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Bedugul Geothermal Prospect and Developments

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ABSTRACT

Bedugul is in the center of Bali and north of Denpasar. A geothermal area exists there. The area is about 70-90 km^2 and is bordered mainly from geophysics and geology investigations. Part of the area was proven by the exploration of two deep wells BEL-03 and BEL-02, and core-hole TCH-04. It is inside Bratan's caldera structure. Therefore, the proven area of geothermal prospect is then defined to be about 8 km^2. The area may conserve energy of about 80 MWe for 30 years since its power density is equal to 10MW each km^2. Bali Energy Limited (BEL) will promote a small power of 10 MWe in 2006 to initiate another large 3 x 55 MWe power for the future.

Geothermal energy is a prospective alternative energy that would be used for generating electricity for Balinese desire. Its products should only have a small affect on the environment, and they may increase the existing tourism.

The Balinese have a one management island concept called seamount union. Whenever one changes the mount environment, the sea environment will change. Bedugul is a part of the attractive tourist area in Bali. Therefore when developing a geothermal area in Bedugul, it is necessary to follow the wishes of the Balinese. For example: by keeping Bali clean, the environment is sustained and at the end of the project tourism will have increased.

BEL previously anticipated the need for developing geothermal energy in Bali by conducting an energy workshop in 1977. Recently, BEL has begun introducing geothermal energy to the Balinese.

1. INTRODUCTION

The concession area of Bedugul geothermal was referred to letter 465/KPTS/M/Pertamb./74 on April 10th, 19974. It is delineated by coordinates of 8^{o}10'00" – 8^{o}30'30"S and 8^{o}11'30" – 8^{o}26'30"E, 101 660 Ha, see figure 1.

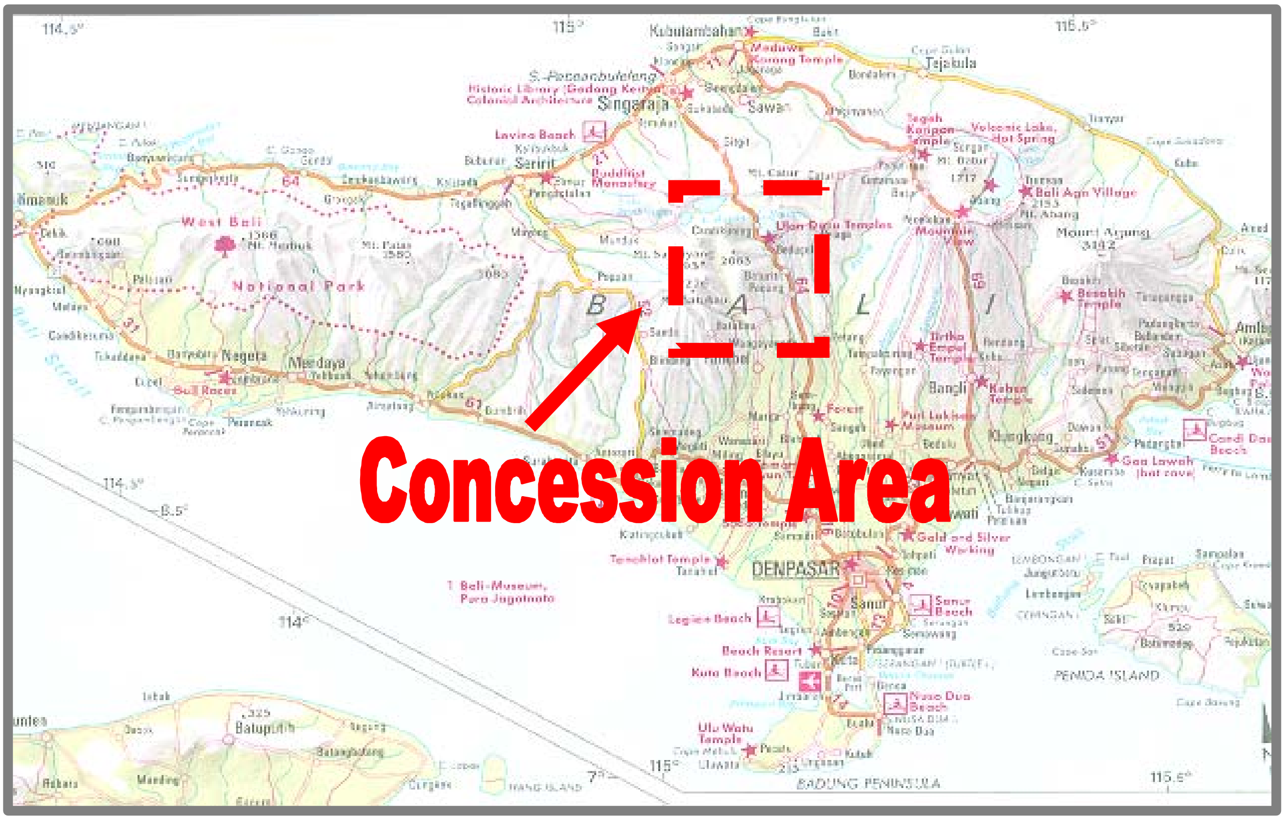

Figure 1: The concession area (WKP) of Bedugul.

In November 17, 1995, the joint operation contract (JOC) was signed by PERTAMINA and Bali Energy Limited. Meanwhile, on the same day the energy sales contract (ESC) was also signed by Bali Energy Limited and pt. PLN (persero). Unfortunately, most of the big projects including Bali geothermal project were suspended when the economic crises took over Indonesia in 1997. During its exploration period before being suspended by the president's decree number 39 in the year 1997, BEL had managed to drill six temperature core holes and three deep exploration wells. They were named BEL-01, BEL-02, and BEL-03. In the last stages of the exploration period at the end of January 1998, BEL performed a 24 hours rig test on well BEL-03. The test yielded the result that BEL-03 was able to produce steam and water of up to 56t/h with an enthalpy of 1744 kJ/kg. After that, the Bedugul Geothermal Project went into suspension.

Five years later, in 2002, continuations of big projects were re-negotiated with the issuance of the President's decree number 15. After 18 months of re-negotiation that produced amendments to the original JOC and ESC contracts, the Bedugul Geothermal Project was once again ready to go forward with full government support. This was partly because there was a concern of a Java-Bali electricity shortage in the near future. Therefore, suspensions of Independent Power Producers (IPP) Projects were revoked including BEL.

2. LOCATION

The Bedugul geothermal prospect is located in the mountain area and it is about 60 km north of Denpasar, Bali, figure 1. Two volcanoes, Mt Batur and Mt Agung are presently active outside of the prospect in the eastern part of Bali. Nature preserves or protected forest, production forest, and botanic gardens cover most of the prospect area, and the rest is property of the community. Small fumaroles and very rare warm springs manifested at the center, while most of warm and cold springs are outside of the area.

3. PROSPECT AND PROVEN AREAS

Since signing the contracts with the government in November of 1995, BEL has completed geological, gravity and resistivity surveys, and drilled six temperature gradient core-holes to the depths of 685-1400m, and three deep exploration wells to the depth of 2686-2826 m. Core-hole data shows that cold, porous volcanic rocks forms a 1000m thick blanket over most of the prospect area, effectively masking the deep geothermal system and limiting surface expressions of heat. Temperature measurements in core-holes combined with resistivity survey results indicate the Bali resource may be quite deep. Production wells may have to be drilled to depths of 3,000 – 3,500 meters.

The Bedugul geothermal system, Bali, is associated with Quaternary volcanic activities in the Pleistocene to Holocene period. The system is in N-S trending volcanic activities in the big Bratan caldera.

Volcanic rocks are distributed on most of the prospect area, and sedimentary rocks are near the lakes within the Bratan caldera. The surface layer consisted mainly of tuff, tuff lapilli, and alluvium; the layer is very loose and tends to erode easily. Flowed pumice ash tuff covers most of the center and eastern part of Bali, which overlies andesitic volcanic.

Surface thermal features within Bratan Caldera include drowned fumaroles (Teratai Bang) and an area of warm ground at an elevation of 1400-1500 meters above mean sea level (amsl). Also it includes as a warm spring on the edge of Lake Buyan. In addition, a hot spring area is present at a lower elevation on the west flank of the volcanic highlands at Yeh Panas at about 600 meters amsl. A cold spring is present on the eastern flank, as well as an extensive area of Hot Springs on the southern flank at elevations of 300-600 meters amsl.

In 2004, Jetro-WestJec has recently reconstructed lithological cutting obtained from wells that show dominated pyroclastic, andesite, and underlain by andesite breccias (could be diorite). They also interpreted that the existence of ignimbrite may indicate the Bratan caldera has erupted three times, 29300, 20150, and 5500 BC.

Lateral distribution of resistivity sub-stratum showed no contrast resistivity boundary found, unless the two areas are at the northwest and the south part of the area, figure 2. A diffuse sub-surface resistivity boundary seems to exist towards east and west. The diffuse resistivity boundary is also indicated by a more extensive area of relatively; low resistivity extends away from the three anomalies of TDEM resistivity in the caldera area to the hot spring areas on the west and south flanks. This strongly suggests that the hot springs on the flanks are fed by topographically driven lateral out-flows of mineral water originating in the caldera area. However, the results of slime holes drilled at the southeast of the area may separate the geothermal prospect area from others. While to the west and the east, the boundary of geothermal area is due to the caldera rim and the geological structure interpreted from geology photo.

The Bouguer gravity anomaly indicated by the NE-SW trending line may suggest a fault system in the northern and the southern part of the area, Jetro-WestJec in 2004, see figure 2. The fault seems also due to rim caldera at the NE edge of the Bratan caldera. The NW-SE lineament is due to caldera rim at the western edge of Bratan caldera.

The geothermal prospect area is then inside the moderate resistive sub-stratum and defined by the geological structure; it is ending with figure of about 30 km^2, figure 2.

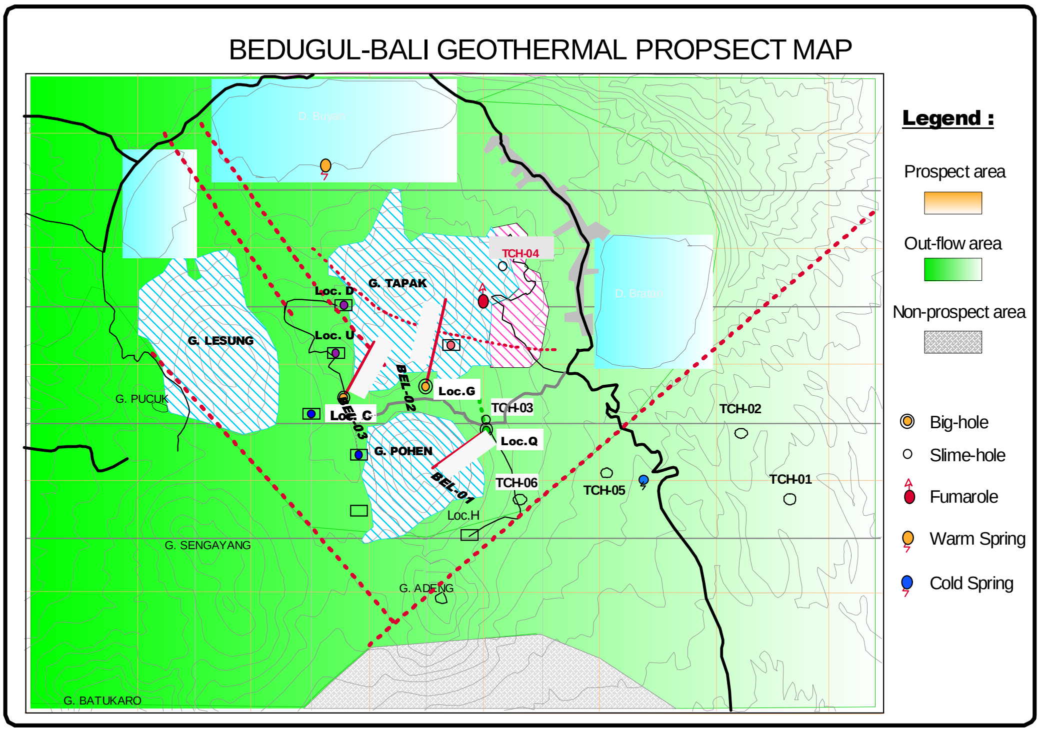

Figure 2: MT-resistivity sub-stratum map

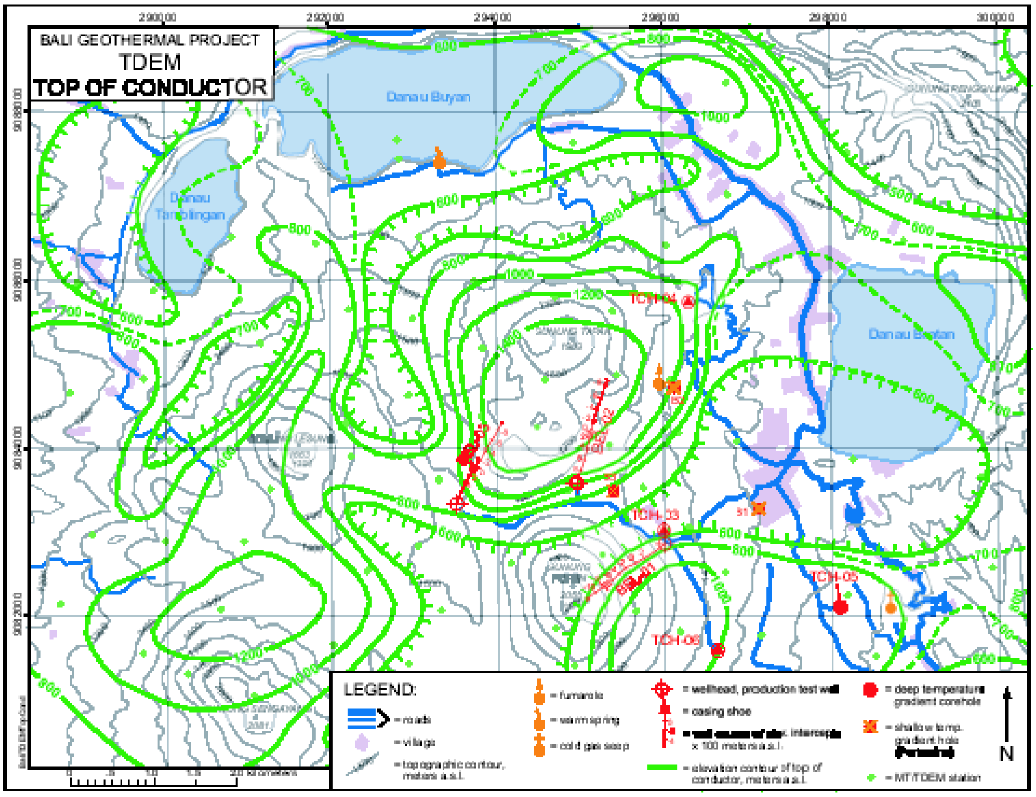

Figure 3: Top of TDEM conductive layer (Geosystem, 1996

A resistivity model was constructed from 1-D resistivity layer that inverted from MT-sounding. Layers of the model were then simplified into three resistivity layers that consist of surface resistive layer, middle conductive layer, and resistive sub-stratum. The middle conductive layer is interpreted as a cap rock.

Top of Time Domain Electro Magnetic (TDEM) conductor may also represent the top of cap rock. By mapping, the top of conductor may indicate cap rock distribution and its shape. The conductor formed dome like structure in center of the area around Mt. Tapak and it is also shown in the south-west of the area, see figure 3. The pattern is also similar to the pattern of sub-surface temperature distributions of deep wells and of core holes.

Key temperature mineral such as epidote mineral, was found at the deep wells named BEL-01, BEL-02 and BEL-03. No epidote was found at all slime-holes, even at the high thermal gradient of core-hole TCH-04.

Sub-surface temperature profiles that were obtained from the three deep exploration wells BEL-02, BEL-03, BEL-01, and one core-hole of TCH-04 have high temperature gradient, suggesting those wells were in an area of up-flow zone, figure 2 and 4A. Other area defined as out-flow zone was indicated by TCH-01, TCH-02, and -05; while the TCH-06 shows a moderate temperature gradient, suggesting the TCH-06 was located on the boundary between up-flow and out-flow zones, figure 2 and 4B.

The conductive layers that exist in the area of the Bedugul geothermal system are very thick. The bottom of the cap rocks can reach to depth of about 1000-2000m below sea level, figure 5. This depth is unusual in comparison to other geothermal systems in Indonesia. In other systsems the bottom of cap rocks are usually located from sea level to 500m below sea level.

A common geothermal resistivity layer with an addition of the presence of ocean water at 30 km north of the prospect area was modeled. The resistivity value of the ocean water was 0.25 Ωm, which was overlying the 100Ωm resistive body, figure 6. The model was then showing long period response. If this is the case, the long period response of MT, which affected into the calculated tick conductive layer is due to deep ocean water. Therefore the MT resistivity model in figure 5, shows that the top of resistive basement is deeper than the inferred hot chloride water level. The hot chloride water was inferred from well test and down hole pressure-temperature results. Since then, it is suggesting that the resistivity model should be corrected from the existence of ocean water at 30 km north of the prospect area.

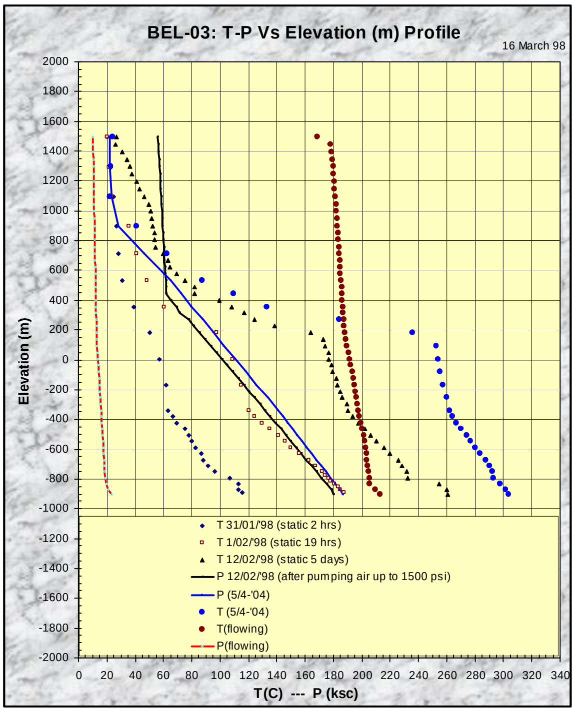

Figure 4A: P-T profile BEL-03, Bedugul, Bali.

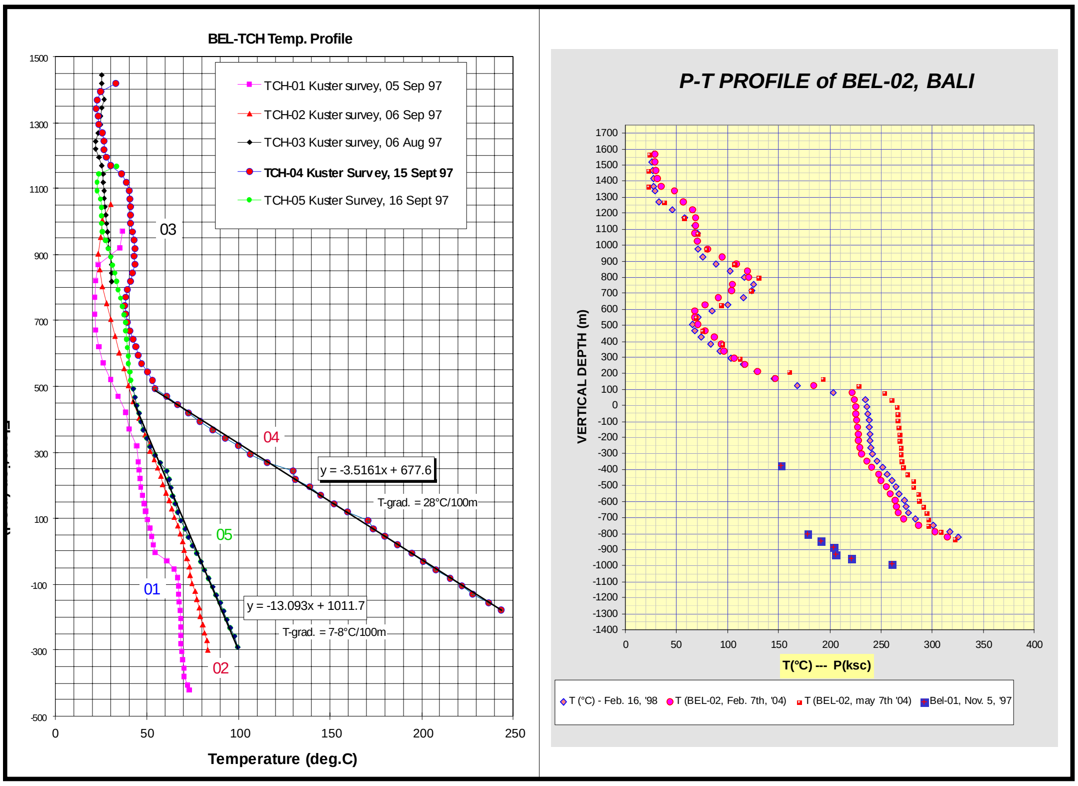

Figure 4B: P-T Profiles of slime-holes and well BEL-02.

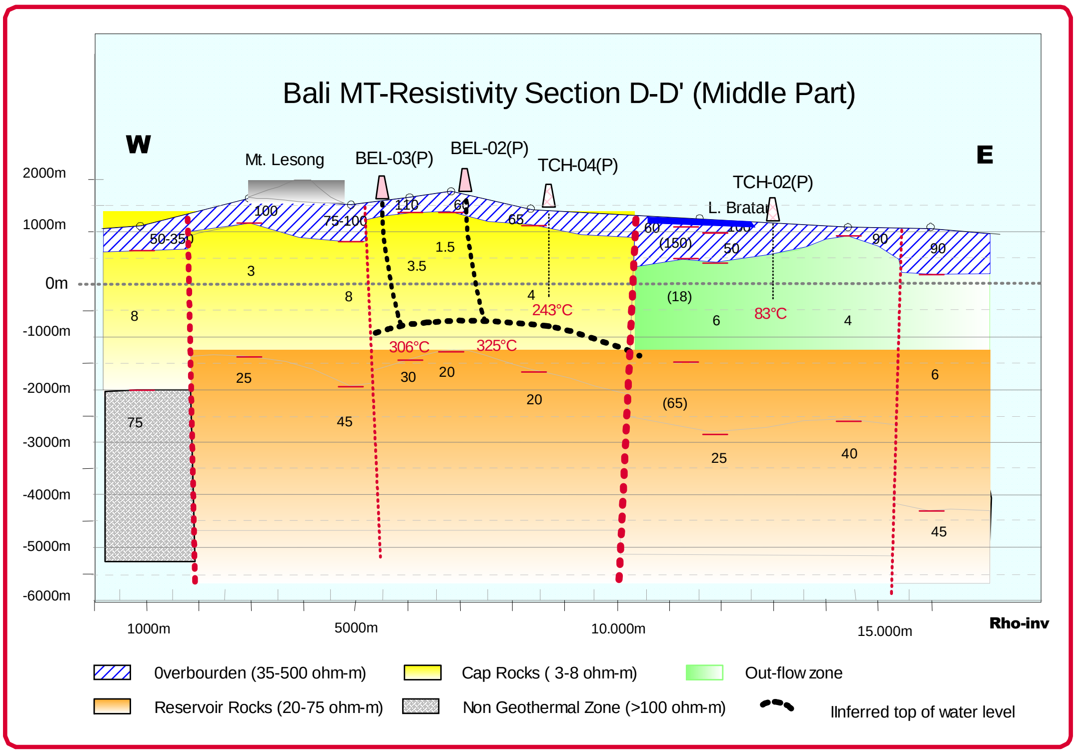

Figure 5: Tentative resistivity model of Bedugul-Bali.

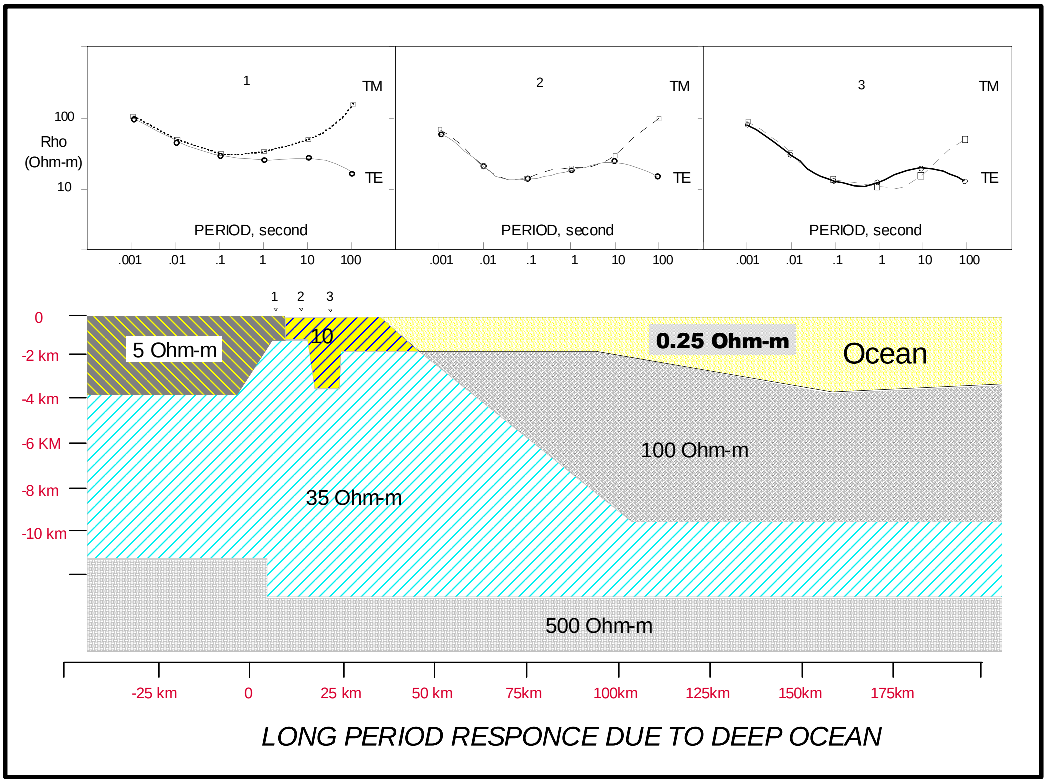

Figure 6: Long MT-period response due to ocean water

The high sub-surface temperature may coincide with the appearance of mineral epidote that was encountered in all the deep wells at depth ranging from sea level down to 1000m below sea level. However, according to drilling records there were only two wells, BEL-02 and BEL-03 that may indicate permeability. No permeability was in the well BEL-01.

To prove the presence of geothermal potential in the Bedugul-Bali geothermal prospect, BEL was then planning to test the well BEL-03.

There is high reservoir temperature, but the top level of the water column reached about 500m to the surface. It suggests that the BEL-03 should be stimulated to discharge. A method by lowering water level down to 1500m deep using nitrogen compressor was chosen to bleed the well and then the production well test was conducted for an additional month.

After no response, the well flowing with about 5000 gallon of nitrogen had been pumped into the well BEL-03. It took 2 x 24 hours to well head pressure up to 1450 psi, which is similar to pressurize the well where the water level is at about sea level, figure 7.

Figure 7: Pumping Nitrogen into the well BEL-03.

Well BEL-03 has been flowed in early May 2004 for 6 weeks showing steam rates from 38 and 36 t/h at a well head pressure of 100 and 200 psi, figure 8A and 8B. It seems very low, since the well is big hole. However, after vertically discharging since end of June 2004, it is expecting to have BEL-03 producing higher steam. Well BEL-02 will be potentially tested soon after BEL-03 is tested, and it is expected to be able to produce steam higher than 38 ton/hour. BEL-02 was drilled to the eastern flank of Mt. Tapak, which has similarity of drilling target with BEL-03.The steam fraction is dominant up to 95% dryness. Since then the steam flashing was interpreted as occurring at the depth of 850m below sea level, which was showed by elevated gradient of pressure at flowing condition, figure 4A.

Total gas content is rather high of about 4%-Wt comparing to the rig test of well BEL-03 conducted in 1998 that was 3%weight. There is a trace of magmatic gases such as HF, HCl, and SO2, table 1. However, its pH is normal. The H_2S concentration was 0.0236-0.0302%-weight in steam, which is very common in ordinary geothermal system. Recent gas analyses indicated that the H_2S content is extremely high, 2.3%-weight. Other high gas CO_2 concentration of 97%-weight was interpreted as derived from sedimentary rocks (limestone). These rocks were outcropped at the south beach of Bali acting as basement.

Since the BEL-03 has been being proven to discharge the steam, part of the prospect area was then defined as proven area. The BEL-02 has similarity in P-T profiles to well BEL-03 and slime-hole TCH-04 indicated high temperature gradient; the caldera structure may provide rock's permeability. So the wells BEL-03 and BEL-02 and the core-hole TCH-04 are acting as the boundary of the proven area. Therefore, the proven area of geothermal prospect is then defined to be about 8 km^2, see figure 9. The proven area is chosen to be used to develop an initial 10 MW power before developing the other 3 x 55 MW power.

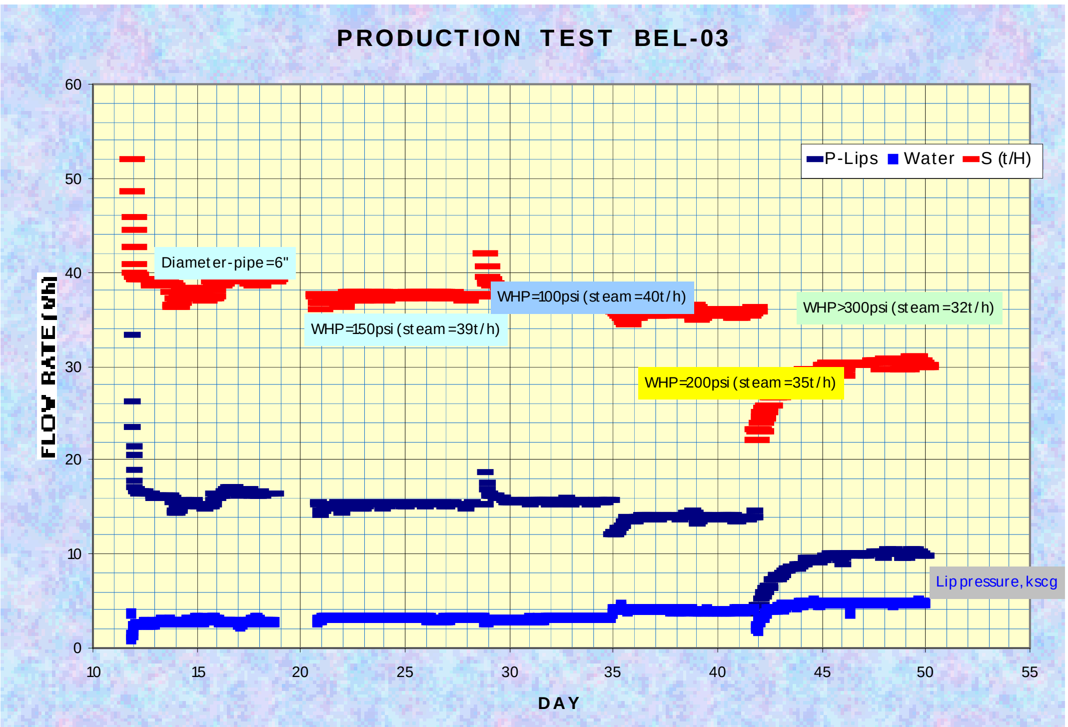

Figure 8A: Flow rate of BEL-03 Vs Time, Bedugul-Bali.

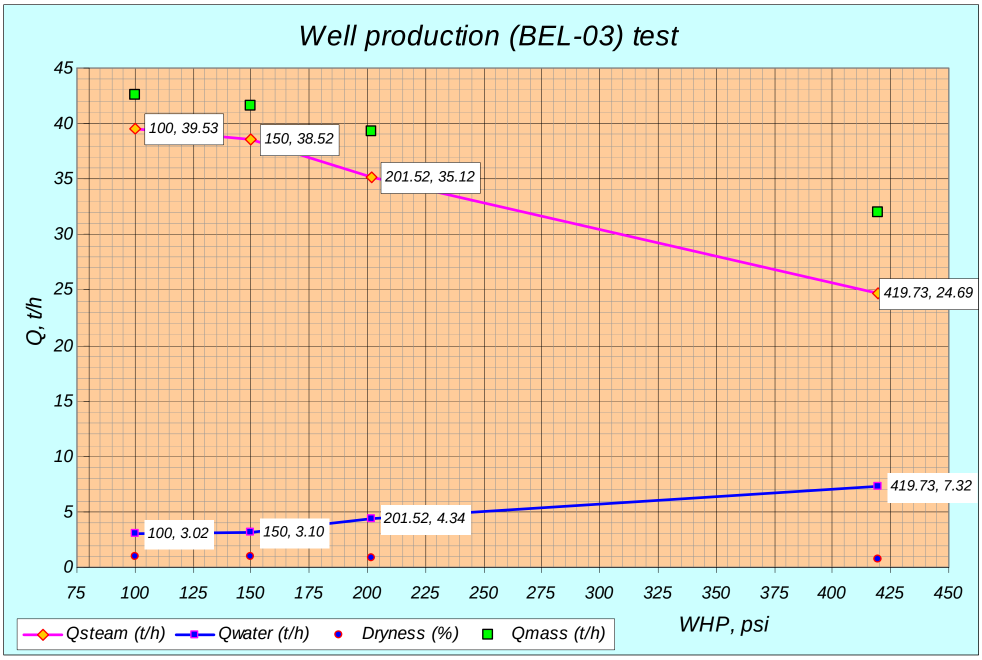

Figure 8B: Production test of BEL-03, Bedugul-Bali.

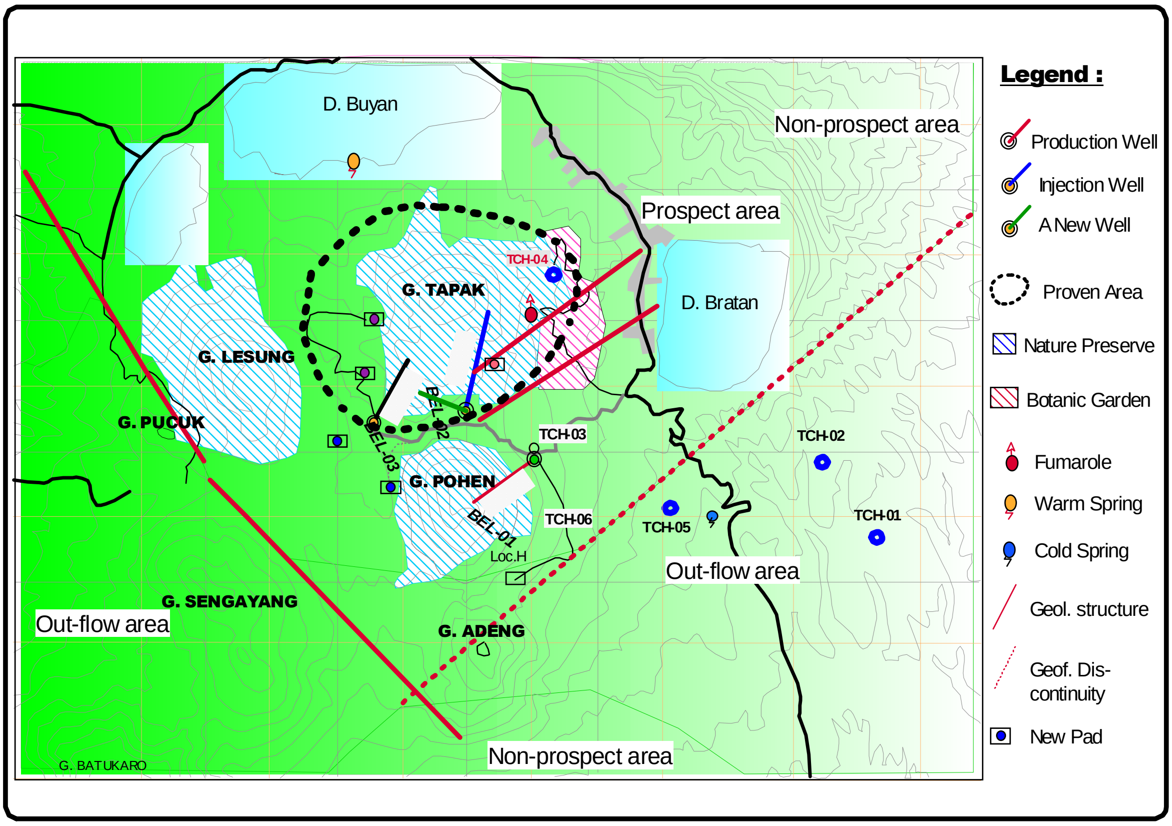

Figure 9: Proven geothermal area, Bali.

Table 1: Gas content of BEL-03 sample analyzed by PT Geoservices, Bandung, 2004.

Parameter	%mole	%weight	Date
CO_2	95.76	96.85	4-May-04
H_2S	3	2.35	4-May-04
Residual gas	1.24	0.8	4-May-04
CO_2	95.67	96.99	17-May-04
H_2S	2.93	2.3	17-May-04
SO_2	0.0005	0.0008	17-May-04
HCl	0.0045	0.0038	17-May-04
HF	0.0407	0.0188	17-May-04
H_2	0.33	0.02	17-May-04
O2	0.332	0.282	17-May-04
N2	0.411	0.265	17-May-04
CO	< .0001	< .0001	17-May-04
CH4	0.0081	0.003	17-May-04
C2H6	0.0084	0.0058	17-May-04
Tot. Gas	1.74	4.12	14-May-04
H2O	98.26	95.88	14-May-04
Tot. gas	1.81	4.26	17-May-04
H2O	98.19	95.74	17-May-04

Table 2. WBS-SPW chemical analyses of well BEL-03.

PARAMETER	Weir-box Sample (WBS)		Separated Water (SPW)	
	May 14th, 2004	May 17th, 2004	May 14th, 2004	May 17th, 2004
pH at 25°C	7.44	7.34	7.41	7.25
Electr. Cond., 25°C, (μS/cm)	14830	13730	12110	11250
Boron (B), ppm	644	700	475	573
Silica (SiO2), ppm	1002	880	141	159
Arsenic (As), ppm	118	109	92	88
Sodium (Na), ppm	2779	2675	2247	2241
Potassium (K), ppm	544	458	483	404
Calcium (Ca), ppm	18.8	10	36.5	21.7
Magnesium (Mg), ppm	0.57	0.56	0.64	0.61
Iron (Fe), ppm	2.7	1.11	0.11	0.07
Ammonia (NH3), ppm	32	16	20	11
Lithium (Li), ppm	2.99	2.85	2.45	2.47
Bicarbonate (HCO3), ppm	299	242	299	221
Chloride (Cl), ppm	4892	4358	3910	3659
Sulphate (SO4), ppm	69	52	27	28
Fluorite (F), ppm	2.8	1.9	2.7	2.8

PT Geoservices, Bandung, 2004

4. DEVELOPMENT

The sub-surface temperatures were ranging from 240°C to 310°C in static condition. It is close to the temperatures calculated by silica-Na/K geothermometers range from 280°C up to 300°C. This static temperature then decreases to 200-215°C at depth below 400m below sea level during flowing, figure 4A. Hot water has been interpreted flashing right at depth of 800-900m below sea level where hot chloride water present. The existence of hot chloride water may also be indicated by high chloride content of the water sample (3000 ppm) that taken from weirbox.

The preliminary results of the chemical analyses of water samples show high contents of silica (475-1002ppm), of chloride (3000-4000ppm), and of sodium (2000-3000ppm), table 2. This may indicate a Bedugul-Bali geothermal system is a water-dominated system. BEL interpreted that BEL-03 has been drilled into the hot chloride water system, since monitoring chloride content of water in the weirbox is relatively high and constant, figure 10. It is about 3000ppm during testing that could be sourced from the hot chloride water system exist at depth. High content of chloride may be also due to hot fluids ($T_{estimated}$=330°C and $Cl_{estimated}$=1750ppm) undergo multiple flash steam separation (P=18bar and P=1bar). If this is the case, the steam dryness is about 45%, which is still lower than the calculated dryness obtained during well production testing, 90-95%. Therefore, there is an extra 45% steam to add in to the well BEL-03. It could come from another source at depth of 200 m above sea level down to 400 m below sea level as shown by temperature convective profile, figure 4A. If this is the case, the high chloride content may source from hot chloride zone at deep level, while the extra steam may come from the overlying steam zone. It can be understood then that chloride and silica content are very high.

Most of the samples are on the precipitation zone, since silica content is higher than the silica (quartz) solubility, figure 11. Therefore, it can be understood that thin deposit of silica was visible on the pit along weirbox to pond. The very high silica content may raise a problem of deposit when hot geothermal fluids flash into steam phase. Therefore, it is advised to extract steam rather then hot water, suggesting only drilling in the steam zone overlying the hot water zone.

There is no doubt that the geothermal system of Bali to be two-phase system as supported by figure 12.

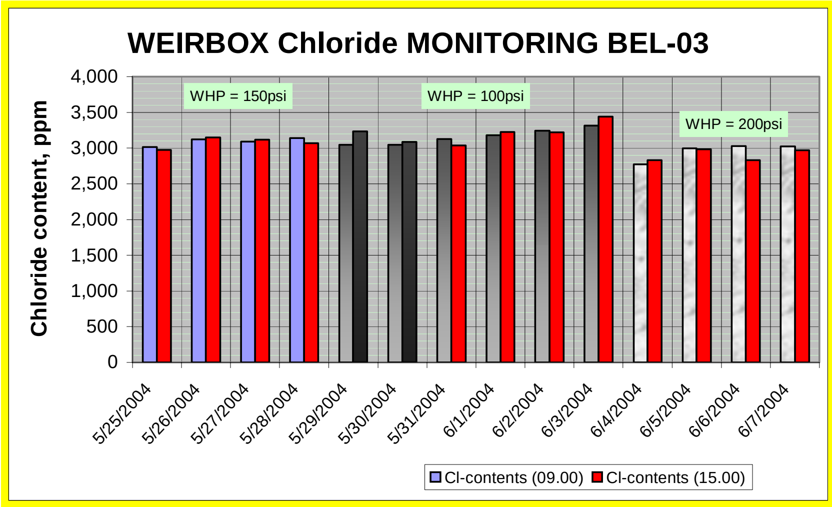

Figure 10: Monitoring chloride content during testing.

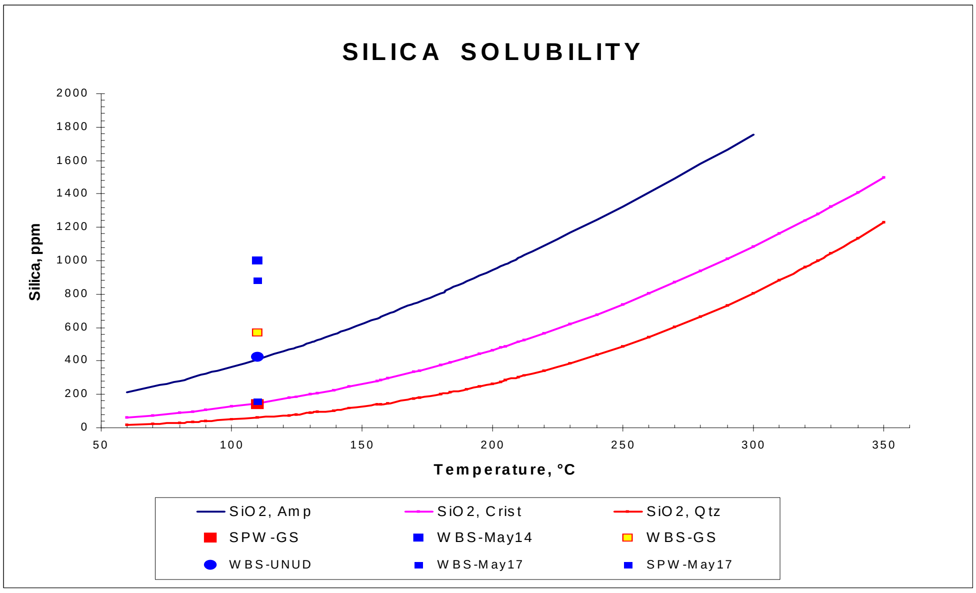

Figure 11: Silica content of weirbox sample and of separated water sample.

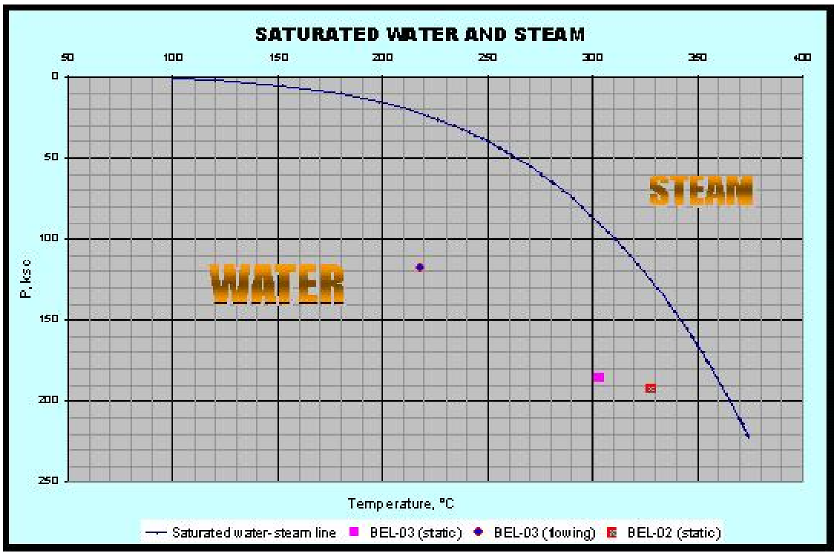

Figure 12: Saturated water-steam graphic showing BEL-2 and BEL-3 are on the water zone

The T-P profile of BEL-03 showed convective temperature gradient of about 240-260°C at a depth ranging from 1400m to 1800m followed by conductive temperature gradient of 7°C/100m with maximum temperature of 310°C, figure 4A. The figure of convective zone may indicate good permeability and there could be any steam zone at its depth. Unfortunately, the convective zone is wrapped blind liner 9 5/8", table 3.

Table 3: Casings set in the well BEL-03.

Casing	Depth, m			
	Measured		Vertical	
30"	0	16	0.0	16.0
20"	0	448.3	0.0	446.6
13 3/8"	371	1656	370.1	1540.0
9 5/8" blind	1409.5	2022.8	1321.3	1853.7
9 5/8" perforated	2022.8	2686	1853.7	2391.0

The energy stored in the rock and its fluids has been calculated using Monte Carlo method, ending the value of most likely potential of 350 MWe, table 4.

There will be no doubt to develop total 175 MWe since their energy potential to be about 350 MWe.

By having a proven area of 8km^2, the energy potential will then be extracted to develop a small-scale power of 10MWe in next two years, 2006; it will be built other 55 MWe every year starting in 2008 and ending with total of 175 MWe in 2010.

Well BEL-03 which is only discharging 38t/h steam will be combined with a new well, which will be expected to fulfill the rest of steam to generate 10 MWe power for 30 years. The new well is going to be drilled at pad C or G with other wells that are used for supplying 3 x 55 MWe power in 2005. An injection well is plan at BEL-02, where it is about 2 km east of BEL-03.

Most of the Bedugul geothermal prospect area is covered with natural preserves and protected forests areas. Since then, the directional drillings have been applied to avoid them; their pads are at out-siding of the prohibited area. Some wells shall be used as injection well to flow brine down to the reservoir zone to avoid negative environment impact.

4. PROJECT SOCIALIZATION

The awareness of the sustaining environment, keep Balinese watching and understanding what is going on with geothermal project. They need electricity, but they do not want the water of the three lakes and their forest including its habitat at Bedugul decrease due to that project, figure 13, and wherever BEL will commit to Bedugul keep sustainable.

Part of Bedugul is covered by Holiness Mountains that should not be changing. The Balinese will consistently keep equalizing the life and its environment from sea to mountain.

Table 4: Resource calculation using Monte Carlo

RESOURCE DATA

Parameters	Minimum	Maximum	Most Likely	Reserve Estimation, Mwe	
Area (km^2)	30	40	35	**Minimum =**	**135.5**
Thickness (m)	800	1100	950	**Maximum =**	**791.3**
Rock Porosity	0.08	0.09	0.1	**Most Likely =**	**355.5**
Rock Density (kg/m^3)	2500	2600	2550		
Rock Spec. Heat (kJ/kg.°C)	0.7	0.9	0.8		
Initial Temperature (°C)	240	300	270		
Initial Water Saturation (%)	60	80	70	**P10 =**	**183.2**
Initial Vapor Saturation (%)	40	20	30	**P50 =**	**317.9**
Final Temperature (°C)	175	185	180	**P90 =**	**525.0**
Final Water Saturation (%)	10	30	20		
Final Vapor Saturation (%)	90	70	80		
Recovery Factor (%)	12.5	25	18.75		
Electical Conversion Factor (%)	10	11	10		
Life Time (Year)	29	31	30		

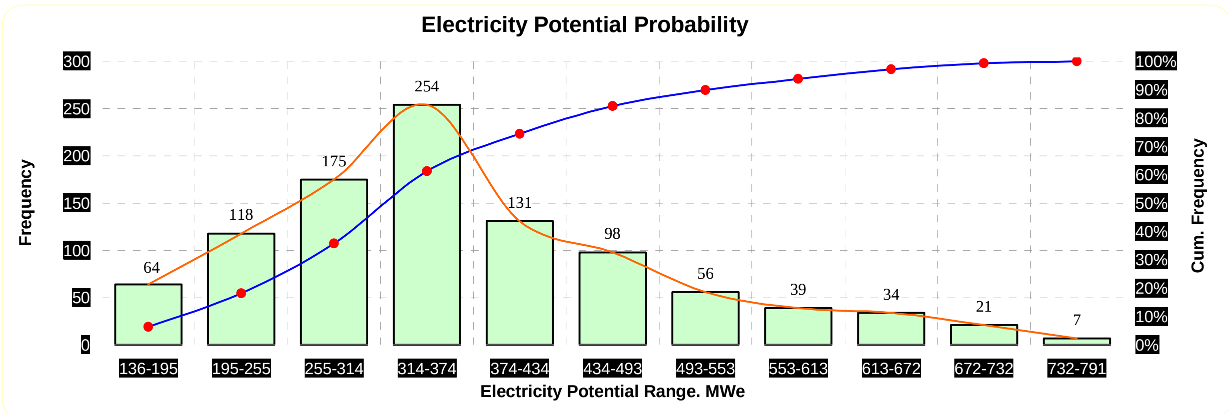

Figure 13: Sustainable protected forest area at the edge of the Bedugul caldera

BEL has been extensively introducing the technology of geothermal energy development to all Balinese since March of 2004. They have been giving them education, presentations, and workshops. In addition they have displayed posters at the super markets, villages, schools, communities, and government, figure 14. It was surprising that Balinese, especially the people who stay in the surrounding prospect area, will not avoid the geothermal project if the negative environmental impact looks relatively low. However, Balinese still are watching the environmental impact resulted from the geothermal project. There is a small group against the project; some of the people misunderstand the geothermal technology and others do not want Bali to change. They are still worried and afraid of a change in the environment due to geothermal development.

BEL suggested that the Bali Environment Institute analyze the environmental impact of geothermal energy development for above 10MWe.

Figure 14: Exhibition of geothermal energy development at the supermarket.

The common question posed to BEL is if there will be job vacations for the local community and other advantages. Questions about tourist attractions are also common.

BEL obeys the traditional customs when scientifically extracting the energy from the earth. Some ceremonial events are being conducted before work begins in order to remember and thank GOD, figure 15.

Figure 15: Cultural ceremonial.

5. CONCLUSION

The Bedugul geothermal prospect area is very comprehensive, and its geothermal reservoir is very deep. There is a huge amount of energy in sub-surface rocks located within the caldera.

The very thick cap rocks may block the hot fluids flowing into the surface. This may result in small thermal manifestations, even though the cap rocks may fracture due to movements. There are other reservoir rocks down at a very deep level.

A small power of 10 MWe will be run before developing other large 3 x 55 MWe power for the near future, since the preliminary proven area could reserve approximately 30 MWe for 30 years life.

BEL has conducted scientific and Balinese culture study to develop the geothermal energy at Bedugul.

6. SUGGESTIONS

BEL is going to perform more work on BEL-03 such as conducting well simulation, running spinner, perforate BEL-03 blind liner to create new feed zone from the reservoir, and down hole sampling, to make apparent the geothermal system in Bedugul, Bali.

BEL is going to pay attention of silica deposit occurrence, since that most of silica content of the samples are on the precipitation zone.

BEL is going to perform more careful gas analyses especially on magmatic gases before running the 10 MWe power.

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