PROCEEDINGS, Twenty-Eighth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 27-29, 2003
SGP-TR-173

THE PATUHA VAPOR-DOMINATED RESOURCE WEST JAVA, INDONESIA

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ABSTRACT

The Patuha vapor-dominated geothermal resource occurs within a Quaternary volcanic highland in west Java, Indonesia. The productive reservoir shows a close relationship with a west-northwest trending structural zone or "volcanic axis" defined by an alignment of late-stage volcanic domes, craters and lava flows. Fumaroles occur in several areas at higher elevations in the field, including a localized area of magmatic gas discharge at Kawah Putih. Magnetotelluric and gravity surveys have defined a region of high resistivity and shallow basement which bounds the south and east margins of the reservoir. Geophysical data has proved less useful in defining the north and west flanks of the productive resource, due to the presence in these areas of shallow outflows of chloride-bearing condensates and clay-rich volcaniclastic sediments. Deep temperature gradient data provided the most reliable initial indication of the extent of the reservoir, as verified by subsequent production test drilling. The productive vapor-dominated reservoir proven by drilling to date near Kawah Ciwidey is about 700 meters thick and covers about 5.5 square kilometers. The total reservoir area may reach up to 20 square kilometers, as indicated by an elongate, deep thermal anomaly which overlaps the volcanic axis.

Productive wells range in depth from 1,091-2,172 meters and exhibit vapor-static pressure profiles. Steam reservoir temperatures range from 209-241 ^oC at pressures ranging from 250-720 psig. Wells produce dry steam with gas contents averaging 1.8 weight %. A total of about 75 MW of steam is available at the wellhead from 9 wells. Lateral pressure gradients in the reservoir suggest that steam flows along the west-northwest structural zone away from a central magmatic vapor plume located below Kawah Putih. Acidic components of the magmatic vapor are neutralized in an inferred zone of condensation and mixing with steam from the geothermal reservoir. The vapor-dominated reservoir is underlain by a deep water zone of very dilute Na-SO4-Cl fluid which appears to be steam condensate. Further drilling is required to demonstrate the productivity of the deep water zone.

INTRODUCTION

The Patuha geothermal field is located in west Java, Indonesia, about 50 kilometers southwest of the city of Bandung (**Figures 1; 2**). The operating Wayang Windu geothermal project is located about 20 kilometers to the east. The Patuha field is situated within a northwest-trending volcanic mountain range, including the nearby peaks of N. Patuha (2414 m); S. Patuha (2390 m); Urug (2201 m) and Walang (2178 m). The wellfield as currently developed extends from elevations of about 1800 to 2000 meters a.s.l. The cool, rainy climate in the mountains supports a mix of tropical rain forest and government-run tea plantations. Scattered small villages which provide housing for plantation workers are located near some of the wellsites. Access to the site is via a graded dirt road from the town of Ciwidey.

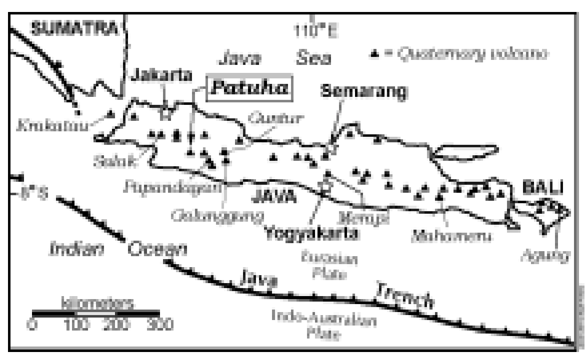

Figure 1. Map of location and regional tectonic setting of Patuha geothermal area

History of Exploration and Development

Initial geothermal exploration work at Patuha was conducted by PERTAMINA, the state-owned firm with responsibility for petroleum and geothermal resources in Indonesia (Lubia, 1986; Fauzi *et al*, 1994). PERTAMINA initiated reconnaissance of

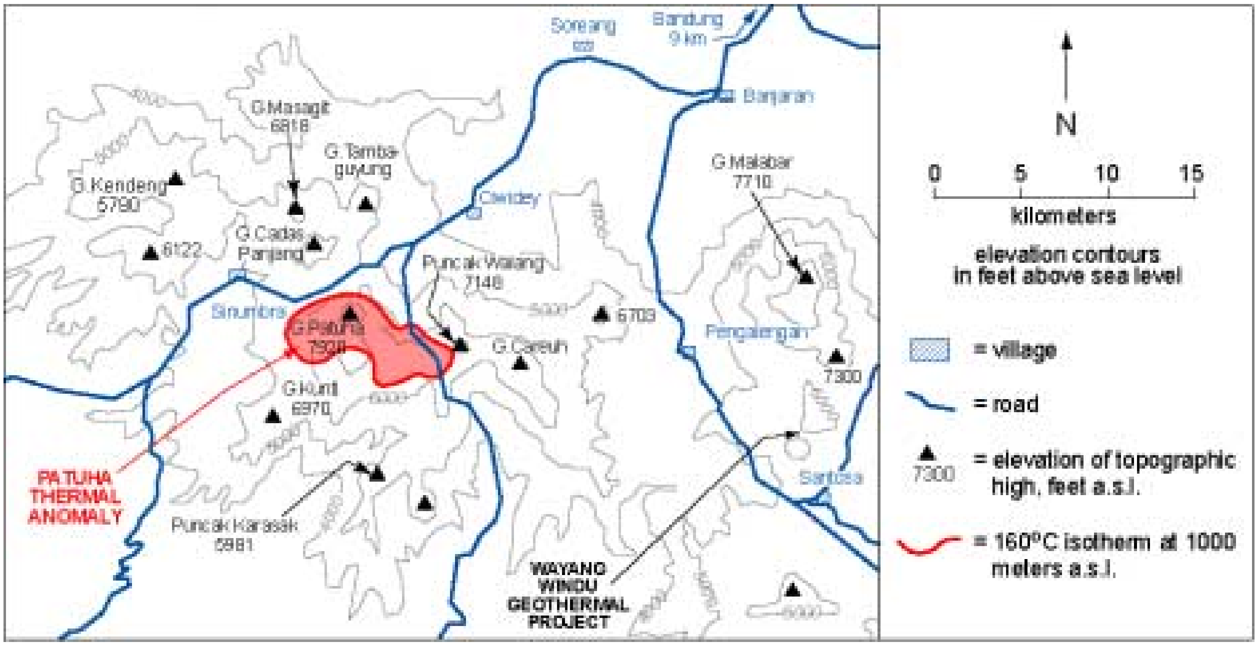

Figure 2. Map of location of Patuha thermal anomaly in Patuha volcanic highland in west Java

thermal features in 1983, followed by geologic mapping. Geochemical surveys were also conducted, which included sampling and chemical analyses of thermal features, streams and soil gas. Geophysical investigations were conducted, including resistivity surveys (magnetotelluric and Schlumberger techniques) and a gravity survey. PERTAMINA also drilled at least 4 shallow temperature gradient holes each to a depth of 200 meters. One hole was drilled near each of the three fumarolic areas (or "kawahs") at Patuha, and another near one of the northern groups of thermal springs. Most of PERTAMINA's exploratory work at Patuha was accomplished during the period 1983-1989.

In late 1994 Patuha Power Ltd. (PPL), an affiliate of the U.S. firm CalEnergy Co., commenced operations on the development of the Patuha resource. PPL's involvement was based on Joint Operations and Energy Sales Contracts signed in December of 1994 with PERTAMINA and PLN, the state electrical utility. From 1996 to early 1998, PPL undertook an extensive program of field exploration and development. During this period PPL conducted gravity and resistivity surveys; drilled 17 deep temperature gradient holes; and drilled and tested 13 full-sized production test wells. Flow testing indicated that 9 of PPL's 13 wells are productive, with a combined power output of approximately 72 MWe. Another well, located about 1 kilometer south of Kawah Putih, was terminated above the reservoir depth after setting 13 3/8 inch casing.

Prior to PPL signing contracts with the government, PT. Yala Teknosa (Teknosa), an Indonesian firm, obtained a concession from the Ministry of Mines and Energy to develop a small-scale geothermal project in the west Patuha area, near Kawah Cibuni. The ~10 square kilometer Teknosa block was contained within PPL's much larger concession area. Teknosa drilled two production test wells in this area, at least one of which is reported to be productive.

Development of the Patuha project by PPL was suspended in early 1998. This was the result of a contractual dispute between PPL and the Indonesian government related to the Asian financial crisis which began in late 1997. At the time of suspension, PPL had closed financing for development of an initial 80 MWe facility, and had commenced delineation of additional energy reserves for a second unit. PPL completed grading of the power plant site and had planned to drill additional wells to supply the balance of the steam requirement for Unit 1. Non-productive wells were to be used for injection of condensate.

Current Project Status

Ownership of the Patuha geothermal project was returned to the government of Indonesia in August 2001, as part of an agreement reached with the U.S. Overseas Private Investment Corporation (OPIC). OPIC had assumed control of the project from PPL in November, 1999 after payment of an insurance claim to PPL. The government intends to develop the Patuha project as a joint venture (PT. Geo Dipa Energi) between PERTAMINA and PLN (Persero), under amended Joint Operations and Energy Sales Contracts. The joint venture will sell power to PLN at a price to be determined in the amended contracts. PT. Geodipa is proposing to develop up to 3 X 60 MWe of capacity at Patuha during the period 2003-2006, with a total new investment target requirement of US$250 million. PT Geo Dipa Energi is presently encouraging submission of proposals from potential investors in the Patuha project.

All wells at Patuha are currently shut-in, and the wellheads are regularly maintained by PT. Geodipa Energi staff.

GEOLOGIC SETTING

The Patuha geothermal resource is associated with arc volcanism resulting from subduction of the Indo-Australian plate beneath the Eurasian plate at the Java Trench (**Figure 1**). The Patuha field is located within a volcanic highland composed of andesitic lavas and pyroclastics of late Pliocene to Quaternary age. Fauzi *et al* (1994) report radiometric ages ranging from 0.12-1.25 million years for these rocks. No historical eruptions have occurred in the area. Analysis of aerial photographs indicates that numerous volcanic centers or vents are present in the area of the geothermal field (**Figure 3**). These have been classified as "late stage" or "early stage" based on the degree of dissection by erosion.

A "volcanic axis" at Patuha is defined by the distribution of late stage volcanic vents, which are concentrated in an elongate, west- to northwest-trending zone with dimensions of about 5 x 10 kilometers. The late stage volcanic vents occur at elevations above 1800 meters a.s.l. and include lava domes, cones, craters and the source areas for young lava flows. The domes at Mount Urug and South Patuha, and the crater within the cone of North Patuha are part of this trend. The volcanic axis shows a close relationship with the Patuha geothermal resource. As shown below, this feature encloses the three main fumarolic areas in the Patuha field, and overlaps the area of the productive reservoir.

The volcanic axis presumably reflects a deeply penetrating, west to northwest -trending structural zone. This may be part of a major structural feature which extends for over 40 kilometers, as indicated by the similar orientation of the mountain range containing the Patuha resource (**Figure 2**). This structural trend is also reflected in Bouger gravity data (not presented here), which shows a pronounced 4 milligal per kilometer regional gravity gradient to the northeast across the region. Fractures within the volcanic axis probably control intrusion at depth of the magmatic heat source for the Patuha geothermal system, as well as the eruption of magma to the surface. Structures within this zone also appear to control fracture development in the geothermal reservoir, and the discharge of fumaroles at the surface.

Subsidiary structural trends identified at Patuha include a 4 kilometer-long, north-south zone defined by the alignment of North and South Patuha peaks and 3 other vents. Northeast-trending structures, orthogonal to the volcanic axis trend, may play a role in the development of the southwest extension of the productive reservoir between the peaks of Urug and South Patuha, and the eastern termination of the resource near Kawah Ciwidey.

Subsurface Geology

Rocks penetrated by geothermal wells at Patuha are dominated by lavas, tuffs, and breccias. Diorite or microdiorite intrusives cut the volcanic section in some wells. Reddish, clay-rich horizons, which may represent paleosols, have been encountered in selected wells. In some cases these zones have produced unstable hole conditions, resulting in operational problems with sticking of drill pipe, setting liner, and/or clogging of openings in slotted liner by mobile clays.

Hydrothermal alteration is well-developed in the subsurface, and includes a zone of clay-rich argillic alteration in the upper portions of the system, overlying a zone of clay-poor, propylitic alteration. The latter is typically marked by the first appearance of hydrothermal epidote, typically in association with quartz, calcite, illite and chlorite. In most wells, the first appearance of epidote coincides with reservoir temperatures well below 200^{o}C, indicating that isotherms in the system may have collapsed by up to several hundred meters since original formation of the epidote. The productive geothermal reservoir occurs within fractured, propylitically-altered rocks of the volcanic sequence.

SURFACE MANIFESTATIONS

Surface manifestations of the Patuha geothermal resource consist of fumaroles ("kawahs"), thermal springs, and cold gas discharges (**Figure 3**). These include the three fumarole areas at Kawahs Cibuni, Putih and Ciwidey, which lie at elevations between 1,800-2,250 meters a.s.l.. Thermal springs have been identified at lower elevations, between 1,600-1,850 meters a.s.l., on the south, west and northwest flank of the volcanic highland. An area of cold gas discharge is present between Kawah Ciwidey and Kawah Putih at 1,950 meters a.s.l. elevation, and also on the south flank of the volcanic highland at 1,800 meters a.s.l. elevation.

Sampling and analysis of thermal waters associated with many of the geothermal features at Patuha was conducted by Fauzi *et al* (1994). Steam-heated

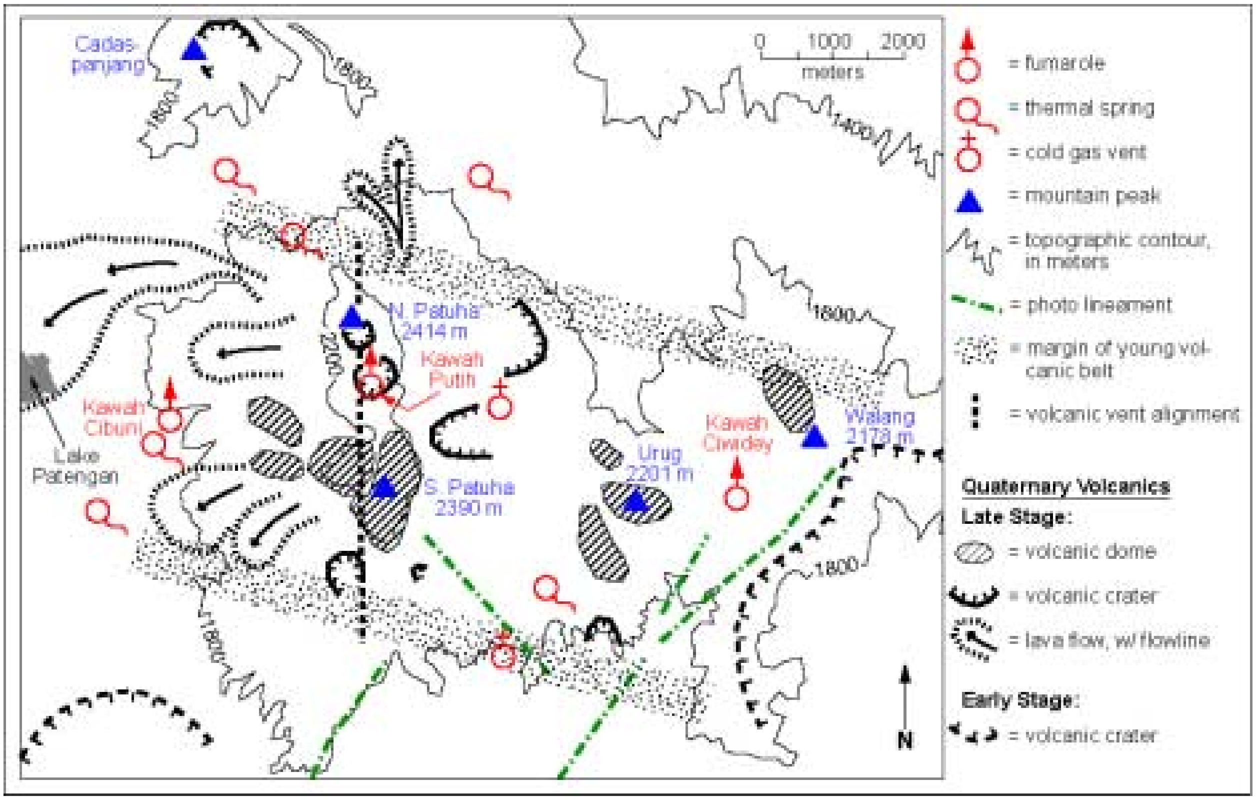

Figure 3. Map of major geologic and thermal features, Patuha area

thermal waters at Kawah Cibuni and Kawah Ciwidey fumarolic areas are dilute acid-sulfate waters with negligible chloride and pH values of 2-3. One of the thermal springs near Kawah Cibuni is a dilute, acid-sulfate-chloride water with less than 400 ppm chloride. In contrast, crater lake waters at Kawah Putih are high salinity, hyper-acid chloride-sulfate fluids, with pH values as low as 0.5 and chloride levels approaching 13,000 ppm (Sriwana *et al*, 2000). Floating globules of sulfur with sulfide inclusions are common in the lake water. Such fluids typically result from the condensation of magmatic steam containing the highly acidic and water soluble gases HCl and SO2. Evaporation at the warm lake surface further concentrates these fluids.

The thermal springs on the north flank of the volcanic highland are relatively dilute, neutral pH Na-Ca-SO4-HCO3-Cl waters, with total dissolved solids below 2,000 ppm. Chloride values in these spring waters range from 150-700 ppm, with variable proportions of sulfate and bicarbonate.

KEY GEOPHYSICAL ANOMALIES

The major focus of PPL's initial exploration program at Patuha was on the collection of deep temperature gradient data using coreholes, supplemented by resistivity and gravity surveys. The combined use of temperature gradient and resistivity data provided the most effective means to delineate the Patuha resource, in advance of production test drilling.

Deep Thermal Anomaly

An extensive, deep thermal anomaly associated with the Patuha resource was delineated by subsurface temperature data obtained from 17 coreholes and 14 production test wells (**Figure 4**). The coreholes were drilled to depths ranging from 650-1200 meters, averaging 803 meters. After setting shallow casing, these were typically cored with HQ hole size to the total depth and completed with 2 7/8 inch tubing for temperature measurements. PPL's 13 completed production test wells were drilled in the eastern half of the anomaly, within 3.5 kilometers of Kawah Ciwidey.

The thermal anomaly is best defined by isothermal contours at 1000 meters a.s.l. elevation (**Figure 4**). This elevation corresponds to depths below surface ranging from about 700-1200 meters, and to the shallowest levels of the steam reservoir. The thermal anomaly is highly elongated in a west-northwest direction, parallel to and overlapping the volcanic axis defined by the late-stage vent trend. The long axis extends for about 10 kilometers and the width varies from 1-3 kilometers. The total area of the anomaly, defined by the 180°C contour at 1,000 meters a.s.l., is 20.0 square kilometers. In the eastern

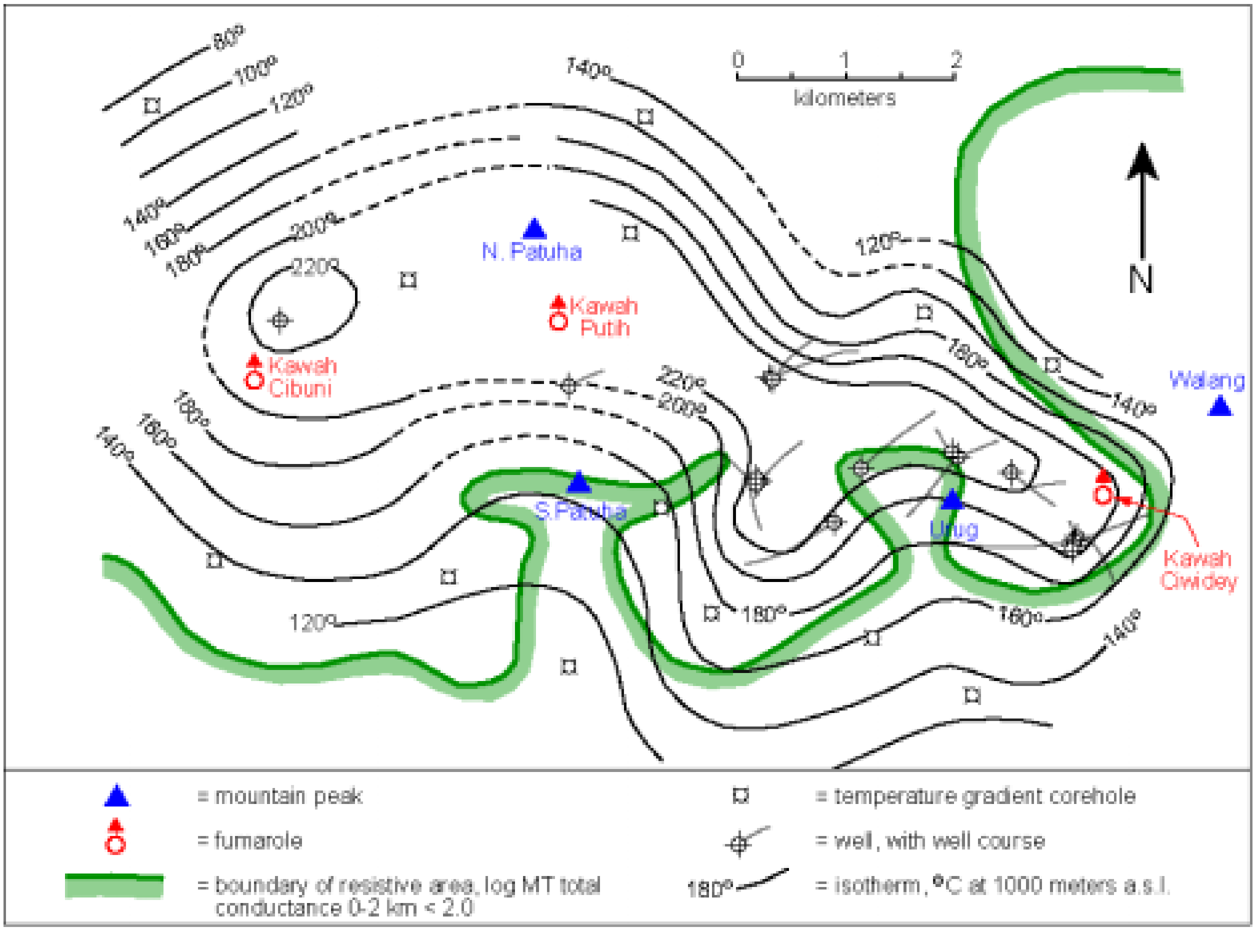

Figure 4. Map of isotherms at 1,000 meters elevation and resistive area boundary

portion of the thermal anomaly, production test drilling has shown that the 200°C contour at 1000 meters a.s.l. elevation closely approximates the outer limit of commercial steam production. This is illustrated by comparison of **Figures 4** and **6**.

Subsidiary structural trends also influence the extent of the deep thermal anomaly at Patuha. The southwest-trending salient or extension of the thermal anomaly between the peaks of South Patuha and Urug coincide with structures with this orientation inferred from photo lineaments (**Figure 3**). These structures may channel steam away from the main west-northwest trending zone associated with the volcanic axis. The eastern termination of the thermal anomaly near Kawah Ciwidey coincides with a northeast-trending lineament. This feature may represent a fault zone which bounds a block of dense, resistive uplifted basement (see discussion below) which truncates the reservoir in this region.

A north-trending embayment or inward bulge in the thermal anomaly occurs in the area of South Patuha peak. This feature coincides with, and has a similar orientation to, the north-south volcanic vent trend in this area described above. Structures associated with this vent trend may allow shallow, cooler groundwaters to penetrate into and quench the steam reservoir, and at the same time provide a source of liquid recharge. This cooler zone is also reflected in a T-shaped zone of higher resistivity extending to the south of South Patuha peak (**Figure 4**).

Resistivity Anomalies and Relation to Resource

Extensive areas of low resistivity were identified at Patuha by combined magnetotelluric and time-domain electromagnetic (MT/TDEM) surveys conducted by Geosystem srl in 1995 and 1997. The low resistivity region includes areas with total MT conductance values to 2 kilometer depth between 100 to 630 mhos (microsiemens), or log values between 2.0-2.8 (**Figure 4**). This conductive area covers over 70 square kilometers, and includes the deep thermal anomaly and the area of proven productive resource. The low resistivity region extends well beyond the margins of the deep thermal anomaly to the north and west, indicating that the resistivity data is of limited use for resource definition in these areas.

In contrast, highly resistive regions bound the south and east flanks of the thermal anomaly, where total conductance values to 2 kilometers depth reach as low as 10 mhos. These resistive regions coincide with areas of relatively high Bouger gravity, indicating they may represent areas of shallow, dense basement rocks or intrusives below the volcanic section. The resistivity data proved most useful for resource definition in the area between the peaks of South Patuha and Walang, where there are abrupt lateral increases in resistivity away from the central conductive region associated with the resource.

In the area of the deep thermal anomaly, drillhole lithology logs indicate that the low resistivity zone correlates with clay-rich, electrically conductive hydrothermal alteration. This alteration forms a blanket over the more resistive, clay-poor propylitic alteration associated with the productive reservoir. The argillic zone is typically about 500 meters thick and first encountered at depths of 100-300 meters.

Extensions of the conductive region to the north and west, beyond the area of the deep thermal anomaly, result from a combination of factors. Shallow outflows of acidic, chloride-bearing condensates from the Kawah Putih area towards discharge at flanking thermal springs are likely to produce extensive argillic alteration and low resistivity values. A 75-80^{o}C aquifer at an elevation of about 1750 meters a.s.l. was identified by inflections on thermal gradient profiles in at least two temperature gradient holes located north of Kawah Putih. Peripheral areas of lower resistivity may also result from accumulations of volcaniclastic sediments on the flanks of the volcanic highland at elevations below 1800 meters a.s.l.. Such sediments are likely to be electrically conductive, due to contained fine-grained, clay-rich interbeds or ash horizons.

RESERVOIR CHARACTERISTICS

Well Discharges

All productive wells drilled to date at Patuha produce dry steam discharges during extended flow testing. Upon opening of the wells for testing there is a brief period of wet discharge when a small liquid fraction is produced, after which the discharge dries out to 100% saturated steam. Chemical analyses of water produced before dry out indicates these liquids are drilling fluids lost to the formation during drilling in the reservoir zone.

Production characteristics of representative wells at Patuha are summarized in **Table 1**. Stabilized steam flow rates as high as 222,000 pounds per hour have been measured in Patuha wells. The average output for all productive wells is about 130,000 pounds per hour, including wells with outputs restricted by scab liners or other obstructions in the wellbore. Total gas levels in produced steam are relatively low, averaging 1.8 weight %, with a range of 0.8-3.0 weight %. Hydrogen sulfide content in steam ranges between 225-480 ppm. Condensate samples of produced steam have negligible chloride content and are mildly acidic due to the effect of dissolved hydrogen sulfide and carbon dioxide.

Well Name	PPL-2A	PPL-3B
well depth (m)	1760	1154
slotted liner diameter (inches)	7	9 5/8
depth to first major permeability (m)	1026	1038
elevation of first major permeability (masl)	+994	+911
maximum temperature (^{o}C)	232	226
steam reservoir pressure (psig) @ 1000 m elev.	386	398
steam flow rate @ ~150 psig WHP (kph)	138	222
brine flow rate @ ~150 psig WHP (kph)	0	0
approximate power output (MWe)	8.6	13.9
total gas in produced steam (wt.%)	2.0	1.8
H_2S in produced steam (ppm)	450	380

Table 1. Summary of production well characteristics, selected Patuha wells

Vapor-Dominated Zone

All productive wells at Patuha tap a relatively shallow, vapor-dominated reservoir. Patuha wells which do not penetrate below elevations of about 500 meters a.s.l., exhibit vapor-static pressure profiles when shut in (**Figure 5**), indicating vapor-dominated conditions. No standing water is observed in these wells. Depths of all productive wells range from 1,019 to 2,172 meters.

Temperature profiles indicate the top of the convective zone in the steam reservoir occurs at depths of about 700-1,000 meters in most wells, or approximately 900 - 1,200 meters a.s.l. The shallowest zones of major permeability in the steam reservoir are typically encountered at about 1,000 meters a.s.l. The thickness of the steam zone reaches about 700 meters, based on the elevation difference between the top of the convective zone and the deep water level (see below).

Maximum measured reservoir temperatures in individual wells range between 209-242^{o}C. Pressures near the top of the vapor zone range from 250-700 psig at 1000 meters a.s.l. elevation. Steam zone pressures decrease gradually away from the central portions of the deep thermal anomaly to the east towards the Kawah Ciwidey area (**Figure 6**), suggesting lateral flow of steam in this direction. Wells close to the eastern margin of the productive reservoir exhibit slight temperature reversals, also suggestive of lateral flow regimes. A similar trend of decreasing pressure away from the Kawah Putih area

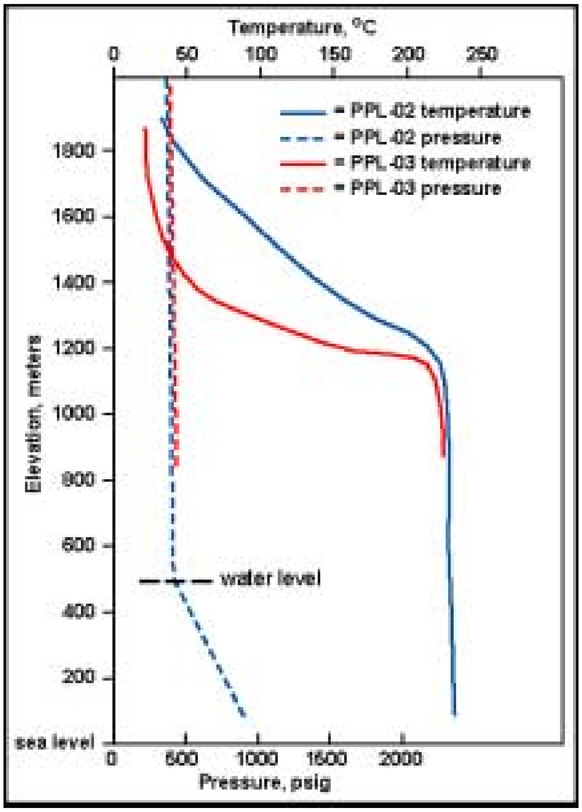

Figure 5. Temperature and pressure profiles for selected Patuha wells

to the west towards the Kawah Cibuni area is inferred but not yet confirmed.

Gas levels in the vapor-dominated zone do not systematically vary across the field. However, the well with the lowest gas content is located closest to the fumarolic area at Kawah Ciwidey. The lower gas levels and pressures in the steam reservoir in this area may in part be due to bleed off of gas and steam by the fumarolic discharge.

The area of proven steam production near Kawah Ciwidey is about 5.5 square kilometers. Steam production has also been proven near Kawah Cibuni in the Teknosa project. The total area of the productive steam reservoir could approach 20 square kilometers, based on the extent of the deep thermal anomaly. A small portion of this area may be unexploitable due to corrosive, magmatic steam near Kawah Putih (see below).

Deep Liquid Zone

Four deeper wells at Patuha intersect a liquid level at elevations between 400-500 meters a.s.l. Only one of these wells (PPL-02) is within the productive area and produces steam at commercial rates. Downhole pressure monitoring of this well during discharge indicates that the water level rises and falls in response to variations in wellhead pressure. These fluids are thus not a "dead leg" in the wellbore, but rather are in dynamic communication with a continuous reservoir of liquid water contained within the adjacent fractured volcanic formations.

Chemical analyses of downhole samples collected below the water level in PPL-02 indicate the deep waters are highly dilute, with dissolved sodium contents of 125 ppm and chloride levels between 40-60 ppm. Representative sulfate and pH values for the fluid were not obtained due to air contamination of the sample chamber, and resultant addition of excess sulfate by oxidation of dissolved hydrogen sulfide. However, sulfate values are probably comparable to chloride, and the fluids are inferred to be dilute, neutral pH, Na-SO4-Cl waters. Silica concentrations indicate a quartz geothermometer temperature of 220 ^{o}C, which is within the range of measured stable temperatures at the sampling point. This corroborates that these dilute fluids are derived from a deep, high-temperature fluid reservoir.

The deep fluid zone has not yet been demonstrated to contribute liquid production to the well flow. The single productive well which penetrates this zone produces only steam. This lack of fluid production appears primarily to be the result of higher fracture permeability at shallow levels in the Patuha system associated with the steam zone, compared to deeper levels. In addition, testing indicates the productivity of deeper zones in PPL-02 appears to have been reduced by plugging of fractures in reservoir rocks and of liner perforations by mobile clays derived from the formation. At a minimum, the deep water zone is likely to contribute some fraction of the total steam production, via boiling of the uppermost levels of the water zone as reservoir pressures draw down during production. This is supported by downhole pressure surveys of PPL-2 during flow, which indicate two-phase conditions in the upper ~100 meters of the water zone. Further drilling and evaluation of the deep fluid zone is required to establish its contribution to the resource base at Patuha.

CONCEPTUAL MODEL OF THE RESOURCE

The Patuha geothermal resource consists of an elongate, structurally controlled, vapor-dominated reservoir with an area of up to 20 square kilometers. The major components of the geothermal system include the steam reservoir, an underlying liquid zone, a central magmatic vapor plume, and shallow thermal aquifers which drain chloride-bearing condensate fluids away from the uppermost levels of the plume (**Figure 7**).

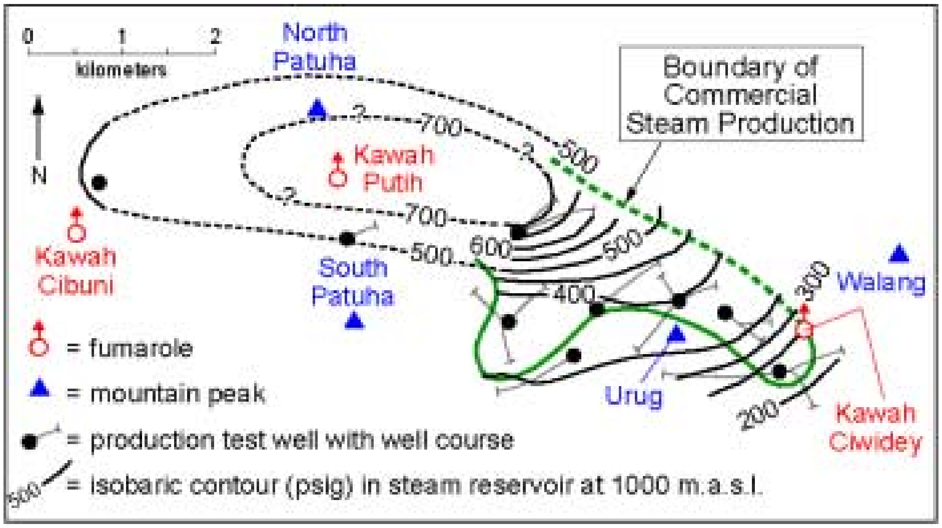

Figure 6. Map of pressures in steam zone and boundary of productive reservoir

The magmatic vapor plume is inferred from the hyper-acidic, high salinity and sulfur-rich lake waters at Kawah Putih fumarolic area, which is located in a summit crater of Patuha volcano. While no wells have penetrated this magmatic zone, similar features have been intercepted by drilling at the Karaha-Telaga Bodas (KTB) field in west Java (Allis *et al*, 2000) and the Dieng field in central Java (Layman *et al*, 2002). By analogy with these fields, the magmatic vapor plume at Patuha is likely to consist of corrosive, superheated steam containing the acidic gases hydrogen chloride and sulfur dioxide, at temperatures well over 300 ^{o}C and pressures in the range of 2,000 psig. A zone of condensation, mixing, and neutralization of acidic gases is inferred to separate the magmatic steam zone from the surrounding vapor-dominated geothermal reservoir.

Steam in the geothermal reservoir flows laterally away from the central area near the magmatic vapor plume, along structurally controlled pathways associated with the west-northwest trending volcanic axis. Structures orthogonal to the main trend appear to control a southwest-trending salient or projection of the reservoir, and also form a boundary to the resource to the east. A north-south trending structure may allow peripheral cooler waters to penetrate and possibly quench the steam reservoir near South Patuha peak.

Pressures and temperatures in the steam zone decline along the flow path towards the east and west ends of the reservoir, where steam discharge occurs at the fumarolic areas of Kawahs Ciwidey and Cibuni. Bleed off of gas and steam at the fumarolic areas may reduce gas levels and pressures in the steam reservoir. Condensate formed within the steam zone percolates downward to the deep water level, where it forms a reservoir of dilute Na-SO4-Cl fluids. Further drilling is necessary to determine if sufficient permeability is present in the deep water zone to allow this fluid to be produced to the surface. However, production from the vapor-dominated reservoir accelerates boiling of the deep fluids due to pressure drawdown, and provides a source of vapor recharge to the steam reservoir.

Shallow thermal aquifers channel acidic, chloride-bearing magmatic steam condensates away from the Kawah Putih fumarolic area to discharge at flanking thermal springs. These waters are neutralized by water-rock reaction along the flow path prior to discharge at the springs. The lack of chloride in the vapor-dominated reservoir and very low chloride levels in the deep water zone suggest these thermal springs are not directly related to the geothermal reservoir. This de-coupling of the productive resource and the chloride-bearing thermal springs is further supported by the ~1,300 meter elevation difference between the top of the deep water level and the springs.

Genesis of Vapor-Dominated Zone

A genetic link between the vapor-dominated geothermal reservoir at Patuha and the magmatic vapor plume is implied by: 1) the central location of the magmatic zone with respect to the steam reservoir, with the latter distributed more or less symmetrically around the former; and 2) the observed trend of increasing pressures and temperatures within the steam reservoir towards the magmatic zone. Based on drilling results for the KTB system, Allis and Moore (2000) proposed a general model for the formation of volcano-hosted, vapor-dominated geothermal systems linked to the dynamics of magmatic vapor plumes. In simplest terms, their model proposes that relatively low, sub-hydrostatic

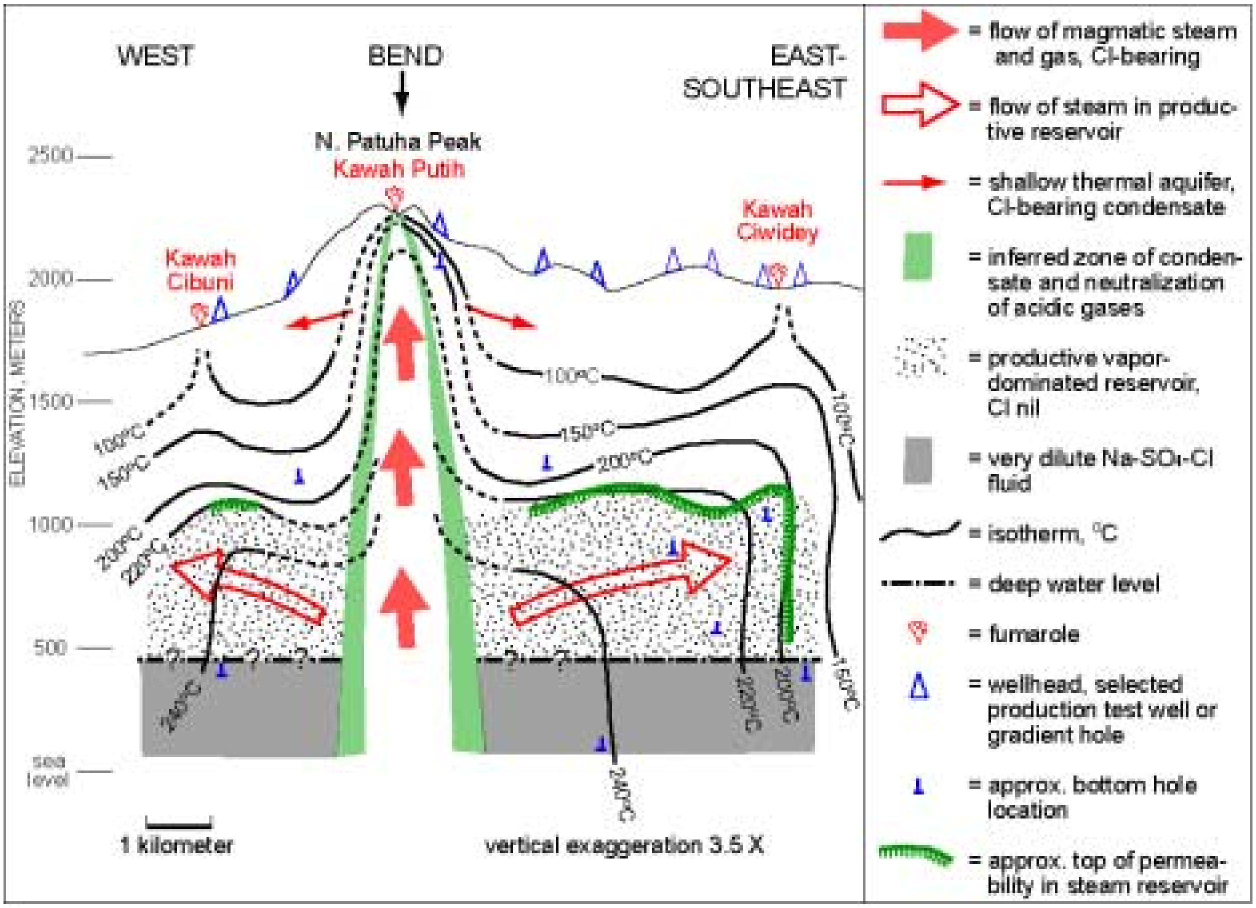

Figure 7. Cross-section illustrating conceptual model of the Patuha resource

pressures are present at deep levels in the magmatic vapor plume. This produces under-pressured conditions in surrounding liquid-dominated regions which are in pressure communication with the magmatic steam. The resultant pressure drop fosters the formation of a vapor-dominated reservoir in areas flanking the magmatic vapor plume.

Patuha differs from the KTB system in that the deep liquid zone is a very dilute steam condensate, whereas the deep water zone at KTB consists of a moderate salinity Na-Cl fluid with up to 8,000 ppm chloride. Moore *et al* (2002) presented petrologic evidence that the moderate salinity deep fluid at KTB represents a mixture of meteoric recharge and steam condensate. They propose that this fluid entered the KTB reservoir after an early hypersaline brine had boiled to dryness. Petrologic studies are required to determine if such hypersaline fluids were ever present at Patuha. However, the dilute condensate character of the deep water zone at Patuha implies that the Patuha reservoir is more tightly sealed and isolated from the regional hydrology than is the KTB system.

ACKNOWLEDGEMENTS

The authors would like to thank the management of PERTAMINA for allowing us to publish this paper. The senior author (Layman) developed many of the ideas included herein while working as an employee of Patuha Power Ltd., and acknowledges the contributions of Elliot Yearsley, Will Osborn, Batara Simanjuntak, Asrizal Masri and Kifle Kahsai to this effort. The authors retain sole responsibility for any errors of interpretation. Alison O. Layman prepared all graphics included in the paper and critically reviewed the text.

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