Success Development Drilling in Ulubelu Green Field in South Sumatra Based on Geological Structure Evidence, Generate 4X55MW

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ABSTRACT

Some geological, geochemical, geophysical methods and three slim holes have conducted in the Ulubelu field from 1992 to1997.

The three slim holes were drilled at a maximum depth of 1200 m as a geothermal model; confirmation did not provide conclusive scientific information, such as the hydrology system and temperature. As a consequence, this field was suspended.

With increasing demand for electricity from 1998 to 2007 in Sumatra, the geological concept of the Ulubelu field was reevaluated. The regional and local geological structure play an important role, which was revealed through landsat and aerial photos. The drilling scenario moved to the Northern side of the three slim holes that follow the graben fault pattern trendjng NW-SE, where there was no evidence of surface thermal. This graben fault structure is also part of the regional heat source lineament from gunung Rendingan in the north to gunung Tanggamus in the south.

All the production wells, with big hole casing configuration, are located in this graben structure corridor which generate 2x55MW on December 2012. Some wells that were drilled outside this graben corridor showed decreasing temperature, which is perfect for a reinjection well.

When this paper was written, the steam for 55MW for unit 3 is ready in the well head, and some additional wells for unit 4 are being drilled, which will be prepared for COD at the end of 2015.

1. INTRODUCTION

The Ulubelu geothermal field is situated in the Lampung Province of Sumatra Island, which is about 100 km to the north-west side from the capital city of Tanjung Karang (Figure 1).

Electricity demand in Indonesia increases year by year, and the government of Indonesia proposed geothermal energy to substitute fossil fuel generated electricity. Ulubelu field, one of the Pertamina working areas in the southern part of Sumatra island, has been developed for the geothermal resources to generate the electricity needed.

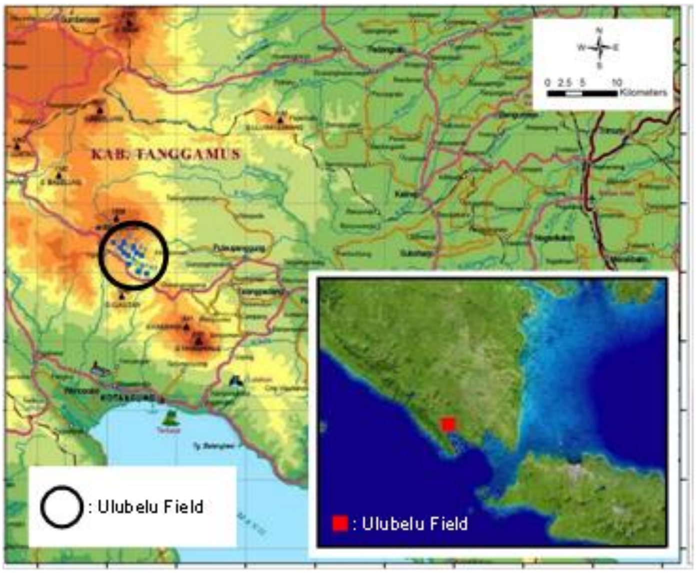

Figure 1: Location Map of Ulubelu Field

Some recent geoscience works have been conducted, such as Geological mapping of Ulubelu (M. Masdjuk, 1991), Geochemical survey (R. Pujianto, 1991) Geophysical survey (A. Rahman, 1991), Lineament Analysis from Landsat Images (1994), Interpretation of Radar and Aerial Photographs (Siahaan E.E., 1997), Interpretation and Analysis Cores and Cuttings of Slim Holes (Siahaan E.E., 1997) and Survey Hydrothermal Eruption (Siahaan E.E., 1998), Magnetotelluric survey (Pertamina, 2011).

Three exploration slim holes were conducted in 1995 with a maximum temperature of 225°C at 1195m depth; in well UBL-1 and the other wells (UBL-2 and UBL-3) this was only around 140°C -150°C at 850m – 900m depth with broken drill pipe inside the well after mechanical back off. In order to develop this field, production wells with deep drilling and big hole completion equipment should be cautiously placed in the up flow zone, so that revaluation of all methods were needed to determine temperatures above 250°C.

1.1 Volcanism

Plate interactions are in the Western Indonesia gormed subduction zone, as well as increased tectonic, magmatic and volcanic activities along the island ridge of Indonesia (parallel with the direction of the plate movement) (Hamilton 1989). The pressure of the plate movement is released periodically through Semangko, first order the strike slip dextral fault (Figure 2) with the first order maximum stress N6°E from Indian Ocean plate. The trough and the magmatic arc are estimated to have formed in the early Miocene (Hamilton 1989), which also recorded the Oligocene volcanism of Kikim tuff and old andesite of Lahat formation in the South Sumatra basin.

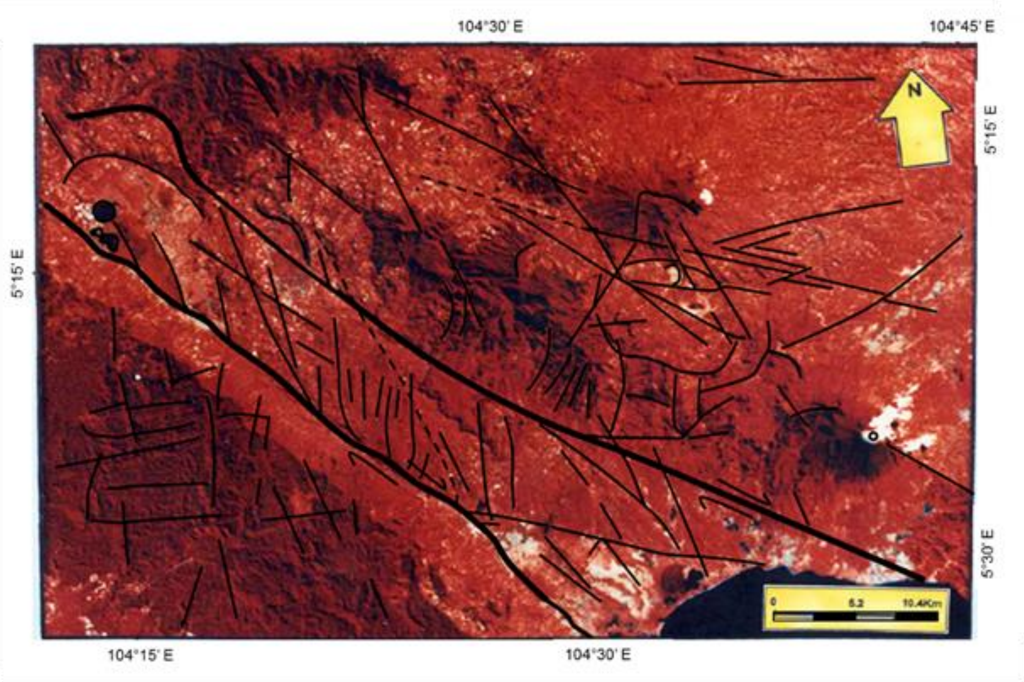

Figure 2: Map of Sumatra Major Fault System in Semangko Bay Vicinity

The volcanism along Sumatra continued from plio-pleistocene time until recent time, which associated along the fault scrapt of the Great Sumatra fault system. The coupling effect in Sumatra island, due to the subduction movement of plate oceanic crust of Indian ocean, made the long collapse graben representing the fractured zone to give way to the volcanism and other hydrothermal, epithermal and ore mineral mining activities.

Volcanic activity in Sumatra island from plio-pleistocene to recent time happened quite intensively from north to south, such as old Lake Laut tawar volcano, old Toba Volcano, old Lake Singkarak volcano, old Lake Maninjau volcano, old Lake Kerinci volcano, old Lake Diateh and old Lake Dibawah volcano in west Sumatra, and old Lake Ranau Volcano in South Sumatra. The Western Sumatra region is where the most intensive volcanic activities take part, compared to other islands associated with the subduction zone.

The first volcanic activity in the Semangko bay vicinity (Southern edge of Sumatra) started from old Lake Ranau volcano, followed by gunung Rendingan, gunung Tanggamus, gunung Kabawok. The volcanic evolution placed along the weak zone of the Sumatra fault, with random movement pattern along the fault. The typical volcanic product dominated by rhyolite, dacite, andesite and basalt lava.

2. DISCUSSIONS

2.1.Tectonic Setting of Southern tip of Sumatra

The subduction and collision between the Indo-Australian and Eurasian plates since early Tertiary, Miocene and Plio-Pleistocene time formed the Sumatra island. The Sumatra fault system with dextral strike-slip displacement was made by the oblique convergence of these plates. The plate collision also formed typical Bukit Barisan Mountain Ridge, which extends for 1600 km along the volcanic chain located at the western site of Sumatra (Siahaan et.al. 2000).

Many geothermal prospects, with high temperature systems above 200^0C, connected the volcanic arc Barisan together with the Great Sumatra transform fault system such as Seulawah Agam, Sibayak, Namora I Langit, Silangkitang, Sibual-buali (North Sumatra), Muara Laboh, Semurup, Kerinci, Hululais, Tambang Sawah, Bukit Daun (Central Sumatra) and Lumut Balai, Rantau Dedap, Ulubelu (South Sumatra).

In the southern side of the Sumatra fault, in the Semangko bay, this right-lateral strike slip fault became normal fault and made a wide graben from Kota Agung up to Sekincau in northwest side; the widest graben valley is in Sungai Penuh, at about 4 km.

2.2. Geological Framework of Ulubelu

The structural lineament maps prepared from the Radar and the MSS imagery Landsat (Figures- 2 and 3). Based on the lineament patterns, some fault segments, collapse structure and circular features can be interpreted in the field.

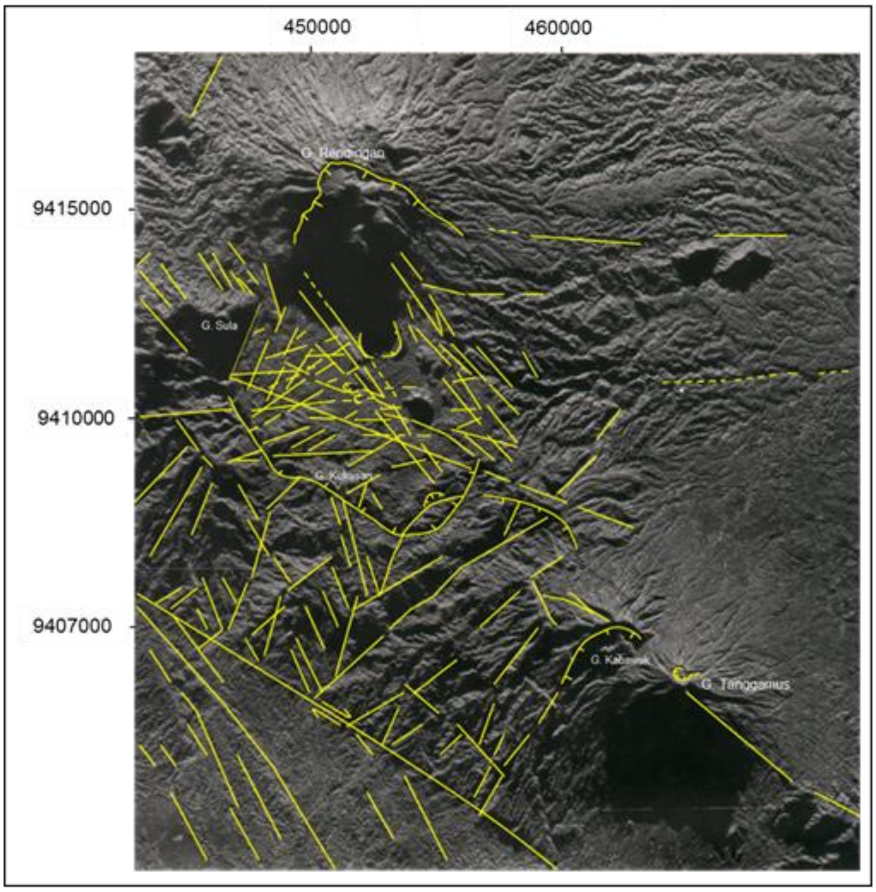

Figure 3: Map of Ulubelu showing Volcanism, Lineaments, Collapse Structure and Craters

The main strike slip left lateral fault, trending NW-SE, faulted Sumatra island from north to south. This fault formed in the early Tertiary time, as the first fault order that influenced the fracturation pattern in the Ulubelu, which formed the NNW-SSE strike slip left lateral fault as the second order. This NNW-SSE fault, reactivated in the plio-plesitosen time, became a normal fault with the productive permeable graben, where most of the production wells are located (Figure 3).

The E-W trending fault, crossed in the middle of the Ulubelu area, controlled the crater of surface thermal manifestations of Pagar Alam and Karang Rejo, such as crater of steam heated sulfate water, mud pools, relict silica sinter with very low intensity of steam blow and very low flow rate of acid turbid water. In the crater rim, hydrothermal breccia with variable intensities of alterations were also found.

The crater of Gunung Rendingan, exposed to the South direction, can be recognized from the last andesite basalt lava and the product of unconsolidated lahar flow to south. This crater structure played important role to the deep hydrology geothermal concept as the Northern border of the system.

The collapse structure circled in the western to southern part of the field, which happened in the Plio-Pleistocene time as the last big tectonic event. The existence of the collapse structure seems to have controlled the geothermal system of Ulubelu; it might be a big prospectus reservoir, as a giant field that needs to be proven by drilling. This western prospect will be drilled in 2015 as a step out exploration expansion strategy.

The collapse structure controls the surface thermal manifestations in Southern side, with quite intensive steam heated sulfate water, mud pools and characterized by the mud volcano, with a maximum height of 1 meter that might be formed and erupted in a couple of days.

In the northern side, where the main production zone is located, there are no surface thermal manifestations even in the crater of Gunung Rendingan. This evidence implies that the development strategy of Ulubelu should not rely on the geographic position and the type of surface thermal manifestations, whereas the other geothermal fields could.

2.3. Development Strategy

The morphology bowl shape of Ulubelu field has an average elevation of 734 msl, the Gunung Rendingan in the northern side has an elevation of about 1750 msl, and Gunung Tanggamus with the youngest strato volcano in the southern side has an elevation of about 2102 msl.

The heat source aligned NNW-SSE direction started from north to south is Gunung Rendingan, Ulubelu field – Gunung Duduk, Gunung Kabawok and ended in Gunung Tanggamus, which is coherent with the high mineral temperature assemblages (epidote, illite) and the isothermal pattern in the deep reservoir.

The hottest part along the NNW-SSE graben in the depth between -400 msl to -800 msl sited in the Northern part around well pad-D, B and C with the measured temperature above 275^{0}C (Figure 4). The Northern field is bordered by the crater rim of Gunung Rendingan, where recent drilling results from well pad-I show a high temperature of about 275^{0}C and produce significant steam (~10MW). This segment will be drilled persistently in well pad J and K. The delineation wells are being drilled around this crater zone in this year of 2014.

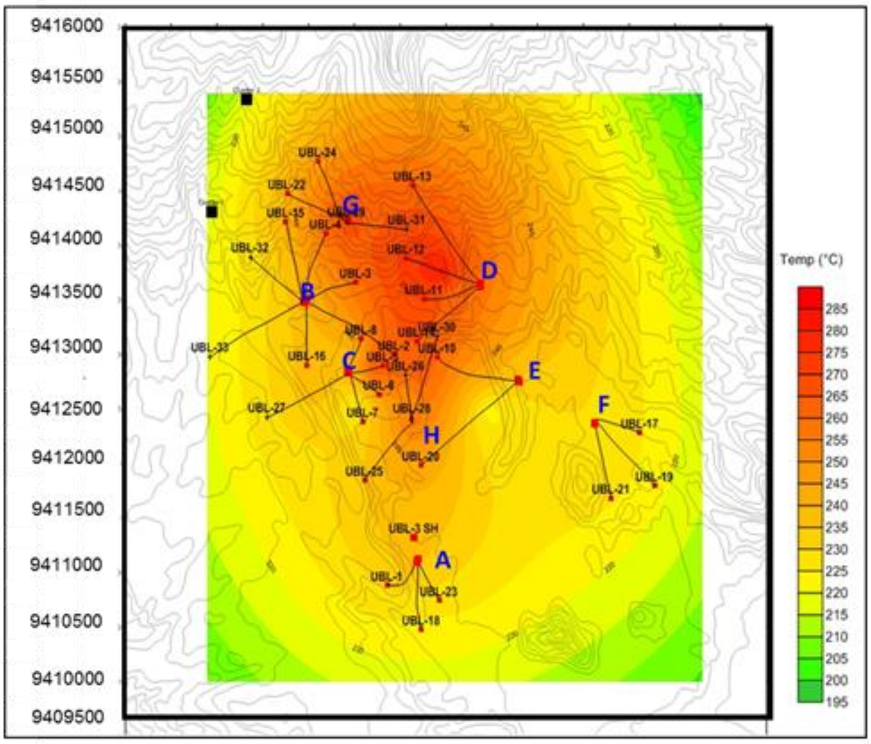

Figure 4: Isothermal at -800msl (PSD Reservoir Group, 2014)

The deep temperature in the eastern side of Ulubelu abruptly decreased, as found in the reservoir of well pad-F. The existence of the eastern zone of NNW-SSE fault graben should be considered in terms of field expansion, barrier fault, non-productive zone and or reinjection wells (Figure 5).

Along the NNW-SSE graben to the south direction, the reservoir temperature decrease gradually down to 265^{0}C, and the water level is still the same depth and the fluid still can be used to support unit 3 and unit 4 with a total capacity of 110MW. The southern and the western side of the field is limited by the collapse structure that still needs confirmation through the performance of reinjection wells, which are being drilled.

The western side is not yet fully understood, because the shallow slim well had mechanical problem with a total depth of only 900m. The expansion area can be suggested to the western side, because there is one well from cluster B encountering the good temperature outside of the NNW-SSE fault plane. Inside, the collapse structure shows good permeability as proven by the fracture intensity, the drilling history of partial loss circulation and total loss along the well sections.

Based on the pressure and temperature measurements and loss circulation data from 30 wells, there are three (3) feed zones in the Ulubelu field to support unit 1,2,3 and 4 (Figure 6 and 7). The deepest feed zone is intersected by the majority wells in well pad D and E and one well from G (G4) and H2, H4, I1, F3 with depth interval between -800 msl to -1400 msl.

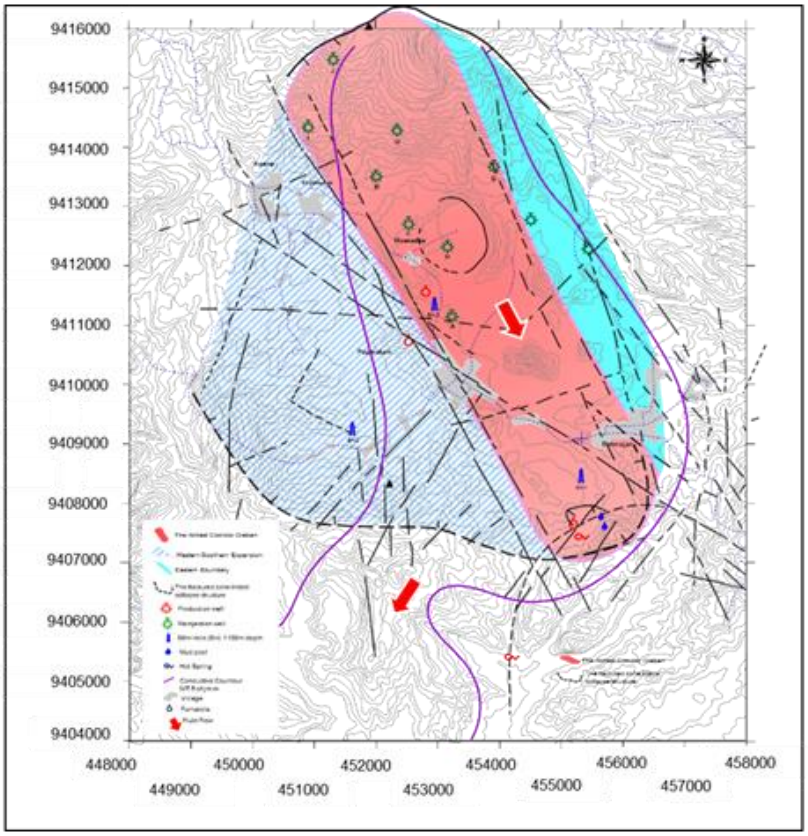

Figure 5: Development Wells of Ulubelu

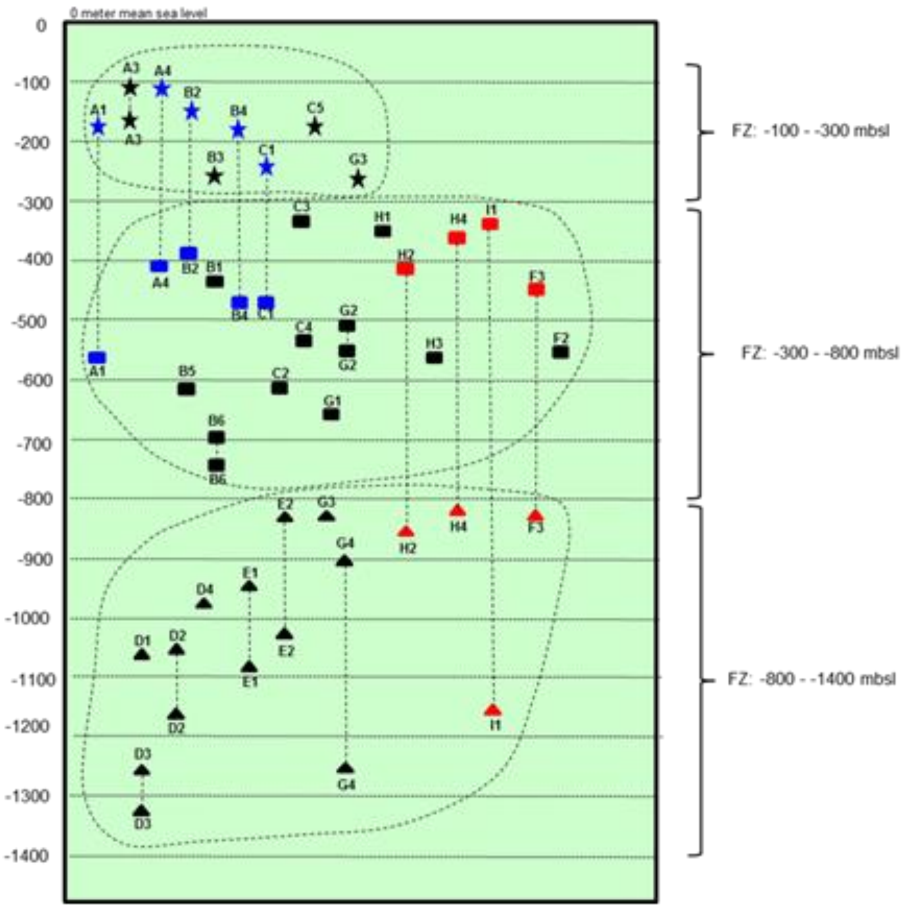

Figure 6: Feed Zone in Northern Part of Ulubelu

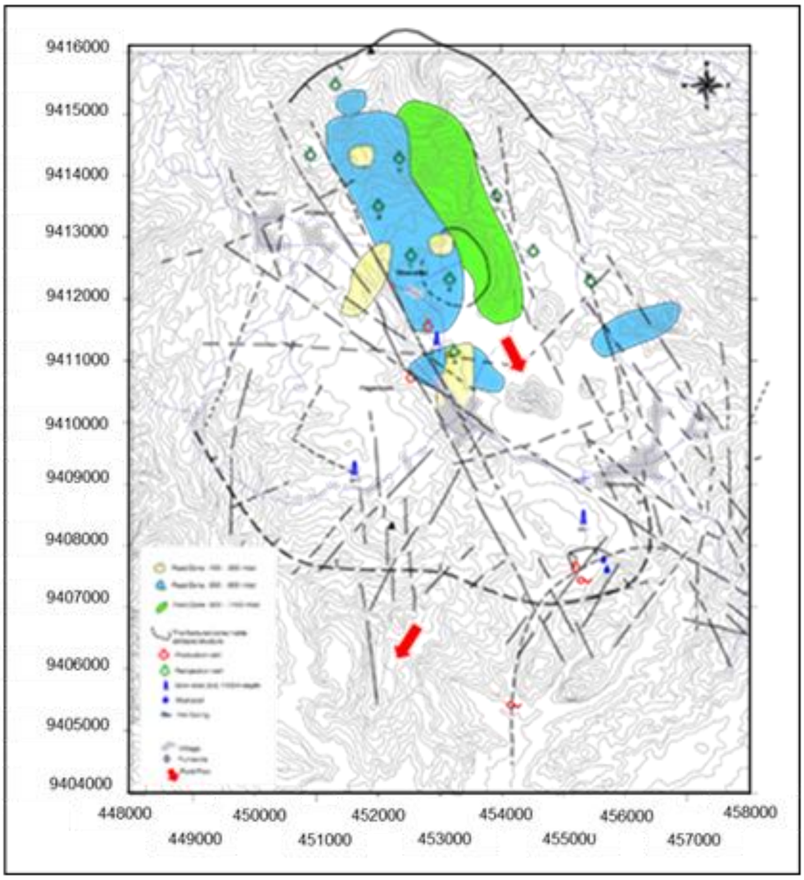

Figure 7: Map of Reservoir Zonation

The main production wells from unit-1, 2 and 3, which are from well pad B about 5 wells, well pad C about 4 wells, well pad G about 2 wells and well pad H about 3 wells. These feed zones are derived from an interval depth of -300 to -800 msl, with average temperatures of about 270^0C.

The shallow feed zone is in between depth of -100 msl to -300msl, where the brine is re-injected back into the reservoir by utilizing 3 wells in well pad A. Those reinjection wells should be moved farther to the southern part of Ulubelu, because the distance is too close to the main production wells, and also the feed zone is quite shallow even though the temperature is above 250^0C.

2.4. Drilling Activity

The PT. PGE-Ulubelu Drilling Campaign was started on August 2007. During the early stage of campaign, 4 standard-hole wells were drilled as exploration production wells. While on the next phase, only big-hole wells were drilled for both production and injection wells. Typical wells design for those types shown on well schematic below (Figure 8).

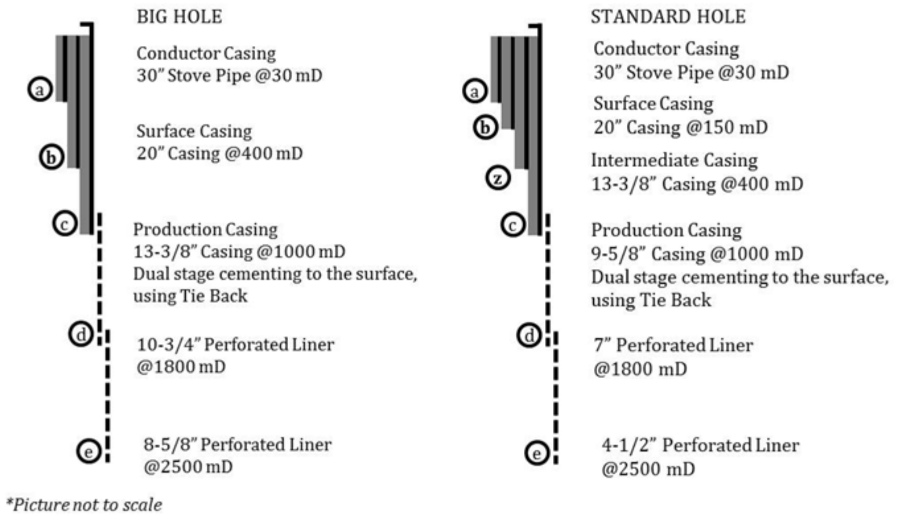

Figure 8: Casing Configuration

About 35 wells were already drilled to supply steam for Ulubelu Power Plant Unit 1 & 2 (2x55 MW) and Unit 3 & 4 (2x55 MW). Average well depth in Ulubelu is 1950 meter measured depth, with average 50.42 drilling days (since spud until well completion test finish) and average cost about USD 4.6 Million. Most of the wells were deveated, which ranges from 0 to 45 degrees.

Well UBL-13 in cluster D is the deepest well in Ulubelu Steam Field (2,537 meter measured depth, completed within 55 days). UBL-28 in cluster H is the fastest well (completed in 24 days with 2,000 meter measured depth).

One of drilling challenges in Ulubelu is permeable & non-consolidated formation at 26" and 17-1/2" section hole. Loss of circulation and caving often occurs, consequently the loss circulation material and a cement plug were considered as the alternatives to minimize the effect. Based on experiences from previous wells, those methods are low-effective, time-consuming and relatively high cost. To overcome these challenges, PT.PGE drilling team using air drilling, not only to obtain returns while drilling in the loss zone, but also to ensure the rate of penetration was faster due to its effect on hole cleaning.

The second biggest challenge in the Ulubelu drilling campaign is the clay problem. The drilling obstacles in well pad A and well pad B are always agitated by this. When entering the reservoir formation with total loss circulation, the drilling operation most likely continues to use water. In the reservoir zone, some problems have arisen besides swelling and brittle clay, such as excessive cutting causing high torque, stuck pipe and some ending with drilling strings lost in the hole. PT. PGE has to lost hole due to this Clay Problem (UBL-22). The KCl mud and treated water (water+KCl) are considered as one alternative to encounter clay problem. Some studies have already been conduct with expert scientists to optimize the KCl usage on drilling mud, and extend the other possible alternatives.

2.5. Production Activity

2.5.1. Production wells support 2X55MW

Ulubelu field is the water dominated system with the average enthalpy of 1100 kJ/kg. Currently, Ulubelu field is the largest geothermal power plant in Sumatra with 2X55 MW capacities. The COD of Unit-1 and Unit-2 was successfully implemented respectively in November and December 2012.

The steam field operated by PT PERTAMINA GEOTHERMAL ENERGY supplies steam to a nearby 2X55 MW power plant operated by PT PLN. The steam is supplied from 3 Clusters (B, C and D), and brine separated in separators will be injected along with condensates from power plants into wells in cluster A and F.

The two phase fluid from production wells in cluster B flows to join those in cluster C and then to the 2X40 MW separator station. The steam from the separator station flows to the power plant. The brine is re-injected into a well in cluster A. Wells in Cluster D connect to the 40 MW separator on cluster D. The separated steam flows to the power plant and the brine is re-injected by separator pressure into a well in cluster F. The type of separator is cyclone with integrated water drum.

Near the power plant, the two steam lines from cluster C and D meet. A flow and pressure balancing line connects the two steam lines which change to two parallel scrubbing lines. After the steam has been scrubbed, both of those are joined together into one single steam line to flow to the power plant. The simplified PFD and HMB (heat & material balance) of Unit 1&2 can be seen in Figure 9.

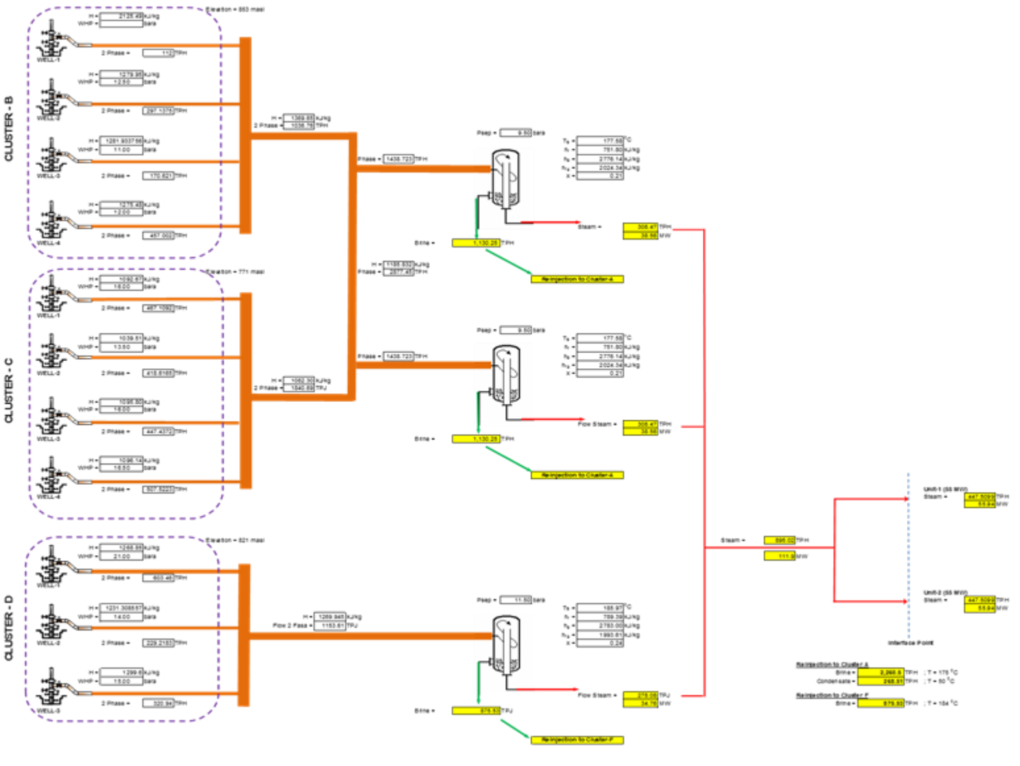

Figure 9: Process Flow Diagram (PFD) and Heat & Material Balance (HMB) Unit 1&2

2.5.2. Well plan to support Unit 3 and 4 (2x55 MW)

The site is located in hilly terrain spread out over an area of about 6 km (N-S) x 4.5 km (E-W). The production well clusters B, G, I and J are located in the northern sector, whereas production well clusters C and H are in the central sector of the Site. The reinjection well cluster R1 is located in the southern sector of the Site. The site has a general fall in elevation from north to south, with relatively steep gradients in the north and moderate to flat gradients in the south. The central separator station shall be located near the production well Cluster-H. The central separator station shall also accommodate the atmospheric flash tank (AFT) for emergency brine discharge and disposal of brine to a central pond.

The two phase fluid from Clusters B, G, H, I and J shall flow into the cross country, two phase gathering pipeline and be conveyed to the central separation station. In the cluster-C, production well UBL-27, which is already connected to Unit 1&2, shall also be connected to the Unit 3&4 gathering system.

In the cluster-B, production wells UBL-32 and UBL-33 shall be connected to Unit 3&4. The other four production wells on cluster B are already connected to Unit 1&2 SAGS. In order to maximize operational flexibility, a cross-over pipeline between the two gathering pipe headers shall be installed.

The separated steam lines from each separator shall join into a common steam header. Two parallel steam transmission lines from the header shall convey steam to the two scrubbers/demisters before supplying steam to the Unit 3&4 steam turbines. About 500m of pipeline sections upstream of the scrubbers/demisters shall be used as scrubbing pipelines, where dissolved silica and chloride in steam are removed with condensate through various condensate pots along this section of pipeline. A pressure balancing line shall connect the two steam transmission lines downstream of the scrubbers.

From the steam header downstream of the separators, a cross-over pipeline shall connect to the steam pipeline of Unit 1&2, providing flexibility to divert part of steam between Unit 1&2 and Unit 3&4.

The separated brine from the separators in the central separator station shall combine into a common brine pipeline and flow under gravity to the reinjection wells located in Cluster R1. Condensate from the hot well pumps shall be conveyed, under gravity, in a pipeline to an injection well also located in Cluster R1.

The summary of production and injection wells in each cluster for Unit 1&2 and Unit 3&4 can be seen in Table-1 below.

Table 1. The Summary of Production and Injection Wells

Unit	Cluster	Type	Number of Wells
1 & 2	B	Production *2 Separator at Cluster C & D	4
	C		5
	D		4
	A	Injection *Cluster A --> Hot brine from Cluster C *Cluster F --> Hot brine from Clueter D	3
	F		3
3 & 4	B	Production *Centralized separator at Cluster-H	1
	G		2
	H		4
	I		3
	J		2
	R1	Injection	5

3. CONCLUSION

The graben structure trending NNW-SSE shows the surface heat flow alignment from Gunung Rendingan to Gunung Tanggamus and proven by the reservoir temperature distribution. This graben corridor is the main productive zone to support the 4X55MW of power generation, with the reinjection wells possibly located in the southern side of the field.

Another implication of structural analysis: the semi-circular collapse structure shows the field boundary to the southern side of the field; this can be a target of expansion drilling, scheduled by the exploration team next year.

Ulubelu field is the largest geothermal power plant in Sumatra, with 2x55 MW capacities being prepared for 2X55MW power generation.

Understanding the regional structural lineaments, structural study and fracture confirmation in the field, by using satellite imagery and aerial photos, provided valuable implication to the success story of development strategy (exploration, development and reinjection wells).

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