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Summary of Geothermal Slimhole Drilling Operation in the Last 10 Years: Lessons Learned for Geothermal Exploration in Indonesia

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ABSTRACT

Government of Indonesia through RUPTL 2021 targets to have around 5,700 MW of geothermal power plant installed capacity in 2030, more than double its current installed capacity. The resource areas are spread throughout the country, and a big part of them is greenfield areas without prior detailed exploration. A low cost and fit for purpose exploration drilling for such fields are crucial to discover and prove the geothermal resources underneath the surface before committing to more massive and expensive development activities. One of the alternatives for exploration and data acquisition is slimhole drilling. Slimhole wells may be drilled in geothermal fields for several reasons, including the relatively low cost, the shorter overall preparation time needed, and the greater geological detail that is obtained from continuously cored holes.

Even though slimhole drilling was widely used for geothermal exploration in the 1990s, it has not been extensively used for exploration in the past 10 years, as most developers favor conducting exploration drilling straight to conventional standard or big hole. This resulted in the loss of many lessons learned, best practices, and contractors available to carry out such drilling method. The lack of well-documented and accessible drilling reports and references further worsens the condition. As government and developers in Indonesia seek to reduce the risk and cost of exploring geothermal resource, the lessons learned best practices for slimhole drilling is important to support drilling planning.

This paper aims to provide a summary and review related to slimhole drilling operations in the last decade through various published references. The detailed operations, commonly faced problems, and mitigations are highlighted and summarized. It is intended that this paper can increase understanding and knowledge related to slimhole drilling for geothermal exploration and how to mitigate the drilling problem.

1. INTRODUCTION

According to the latest data from the Geological Agency in 2019, geothermal potential in Indonesia is recorded of 23.9 Gigawatt (GW) but until 2020, only about 2,130.6 Megawatts (MW) or 8.9% of its total potential has been developed. As shown in Figure 1, the distribution of geothermal prospects in Indonesia are mostly still in the preliminary survey phase or detailed survey. From these data it can be said that the exploration phase is the most critical phase in the development of geothermal energy in Indonesia.

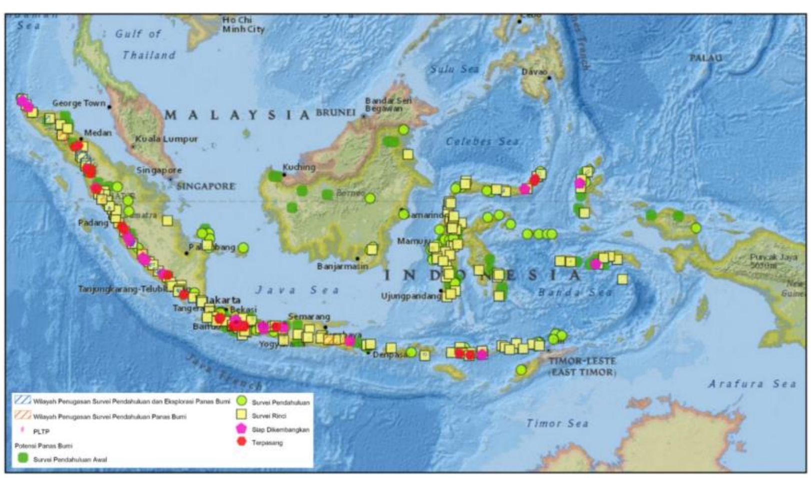

Figure 1: Geothermal Prospect Area Map Spread Throughout Indonesia (EBTKE,2020)

At the exploration stage, the level uncertainty related to geothermal resource is still very high, this is also followed by quite high costs for conducting exploration drilling. The uncertainty mainly due to the lack of direct data availability, while the available information is generally still based on the interpretation of 3G (Geology, Geochemistry, and Geophysics) data. The high uncertainty combined with the high cost of exploration drilling is deemed as one of the biggest challenges in developing geothermal in Indonesia.

One way to reduce the risk in the early exploration is by reducing the cost required for exploration drilling (Adityatama, et al., 2020). There are 4 types of wells in geothermal, namely standard wells, big hole wells, thermal gradient wells, and slimhole wells. One way to reduce expenses during exploration drilling is to use a slimhole well as exploration well. A slimhole well is a well that has a size of less than 6" (six inches) in diameter and designed to reach/evaluate reservoir zones (K.M. Mackenzie, 2017). Compared to standard/ big hole well, slimhole typically has a lower cost, this is because there are cost reductions in several aspects, namely rig, casing, drilling fluid, cement, drilling crew, and wellpad construction.

The slimhole drilling method itself is not new for geothermal exploration worldwide, especially for exploring a new prospect in greenfield areas where the uncertainty is at the highest level. In Indonesia itself, slimhole drilling was extensively used for geothermal exploration in the 1990s, even though after 1998 to 2020, only two slimhole campaigns were done in Indonesia. The absence of slimhole drilling campaign for geothermal exploration in Indonesia makes creates several challenges, such as the lack of rig availability and best practices, as slimhole drilling operations can be very different with conventional rotary drilling used for bigger wells.

The purpose of this study is to briefly review the recent (<10 years) slimhole drilling operation worldwide and in Indonesia. The study was conducted by literature review from various sources such as published papers and/or report. Several points from the campaigns were summarized, such as the objective of the drilling, the depth and temperature, the drilling problems encountered during the operation, and the outcome of the campaign. Authors expects this study can be used as a reference for future geothermal exploration drilling planning, especially considering that the "low-hanging fruit" fields in Indonesia have been exploited (Febrianto, Bidder, Hochwimmer, Ussher, & Libbey, 2019), thus requiring alternative methods to reduce risks in exploration phase.

2. SLIMHOLE DRILLING CAMPAIGN WORLWIDE IN THE LAST 10 YEARS

2.1 Apacheta, Chile

Apacheta is located 105 km NE of Calama City and 55 km NW of the El Tatio hydrothermal system. Geologic Enviroment for Apacheta is Plio-Pleistocene volcanic complex located within a NW-trending graben. In 1998, the Chilean National Mining Company (CODELCO) constructed a 180-meter-deep well (PAE-1) that produced steam at 88 °C. Fluid discharges generating superheated steam (up to 118 °C) at high flow rates can be found around the 5150 m high Apacheta volcano's eastern slope. There are no hot springs, just the 88°C steam well and the 109° and 118°C fumaroles with gas compositions that indicate reservoir temperatures of ≥250°C. Project feasibility studies began in 2005, then four wells were drilled from 2009 to 2010, whose depths reached between 1300 and 2000 m.

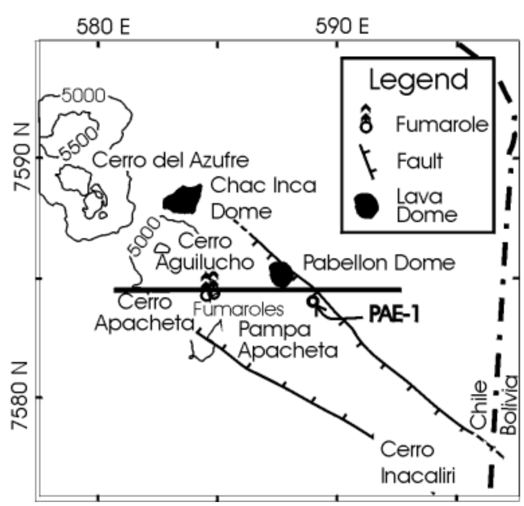

Figure 2: Map of Apacheta Prospect (Urzua, L., et.al,2002)

In 1999, The Cerro Pabellon geothermal system (CPGS) was discovered in the Pabelloncito graben and defined as a high-enthalpy two phase reservoir, covering a potential area of ~5×5 km^2. For the deep reservoir, between 500 and 2000 m depth, geothermometers indicate apparent temperature equilibrium in the range of 280-290◦C, higher than the 255◦C measured in wells, indicating that these higher temperatures are possibly found deeper in the system (Maza, S et al., 2021). In 2014 exploration drilling was carried out using the slimhole drilling method. Slimhole drilling activities reach a depth of 700 meters with a temperature obtained of 210 ^{0}C (Mackenzie, K.M., et al., 2017). Regarding the slimhole well data, there is not enough information to determine whether or not it intersected a reservoir.

2.2 Mariposa, Chile

The Mariposa Geothermal system discovered by Magma Energy Chile Ltd., is located in the Andes of the Maule region, included in the Tatara-San Pedro-Pellado Volcanic Complex (e.g., Dungan et al, 2001; Singer et al., 1997) and the western portion of the Laguna del Maule volcanic field (Hildreth et al., 2010). The results of two MT campaigns in the project area, have confirmed an extended (27 km^2) low resistivity anomaly distributed between the Laguna del Maule and Pellado geothermal concessions. Geothermal manifestations around the MT anomaly's border have reported favorable gas chemistry data, indicating the presence of a liquid–dominated reservoir at depth. Geothermometers used on samples from various years report steady conditions and reservoir temperatures in the 247-290 °C range. There is no evidence of acidic conditions.

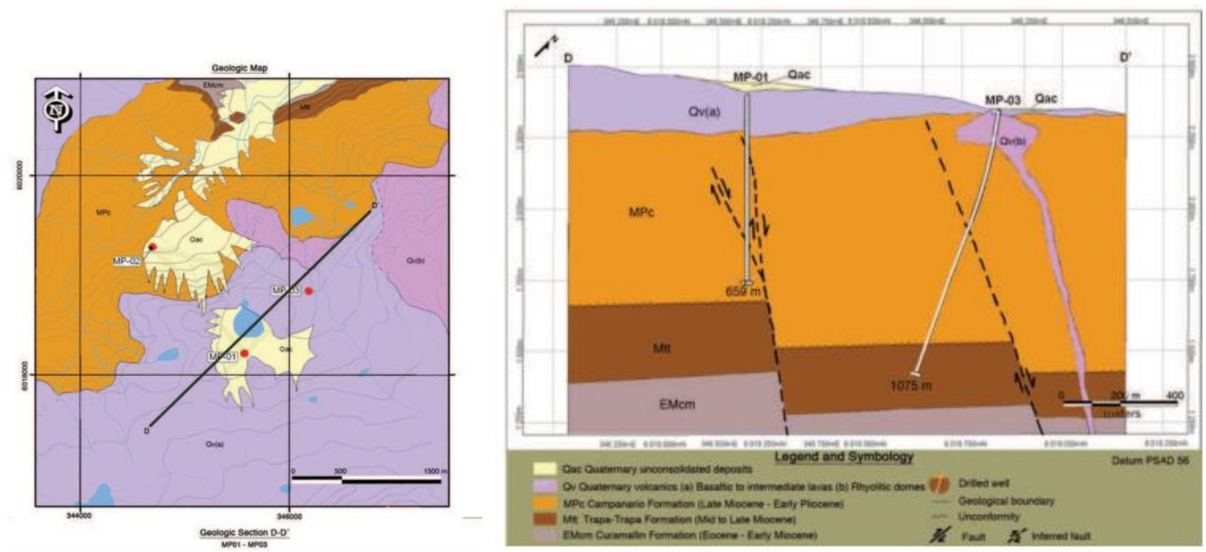

Figure 3: Geologic Map of Section D-D' in Mariposa Field (Hickson, C. J., et.al, 2011)

Three slim holes (core) have been drilled inside the MT anomaly. The holes (MP-01, MP-02 and MP-03) passed through thick Quaternary volcanic cover (high resistivity) reached a clay-rich layer (interpreted as a clay-cap) at 650-890m TVD. The hole transacted the clay cap (based on MT, methylene blue and XRD analysis) and reached the top of the reservoir. Technical difficulties and drilling under the rigorous winter conditions of the Chilean Andes (snow storm in 2009), have prevented the deeper zones of the reservoir to be reached. The wells have recorded bottom hole temperatures close to 200°C (MP-01 at 202°C, MP-02 at 192.8°C, and MP-03 at 205°C). The thermal regimes recorded using KUSTER logs in the three wells show increasing temperatures with depth, implying that the conductive behavior continues down the holes to higher temperatures. In the Mariposa Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

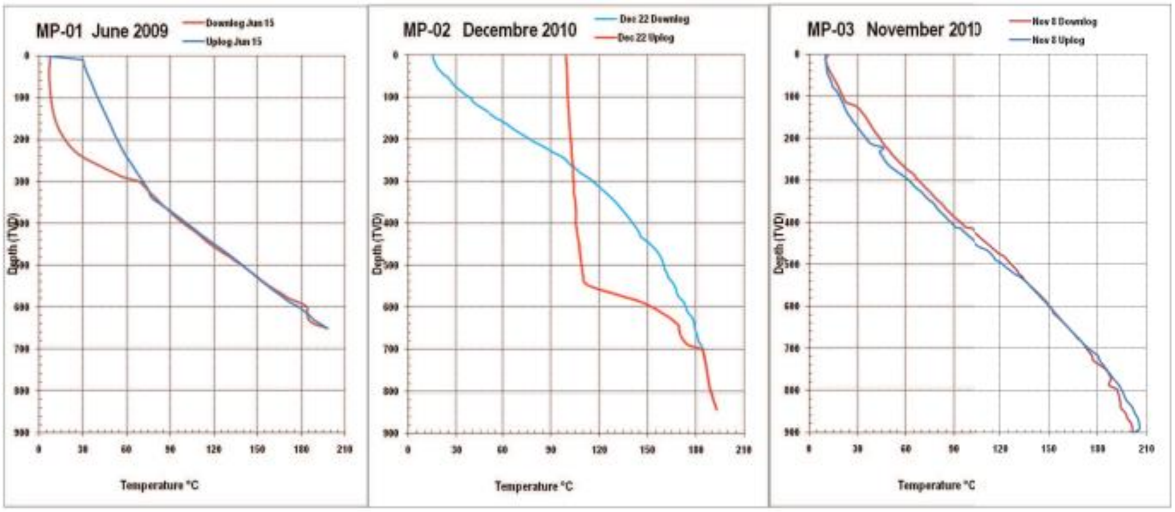

Figure 4: Temparature vs Depth Logs for MP-01, MP-02, and MP-03 Slimhole (Hickson, C.J., et.al, 2011)

2.3 Irruputuncu, Chile

The Irruputuncu project is favourable in geological and structural surveys suggestion for the presence of an active hydrothermal system below Irruputuncu volcano. Two magnetotelluric (MT)-transient electromagnetic (TEM) campaigns were done. The first one, conducted between March and April 2009, shows a resistive structure that likely reflects the existence of a high temperature geothermal reservoir (Eysteinsson et al., 2010). The second survey complemented the existing net of stations and was conducted between September and October 2010. The MT-TEM joint 1-D inversion shows that beneath the easternmost part of the survey area, under the western slopes of Irruputuncu volcano, a high resistivity core lies below the low resistivity cap (Hersir & Árnason, 2011).

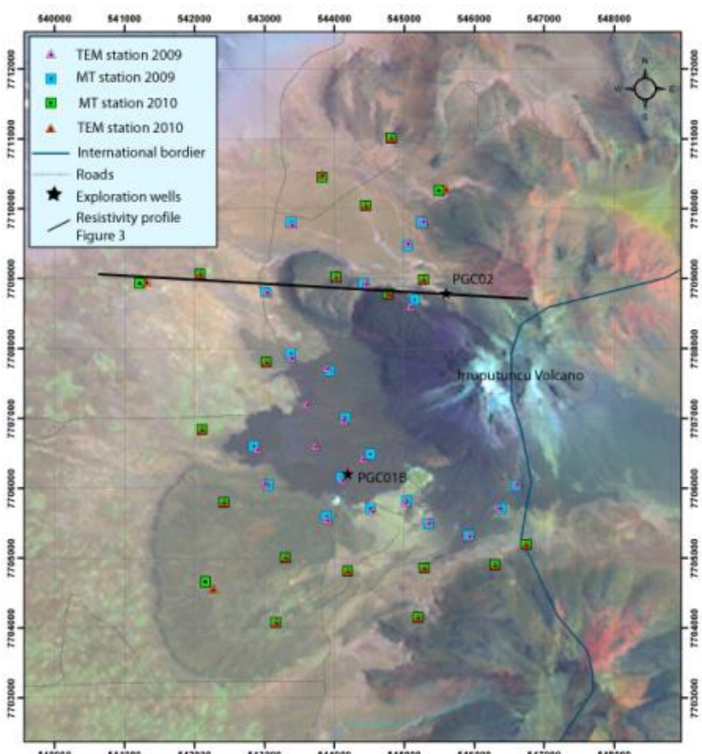

Figure 5: MT and TEM Stations at Irruputuncu Project (Reyes, N., et.al, 2011)

Two exploratory slim wells have been drilled in the Irruputuncu project. Well PGC01B reached a depth of 800 m. Several temperature-pressure profiles have been recorded, with a maximum temperature of 150ºC at 700 m. Well PGC02 reached 1430 m deep, and crossed a sequence of volcanic and volcano sedimentary rocks. The temperature profiles recorded a maximum temperature of 193ºC at 1371 m depth, which suggests cooling of the system when compared with the observed alteration mineralogy. Both wells are dominated by argillic alteration assemblages and conductive temperature profiles, indicating a potential deeper reservoir (>220ºC), as suggested by TEM-MT data. In the Irruputuncu Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

2.4 Tinguiririca, Chile

The Tinguiririca Geothermal field, located only 150 km southwest of Santiago, developed on the Pleistocene–Holocene volcanic rocks of the Tinguiririca volcano. The geology of the area consists mainly on Mesozoic and Cenozoic marine and volcanoclastic sequences, folded and thrusted according to major extensional and compressive deformation events. Geothermal manifestations in the Tinguiririca volcanic field comprise steam vents, bubbling mud pools and flowing hot springs associated with steam-heated, acid sulfate and near neutral pH bicarbonate waters (Clavero et al., 2011). A first explorative 815 m depth deep slimhole well (Pte-1 borehole) was drilled by Energia Andina on the southwestern flank of the volcanic complex.

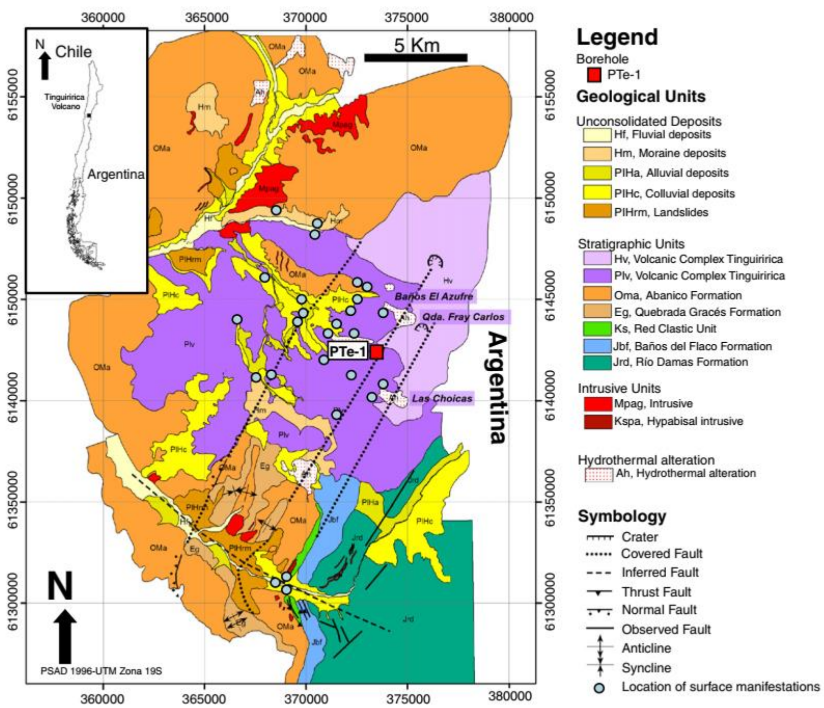

Figure 6: Geological Map of Tinguiririca Geothermal Field (Vazquez, M., et.all, 2014)

Droguett et al. (2012) determined the geothermal alteration mineralogy of the Tinguiririca geothermal field, using petrographic techniques, XRD and SEM. Samples were collected along the Pte-1 borehole, where the temperature was directly measured along the 813 m drill core. The multidisciplinary approach for the exploration carried out at the Tinguiririca Volcanic Complex, shows the existence of an extensive geophysical anomaly on its western-southwestern flank. Water and gas chemistry suggest temperatures in the range of 230-300°C, associated to a heat source beneath the volcanic complex. The geothermal reservoir is likely hosted within the Oligo-Miocene units as well as the lower part of the Pliocene volcanics. First drilling results proved the existence of an active geothermal system and are consistent with the preliminary geothermal model. In the Tinguiririca Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

2.5 Tolhuaca, Chile

The Tolhuaca geothermal reservoir formed as a liquid-dominated hydrothermal system in a topographically-elevated young volcanic rift zone on the flank of Tolhuaca stratovolcano. The Tolhuaca geothermal field lies along a NW trend of young volcanoes in the Southern Volcanic Zone of the Andes in Chile about 600 km south of Santiago. The geothermal prospect was identified from three fumarole areas spaced along 2.5 km of the Pemehue volcanic trend along with surface alteration and numerous steam-heated hot springs.

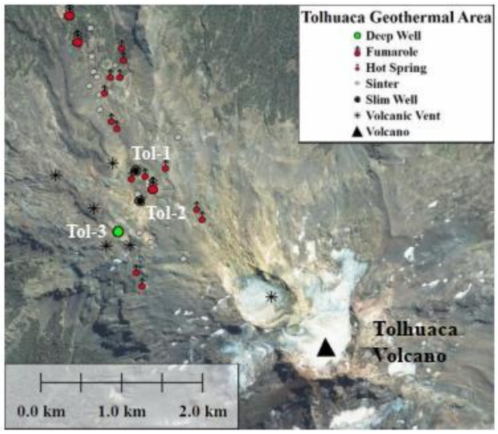

Figure 7: Ikonos Image Showing Thermal Areas and Wells (Melosh, G., et.all, 2012)

The exploration process has included geologic, geochemical, and geophysical surveys and the drilling of two slim wells to 1073 m (Tol-1) and 1274 m (Tol-2) depth. The two deep slim wells reveal the presence of a shallow hot aquifer. Tol-1 produced dry steam from depths between 116 and 161 m depth during an interim rig test. The maximum flowing pressure in that test suggested a stable formation temperature in this zone of about 170°C. Tol-2 produced dry steam in a well kick from near the same elevation. Tol-3 shows the influence of the same zone in the temperature logs and alteration.

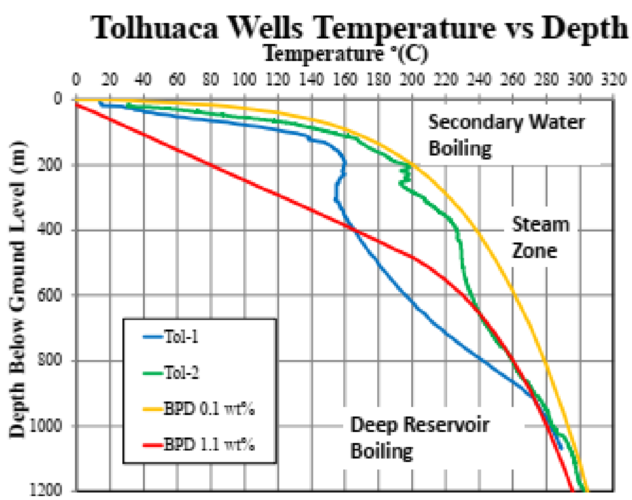

Figure 8: Tol-1 and Tol-2 Temperature-Depth Profiles with Boiling Point vs Depth (Melosh, G., et.all, 2012)

During a short flow test following well completion, Tol-2 vigorously produced single phase liquid to the surface. The hole was open from 293 to 1274 m. The well could only be tested briefly at about 5% total valve opening due to limited test facilities and well control issues. In the Tolhuaca Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

2.6 Mita, Guatemala

There is a large volume of hot water in close proximity to the ore deposit. Field geology, geochemistry and geophysical (MT) surveys to investigate the geothermal resource were completed in 2007 and 2008. The next stage of investigation comprised four inclined (at up to 30° from vertical) slimholes drilled to depths of 1200-1530 m. The first of these holes targeted the interpreted upflow zone, but was not particularly hot, and was impermeable. The second and third slimholes were also not very permeable, but they were hotter and did discharge, and it was not until the fourth hole that good permeability was encountered. Max temps of 195-217°C. Resource was delineated at much lower cost than conventional wells. Flow tests provided information about the wider permeability characteristics of the reservoir. In the Mite Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

Figure 9: Discharge Testing Slimhole well MG-04 (White, P., et.al, 2010)

2.7 McGinness Hills, NV, USA

The McGinness Hills geothermal area is located approximately 11 miles northeast of Austin, NV, within the basin and range physiographic province and along the hills on the eastern flank of the Toiyabe Range. The first major development decision is where to drill the first set of exploration wells. Exploration efforts performed by Ormat included 1) water chemistry, 2) detailed geologic mapping 3) gravity survey 4) CSAMT, MT, & Schlumberger sounding electrical surveys, 5) 3D GIS modeling, 6) shallow temperature gradient core hole drilling, and 7) drilling of initial slim holes and full-size wells.

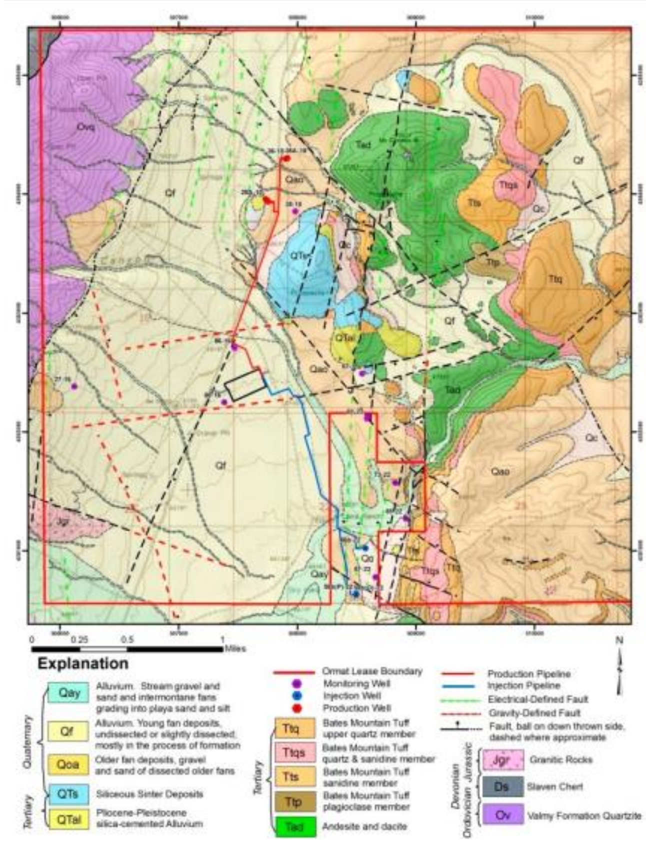

Figure 10: Geological Map of McGinness with Well Locations (Nordquist, J. & Delwiche, B., 2013)

The first well selection for slimhole drilling was well 38-10. This well was selected to test the temperature and permeability of both WNW and ESE dipping faults inferred to exist locally. This well was drilled in May-June 2009 and was completed to a depth of 2,138 ft. The well flowed approximately 112 gpm with a productivity of 0.44 gpm/psi and saw maximum producing temperatures of 153°C. In the McGinness Hills Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

2.8 Montelago, Philippines

The Montelago geothermal prospect on Mindoro Island, the Philippines, has been the target of development studies over a period spanning several decades. The volcanism present in the prospect area are part of a narrow north-west trending volcanic chain of Pleistocene-Quaternary age. Two slim holes down to 1,200 m depth below the surface were drilled to test the conceptual model of the Montelago geothermal prospect. Both wells were fully cored and the drill cuttings were described using hand lens and microscope. The temperature at the depth interval in which epidote is found is below 200 C. In the Montelago Field, there is no further information was found regarding slimhole well drilling activities (drilling hazard and production casing size).

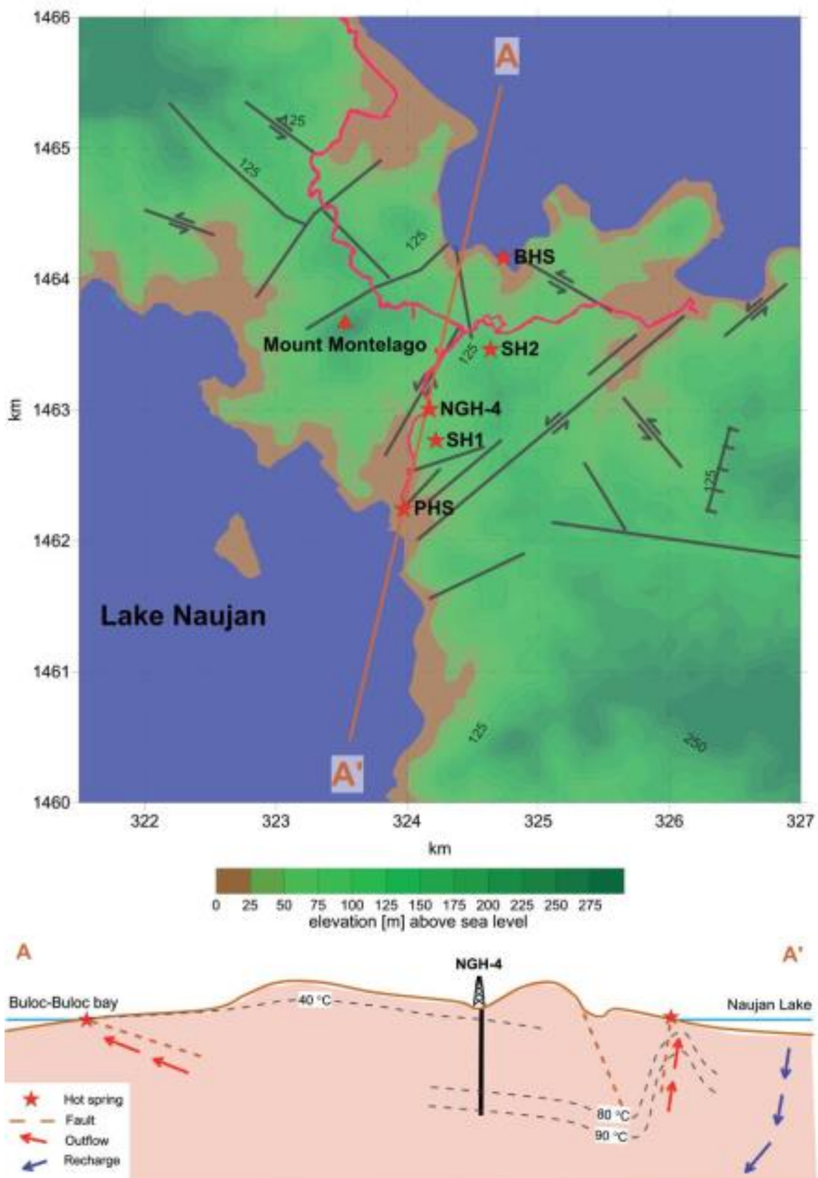

Figure 11: Map of Prospect Area of Montelago Field (Leeuwen, W. A, et.al, 2016)

3. INDONESIA SLIMHOLE DRILLING CAMPAIGN IN THE LAST 10 YEARS

3.1 Blawan-Ijen

3.1.1 Background Project

Blawan-Ijen Field that is located at eastern end of Java Island is one of the geothermal field in Indonesia. Old Ijen volcanic is characterized by N-S trending lineaments, especially expressed by major fractures which can be correlated to a fracture belt that cut across the ancestral caldera. In the Ranti-Jampit and Raung-Suket areas, where recent volcanics predominate, the NNW-SSE trending lineaments prevail. While in the central part of the study area the alignment of volcanic centers from Mt. Suket to Mt. Merapi is outlined by a belt of lineaments of E-W direction, traversing the whole concession area.

In 2016, MCG conducted 2 slimhole drilling as part of exploration activities. Slim hole well offers significant decrease of risk at lower cost compared to standard hole by reducing the exploration upfront cost while still be able to accomplish resource estimation goal (Finger, 1998; Nielson & Garg, 2016; White et al., 2010). Slim hole Ijen-01 is the first exploration well drilled by MCG at the Ijen-Blawan geothermal prospect. This well was programmed to penetrate and case off the interpreted thick clay cap and reach a maximum depth of 2,000 vertical depth, where hot, neutral chloride water hypothetically exist. The drilling operation of Ijen-01 succeeded in reaching a depth of 2000 m in a total period of 169 days (4,045 hours). However, the total duration of drilling deviated significanly from the initial plan which was only for 61 days. The problems faced in the Ijen-01 slimhole well drilling are stuck pipe, rig equipment failure, dealing with total lost circulation, etc.

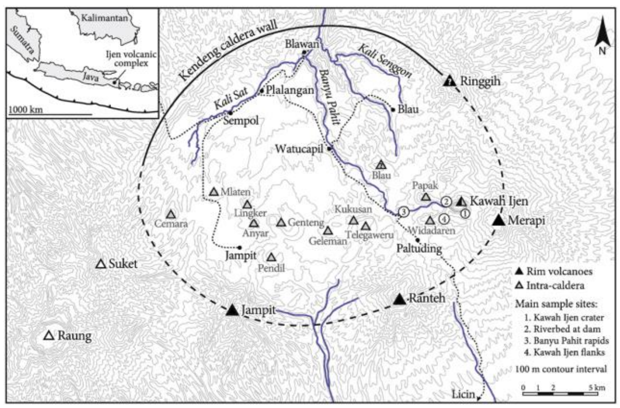

Figure 12: Overview Map of Ijen Caldera (Hinsberg, 2010)

3.1.2 Outcome

Regarding sub-surface information, Ijen-01 successfully obtained downhole information as follows:

- Lithological log from surface to total depth (TD), from 12mVD – 2000 mVD.
- Coring recovery up to ~95%.
- Loss circulation encountered at reservoir section started at 1394 m-MD (partial) and become TLC 1427 m-MD until reached total depth.
- Based on PTS survey, at 1,990 m-MD the maximum temperature reading is 283 °C, maximum pressure of 2594 psi, and pH of 7.
- The well was able to flow continuously for 5 days prior the well was shut by the company

Also based on Ijen-01 drilling result, slim hole method has proved to be an appealing option for any geothermal developer company for obtaining subsurface data to update conceptual model and future drilling plan (well targeting and casing size), with a significantly lower cost compared to standard hole drilling.

3.2 Tangkuban Perahu

3.2.1 Background Project

A geothermal reservoir with the potential to support two 55MW power plants could be associated with the broad Sunda – Tangkuban Parahu “TBP” volcano. The Kancah area, on the south flank of TBP, was identified as the priority location for drilling of the first planned 3 slim holes. These will be rotary drilled to about 630 m, then core drilled to target depths of about 1500 m TD. Data from the exploratory core holes will be used to target full-sized production test wells. In view of exploration risk and cost incurred, the slim-hole and core drilling cost is known to be lower than production drilling, due to the lower size of rig used and smaller area released for pad, access road and others infrastructure required. The target of drilling K-3 is to get as much possible subsurface geothermal data, to include at least geothermal alteration mineral and high temperature down hole, before to decide drilling on deeper production wells.

MT survey suggests the TBP reservoir is underneath of low resistivity formation at depth 1500 – 2000 m below sea level or about 2500 – 3000 m below ground surface. The target of TD coring of 1500 depth to expect the up-flow reservoir water through the south – west to north – east targeted fault line, and lateral flow through fracture on lava flow and been detected in the core log of the K – 3, exploration well. Hot fluid flow channeling along fracture orientation will silicified in the rock, and to alter the host rock to become geothermal mineral such as hematite, adularia and epidotic.

The Kancah – 3 hole was spudded on April 22, 2014 and as of May 22, 2014 the exploration drilling for K-3 is stop. During the KCH-03 well drilling process, several disturbances were encountered, namely:

- No drilling fluid return at 0 – 28 m, 54 – 98 m, and 612 m
- Drill String was stuck at 593 m depth
- Drill pipe was broken and become fish at 333 m depth (The fish in the hole consist of DP 3 1/3 inch 10 joints, DC 4 ¾ inch 10 joints, drilling jar, stub, bit sub and bit 6 1/8 inch)
- When running the drilling jar to fish, after 167 running of the jar, then malfunction of the top drive, and drilling was stop.

3.2.2 Outcome

The exploration drilling for K-3 is stop after the malfunction of the top drive and having concern further potential cause damage on equipment's presented a safety hazard to the rig personal.

Permeable formations presented by intercepting total loss circulation (no drilling fluid return) at depth of 0 - 28 m, 54 – 98 m, and 612 m during drilling K-3 should have been concerned before starting to drill the second K-1 and third exploration drilling K-3, to mitigate as best possible pipe stuck due to accumulation of drilling cutting above the bit that not been recovered by high viscosity drilling fluid. Preparation of LCM and suitable cementing ingredients are crucial to success the drilling of K-1 and K-2.

4. SUMMARY AND ANALYSIS

The use of slimhole drilling for exploration has been widely used outside Indonesia. As shown in Figure 13, based on the previous experience slimhole wells can be drilled up to a depth of 2000m and temperatures up to 300 °C. More complete data for all wells can be seen in Table 1.

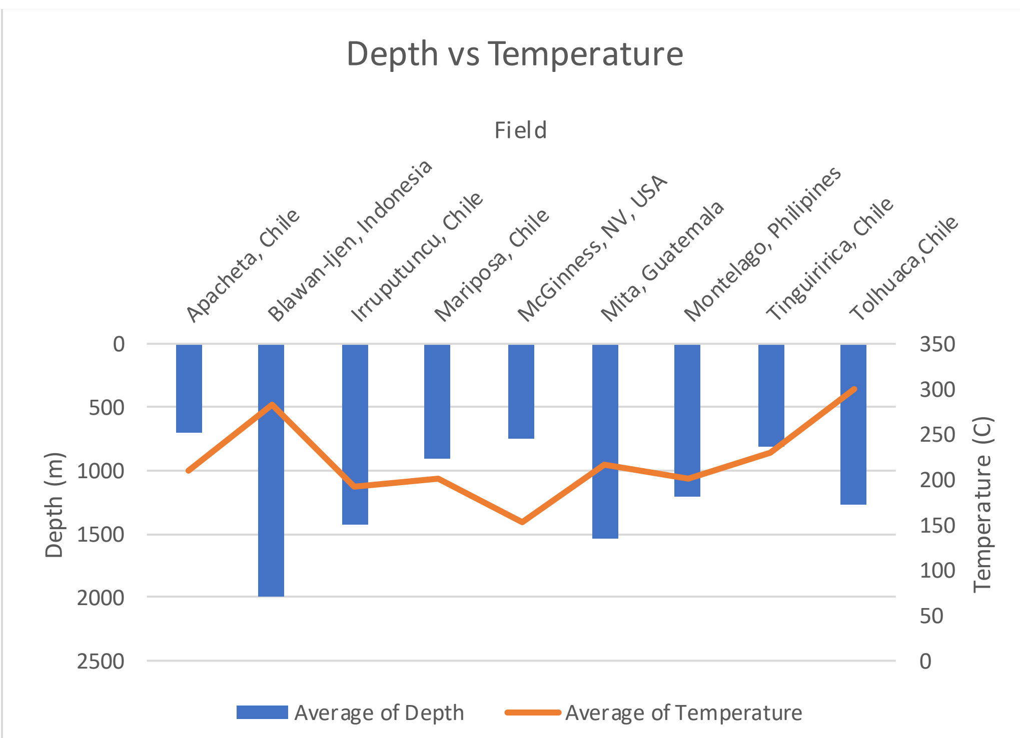

Figure 13: Depth and Temperature of Each Field

Based on the available information, the most recorded common drilling hazard in geothermal exploration well data is lost circulation (Table 1). Severe lost circulation occurred in Blawan-Ijen and Tangkuban Perahu campaign and caused stuck pipe (Adityatama, et al., 2020). Lost circulation itself can indicate the presence of high permeability, but severe loss circulation may lead to poor hole cleaning, thus causing stuck pipe. One of the ways to overcome excessive lost circulation is to use LCM. LCM is solid material intentionally introduced into a mud system to reduce and eventually prevent the flow of drilling fluid into a weak, fractured or vugular formation. It is also important to prepare the cement material as needed to prevent excessive lost circulation.

In this study, not all of the wells have complete data regarding the well design and rigs used. There are only 2 data were obtained from the Blawan-Ijen field and the Tangkuban Parahu field. In both well designs, it can be seen that the tubing size used is the same size, namely 2-7/8 inch. The typical depth of the well design is around 1500 to 2000 m. For the type of drilling rig used is the KWL-1600H multipurpose rig for the Blawan-Ijen field and MCQ 700 Hydraulic drilling rig. In selecting a drilling rig, it is necessary to adjust it to the needs of each field and the availability of the desired type of rig.

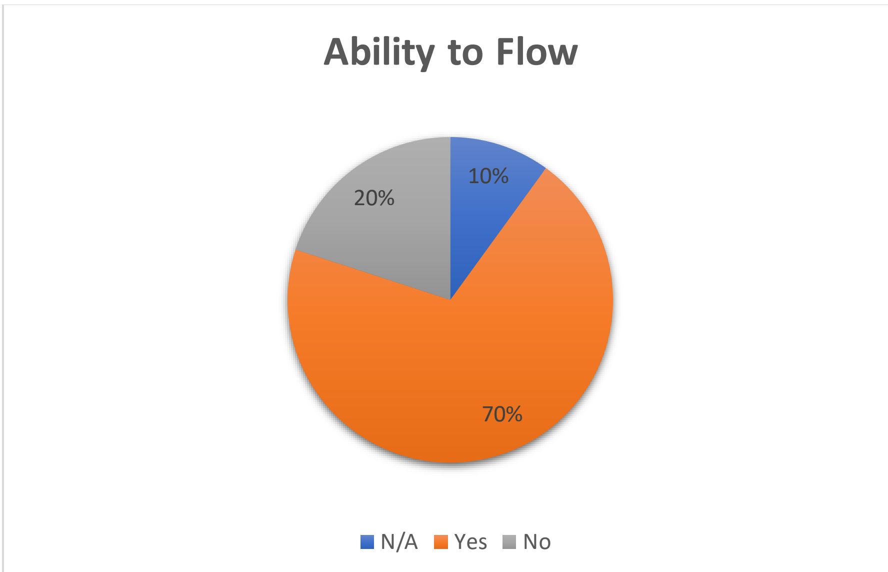

Figure 14: Slimhole Well ability to flow (N/A means no data was found in the reports or published references)

There is also main disadvantage of slimhole drilling which are that the wells are generally not suitable for commercial geothermal production or injection. Even though ~70% of the wells reviewed in this study were able to flow (Figure 14), but as the size of the well are smaller, they cannot produce steam or hot water economically compared to bigger-sized well. The brief summary of the outcome of the drilling campaign is as follows:

- The Apacheta Well, Chile does not have sufficient information to determine whether the well was successful or not.
- The Irruputuncu case, the well drilling was successfully carried out to the targeted depth but the drilling did not reach the reservoir. The company decided not to continue the exploration drilling process.
- In the case of Tangkuban Perahu, many drilling problems were encountered. At the beginning of the drilling, cracks were found in 5 different places. The cracks happen because the surface casing plan is too deep and the conductor surface is too shallow. Lost circulation and stuck pipe also occur along the drilling process due to equipment failure. This incident occurred due to lack of preparation and experience in doing slimhole drilling.

Table 1: Comparison Table between Each Field

Comparison	Apacheta, Chile	Mariposa, Chile	Irruputuncu, Chile	Tinguiririca, Chile	Tolhuaca, Chile	Mita, Guatemala	McGinness, NV, USA	Montelago, Philipines	Blawan-Ijen, Indonesia	Tangkuban Perahu, Indonesia
Depth	700	659 - 900	800 - 1430	815	1073 - 1274	1200-1530	752	1200	2000	620 - 1500
Temperature	210	200	150 to 193	230	280 to 300	195-217	153	200	283	250 - 300
Flow	No information	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No

Comparison	Apacheta, Chile	Mariposa, Chile	Irruputuncu, Chile	Tinguiririca, Chile	Tolhuaca, Chile	Mita, Guatemala	McGinness, NV, USA	Montelago, Philipines	Blawan-Ijen, Indonesia	Tangkuban Perahu, Indonesia
Geothermal System	Volcanic geothermal	Volcanic geothermal	Volcanic geothermal	Volcanic geothermal	Volcanic geothermal	Volcanic geothermal	Non-volanic geothermal	Non-volcanic geothermal	Volcanic geothermal	Volcanic geothermal
Fluid Type	Liquid-dominated	Liquid-dominated	No information	Liquid-dominated	Liquid-dominated	Liquid-dominated	Liquid-dominated	Liquid-dominated	No information	No information
Drilling Hazard	No information	Snow strom in 2019 which hinders the drilling process	No information	No information	Well control issues	No information	No information	No information	Loss circulation encountered	Loss circulation, stuck pipe, and top drive malfunction
Production Casing Size	No information	No information	No information	No information	No information	No information	No information	No information	2-7/8"	2-7/8"

5. CONCLUSION

Based on the above explanation, we can conclude as following:

- One of the main reasons for using slimhole wells is to reduce costs in various aspects. Slimhole also has shorter overall preparation time required and greater geological detail obtained from continuous core holes. It is not applicable for all sectors but it is likely to be used more frequently in the future, especially given continued technology developments.
- Slimholes can be used up to 2000 m in well depth and at temperatures up to 300°C. The average drilling of exploration wells in geothermal Indonesia is around 2000 m, therefore the use of slimholes can be a good choice in conducting exploration drilling.
- The most common drilling hazard in slimhole well is lost circulation. To overcome lost circulation, it is necessary to prepare LCM and/or suitable cementing ingredients during drilling operations.
- The typical depth of the well design is 1500-2000 m with 2-7/8 inch tubing size. For selecting a drilling rig, it is necessary to adjust it to the needs of each field and the availability of the desired type of rig.
- The effectiveness of using slimhole for the last 10 years as an exploration well was 70% with seven flowing slimhole wells, two unflowing slimhole wells, and one slimhole well that can't be decided.

Slimhole wells may be drilled in geothermal fields for a number of reasons, including the relatively low cost, the shorter overall preparation time needed, and the greater geological detail that is obtained from continuously cored holes. In more difficult fields without clearly defined surface manifestation, slimhole drilling is likely to become important for better defining well targets and improving the chances of success of future deep production drilling. It may not be necessary or appropriate for all fields, but is likely to be used more often in the future particularly given the ongoing technological advances enabling deeper drilling using smaller equipment.

6. PATH FORWARD

During the writing of this paper, Geological Agency of Indonesia is currently conducting slimhole drilling in two fields, Cisolok-Cisukarame in West Java, and Nage in East Nusa Tenggara (Ministry of Energy and Mineral Resources, 2021) using two multipurpose rigs capable of rotary drilling and full coring. The result of the campaign and the lessons learned from the operation will be extremely valuable for future exploration drilling campaign in Indonesia. Authors look for the report to be published in order to update this paper.

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