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Integrated Stuck-Pipe-Prevention Campaign in Geothermal Drilling Project in Indonesia: A Proactive Approach

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ABSTRACT

It is widely known that drilling costs are one of the largest cost components in a geothermal development project. The drilling costs may increase significantly when the drilling days become prolonged due to many non-productive-time (NPT) event. Since geothermal drilling targets lost circulation zones at reservoir depth, the chance of getting stuck pipe events becomes higher. Many publications reported that lost circulation events that lead to stuck pipe event have become top NPT contributor to costs in many geothermal drilling projects.

This study aims to design an integrated stuck-pipe-prevention campaign to minimize the possibilities of stuck pipe events in a geothermal drilling project and eventually decrease the overall project cost. In order to design such a campaign, the authors initiate the study by mapping every root-cause that have caused stuck-pipe event in the past, based on literature reviews and authors experiences. The next step is to generate as many preventive action and mitigation options for each root-cause that have been identified, which covers not only engineering, equipment and technology aspects but also human and environmental aspects such as drilling personnel competencies, local community issues, logistic challenges and drilling contracting type.

Finally, this paper presents a guideline in implementing integrated efforts to prevent stuck pipe event in geothermal drilling with a proactive approach using Indonesia's geothermal environment as the case study.

1. INTRODUCTION

Indonesia is one of the countries that is considered to have the largest potential of geothermal energy in the world, which is believed at around 25.39 GW (Pramana, 2019). However, the utilization of geothermal energy in this country, from 1983 to 2018, has only reached 1948.5 MW, equivalent to 7.6% of the total potential total (Umam, 2019). Many authors have addressed their concerns that to achieve the national target of 7200 MW of geothermal energy utilization in 2025, Indonesia must solve various challenges that have been identified (Umam et.al, 2018a; Darma, 2016; Poernomo et al., 2015; Hasan and Wahjosoedibjo, 2015).

One of the main challenges identified in developing geothermal energy in Indonesia is the high drilling cost. Drilling costs are the 2 highest cost components in a geothermal development project along with the power plant cost component, which is 34% and 35% respectively (ESMAP, 2011). Although the two cost components look the same, controlling drilling costs is believed to be more difficult than controlling the power plant costs because the drilling project relates to sub-surface conditions that have more uncertainty, especially in the exploration phase. The power plant construction project, on the other hand, is considered to have less risk because it is built on a more visible and easily assessed land surface.

1.1 Research Background

In Indonesia, based on several studies that have been conducted, the cost of drilling for standard hole types can range between US$ 2,000 – US$ 4,000 per meter (Purwanto et al., 2018; Purba et.al, 2019; GeothermEx, 2010).

This cost will potentially increase when non-productive-time (NPT) that occurs in the well is high. Figure 1 shows an example of three data from geothermal drilling projects in Indonesia. In field C, the total NPT of the 3-year drilling campaign reached 3,463 hrs, where the biggest contributor was the stuck pipe event. A similar phenomenon is also seen in drilling projects in field A and field B, two geothermal fields in Indonesia, which show the stuck pipe event being the largest NPT contributor. Several authors have reported the same phenomenon in Kenya and Iceland (Thorhallsson and Sveinbjornsson, 2012) where the main NPT contributor in geothermal drilling is stuck-pipe events.

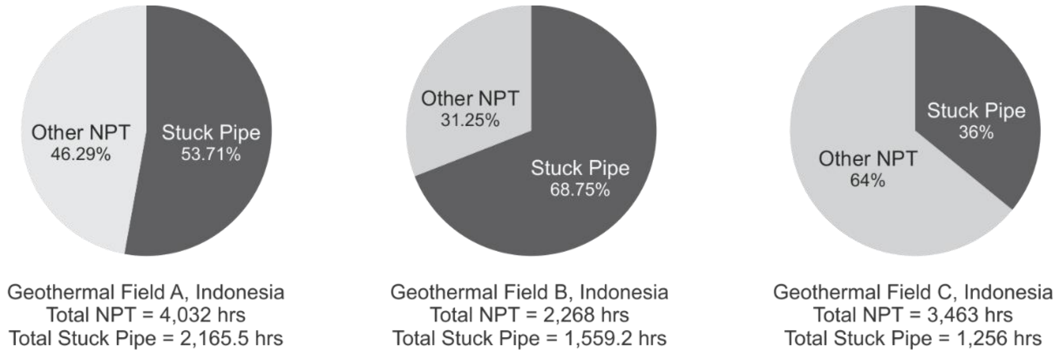

Figure 1: Stuck-pipe statistics of three geothermal fields in Indonesia

The consequences of a stuck pipe are very costly, which include lost time when releasing the pipe, time and cost of fishing out the parted BHA, and efforts to abandon the tool(s) in the hole. Assuming the summation cost of all drilling equipment per hour is US $ 3,000, the total cost lost due to the stuck-pipe event on the field A, B and C (Figure 1) is US $ 4,980,000 on average, excluding the cost of downhole equipment lost in hole. This figure is a potential cost saving if the drilling organization involved successfully minimizes or eliminates the stuck pipe events. Unfortunately, based on authors' observations, there are still many drilling organizations running geothermal drilling project in Indonesia that are still reactive, (instead of proactive), against the stuck-pipe risk. They only react when a stuck pipe has occurred and do not take active preventive actions from the early phase of the project.

1.2 Research Objective and Method

1.2.1 Research Objective

This study aims to design a stuck-pipe-prevention program for applications in geothermal drilling projects in Indonesia. The authors believe that the program or the campaign must be an integrated and proactive effort in order to increase the success rate. Integrated effort means the campaign must involve all related teams, not only drilling teams, from the beginnings of the early planning phase. To be proactive in this regard means, this campaign should encourage the drilling team to intentionally and continuously identify and prevent potential problem rather than reacting.

For the purpose of achieving the objectives, the authors of this study pursue to analyze actual geothermal drilling data in Indonesia. Unfortunately, not all the data that has been acquired by the authors has been published publicly, which dictates that several of the field datasets presented in this paper are anonymized.

1.2.2 Research Questions

The methods used in this study are literature review and group discussion. To achieve the study objectives, the authors explored several questions as follows:

1. What is the uniqueness of geothermal environment that potentially lead to stuck-pipe events during drilling?
2. What kind of stuck-pipe mechanism most likely occurs in geothermal drilling?
3. Based on answers of previous questions, what preventive action options are available?

The authors expect this study can eventually become the groundwork of creating a guideline for implementing integrated proactive campaigns to prevent stuck-pipe events in geothermal drilling, in Indonesia in particular.

2. STUCK-PIPE IN GEOTHERMAL

Stuck pipe, based on several publications (API, 2007; PetroWiki, 2015; Anadrill, 1997) can be described as a condition where the drill string or drill pipes, entirety or partly, sticks or hangs and cannot be freed from the hole without damaging the pipe, and without exceeding the drilling rig's maximum allowed hook load or maximum overpull. This condition may occur in any kind of drilling operation, both in petroleum and geothermal.

In Indonesia, most of drilling personnel come from oil and gas background, which has several major differences from geothermal. These differences include temperature and pressure reservoirs, fluid characteristics, rock formation types, and surface conditions Failure to recognize these factors often leads to a higher chance of a stuck pipe event. Umam et al. (2018b) discussed the importance of recognizing these differences, especially for drilling personnel who migrated from the environment of oil and gas to the geothermal environment.

2.1 Stuck Pipe Root Causes

In order to produce a suitable stuck pipe prevention and mitigation plan, the first step is to identify the stuck-pipe potential factors by referring to Indonesia unique geothermal system characteristics.

2.1.1 Reservoir Temperature

Almost the entire surface of the earth experiences a flux of heat through the crust upward to the ground. And the average of thermal gradient in the shallowest part of the crust is around 30℃/km. Higher temperatures are encountered when drilling or mining deep into the crust, and temperatures more than 100℃ are often found in deep oil or gas wells (Grant and Bixley, 2011). While in geothermal, the anomalous heat flow show is shown. The high heat flows become the marker to identify the existence of geothermal systems underneath (Suryantini, 2013). In Indonesia, the average temperature of geothermal reservoir ranged from 230 – 285 ℃ (Pambudi, 2017) within 1.5 – 3 km depth.

The temperature characteristics of the geothermal reservoir are different from petroleum reservoirs which generally range far below 150 ℃. In Indonesia, the drilling downhole tools used in geothermal come mostly from petroleum industries which have a low temperature rating design, resulting in shorter life expectancy when run in a high temperature geothermal well.

2.1.2 Fracture and Fault System

Porosity and permeability between geothermal system and sedimentary systems are different. In sediments, it is well known if the nature of the primary porosity is intergranular, intragranular or the other pores in the sediments(Worden & Burley, 2003). While in geothermal systems, the primary permeability is in fractured rock. Surface manifestations, such as warm springs, are founds along major faults and fracture lineations, suggesting that those system provide the pathways for the hot water that feed the springs (Grant & Bixley, 2011). In other cases, the fault system could be the seal for geothermal system too. Therefore, it is needed to identify the best fault direction of a geothermal system and nature of the permeability (Zoback, 2007).

The consequence of these reservoir characteristics is that the possibility of Partial Lost Circulation (PLC) and Total Lost Circulation (TLC) is very large in geothermal drilling since it aims for faults and fractures. Statistics on the drilling operation in three geothermal fields (Figure 2) show that the possibility of stuck pipes is higher when PLC and TLC occur, compared to full return conditions or normal circulation.

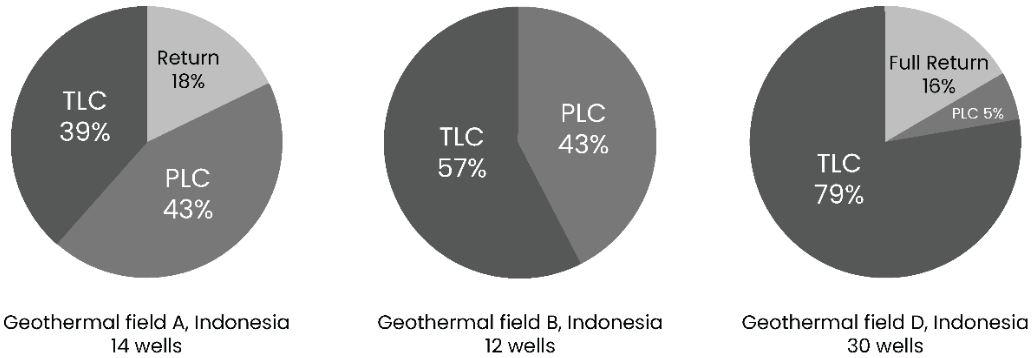

Figure 2: The statistic of fluid circulation status when stuck pipe happened in three geothermal fields in Indonesia

2.1.3 Reservoir Pore Pressure

Most subsurface reservoirs have a vertical pressure distribution that is close to hydrostatic (Grant & Bixley, 2011). While geothermal pressures, are normally under-pressured, yielding subnormal pressure gradients. Those conditions need to be considered especially when drilling. In petroleum, the formation pressure is usually over pressured (high pore pressure). Thus, treatment of geothermal and petroleum pressure regimes is different. In the application, the drilling fluid pressure should be lighter than the pore pressure (Finger & Blakenship, 2010).

The subnormal pressure gradient in geothermal makes the high likelihood for PLC and TLC when performing drilling operations, especially when entering the reservoir zone. As shown in Figure 2, statistics show the possibility of a stuck pipe increasing during PLC / TLC event.

2.1.4 Hard and Abrasive Formation

Common rock types in geothermal reservoirs include granite, granodiorite, quartzite, greywacke, basalt, rhyolite and volcanic tuff. Compared to the sedimentary formations of most oil and gas reservoirs, geothermal formations are harder and more abrasive. The average of compressive strength in geothermal formation is around ± 240 MPa. The level of abrasiveness is high because the quartz content is above 50% (Finger & Blakenship, 2010). Therefore, the formation will shatter the drilling equipment easily.

2.1.5 Reservoir Fluid Characteristic

In geothermal, the principal types of reservoir or thermal fluids consists of three types, chloride water, bicarbonate water, and sulphate water (Nicholson, 1993). The chloride water indicates the true reservoir fluids, with silica rich content and neutral pH but can be slightly acid depending on the content of CO_2. The water is very clear, bluish and greenish. Often silica sinter precipitates around the springs. The bicarbonate water (HCO_3) is formed by the CO_2 gas adsorption and steam condensates to the water. This can make these fluids slightly acidic and usually located on the margins of the system.

The last is sulphate water (SO_4^{2-}). It is formed at the shallowest part of the system and the upper part of heat source. It occurs due to steam condensate in near surface water (steam heated water). High SO_4 is present due to oxidation of H_2S; it is very acid due to low pH. While these gases contribute to the corrosion problem, H_2S limits the materials that can be used for drilling equipment and for casing to the lower strength steels, because higher strength steels will fail by sulphide stress cracking. H_2S also presents a substantial safety hazard during the drilling process. These material limitations, and the associated safety hazards, increase the cost of drilling geothermal wells (Finger & Blakenship, 2010)

2.1.6 Surface Water

Surface manifestation are features at ground surface where fluids discharge, mainly as single-phase fluids (e.g hot springs, seepages, hot pools). These features resulting from fluid-rock interactions, mixing, condensation, and other processes that happen in the near and sub-surface (Browne & Hochstein, 1999). Acid waters often be encountered in geothermal system, especially in Indonesia, where the most of its systems are volcanic geothermal system. The magmatic plume underneath continuously emits acids gas through condensates steam which affects the surface water (Nicholson, 1993).

Dwinanto et al. (2018) reported that Sokoria geothermal field encountered corrosion problems on their bottom hole tools (i.e. drill pipe, BHA, wireline) and surface equipment (i.e. pumps, valves, steel pipes) due to chemistry of formation fluid and surface water. It suggests conducting corrosion monitoring programs as one of the action plans in minimize risk related to corrosion rate.

2.1.7 High-relief Terrain

Indonesia's geothermal systems are mostly located along high-relief volcanic arcs and are generally identified through surface manifestations that discharge water or steam at boiling temperatures at ground level (Hochstein & Sudarman, 2015). Utami (2010) describes in detail the various challenges that will be faced when performing civil works in geothermal areas in Indonesia due to the unique characteristics of volcanic areas where heat, rocks and liquids interact dynamically, naturally and actively. Figure 3 shows a simple diagram of the thermal and hydrological structure of a geothermal field in a steep volcanic area.

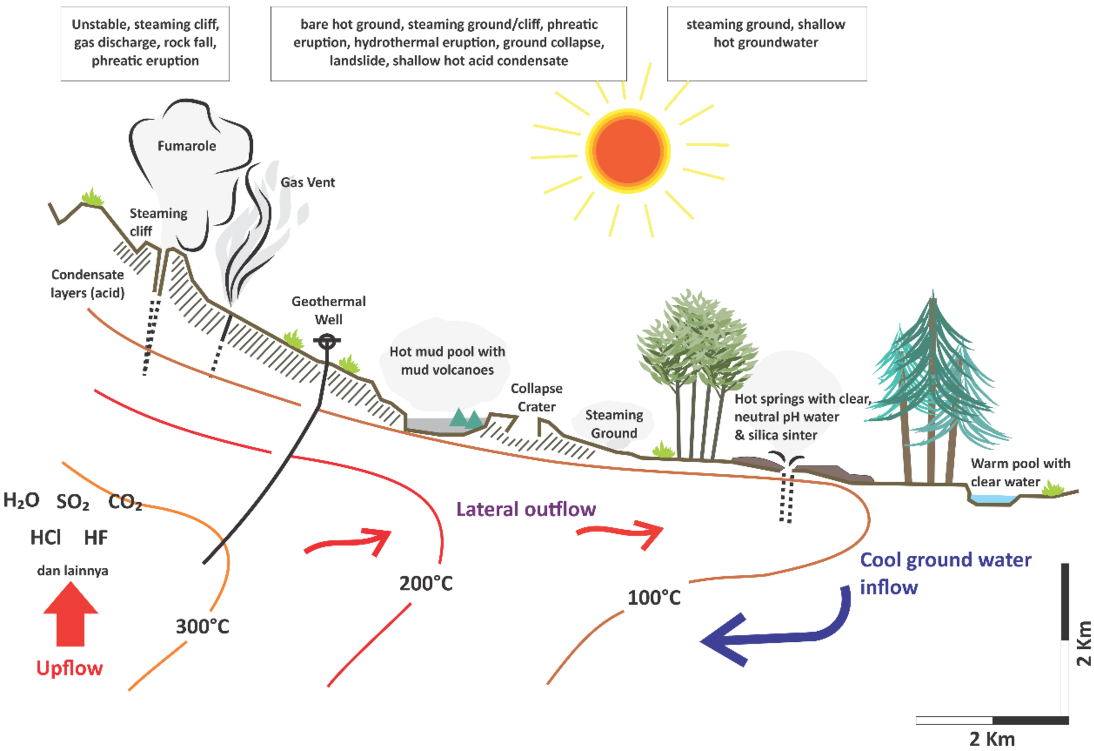

Figure 3: Simplified diagram of geothermal system in high-relief such as Indonesia (modified from Utami, 2010)

Indonesia's geothermal conditions in the high-relief terrain create difficulties in finding a flat surface area to construct drilling wellpad. Often wellpads for drilling are located far from the target reservoir, which dictates that the drilling engineer must design a high-angle well trajectory. Stuck pipe data from 3 geothermal fields in Indonesia shows that in fields A and D (Figure 4) stuck-pipe incidents mostly occur in high-angle wells with inclination more than 30 degrees, 69% and 58% respectively.

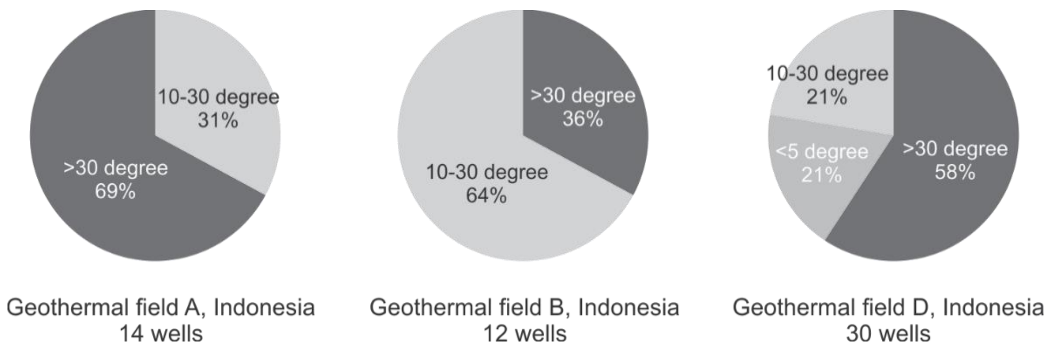

Figure 4: The statistic of hole deviation/angle where stuck pipe events happened in three geothermal fields in Indonesia

2.1.8 Reactive and Unstable Formations

This characteristic is found in petroleum and geothermal environments so it cannot be clearly stated as unique in geothermal. However, in some Indonesian geothermal fields, reactive formation layers are found that have the potential to cause major hole problems. Widianto et al. (2017) reported that the stuck pipe that occurred in Namora I Langit field was also caused by a problematic paleosol layer. This formation type was found in each well drilled in Namora I Langit.

In general, they define paleosol as preserved ancient or fossil soils found buried within either sedimentary or volcanic deposits. Mixed layer smectite, illite smectite with some kaolinite, and chlorite. Understanding paleosol, or other unstable formation behaviors and depth become very important since it might contribute stuck-pipe event. Several ways to study it are by conducting X-Ray diffraction (XRD) and Linear Swell Meter (LSM) tests on the sample.

2.1.9 Cause and Effect Diagram

Based on this uniqueness of the geothermal environment, the authors have developed a cause and effect relationship between stuck-pipe event and the possible causes, illustrated in a fishbone diagram (Figure 6).

2.2 Stuck Pipe Mechanism

Anadrill (1997) and IDEAS (2014) have developed a stuck-pipe mechanism category based on their possible causes. Authors of this study decide that based on these categories, the most likely causes of stuck pipes in geothermal can be summarized as follows (Table 1).

Table 1: Summary of Stuck-Pipe Mechanisms in Geothermal

Stuck-pipe mechanism	How does it happen?	Main reasons	Indications at rig
Hole cleaning (Figure 5a)	Mostly occurs in deviated wells where cuttings and cavings settle to the low side of the hole and form cuttings beds. It also happens when the pumps are turned off and pack off the drill string.	• Low annular flow rate. • Inappropriate mud properties. • Insufficient circulation time. • Inadequate mechanical agitation.	• Erratic pump pressure. • Poor weight transfer to bit. • Difficulty orienting tool face. • Absence of returns to shakers. • Presence of reground cuttings (low gravity solids). • Overpull inside casing.
Fractured and faulted formations (Figure 5b)	Naturally fractured rock can often be found near faults, which can be broken into large or small pieces. If they are loose, they can fall into the wellbore and jam the string in the hole. May occur in tectonically active zones and fractured limestone. This mechanism can occur while drilling.	• Drilling through a fault. • Drilling through fractured limestone. • The naturally fractured rock is loosed and falls due to drill string vibration.	• Drill string torqueing up and sticking. • Hole fill during connections. • Found fault damaged cavings at shakers. • Instantaneous sticking.
Reactive formations (Figure 5c)	If water-sensitive shale is drilled with less inhibition than is required, the shale absorbs the water and swells into the wellbore.	• Drill into shales and clays formations. • Drill with incorrect mud specification or an insufficient concentration of inhibition additives.	• An increase or fluctuations in pump pressure. • Hydrated or mushy cavings. • Shakers screens blind off, clay bails form. • Increase in LGS, filter cake thickness, plastic viscosity, PV, YP and MBT • Circulation is impossible or highly restricted. • Typically occurs while POOH.
Unconsolidated formations (Figure 5d)	A consolidated formation falls into the wellbore because it loosely packed with little or no bonding between particles, pebbles, or boulders. Normally occurs while drilling shallow unconsolidated formations.	• Formation collapse is caused by removing the supporting rock as the well is drilled. • Hydrostatic overbalance cannot support unbonded formations, such as sand, gravel, small riverbed boulders, etc.	• Increase in pump pressure. • Fill on bottom. • Overpull on connections. • Screen shakers blinding.
Junk (Figure 5e)	Debris can fall into the wellbore from the surface or from downhole equipment, which then jams the drill string in the hole. It is also possible that the drill string itself become junk due to parted during drilling.	• Poor housekeeping on the rig floor • Unproper hole covering system on the rig floor. • Failure of downhole equipment (corroded, washed out, fatigue, parted, etc.). • Corrosion issue on downhole tool often caused by high CO_2 and H_2S content of formation fluid and surface water.	• Sudden erratic torque. • Circulation unrestricted. • Found metal shavings at shaker. • Inability to make hole. • Missing hand tools or other equipment from rig floor. • Repair and maintenance work recently performed on the rig floor.
Tectonically stressed formations (Figure 5f)	Occurs in formations where movements of the earth's crust compress or stretch the formation rock (in or near mountainous regions). When a well is drilled into such a formation, the rock can collapse into wellbore.	Wellbore collapse can occur if the restraining pressure provided by the density of the drilling fluid is significantly lower than the stresses on the rock near the wellbore.	• Splintery cavings at the shakers. • Increase torque and drag. • If stuck, circulation is likely to be impaired or nonexistent. • Increase in volume of returns at the shakers relative to hole volume drilled. • Pack-offs and bridges may occur.

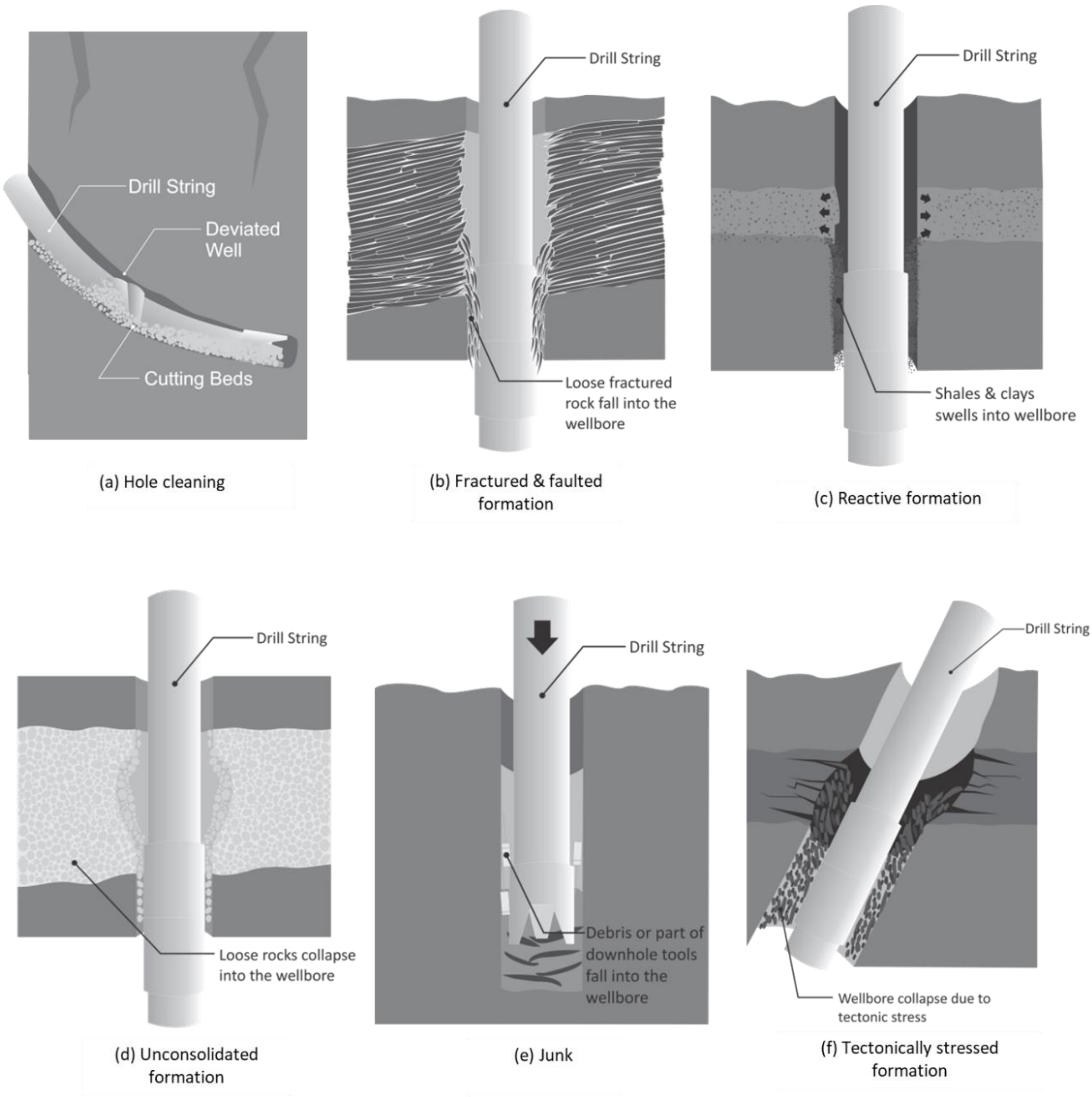

Figure 5: Illustration of possible stuck pipe mechanisms in geothermal drilling

3. PREVENTION OPTIONS

Once the authors managed to map all possible causes, the focus of the study was shifted to develop a list of possible preventions as summarized in Table 2. These options are based on literature reviews, author discussion and personal communication with several geothermal drilling engineers in Indonesia. These preventive options are divided into 3 categories based on their implementation time: in the early planning phase (6-24 months prior to spud), before operation (1-6 months prior to spud) and during operation.

Table 2: Summary of Stuck-Pipe Preventive Action Options

Stuck-pipe mechanism	**Early planning phase** (6-24 months prior to spud)	**Before operation** (1-6 months prior to spud)	**During operation** (especially for drilling supervisor, drillers, mud engineer and mud logger)
Hole cleaning (Figure 5a)	• Involve cross-discipline team (geoscience, drilling, civil, land acquisition and community relation) in the land acquisition process to get the most optimum wellpad location. • Drilling team to always use offset well data analysis in the well planning process. • Suitable discussion between geoscience and drilling team on	• Ensure all key field personnel attending the Risk-Assessment-Workshop and DWOP (Drill Well on Paper) with focus on stuck-pipe prevention. • Develop and socialize drilling fluids (mud) strategy for several scenarios (Mud sweep, PLC, TLC, “blind drilling” and high bottom-hole temperature). • Optimize mud properties such as	• Use all possible onsite-meetings as an opportunity to remind driller and floor hand on stuck-pipe prevention risk (pre-spud meeting, pre-job safety meeting, etc.). • Post a stuck-pipe indications poster in front of driller console as reminder for the driller in charge. • Keep the drill string moving as much as possible in the open hole. • Enough circulating time prior to

	strategy of setting the production casing depth and potential troublesome formations. • Design the well trajectory not to exceed 30-degree inclination, if possible. • Prior to rig and drilling equipment procurement, get clear understanding on rig and drilling equipment specification needed to be able to perform proper hole cleaning action. • Proper competency assessment on all driller candidates. • Consider special stuck-pipe-prevention training program for selected driller. • Cautiously consider utilization of aerated drilling method to improve cutting transportation to surface. • Consider utilization of PWD (Pressure While Drilling) to help monitor hole cleaning condition by monitor real-time pressure trend. • Conduct water source mapping and develop a water supply strategy.	increase yield-point (YP) in near-vertical wells. • Consider requiring rig to provide 3rd mud pump and larger drill pipe to maximize annular velocity. • Proper rig and drilling inspection prior to mobilization, especially on top drive, mud pumps, shale shakers and water supply equipment. • Design BHA & drilling parameter to have annular velocity at least 120 ft/min. Validate the design using hydraulic analysis. • Ensure water source and water supply equipment is enough to anticipate "blind drilling" strategy (able to supply continuously up to 1,200 gpm). • Develop T&D (torque and drag) simulation to help drilling supervisor, driller and other rig key personnel in monitoring the T&D trend while drilling.	tripping out. • Rotate before tripping out of hole if motor is used. • Keep the pumps running. Consider using "Non-stop circulating drilling" method during connection. • Lower ROP to anticipate cuttings "overload". • Continuously monitor shale shakers for optimum cutting removal. • Continuously monitor mud properties • Maximize mechanical agitation of cutting beds by rotation and reciprocation. • Continuously monitor T&D (torque and drag). Sudden trend change in T&D is an indicator of hole problem. • Rig repair should be done with drill string inside the casing.
Fractured and faulted formations (Figure 5b)	• Suitable discussion between geoscience and drilling team on fracture and fault depth and strategy of setting the production casing depth. • Drilling team to always use offset well data analysis in the well planning process. • Proper competency assessment on all driller candidates. • Consider special stuck-pipe-prevention training program for selected driller. • Utilization of BHA design optimization tool/software (i.e. minimize collar, jar size & placement, stabilizer size & placement) to minimize drill string vibration, thus minimize risk of pack-off due to fractured formations.	• Ensure all key field personnel attending the Risk-Assessment-Workshop and DWOP (Drill Well on Paper) with focus on stuck-pipe prevention. • Ensure proper inspection on BHA prior to mobilization. BHA approved must meet "minimize-vibration" design criteria. • Develop T&D (torque and drag) simulation to help drilling supervisor, driller and other rig key personnel in monitoring the T&D trend while drilling.	• Use all possible onsite-meetings as an opportunity to remind driller and floor hand on stuck-pipe prevention risk (pre-spud meeting, pre-job safety meeting, etc.). • Post a stuck-pipe indications poster in front of driller console as reminder for the driller in charge. • Enough circulating time to ensure the hole is clean. • Give time for formations to stabilize by control drilling speed. • Control tripping speed when the BHA is opposite fractured formations and fault zones. • Continuously monitor T&D (torque and drag). Sudden trend change in T&D is an indicator of hole problem.
Reactive formations (Figure 5c)	• Proper discussion between geoscience and drilling team on strategy of setting the production casing depth and potential troublesome formations. • Drilling team to always using offset well data analysis in the well planning process. • If possible, get soil and clay sample from offset wells or outcrop for clay swelling and clay mineral testing in the laboratory (i.e. XRD and LSM test). • Proper competency assessment on all driller candidates. • Consider special stuck-pipe-prevention training program for selected driller.	• Ensure all key field personnel attending the Risk-Assessment-Workshop and DWOP (Drill Well on Paper) with focus on stuck-pipe prevention. • Develop and socialize drilling fluids (mud) strategy such as utilization of inhibited mud system, based on clay swelling test. • Develop a wiper trip and reaming strategy for the shale sections. • Minimize BHA length during BHA design. • If possible, avoid additional open hole operation (i.e. wireline logging, SFTT, survey runs, etc.) in the reactive formation section. • Develop T&D (torque and drag) simulation to help drilling supervisor, driller and other rig key personnel in monitoring the T&D trend while drilling.	• Use all possible onsite-meetings as an opportunity to remind driller and floor hand on stuck-pipe prevention risk (pre-spud meeting, pre-job safety meeting, etc.). • Post a stuck-pipe indications poster in front of driller console as reminder for driller in charge. • Minimize open-hole time in shale sections. • Ensure hole cleaning is adequate to clean excess formation fluids. • Continuously monitor T&D (torque and drag). Sudden trend change in T&D is an indicator of hole problem.
Unconsolidated formations (Figure 5d)	• Drilling team to always using offset well data analysis in the well planning process. • Proper discussion between geoscience and drilling team on strategy of setting the production	• Ensure all key field personnel attending the Risk-Assessment-Workshop and DWOP (Drill Well on Paper) with focus on stuck-pipe prevention. • Develop and socialize drilling	• Use all possible onsite-meetings as an opportunity to remind driller and floor hand on stuck-pipe prevention risk (pre-spud meeting, pre-job safety meeting, etc.). • Post a stuck-pipe indications poster in

	casing depth and potential unconsolidated formations (i.e. sand, porous formation, boulder, etc.). • Proper competency assessment on all driller candidates. • Consider special stuck-pipe-prevention training program for selected driller.	fluids (mud) strategy such as preparing high-gel mud in the slug tank for cutting lifting. • Consider developing "drill and pull-back" strategy to see the hole reactions (stabilization time) by monitor the "fill-on-bottom" depth. • Develop T&D (torque and drag) simulation to help drilling supervisor, driller and other rig key personnel in monitoring the T&D trend while drilling.	front of driller console as reminder for driller in charge. • Continuously monitor pump pressure and drill cuttings in the surface. • Avoid excessive circulating time in the unconsolidated formations to reduce hydraulic erosion. • Control ROP to allow time for the filter cake to build up and to minimize annulus loading. • Continuously monitor T&D (torque and drag). Sudden trend change in T&D is an indicator of hole problem.
Junk (Figure 5e)	• Proper communication between drilling and procurement team before and during tender process to avoid getting "unmotivated" rig team. • Proper discussion between drilling and geoscience team on bottom-hole temperature estimate that will be encountered drilling to determine downhole tool temperature rating and minimize failure risk when run in hole. • Conduct assessment and analysis on formation fluid and surface water source regarding corrosion problem on downhole tool (i.e. BHA, drill pipe, etc.). • Proper competency assessment on all driller candidates. • Consider special stuck-pipe-prevention training program for selected driller.	• Ensure all key field personnel attending the Risk-Assessment-Workshop and DWOP (Drill Well on Paper) with focus on stuck-pipe prevention. • Ensure thorough inspection by reliable 3rd party inspector on all downhole tools (BHA, drill pipe, logging tool, wireline, drill bit etc.) to minimize risk of drill string failure (washed out, fatigue, parted, corroded) during drilling. • Proper discussion with drill bit engineer on the drill bit application in similar geothermal field to get realistic estimate on bit rotating hours, thus minimize the risk of drill bit failure.	• Use all possible onsite-meetings as an opportunity to remind driller and floor hand on stuck-pipe prevention risk (pre-spud meeting, pre-job safety meeting, etc.). • Post a stuck-pipe indications poster in front of driller console as reminder for driller in charge. • Always ensure good housekeeping on the rig floor. • Regular inspection of handling equipment. • Always keep the hole covered. • Inspect downhole tool before it is run in the hole and while being run through rotary table. • Consider utilization of corrosion ring or corrosion coupon to monitor corrosion rate on downhole tool or drill strings.
Tectonically stressed formations (Figure 5f)	• Proper discussion between geoscience and drilling team on strategy of setting the production casing depth. • Conduct geomechanics study prior to development of well trajectory plan. • Consider to case off tectonically stressed formations as quickly as possible. • Consider drilling the formations using "casing drilling" method.	• Ensure all key field personnel attending the Risk-Assessment-Workshop and DWOP (Drill Well on Paper) with focus on stuck-pipe prevention. • Develop T&D (torque and drag) simulation to help drilling supervisor, driller and other rig key personnel in monitoring the T&D trend while drilling.	• Use all possible onsite-meetings as an opportunity to remind driller and floor hand on stuck-pipe prevention risk (pre-spud meeting, pre-job safety meeting, etc.). • Post a stuck-pipe indications poster in front of driller console as reminder for driller in charge. • Continuously monitor T&D (torque and drag). Sudden trend change in T&D is an indicator of hole problem.

4. CONCLUSIONS AND RECOMMENDATION

4.1 Conclusions

Some conclusions to be drawn at this point are:

1. This study has successfully formulated a preliminary concept of a stuck-pipe prevention campaign, which is believed to accomplish the two desired criteria, specifically "integrated" and "proactive". The concept is designed based on statistical stuck-pipe data in several geothermal fields in Indonesia, therefore it should be appropriate for implementation in the country.
2. The "integrated" principle is accomplished since the concept encourages the drilling plan to be discussed between all related teams, including drilling, geoscience, civil works, land acquisition, community engagement, permitting, and logistics. If the communication between the cross-discipline teams can be implemented properly and all the team members committed to do the action plans in their respective fields according to mutual agreement, the authors believe that stuck-pipe factors could be significantly reduced.
3. While "proactive" criterion is achieved because this concept encourages active communication between all the teams involved through the initial stages of drilling program planning. Through active communication between all team members, the potential stuck-pipe causes will be mapped thoroughly and ultimately results in an appropriate prevention and mitigation plan.
4. Most of the stuck pipe events in geothermal are caused by pack-off mechanisms where indications or signs can be seen from the torque and drag or pick-up weight. If the drilling team manages to make a good torque and drag (T&D) monitoring system and successfully educates the field personnel (i.e. drilling supervisor, driller, mud engineer, mud logger, etc.) to read the signs, the success rate of the stuck-pipe-prevention campaign will increase.

5. However, the authors are aware that, in real life, this concept must be detailed by adjusting it to the actual situation in each geothermal field that has their own uniqueness. Creating an ideal stuck-pipe-prevention campaign for a geothermal field is mainly determined by the initial data collection activities, which gives accurate field characteristics.

4.2 Recommendation

There are several findings when conducting this study that should be considered in conducting future studies:

1. There are not many publications or conference papers reporting stuck pipe events that occur in geothermal drilling operations in Indonesia. Although through informal discussions, the authors found that stuck pipe events always occur in every geothermal drilling operation in Indonesia, both in the exploration and development phases. The authors also have not yet found any official report released by the Indonesian government regarding the stuck pipe data in Indonesian geothermal fields. This makes the process of identifying and analyzing root causes less comprehensive because it is not based on complete data from geothermal fields in Indonesia.
2. Very few training and courses in Indonesia have been found regarding stuck-pipe prevention for geothermal applications, where most of the available training is intended for oil and gas applications. This most likely will increase the probability of a stuck pipe event in geothermal since drilling personnel involved are inclined to anticipate problems in the geothermal environment using an oil and gas perspective.
3. Based on the authors experience and through personal communications with several geothermal drilling engineers in Indonesia; this study found that communication methods that are often used to deliver drilling programs are still one-way, namely from the geothermal company to the drilling contractors, which makes minimizes the input from the drilling contractor's participation in planning stuck -pipe-prevention programs.
4. The driller is the most decisive key personnel in the stuck-pipe-prevention campaign because he or she, most likely, is the first person to witness the first indication of stuck pipe. The driller's first immediate response will determine the next event, whether it is free or stuck pipe. However, this study found that drillers in Indonesia were often not involved from the beginning of the stuck-pipe-prevention program.

Therefore, some recommendations from this study are:

1. A proper communication between government, geothermal companies and academia to cooperatively create a geothermal drilling database system for Indonesia is required. A database that is built on actual data from all geothermal fields in Indonesia will be useful for geothermal companies to create more detailed and accurate analysis on stuck-pipe occurrence.
2. Guidelines for stuck-pipe-prevention workshops are required to bridge communication between drilling engineer, as the planner, and drilling supervisor and driller, as the executor. If communication between the office personnel and the field personnel is properly establish from the early phase of the project, it is believed stuck pipe risks can be minimized.
3. Training or certification programs for geothermal drillers on the stuck-pipe-prevention topic is necessary. This is to ensure that all drillers, as the key personnel at the rig site, have met the minimum competency standard in reading stuck-pipe signs and properly trained to take the first immediate response.
4. Government and/or geothermal association in Indonesia to encourage and facilitate more discussions on stuck-pipe prevention among geothermal drilling engineers through workshops, seminars, conferences and focus group discussion (FGD).

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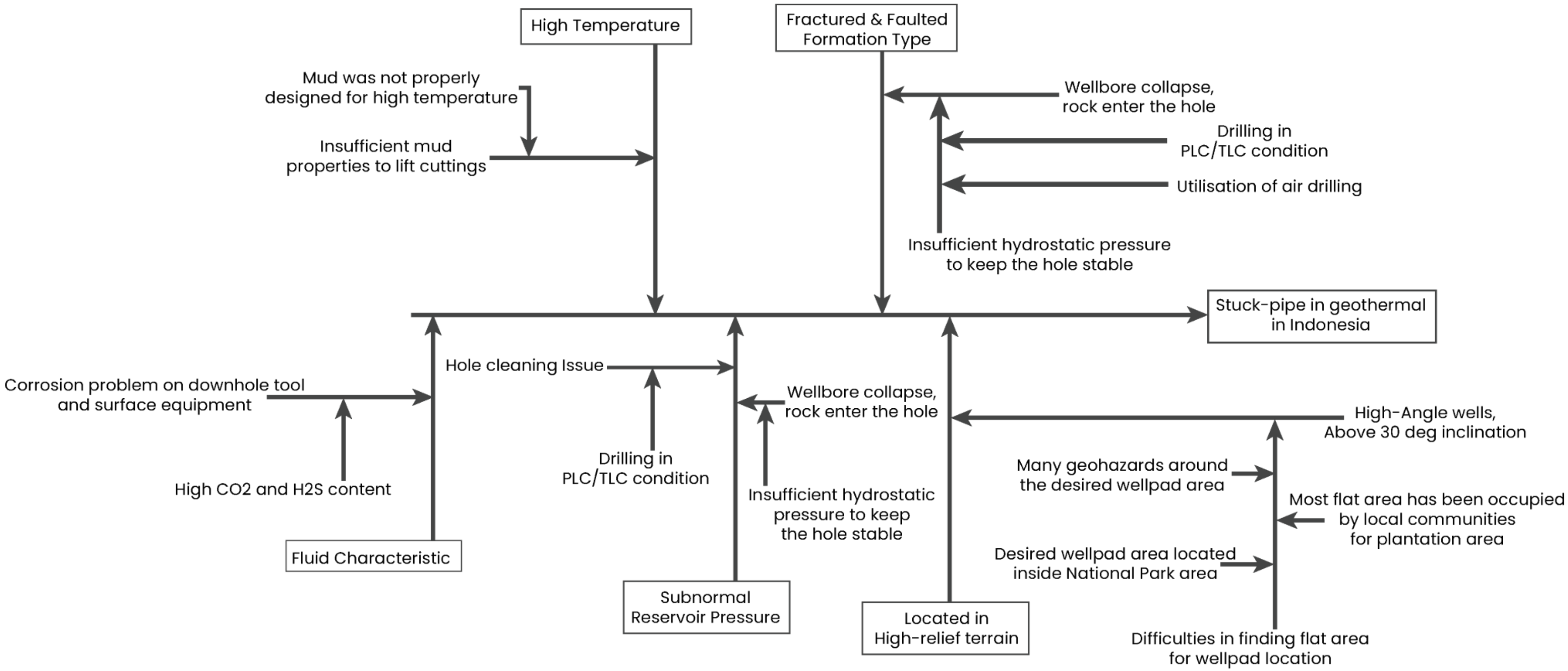

Figure 6: A simplified cause and effect diagram of stuck pipe in Indonesia geothermal environment