Problems Encountered While Drilling and Completion Stages in Asal Rift Wells, Djibouti

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ABSTRACT

Geothermal well drilling is a complex process which frequently is leading to operational problems. From 1975 to 1988, six geothermal wells were drilled in Djibouti (Asal Rift) in an area which has high temperature potential, but also problems of low permeability and high salinity. This paper presents the analysis and interpretation of problems of wells A3 and A6 in Asal Rift, where the drilling of well A3 has presented a kick in a depth about 1000 m (weight of drilling fluid less than formation pore pressure) that has resulted the abandon of the drill string in the well. Similarly, fluid losses are observed in well A6, and the situation turns into a total lost circulation which millions of cubic meter of cement were used in order to cement each casing. The open part of the hole A6 (uncased) collapsed after fluid losses. This study focuses on the above problems which are not natural but it is due to human error, the improper handling of the tool during the operation. This may involve the improper design of drilling components regarding given geophysical data of formation, proper usage of drilling fluid to avoid bit balling, formation sloughing, maintaining hydrostatic pressure and proper usage of blow out preventer to control abnormal pressures, so that a good drilling performance will be taken into account by setting up a benchmarking process that is termed to be as "a necessity for survival".The consequences of failure are severe. Even the most simple problem situation can result in the loss of millions of dollars in equipment and valuable natural resources. These situations can also result in the loss of something much more valuable human life. Understanding and anticipating these problems, understanding their causes, and planning solutions for the new drilling program of Asal Fialé are necessary for overall-well-cost control and for successfully reaching the target zone.

1. INTRODUCTION

Reduction of drilling cost and time is one of the main goals of drilling communities, and to achieve those goals, they commonly battle with wellbore instability related drilling problems often unarmed. Many operators drilling in the world often face extremely challenging environments to drill due to wellbore instability related to the tectonic stresses and associated faults, fractures, complex structures, and anomalous pore pressure. Additional challenges arise due to complicated and highly deviated well designs (case of future Asal Fialé wells) where planes of weakness in the formation being drilled and their relative angle with respect to the well path become crucial factors in assessing stability of the borehole. Therefore, to successfully achieve the most cost and time effective drilling, it is prudent to be armed with proper assessment and understanding of wellbore stability along with optimizing the most appropriate drilling strategy. The geology and structure of asal rift is complex with multiple sheets of overthrust fault and highly dipping beds. Asal rift is filled with Plio-Pleistocene volcanic and sedimentary formations called the Afar stratoid series, which means different rock properties. The series span the last 4 million years and the last volcanic eruption occurred in 1978 in Ardukoba. Asal rift is also subject to earthquakes. High-temperature geothermal fields are present within this active rift segment due to volcanic and tectonic activities, and the six exploration wells were drilled near the central part of this segment as a part of the national effort for geothermal development.

The geothermal exploration program of the Asal area, including field studies and exploration drilling between 1970 and 1990, revealed the high salinity, deep Asal geothermal reservoir and other potential geothermal areas. However, all these investigations did not yet lead to any exploitation of the geothermal energy. The field has been explored and drilled with a reservoir characterization. Based on the information obtained from the six vertical wells, most of those wells were completed without any wellbore-stability related challenges. But two of them experienced severe wellbore-stability issues in drilling and completion stages. In wells A3 and A6, problems encountered while drilling and completion stages, although these problems have not been thoroughly or not at all mentioned in previous report. The problems encountered during the drilling of these wells steamed likely from improper handling of the tools during the operation. In case of well A6 for example, the open part of the hole (uncased) collapsed after fluid losses and total circulation loss occurred, but the real reason(s) for this collapse is still unknown since data has not been analysed to shed light on the conditions, natural or man-made, leading to the collapse. This paper report the analysis, and interpretation the problematic that have occurred in wells A3 and A6, and offer adequate solutions that could be used in the Asal Rift or in any other area where geothermal drilling could face low permeability and high salinity.

2. PROBLEM DIAGNOSTICS: CASE OF ASAL RIFT WELLS

A problem diagnostic methodology will be described and applied for these vertical wells in Asal-rift Field in order to narrow down and to identify the intervals and the factors affecting the wellbore stability in the Asal rift Field. To analyze the instability problem, a comprehensive rock mechanical study has to be carried out to characterize rock strength and in-situ horizontal stresses

2.1 Asal geothermal field

2.1.1 Geography and Geology

The Asal geothermal system is located on the isthmus between Lake Asal and Ghoubet al Kharab gulf (Figure 1) at a distance of about 120 km from Djibouti City. The Asal Rift is a northwestward extension of the Gulf of Aden-Tadjourah. It extends from the

Gulf of Goubet in the SE to Lake Asal in the NW. The lake is 9–10km wide and is bounded by major normal faults to the SW and NE. The rift due to its unique nature as a landward extension of an oceanic ridge (the Tadjura Ridge) has been studied quite extensively (Barberi et al., 1975; Beyene and Abdelsalam, 2005).Altitudes range from -155 m at Lake Asal to +300 m at the highest point of the Rift valley floor. The area is bounded by the high plateaus of Dalha to the north (above 1000 m elevation) and by 400-700 m high plateaus to the south, which separate Asal from the Gaggade and Hanle sedimentary plains (Figure 1). The region is arid desert, with an average rainfall of 79 mm per year. Hydrogeological studies of the region show a general groundwater flow toward Lake Asal, which is the lowest point of the area, and is occupied by a salt lake saturated in sodium chloride and calcium sulphates. The area is controlled by tectonic faults, still active.

The Asal Rift is tectonically the most active structure in the zone of crustal divergence in Afar. The Asal area constitutes a typical oceanic type rift valley, with a highly developed graben structure displaying axial volcanism. The Asal series are relatively complex in structure, because of different series of active volcanism in recent Quaternary times, each with very different characteristics depending on the sites of appearance. Generally, the Asal series are composed of porphyritic basalt formations and hyaloclastites. is marked by Pleistocene clays. The basalt series of Dalha are characterized by sedimentary layers inbetween the basalt flows. Three main geological formations are known in the region and intersected by the wells. These are the Asal series (recent basalts on the geological map in Figure 1) with volcanism dating from the last 800,000 years (volcanism of the external margins of Asal, central volcanism and axial volcanism); the initial basalts series, or the stratoid basalts series, covering the period from 3.4 to 1 My; and the Dalha basalts series, dating between 9 and 3.4 My.

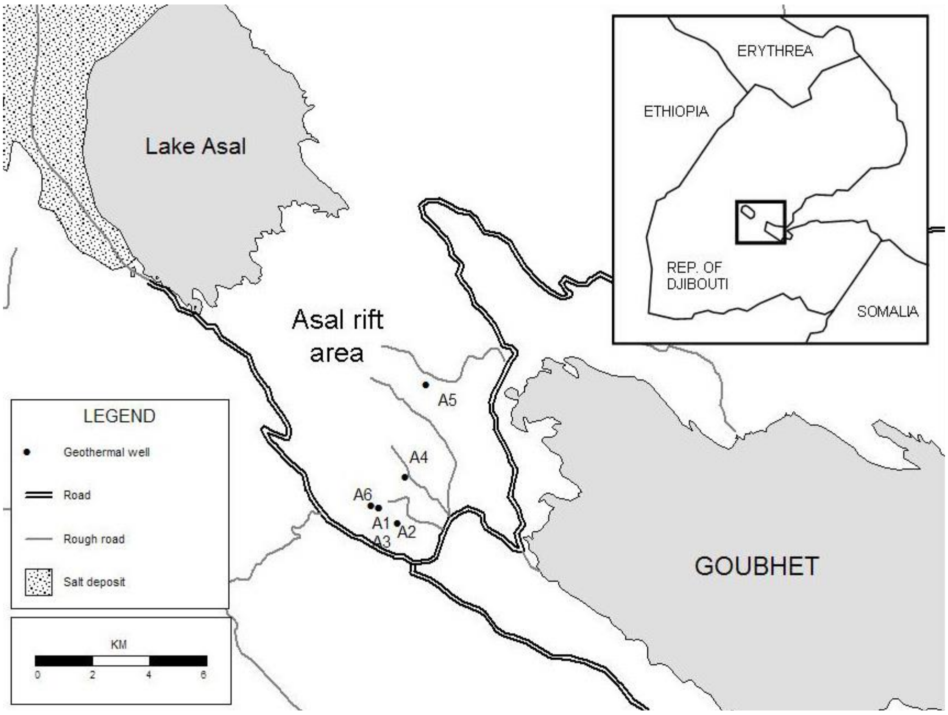

Figure 1: Asal geothermal field.

2.1.2 Geophysical investigations

The result of a gravimetric survey (BRGM, 1980a) exhibits three main characteristics. The anomalies' principal direction appears in good accordance with the principal tectonic trend of the rift, NW-SE, and high horizontal gradients are aligned with the main axis of recent fractures, thus confirming the existence of these geological structures at depth. Secondly, numerous anomalies demonstrated by the survey reflect the local heterogeneity and their superficial origin in conformity with the geological observations, showing numerous structural units and a particularly dense fracture network. Finally, in the central part of the rift a clear anomaly corresponds to the principal inflow of magma where recent volcanic activities were observed. The transversal magneto-telluric profile in the Asal rift generally showed conducting layers underlying resistant layers in some areas in relation to the presence of hyaloclastites overlain partially by recent basaltic formations. The study mainly points out the heterogeneity of the structures. The correlation between the different measuring stations is relatively difficult due to variations in thicknesses. Another profile in the vicinity of the recent Ardoukoba volcano suggests the presence of saline water in hyaloclastites, basalts, scorias and fissures. Spontaneous polarisation (SP) profiles measured across the rift clearly describe a SP anomaly near the recent volcano of Ardoukoba. The interpretation of the profiles indicates that the general anomaly in the central part of the rift results from a thermal source. This signifies that the heat flow is generally high in this region.

2.2 Asal Wells characteristics

In 1975, two deep wells, A1 (1554m) and A2 (1147 m), were drilled in the SW part of the Asal Rift; i.e. in the "old well field" or Gale le Goma area (see Fig. 1). A1 encountered a feed zone at 1137m depth, while A2 showed no permeability but temperatures above 260°C (Aquater, 1989). A1 produced about 38 kg/s of a two-phase fluid (20% steam at 6 bar wellhead pressure). Four deep wells were drilled in 1987–88. Wells A3 and A6, located in the same area as A1 and A2, close to a phreatic crater (Fig. 1), encountered the same reservoir as A1 with temperatures of about 280°C (Daher, 2005). Well A4, drilled about 1.5km NE of the phreatic crater, showed temperatures close to the boiling curve at elevations lower than 200m b.s.l. and about 350°C at bottom hole.

However, only low permeabilities were encountered in A4. Based on the resistivity, we assume that in this area the same maximum reservoir temperature (~280°C) as in Gale le Goma will be encountered. Well A5, drilled in the Inner Rift (or Fiale area) about 700m west of Lava Lake, presented sharply increasing temperature below 200m b.s.l. with a local maximum of about 180 ◦C at 400m b.s.l. Below that elevation the rocks have cooled dramatically, down to 60–70°C around 800mb.s.l., as compared to temperatures indicated by alteration mineralogy. Below 800m b.s.l. the temperature rises steeply with depth and reaches about 350°C at bottom hole. Very low permeabilities were found in A5; higher values are expected in other parts of this area. Even if the permeability is very low in this well (around 0.4 darcy-meter; Daher, 2005), it may be increased by hydraulic stimulation. Since this operation involves

3 Methodology of Interpretation on data analysis of wells

Several factors play key roles when it comes to analyzing wellbore-stability problems in a field during drilling and completion operations. Aadnoy and Looyeh, (2011), categorized the wellbore-stability issues as being caused by solid-fluid interactions, complex stress conditions, wellbore deviation and orientation, lack of appropriate drilling and operating practices, pressure alterations, and temperature change. In addition, the presence of faults, unconformities, stress alterations due to fluid flow into a formation and formation anisotropy can also impact on the formation to cause an unstable behavior. Typically, a combination of these factors influence failure at the wellbore.

The first step in diagnosing wellbore-stability problems is to confirm the existence of wellbore-stability issues. Then, the causes of possible rock failure can be narrowed down by excluding the key operational factors that did not create the problems. One of the techniques to narrow this search is to carry out a comparative study using the data analysis for wells drilled with and without wellbore-stability issues. If one of the factors was identical for both unstable and stable well cases, we can temporarily exclude the specific factor from the data processing with an assumption that this factor did not play a significant role in rock failure. At the end of this elimination process, only a limited number of parameters will be identified as contributing to the wellbore failure. Yet, unless a complex wellbore-stability dataset is available, the diagnostic analysis only helps in identifying possible factors without offering any solution. One of the most powerful tools that can significantly help in identifying the major factors of a failure mechanism is an annular pressure gauge. The annular pressure gauge is located at the drilling bottom hole assembly (BHA) and provides the value of the annular pressure in terms of the equivalent static density (ESD) or equivalent circulation density (ECD). Analysis of ESD and ECD data acquired using this tool can help in determining poor drilling practices such as insufficient hole cleaning and/or high surge and swab pressures. Sometimes, only a stabilization of the ECD during drilling (e.g. improved hole cleaning) and tripping (e.g. control of swab and surge pressures) can result in solving wellbore-failure occurrences. However, a rigorous wellbore-stability analysis is always preferable to understand the influence of all key operational factors on wellbore-stability behavior. Unfortunately, no annular pressure gauge has been used yet in this field of our study. Therefore, it is difficult to state if excessive swab and surge pressures were the reasons for the wellbore failures of these wells.

The use of an annular pressure gauge in the directional BHA during drilling wells in the future is under consideration and could be the subject of future Fialé wells. Then, the presence or absence of wellbore-stability of these wells needs to be investigated based on several key operational parameters. These parameters include:

- Lithology
- Drilling fluid type and weight used in the problematic intervals
- Wellbore inclination and azimuth at the unstable horizon
- Exposure time at the horizon
- Hole cleaning performance

This diagnostic can be used to investigate the preliminary reasons for the absence or existence of wellbore-stability incidents of Asal 3 and Asal 6 wells. Although both wells were drilled through the same horizons, the severe wellbore-stability issues were encountered while drilling the A3 and A6 well. However, no significant problems occurred in the others wells.

3.1 Theory of Wellbore Stability Analysis

The aim of the 10 step process is to achieve following elements that make up the MEM using several proven correlations to determine them from petrophysical and sonic logs:

- Elastic mechanical properties
  - i. Young’s Modulus
  - ii. Poisson’s Ratio
- Rock strength
  - i. Unconfined Compressional Strength (UCS)
  - ii. Tensile strength
  - iii. Friction angle
- In situ stress
  - i. Vertical tress
  - ii. Maximum horizontal stress
  - iii. Minimum horizontal stress
  - iv. Direction of principal stresses
  - v. Pore pressure

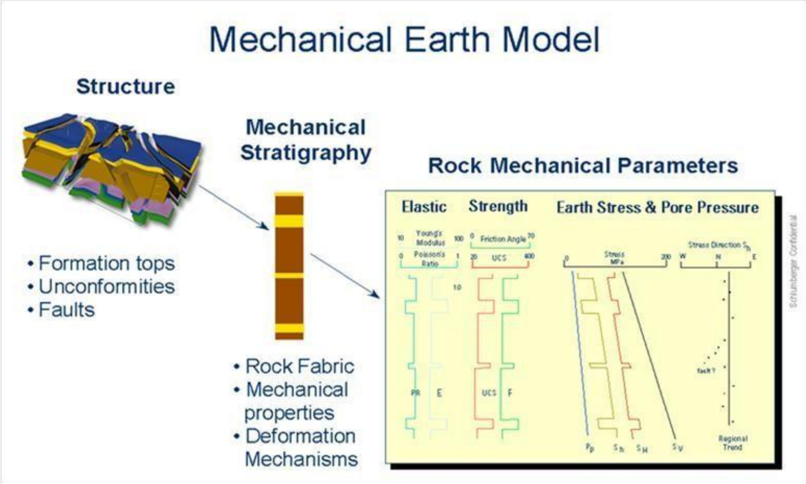

Figure 2: The Mechanical Earth Model (MEM) Concept.

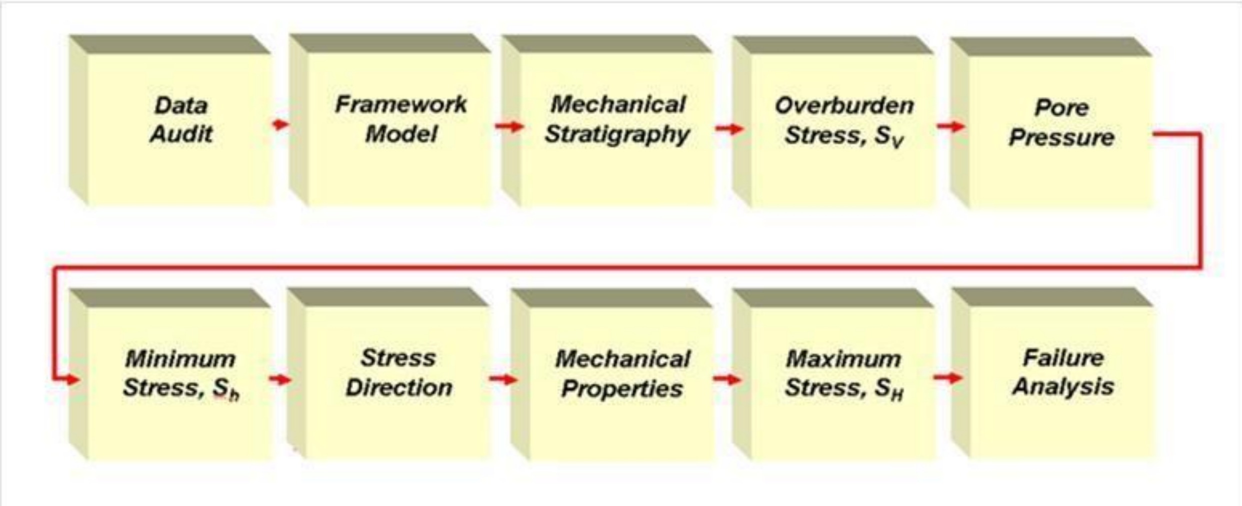

Figure 3: A 10 – step workflow for construction of a Mechanical Earth Model (MEM) and Failure Analysis for Wellbore Stability.

Successful drilling requires that the drilling fluid pressure stay within a safe mud-weight window defined by the pressure limits for wellbore stability. The lower pressure limit is either the pore pressure in the formation or the limit for avoiding wellbore collapse (breakout due to compressive/shear failure). Normal burial compaction trends lead to hydrostatically pressured formations, where the pore pressure is equal to that of a water column of equal depth. If the drilling fluid pressure is less than the pore pressure, then formation fluid or gas could flow into the borehole, with the subsequent risk of a blowout at surface or underground.

Typically, a "safe" mud weight is computed so that

$$P_p < P_w < \sigma_h \quad (1)$$

Where P_p is the formation pressure, P_w is the drilling fluid pressure, and σ_h is the minimum horizontal stress.
A borehole is considered "stable" when the mud weight is such that no shear or tensile failure develops. To compute the stable mud weight window, the stresses around the borehole must be determined first, and then use certain failure criteria to compare the stress state at the borehole wall with the rock strength.

The best way to validate the WBS model is to verify the predictability of the model with field observations. By conducting WBS analysis using the log-based computed rock properties, estimated pore pressure and horizontal stresses, and then comparing the predicted WBS with the drilling events observations in these wells, one can see how robust the MEM is. Accurate estimation of stresses is critical to wellbore stability analysis. Before a well is drilled, compressive stresses exist within the rock formations. With the exception of structurally complex areas (e.g. near salt diapirs), the in-situ stresses can be resolved into a vertical stress, (σ_V), and the horizontal stresses (σ_H and σ_h), which are generally unequal. When the well is drilled, the rock stresses in the vicinity of the wellbore are redistributed as the support originally offered by the drilled out rock is partially replaced by the hydraulic pressure of the mud. The redistributed stresses are normally referred to as the hoop stress, σ_t, which acts circumferentially around the wellbore wall, the radial stress, σ_r, and the axial stress, σ_a, which acts parallel to the wellbore axis as shown in Figure 4.

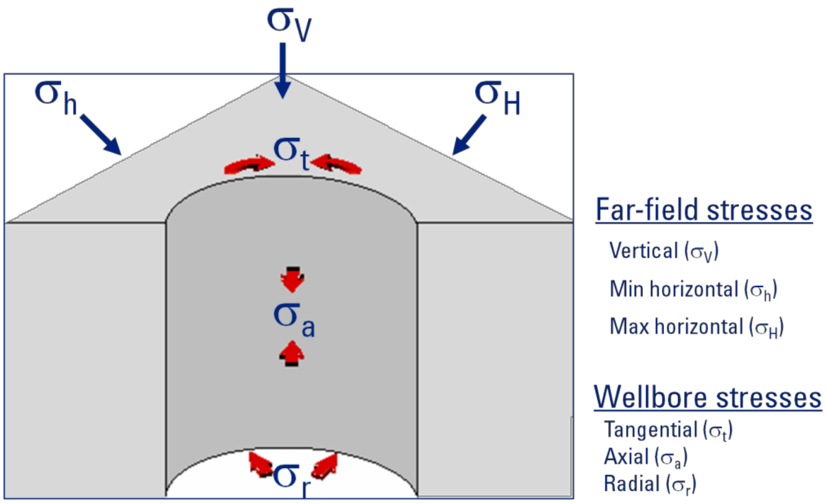

Figure 4: Redistribution of stresses near wellbore.

3.2 Analysis of data of well A3

A detailed investigation was carried out and well-logging data was carefully analyzed to diagnose the troubles encountered at Well A3during the drilling from 900 m to 1150 m depth of 1316 m of true depth. The key operational data investigated for this analysis were the number of days spent on drilling this horizon, true depth (TD), MW, ECD, borehole inclination and azimuth, lithology and operational comments. The integration of all the data made the diagnostic process faster and more flexible. The key aims of this diagnosis are to identify the formation(s) and lithologies that complicate drilling operations and to estimate the non-productive time (NPT) due to the wellbore stability if there is any NPT that can be eliminated.

Well A3 was vertically drilled up to 1316 m (TD) with an open hole size of 8 ½ inches. The drilling of Asal 3 started 12 June 1987. Drilled $17_{1/2}$" hole and opened to 24" down to 221 m. The 20" casing was set at 191 m. I took many days to get the 20" casing down as had no 24" reamer. It would have been better to by $18_{5/8}$" casing instead of the 20" casing.
The $17_{1/2}$" hole was drilled down to 399 m and the $13_{3/8}$" casing installed to 397 m. The $12_{1/4}$" hole was drilled to 1019 m and the $9_{5/8}$" installed to 1016 m. This casing scaled off all week clay zones above the solid rock formation. It was no safe to go deeper before installing the casing as the production zone in Asal 1 starts at 1040m. When drilling the $8_{1/2}$" hole at 1075 m, they lost all circulation and drilled on with no return to surface. The Aquater scientists wanted to stop and test every lost circulation zone but because of bad experience of flow testing during drilling, they drilled on with no return down to 1316 m. Then they decided to test the well and take a core.
They used air lift to put the well into production through two 3" outlets below the blowout preventers. This first flow test was only 1 ½ hour of steam production then they closed the well again. The BOP was then removed and the flow test pipes connected to the silencer for a full flow test. They tried to start the well by pressing down the water level but because of too much cooling from the drilling operation it did not start. They tried this two times without success. They decided to use air lift and pull out the drill pipes through the stripper when the hole started to flow. No BOP was installed. They ran 270 m of $4_{1/2}$" plain end drill pipe with check valve in the first joint.

The well started flowing and everything want well until they had pulled out 20 pipes and 10 were still in the well. Then the pressure at the wellhead was so high about 18 bars that the drill pipes were pushed out of the well and the same time the stripper rubber was overheated. Pulling out the drill pipes had taken much more time than they estimated mainly because of back of experience of the crew to work under these circumstances and some other delays. To avoid uncontrolled blowout of the steam, they decided to connect the Kelly and push the tool joint into the stripper rubber to stop the flow. Then the steam through the tripper outside the drill piper stopped and the pumped the rest of the water they had on site in the well to cool it down.
The turbulence in the well was so effective that the drill pipes were unscrewed at the joint to the Kelly that had not been made up fast enough and fell to the bottom of the well. The top of the drill pipes is at 1187 m.

After this flow test, they knew that Asal 3 is a very powerful steam producer but it was also clear that the salinity of the water was very high. The area around the rig was all while of salt after this test. After this flow test the well was easy to start with pressurization to about 40 bars or more. After the test they decided not to drill deeper and leave the drill pipes in the bottom of the well as they had little influence on the inflow into the well and the steam production. The main inflow is at 1075 m and at 1220 m. It was possible that the inflow at 1220 m could be plugged if the sand from the formation fills the annulus outside the drill pipes.

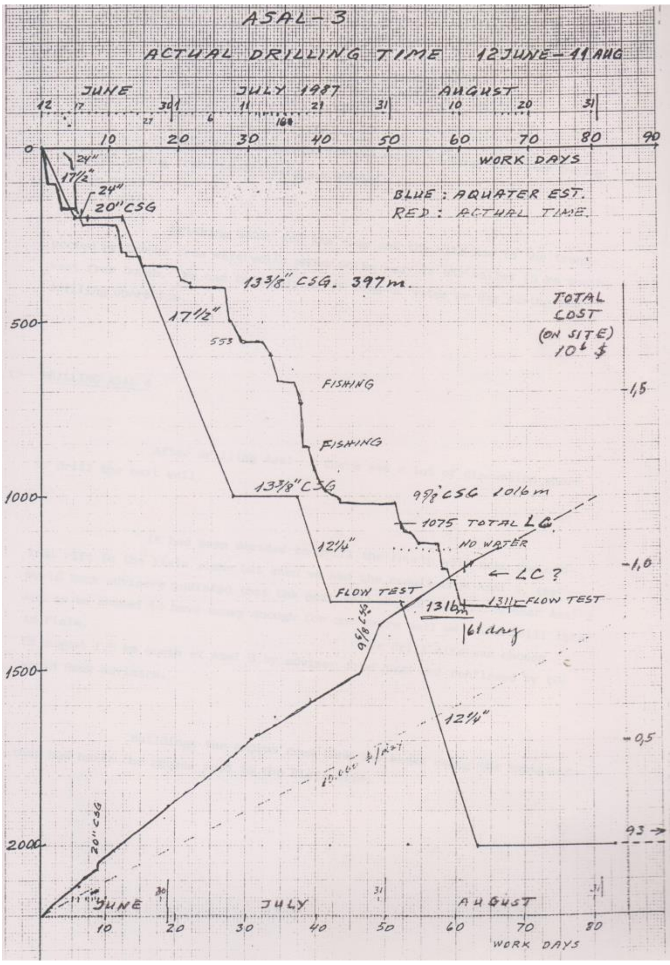

Figure 5: Drilling time (working days/Depths) of well A3.

3.4.1 Effect of string of drill pipes

After well completion and since it was unable to start producing by itself, air-lift induction was performed. A t the end of the maneuver a string of about 90 m of 4 $_{1/2}$" drill pipe was lost, remaining inside the well during all production tests. Although a decrease in output capacity from the well could be expected due to the presence downhole of the additional restriction of the drill pipe, it is believed that since it was always present during the whole productive history of the well. It could not produce by itself the output decline previously described, unless it could be combined with the simultaneous effect of other factors. The top of the drilling string was detected at a depth of about 1190 m. It always remained within the single-phase flow section of the well, down below the flashing zone; therefore, no scale build-up could be expected at the drilling string. On the other hand, although the presence of some wall collapse below 1190 could not be completely excluded, it seems unlikely since no increase in skin factor *or* decrease in productivity index was detected from well tests performed at different times (Aquater, 1989). In addition to this, the contribution to total output coming from the deeper zone located below 1225 m was apparent, as evidentiated by an increase in flowing temperature from about 262 to 264 °C . Taking into account all these facts, it seems unlikely that the observed decline of well output in time could be associated with the downhole presence of the drilling string.

3.5 Analysis of data of well A6

To diagnose the troubles encountered at Well A6 during drilling from 0 m to TD 1735 m, a detailed analysis of conducted operations and well-log results was performed. The collected key operational data for the analysis includes the number of days spent on drilling this horizon, MD, TD, MW, ECD, borehole inclination as well as azimuth, lithology and operation comments. The purpose of this diagnosis is to identify the formation and lithology that complicate drilling operations and to estimate the NPT due to the wellbore-stability issues if any exist. Also, the MW, ECD, wellbore inclination and azimuth will be evaluated to find the influence of these parameters on wellbore-stability troubles during drilling of this well.

It was decided to drill Asal 6 deviated below 800 m in order to cut two or more parallel fractures that are believed to be almost vertical. They rented the tools, down hole motors and non-magnetic drill collars... etc to do this deviation. Because of unexpected drilling problems they revised the drilling program many times and at the end the well was drilled vertical like the other.

The drilling started 8 April 1988 and the 20" casing was run and cemented to 17 m depth. The plan was drill 17$_{1/2}$" to 400 m but at 222 m they drilled into fissure and lost all circulation. They never succeeded in plugging this zone. They drilled on using air foam. At 278 m they drilled into clay and after that they had cavings when drilling with air and total loss when using water or mud. A lot of cement was used to try to plug the lost circulation zones but with very limited luck.

They decided at last to run $13_{3/8}$" casing to seal off this zone. The $13_{3/8}$" casing was run to 281 m only to the top of the clay instead to the bottom as we had planned to. This did not solve the problem. The clay is very thick, from 278 to 385 m with basalt larger at 350 to 370 m. It proved to be very difficult to drill this part. They used over 100 tons of cement trying to stabilize it and plug the lost circulation zones. Because of this severe lost circulation along the well, they buy the cement locally because of delays in delivery of cement. At the end, they ran the casing to seal this part off.
The $9_{5/8}$" casing was run to only 388 m. This depth was planned for the $13_{3/8}$" casing. Now it was clear that they would have to install 7" casing down to about 900 m depth to seal off lost circulation zones above the hot reservoir. At that time they decided to cancel the idea of deviated drilling of Asal 6 and to drill $8_{1/2}$" vertical hole to full depth and install the 7" casing later. It was not possible to drill with $4_{1/2}$" drill pipes inside 7" casing, the tool joints are too big. At 962 m they lost all circulation and from that depth they drilled with no return to surface. To ensure enough supply of water for non-stop drilling they put Asal 3 on production and used the brine mixed with seawater as drilling fluid. A core was taken at 990-996 m. Recovered only 1 m of core. Asal 6 was drilled up to 1761 m.
The reason for stopping at this depth was broken drill pipe and during fishing another pipe broke. They fished all the pipes out but it was decided to stops as some more drill pipes could be unsafe for deeper drilling. Drilling of Asal 6 was finished 9 June. There were different opinions on how and to which depth the 7" casing should be installed. After hard discussion they decided to hang 7" Solid casing from 355 m down to 938 m and not to cement it. The 7" casing was installed 12 June and the air lift test started 14 June. Temperature measurement showed that most of the water was coming from 500-600 m flowing down outside the casing and out. Inflow temperature only 120-130°C. Very little water was coming from below. This showed that they would have to cement the 7" casing so they decided to pull it out to install suitable equipment for the cementing operation. One idea was to hang the liner at about 350 m install shotted liner from 950-1000 m to secure the very loos layer at 990-1000 m where they drilled very fast. This part is likely to cave in during production. To install it this way we would have to cement it from the top and down using stage cementer with plug installed below the liner hanger and cement baskets to prevent the cement to flow down through the annulus outside the casing. This was not accepted neither by the World Bank no the Italians. Then they had to cement if the usual way from bottom up, using plug in the well above the loss zone. This does not allow to install shotted liner below the casing and will leave the weak zone unprotected below the casing. The 7" casing was pulled out again. They purchased an open hole packer to plug the well but they could not make it set and after two attempts it was damaged and could not be used. Later they used homemade plug and the well but it sank down to 1160 m below the first inflow zone. They had to fill with gravel up to 926 m and put a cement plug on top of it before installing the 7" casing from 364 m to 919 m. Then they cemented the casing the usual way from bottom to up. To drill out cement and gravel they used the $3_{1/2}$" VAM tubing from the water supply line and drilled with the brine from Asal 3. They used 6" rock bits to drill out the cement and gravel. The well was cleaned down to 1735 m. Then they decided to stop because of the big risque of getting stuck and loose the drill pipes.

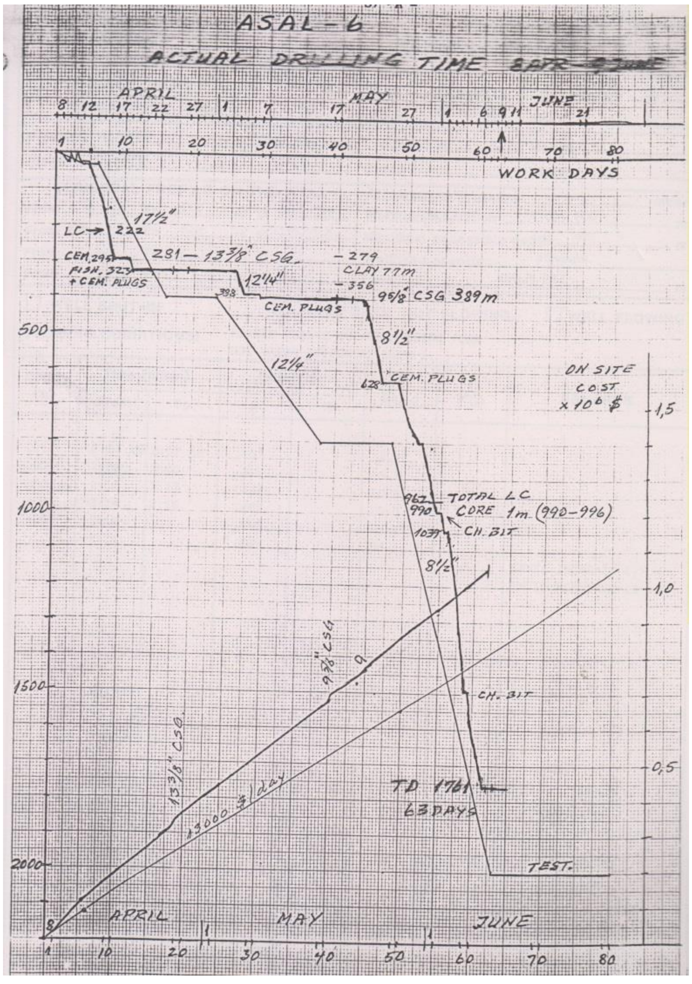

Figure 6: Drilling time (working days/Depths) of well A6.

The 7” casing stuck and collapse occurred in this well. We pointed out the situation of the well and the main existing problems as follows:

1. How to cross the clay zone;
2. Circulation loss in the rhyolite levels;
3. Lack of Portland and geothermal cement.

4. Correlation between Asal 3 and Asal 6 well

Asal 6 well was drilled 300 m about NW of Asal 3. The elevation is the same for the two wells. The two stratigraphyes conform quite closely one to each other so that no major faults should exist between the two wells. The maximum difference, in depth, between correlable units is in the order of 45 m, which can be regarded as a normal variation of thickness. In upper part of the wells down to 625 m about there is no relevant shifting between the units. Bottom of hyaloclastites is at 247 m in Asal 3 and at 230 m in Asal 6. Bottom of the reddish/blackish claystone is 338 m in Asal 3, 356 m in Asal 6. It should be noted that the top of the three tuffs levels are at the very same depths in the two wells: 383 m in A3 for the upper one; 515 m in A3 and 512 m (about) in A6 for the medium one; 602 m in A3 and 603 m in A6 for the lower one. In the lower part of the well, below 625 m about all the unit occur, in A6, at a shallower depth (25 to 45 m about) than in A3. The bottom boundary of the lower clay unit occurs at 898 m in A3 and 872 m in A6. The upward shift of the units, in A6 applies also to the first productive zone, which was encountered at 1075 m in A3 and at 962 m in A6. According to the two logs, the acidic, recrystallized products occurring in A6 between 645 – 742 m, seems to be the lateral equivalent of the trachytic and rhyolitic types encountered in 13 between 678 – 778 m. So it seems that trachytic and rhyolitic products tend to grade one to each other. This is in somewhat good agreement with the microscopic observation made on A6 series, at these depths, were the rock types seems to be an intermediate term between trachytes and rhyolites.

In fact a textural feature of the two rocks seems to occur together in the same sample. Inside the acidic sequence there are some thin layers of doleretic-textured olivine basalt which do not correlate: 633 – 653 m in A3; 676 – 701 m in A6.
They can be either thin flows which pinch out or, possibly, dykes. The two stratigraphycally equivalent olivine-basalt; 778 – 835 m in A3, 742 – 803 m in A6, as well as some olivine-basalt cutting sample below the lower clay unit, in both wells, shows the same cataclastic features and evidence of stress, so that one possible hypothesis is that shearing and stress are diffused in all the area but are “recorded” only on the more competent and brittle olivine-basalt, as long as certain rocks are more likely than others to develop and sustain faulting and fracturing.
The two wells closely conform also for what concern the hydrothermal zoning. In both wells:

- The argillic, low-rank zone, extends down to the top of the pleistocenic clays. 287 m in A3, 279 m in A6;
- The phyllitic zone extends in between the bottom of the pleistocenic clays (338 m in A3, 356 m in A6) and the top of the lower clay unit (853 m in A3, 807 m in A6);
- The high-rank-mineral zone (Propylitic), (Epidote, Prehnite, adularia) starts below of the lower clay unit (898 m in A3, 872 m in A6).

The limits among the various zones are quite sharp, and it is quite clear how the clay levels act as “cap layers” which separate zones of different thermality. This is in good agreement with the temperature with the temperatures of the aquifers at the various depths. These temperatures are 100 – 110°C for the shallow aquifer at 250 – 270 m; 130°C about for the quifer in the rhyolites, 400 – 500 m; 260°C about for the aquifer corresponding to the first deep circulation loss (1075 in A3, and 962 m in A6).
So far, in both wells, the rank of alteration corresponds to the well temperatures at the various depths. Distribution of temperatures, aquifers and hydrothermal zoning suggest, for the sector between A6 and A3 wells and horizontal distribution of thermality. The various aquifers are at different temperatures and got different salinities, close to seawater for the upper zones, much higher for the lower, productive one (analyses on A3 well). They are not consequently in hydraulic connection.

As long as no cores were collected immediately afterwards the total loss zones the problem of the nature of these zones is still open, and no data are available to give sure answers. This zone can be a major fault or fracture fissure, a contact between lava flows or a strongly fractured horizon. The hypothesis of the contact is somewhat supported by the observation made on the last cutting samples, (960 m) immediately before the total loss of 962 m in Asal 6. The olivine-basalt is quite fresh, cataclastic features are quite scarce. A major fault or fracture fissure normally implies a more or less extended zone of disturbance around it. The rock, 2 m from the master joint (or fault) should be expected to be more altered. A core was collected in A6 at 990 – 996 m, it drilled a sedimentary, impervious horizon. The main geological findings emerging from the comparison of A6 and A3 logs is that the first productive zone occurs closely below the bottom of the lower clay unit, 90 m in A6, 174 m in A3 and close, at the same time, to the first occurrence of high rank minerals phases (Epidote, Prehnite, adularia). These hints may be precious to drive other wells drilled in the same area.

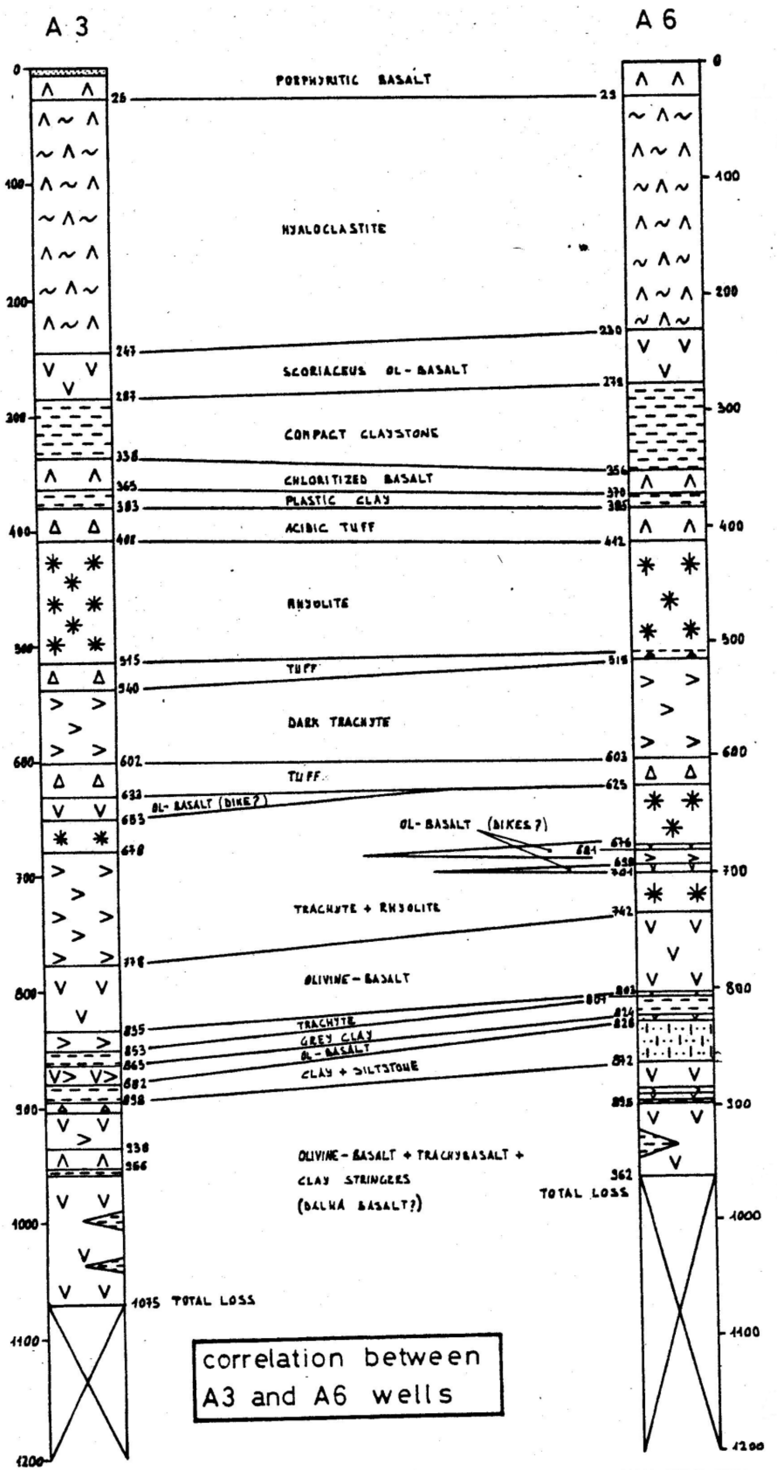

Figure 7: Correlation between A3 and A6 wells.

Conclusions and Recommendations for Further work

To investigate why borehole failed, a comprehensive review of drilling history, cavings, and logs was undertaken. The mechanisms considered for the instability include overpressure, chemical reactions, fractures, weak bedding plane, and inadequate mud weight. After analysing the drilling of these wells by using data, and well logs, the ultimate goal of such investigation was to prepare simulation models on wellbore stability, according the geomechanical properties that would identify the problems encountered during the drilling and foresee solutions for further drillings in my PhD study. We carried out in A3 well, a kick occurs in a 1000 m, which the main problem was the weight of drilling fluid had been less than formation pore pressure, that has resulted the abandon of the drill string in the well. Similarly, fluid losses are observed in well A6, and the situation turns into a total lost circulation which millions of cubic meter of cement were used in order to cement each casing. The open part of the hole A6 (uncased) collapsed after fluid losses. As long as no cores were collected immediately afterwards the total loss zones the problem of the nature of these zones is still open, and no data are available to give sure answers. This zone can be a major fault or fracture fissure, a contact between lava flows or a strongly fractured horizon.

An integrated wellbore-stability analysis study have to be implemented to effectively plan the future drilling operations in the Asal Fialé field, to maximize the drilling margin for the future wells drilled, and to optimize the future field development.
The conclusions and recommendations of this analysis are as follows:
1. A special wellbore-stability problem-diagnostic scheme was first used to identify problematic horizons. The possible causes of wellbore stability issues were narrowed down. It was found that the well trajectory, drilling fluid density, and types of water-based mud have a dominant impact on the occurrence of the wellbore-stability problems.
2. The analysis identified three instability mechanisms — wellbore wall collapse, differential sticking, and mud invasion/pore pressure penetration.
3. Even without geomechanical core measurements, it will be feasible to obtain reliable required input data utilizing available well log, drilling, geological data, as well as the tectonic history of the interest area to solve wellbore-stability issues. It should be emphasized that availability of the key wells with critical well-log data is of utmost importance to conduct wellbore-stability studies without available core measurement data.
4. Outcomes of this analysis would be helpful in reducing the cost and non-productive time during drilling operations of the future Asal Fialé wells.

Despite the severity of the problems, we carried out that one-half the lost circulation problems of Asal 6 well can be avoided and many are driller induced. Proper planning and rig operation are important. Some of the techniques involved in proper planning and operation are listed below:

i. Insofar as possible, use nearby well logs and geologic information and carefully plan the hole and the casing program.
ii. Treat the well bore gently. Raise and lower drill strings and casing slowly. Do not spud or swab. Start fluid pumps at slow rates and increase slowly. Maintain fluid velocity in the annulus at the lowest rate to assure cuttings removal. Do not drill so fast as to overload the annulus with cuttings.
iii. Make frequent measurements of mud properties to maintain minimum weight, viscosity, and filtration.

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REFERENCES

Aadnoy, B. S., and and R. Looyeh, 2011, Petroleum rock mechanics: Drilling operations and well design. 1st ed. Oxford: Elsevier Inc.

Aquater, 1989: *Djibouti geothermal exploration project, Republic of Djibouti, final report*. Aquater, Italy, report, 159 pp.

Aquater, 1989: *Master logs 1/10000, Asal 3 well report*. Aquater, Italy, logs report.

Aquater, 1989: *Master logs 1/10000, Asal 6 well report*. Aquater, Italy, logs report.

Barberi, F., G. Ferrara, R. Santacroce, J. Varet,1975. Structural evolution of the Afar triple junction, In: Afar Depression of Ethiopia, Pilger A., Rosler A. eds., Stuttgart, 1, 39-54.

Beyene, A., Abdelsalam M.G., 2005. Tectonics of the Afar depression: a review and synthesis, Journal of African Earth Sciences, 41, 41-59.

Daher, E, 2005: Analayis of geothermal well test data from the Asal rift area, Republic of Djibouti, United Nation University Geothermal Training Program, UNU-GTP, Yearbook 2005.