SCHEME

Steamfield and Power Plant Design

Based on the results of the testing of the wells, an optimistic development of 20 MW will be implemented in Maibarara Geothermal Field. As presented in the previous section, the 20 MW is sustainable for a 25-year operation. The two wells tested (Mai-6D and Mai-9D) yield approximately 17 MW of steam at operating wellhead pressure. The balance will be supplied by drilling one more production well for start-up. The hot brine from these production wells will be reinjected back into the reservoir. Likewise, the condensates from the power plant will also be reinjected back via a different well from the hot brine.

To make the development economically viable, a compact field will be built. The fluid conveyance system from the wells to the separator vessel will not be constructed long since the production wells are situated in the same pad. The power plant will be built around 100 meters away from the pad, thus steam line will be short. The reinjection wells are near the power plant and the separator, thus, getting away with long brine and condensate lines. Figure 15 is a schematic diagram of the field's set-up.

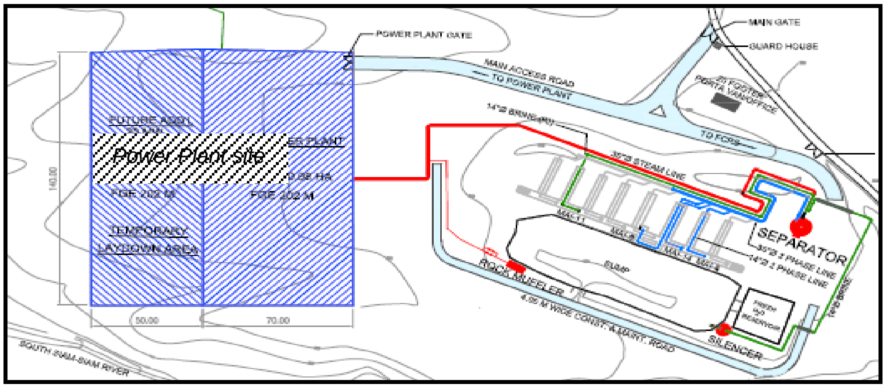

Figure 15: Schematic diagram of steamfield and power plant layout.

The power plant is designed and optimized for a single-flash, condensing steam power cycle based on the enthalpy and fluid flow characteristics of the production wells. Gas extraction system will be a hybrid type with a steam ejector back-up. Cooling Tower will be an induced draft counter flow.

Environmental and Social Issues

Since the start of development, the MGI have always been conscious on the impacts of the activities both to the environment and the stakeholders around the project. To mitigate harmful effects, measures are in put place on each phase of the development. During discharge testing of the wells, the effluents were reinjected back to the reservoir via Mai-11D. Not one instance during the testing of the wells, were the brines discharged on the surface. This practice will be continued throughout the operation of the field. Both brine and cold power condensates will be reinjected back to the subsurface; thus reinjection wells are major consideration in the development.

Prior to conducting the work over and testing of the wells, the necessary information drive have been implemented to the communities surrounding the project. The expected outcome (temporary noise, temporary effect of steam from silencers, etc) of the activities have been made aware to the people living nearby.

As early as the development phase, corporate social responsibility (CSR) programs have been extended to the communities. Several activities addressing the needs of the people around the project have been implemented. With full steam field and power plant operation in the coming years, a program to enhance the community capabilities has been started.

5. SUMMARY

The Maibarara Geothemal Power Project is an integrated project operated by Maibarara Geothermal Inc. (MGI). This project, explored and initially developed by Philippine Geothermal Inc. (PGI), was offered for bidding upon the enactment of the Renewable Energy Act of the Philippines in 2008. Realizing the potential of the geothermal field, PetroEnergy Resources Corp. bidded and won the service contract to develop the resource. Since its award in 2010, the 20-MW project has been in full scale development towards a 2013 3rd quarter commissioning.

Three of the original wells drilled will be used for start-up, 2 as production and 1 for reinjection. Retesting of the wells and re-validation of the reserves, point to a P50 of ~28 MW for a 25-year plant life. Drilling of one production well and one reinjection well is necessary to operate the 20-MW power plant. A compact field development is planned to make the project viable.

Measures are in place to minimize the environmental impacts of development and future production. Strict adherence to environmental regulations is being followed. Steps are also undertaken to partner with the project stakeholders in our corporate social responsibility and community assistance programs.

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Appendix 1 – Major milestones for the Maibarara Geothemal Power Project

February 2010	Maibarara Service Contract was awarded to PetroEnergy Resources Corp
May 2010	Maibarara Geothermal Inc. Joint Venture formed to handle Maibarara Geothermal Power Project
August 2010	Environmental Compliance Certificate was given to the project
January – May 2011	Work over of three wells; retesting and validation of resource
August 2011	Third party validation of resource
September 2011	Loan approval for project financing and awarding of EPC for PP