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ZONAL ISOLATION SURVEILLANCE – A CASE STUDY A THROUGH-TUBING MEASUREMENT AND ANALYSIS METHOD WHICH CAN IDENTIFY AND DIAGNOSE FLUID MOVEMENT IN ANNULI CAUSED BY LOSS OF ANNULAR INTEGRITY

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ABSTRACT

Loss of annular integrity in a well can create loss of zonal isolation, which can significantly impair the productive capability and efficiency of the well. Effective remedial action must be based on a clear understanding of the underlying causes. It has previously been difficult or near-impossible to locate and explain the undesired fluid movements symptomatic of loss of annular integrity. Without this information, repair or control is at best a matter of informed guesswork or trial-and-error.

An oil well in offshore Java was logged with the conventional production logging suite (PLT) in order to identify the water source affecting 100% of water cut production from a reservoir believed to contain oil. Nearby well on same structure proven to produce 1800 bopd, which cutting log, petrophysical data, pressure test data during drilling also suggest high confidence of oil in the reservoir. However the PLT survey failed to give an answer. The PLT data suggest that 100% water is coming from perforated interval, which is contradictive to the believed that the reservoir should produce oil.

Acoustic Spectral Noise Analyzer Tool combined with fast response temperature were run in order to provide the answer to the dilemma of where water is coming from. In conclusion, the results were satisfactory for the operator as it shows water is coming from unperforated interval flowing to wellbore thru channelling behind casing to perforated zone, preventing less mobility oil to flow out from reservoir to wellbore.

The development of an ultra-sensitive Acoustic Spectral Noise Analyzer Tool combined with temperature analysis techniques can significantly improve zonal isolation surveillance.

Keywords: annular integrity, spectral noise, temperature.

INTRODUCTION

Achieving zonal isolation by cementing annulus space between casing and well bore wall is an important job in many oil wells. Cementing of the annulus may take place during drilling stage of the well bore or completion of the well. While cementing the annular space behind several casings strings or whole casings in the well may be cemented properly in place to get a hydraulic seal.

The main purpose of cement over the production intervals is to provide isolation in the neighbouring zones. Hydraulic isolation allows the well operator to selectively complete certain zones and assures that fluid will not move into or from the neighbouring zones through the borehole behind casing. Failure of isolation can cause myriad of problems such as (Smolen, JJ, 1996):

- Water production
- Depletion of gas drive mechanism
- Loss of production to the neighbouring zones
- Contamination of fresh water reservoir

Despite the efforts to get good zonal isolation, migration of formation fluid in the annulus takes

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place. Migration implies here the entry of formation fluid from the formations pores into annulus behind casing due to a pressure imbalance at the fluid-bearing formation face, followed by upwards migration of the fluid in the annulus. The fluid flows to a lower pressure zone or possibly up to surface. Water/gas leakage in the production casing annulus has been recognized as a major completion problem in the oil well. A successful cement job results in complete zonal isolation on a permanent basis.

Conventional CBL tool is an "integrating" tool, it has monopole transducer which will read the average quality of cement around the wellbore. It will give same response to following different conditions: 100% cemented pipe with low compressive strength cement OR Partially cemented pipe with high compressive strength cement (e.g. channels) OR – Micro-annulus. While newer segmented ultrasound Cement Evaluation only be able to provide cement quality information right behind the casing. It has difficulty detecting formation bond, may give false readings in high-viscosity mud and cannot distinguish between Micro-Annulus and absent cement. Figure 2 is typical cementing problem may happen. Conventional CBL will only give the average presence of the cement, while segmented ultrasound cement evaluation will not be able to detect cement flaw type III, IV and some of type V which not directly in contact with casing.

Wellbore temperature profile data has been used to characterize down-hole fluid flow since at least 1918 (Van Orstrand), enhanced by additional simple acoustic energy levels to be correlated to fluid movement on 1955 (Enright). On simple case where the flow rate is quite high and temperature anomalies can be seen obviously both data acquisition and the results may be treated as correspondingly simple. Most of the occasions show that this is not the case.

This paper will explain about surveillance using spectral passive noise tool and integrates it with logging data, surface data, well completion and well history information to provide clear identification of undesirable fluid movements in well annuli. The qualitative and quantitative analysis provides effective support to justify the occurrence of these movement for decision process in the remediation of well integrity problems.

Description of the Technology Deployed

Acoustic Leak Flow Analyzer – a spectral passive noise tool.

Acoustic energy log commonly used since 1955 (well known as "noise log"), typically focus to see within the audible part of the acoustic spectrum, typically between 1 kHz and 20 kHz on several band pass filter only (McKinley et al. 1972), while the technique in this paper record audible and ultrasound frequency spectrum between 8 Hz and 60 KHz with very high frequency resolution, up to 512 channels.

The tool uses very sensitive acoustic sensors to be able to measure sound produced downhole by either gas or liquid flow. Measurements are taken over a wide frequency range, enabling a very effective way of leak detection as well as detection of various kinds of gas, water, or oil flow, including flow behind the pipe.

- Fluid movement thru media will produce noise. The noise comes from both fluid itself and vibrating elements streamlined by fluid flows.

- The fluid noise is result of internal friction and normally audible in high speed turbulent flows.

- In wellbore, fluid flows generate noise through the vibration of various features of the geological environment and wellbore components.

- Noise frequency spectrum depends on the type of channel through which fluid/gas moves.

- Noise intensity or volume increases with linear flow rate, as function of fluid type and pressure gradient.

Having very high frequency spectrum resolution enabling us to differentiate the flow type, whether laminar flow inside wellbore, channeling flow behind casing, leaking thru jewelries and formation flow.

Area of deployment

A high water cut problematic well were selected for field deployment. The objective of the surveillance were:

- To identify behind casing channeling, if there is.
- To identify the actual production zones.
- To identify the source of high water cut

The well is located in Java Offshore, was drilled on early 1980's (Figure 2), well was workovered in 2016 to produce oil from a reservoir which is proven to produce 1800 bopd with very low water cut on same structure of nearby well. The zone was perforated, the well can flow on gas lift arrangement with fluid rate up to 1200 bfpd with flowing tubing Pressure 140 psi and A-annulus Gas lift injection Pressure 465 psi. Unfortunately fluid sample showed the well producing unexpected high water cut of more than 95%. The main facilitating conditions for water production could be the unknown cement hydraulic isolation quality.

The driver of doing the wellbore flow surveillance are to get clear picture of wellbore flow problem for near future workover remediation plan. 1.338" OD Acoustic Spectral Based Annular Leak Flow Analyzer tool (ALFA), High Resolution Temperature Tool (HRTT) and Casing Collar Locator (CCL) was ran to perform well flow diagnostic. A survey was undertaken from 3043 ft to surface inside production casing/tubing and the result are shown in Figure 4, 5 and 6.

The ALFA are include temperature and CCL. The temperature sensors are critical to the effective interpretation of an ALFA survey, so the first run into the well was a baseline log recorded while logging down. This pass was recorded from surface to maximum logging depth.

Because the ALFA survey records a dynamic and unknown environment, almost the entire period in the well are recorded (up, down and stationary). Survey design is highly dependent on the specific integrity investigation (depth, leak rate, well structure). The following factors was considered:

- Annulus pressure. Consider varying annulus pressure as a means of perturbing any observed flow, or the converse.

- The effect of tool movement –tool string configuration and/or logging speed adjusted to minimize 'tool-stick', which will have a detrimental effect on log data, particularly temperature and to a lesser extent, ALFA.

- Stationary measurements are a reference point for any ALFA dynamic log.

- ALFA survey was planned such that the well was logged under at least two different annular pressure regimes (i.e. the annuli where flow is expected/suspected) should be 'perturbed' by varying the pressure by intervention at surface. In this case, the survey was undertaken in 4 different condition, which are:
  - Flowing 100% choke size on Gas Lift Operation
  - Flowing 60% choke size on Gas Lift Operation
  - Shut in
  - Water injection to perforated zone (Since Gas Lift Mandrel flow activity creating dominant frequency spectrum noise, injection pass is to evaluate flow path behind casing in area above the Gas Lift Mandrel).

Result and Key outcomes

The data acquired in the well was of good quality. All the ALFA was run with a HRTT, which provided a good benchmark to compare and qualify the flow problem in the well. CCL was run to give precise/accurate depth correlation of the responses.

We are using a deep and thorough analysis which combines and cross-references several important data sources and analysis techniques, which the processes are:

- Mapping of the audible and ultrasound noise energy map of the well bore which associated with fluid movement activity (through-tubing Spectral Passive Noise ALFA log)

- A thermal profile of the well (through-tubing High Resolution Temperature Tool HRTT log).

- Manipulation of annuli or tubing at surface before or during logging, by the production or injection of fluids in a planned program sequence.

- Measurement of hydrostatic pressure and fluid density in the well bore.

- Analysis and interpretation of other data as appropriate, including but not limited to cement bond logs, pore-pressure data, lithology, drilling and cementing records, reservoir flow history and annular wellhead pressure data

The analysis is open, transparent and logical, encouraging a teamwork response to problem-solving. The method can often identify and differentiate flow in multiple annuli.

Effectiveness of evaluation

By gathering the result of Spectrum frequency Map and temperature data, flow behavior of the well can be concluded:

- During 100% choke and 60% choke flow:
  - Perforated reservoir is not actively

producing fluid to wellbore (Figure 6). There is no high frequency noise activity on that interval.

- The most active contributing reservoir is water zone right below perforated zone, and several reservoir above it (Figure 5 and Figure 6). High frequency noise is detected, associated with a fluid flow thru very tight pores, which is reservoir pores.

- There is indication of behind casing channeling flow from far below perforated zone to perforated zone, high possibility contributing the water production as well (Figure 6). The source of fluid flow is not recorded due to have been covered by a cement plug.

- Temperature data showing no heating effect at the top of perforation interval, associated with fluid inflow from above zones through the channeling

- During Shut in condition:
  - There is no frequency spectrum noise detected other than on surface which associated to surface activity of sea wave and flow activity nearby well around their wellhead.

- During Water injection to perforated zone:
  - Medium frequency spectrum is detected from perforated zone up to 250 ft. High possibility associated with a channeling flow activity.

- Detail behavior of the well is presented in Table 1 and Table 2.

The essence of the final deliverable is a map of fluid flows in and between formations, annuli of the well completion, and surface.

The results have enabled the prioritization of the workover program for these wells. With a high cost of each workover, by knowing the exact problem of the well, operator has ability to plan effective and efficient remediation action.

CONCLUSION

Annular integrity problems restrict the operational viability of a production well, and annular zonal isolation surveillance can be successfully applied to provide clear identification of undesirable fluid movements in well annuli. The qualitative and quantitative analysis provides effective support to justify the occurrence of these movement for decision process in defining effective and efficient remediation solutions.

Production Logging tools are a great tool for inside wellbore flow profiling and passive spectral noise log completing the surveillance by providing behind casing flow behavior.

With a diameter of 1.338" (34 mm), the tool can be run through most of the commonly used tubing sizes and used to inspect well flow profile through the tubing. This allows for greatly reduced operating costs and time to evaluate the well flow behavior without the need to pull-out the tubing string to evaluate the behind casing flow behavior.

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TABLE 1

WELL FLOW SURVEILANCE CONCLUSIONS

Depth/ Interval	Depth of Leak	Accessories	Ref. log
832 ft	Active during 100% choke production	GLM#1	Fig 1
1491.8 ft	Active during both chokes production	GLM#2	Fig 1
2382.5 ft	High Activity during 100% choke and minor activity at 60% choke production	GLM#4	Fig 1
2435 ft	Reservoir activity	Formation	Fig 2 & 3
2435 – 2954 ft	Channeling	Behind Casing	Fig 2 & 3
2949 – 2965 ft	Minor activity	Top of perforation interval	Fig 2 & 3
2976 – 3020 ft	Major activity	Reservoir	Fig 2 & 3

TABLE 2

LOG INTERPRETATION

Accessories/ Depth	Leak	Frequancy range detected	Associated survey condition	Remarks	Ref. log
GLM#1 832 ft	Active	0 – 60 kHz	100% choke condition	Temperature anomaly was observed at this depth	Fig 1
GLM#2 1491.8 ft	Active	0 – 60 kHz	100% and 60% choke conditions	Sharp temperature anomaly was detected	Fig 1
GLM#4 2382.5 ft	Active	Up to 60 kHz	High Activity during 100% choke and minor activity at 60% choke production	Sharp temperature anomaly was detected during 100% choke condition	Fig 1
Formation 2435 ft	Reservoir activity	0-20 kHz	Injection condition	Post cooling anomaly during shut-in condition	Fig 2 & 3
Behind Casing 2435 – 2954 ft	Channeling	0-15 kHz	Well production and Injection conditions		Fig 2 & 3
Behind Casing 250 – 2954 ft	Channeling	0-15 kHz	Injection conditions	Medium frequency noise is associated with channeling flow	Fig 2 & 3
Top of perforation Interval 2949 – 2965 ft	Minor activity	0-30 kHz	All well conditions	Temperature data showing no heating effect at the top of perforation interval, associated with fluid inflow from above zones through the channeling	Fig 2 & 3
Reservoir 2976 – 3020 ft	Major activity	0-60 kHz	All active conditions	Huge temperature heating effect	Fig 2 & 3

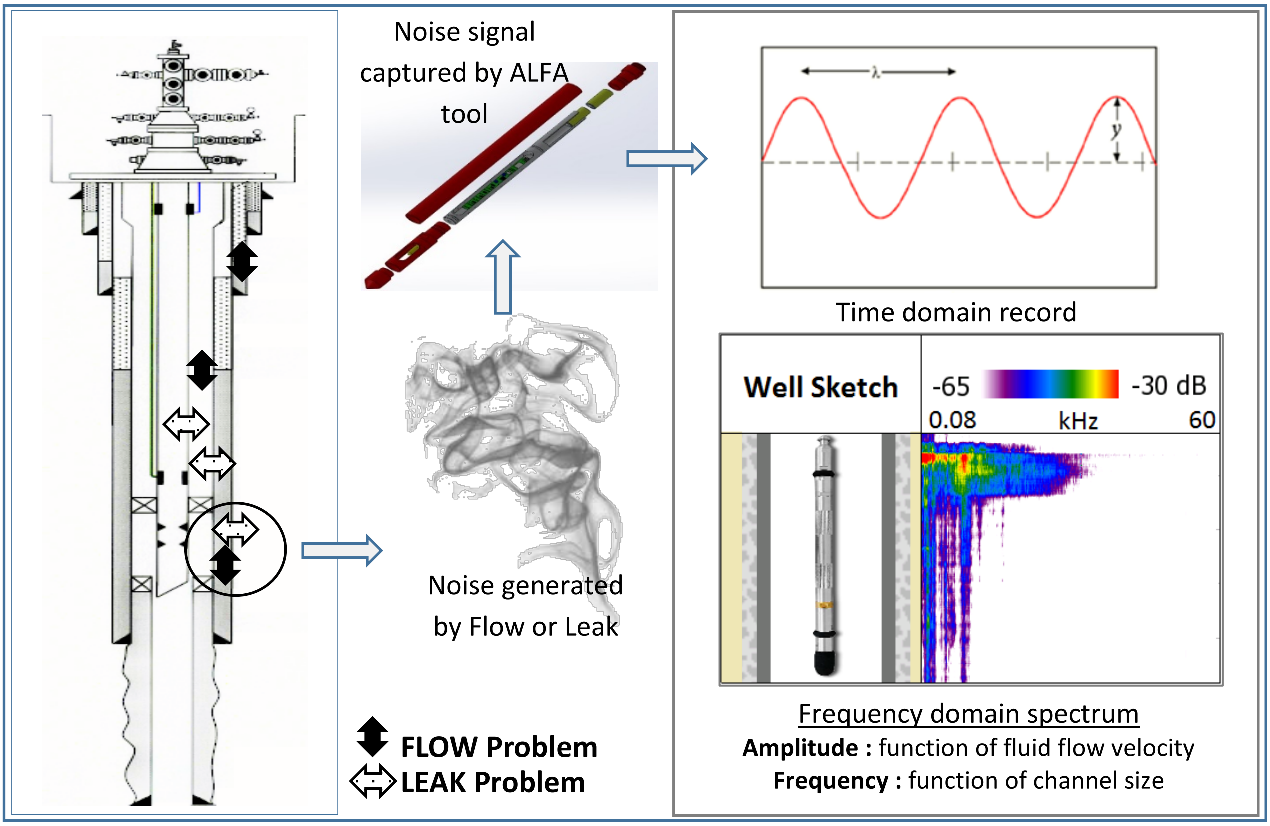

Figure 1 - Principle of Spectral Passive Noise Tool

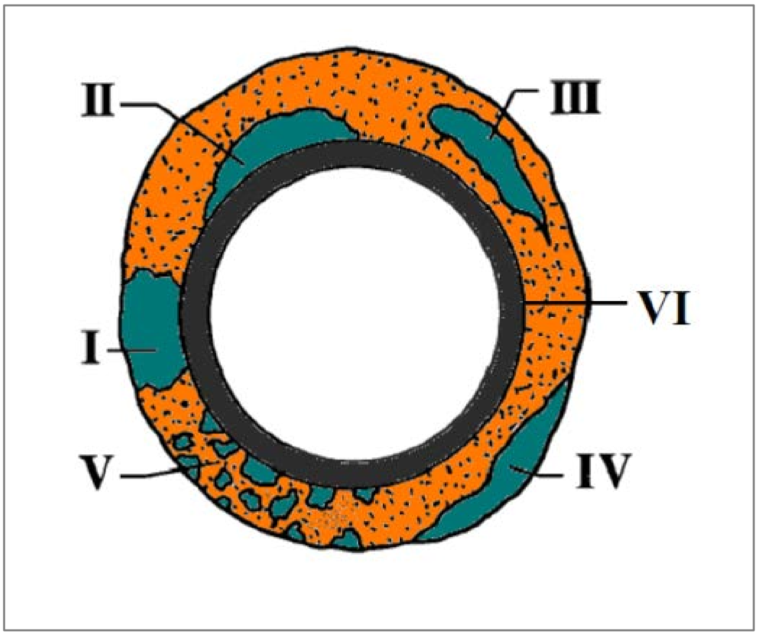

Figure 2 - Types of cement channels (Smolen, JJ, 1996)

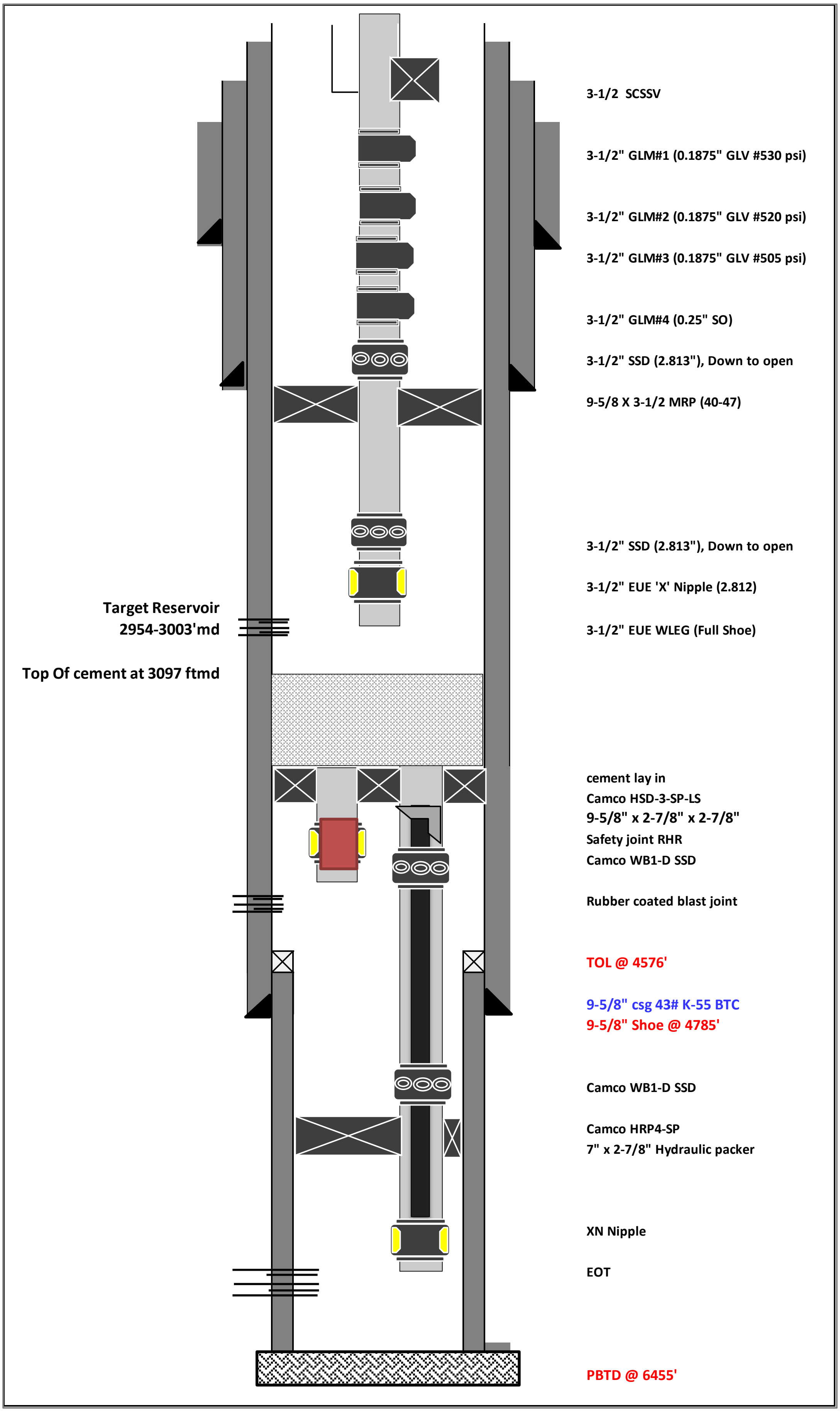

Figure 3 - Schematic of Well

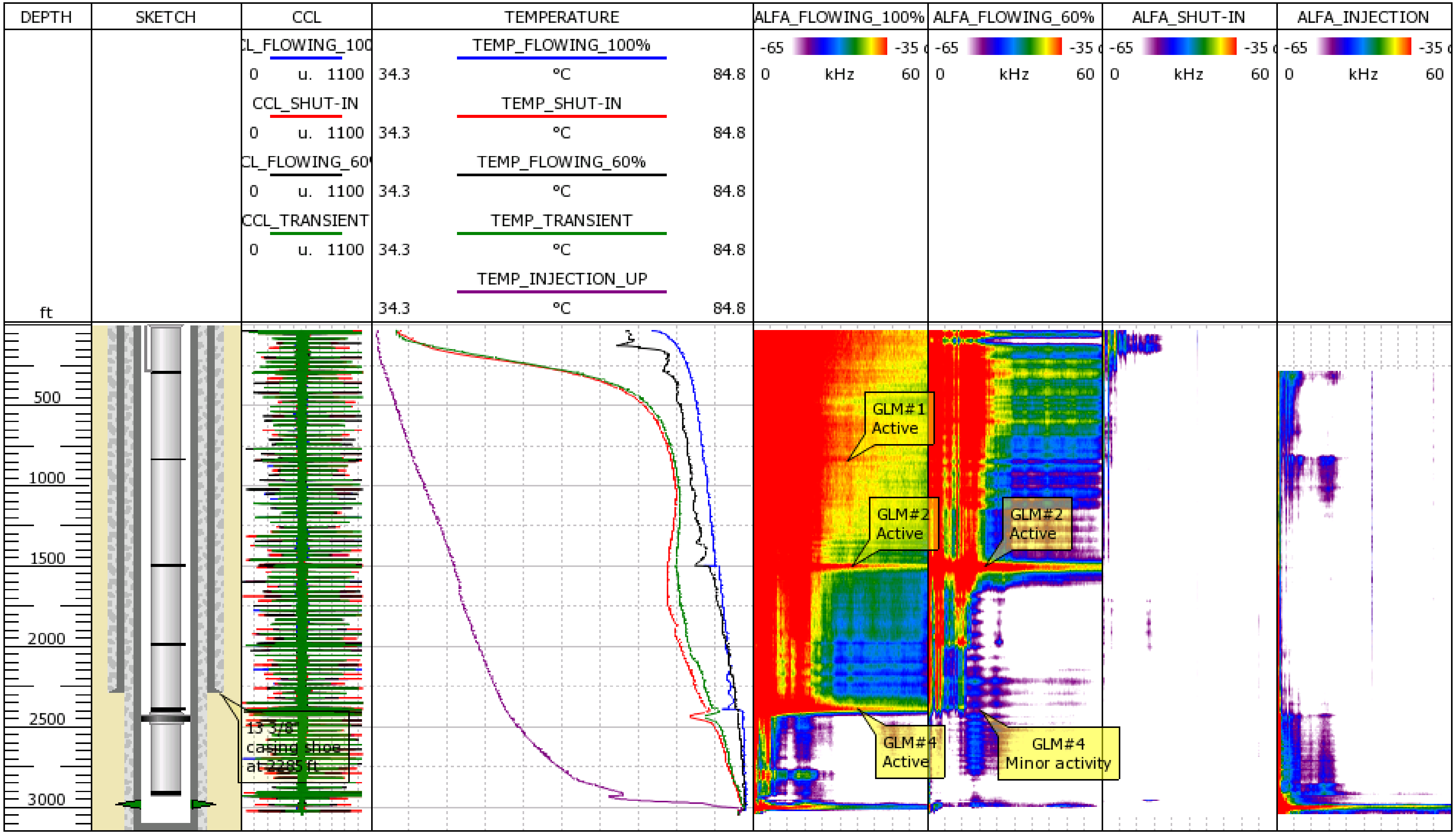

Figure 4 - ALFA-TEMP data, whole section of the well.

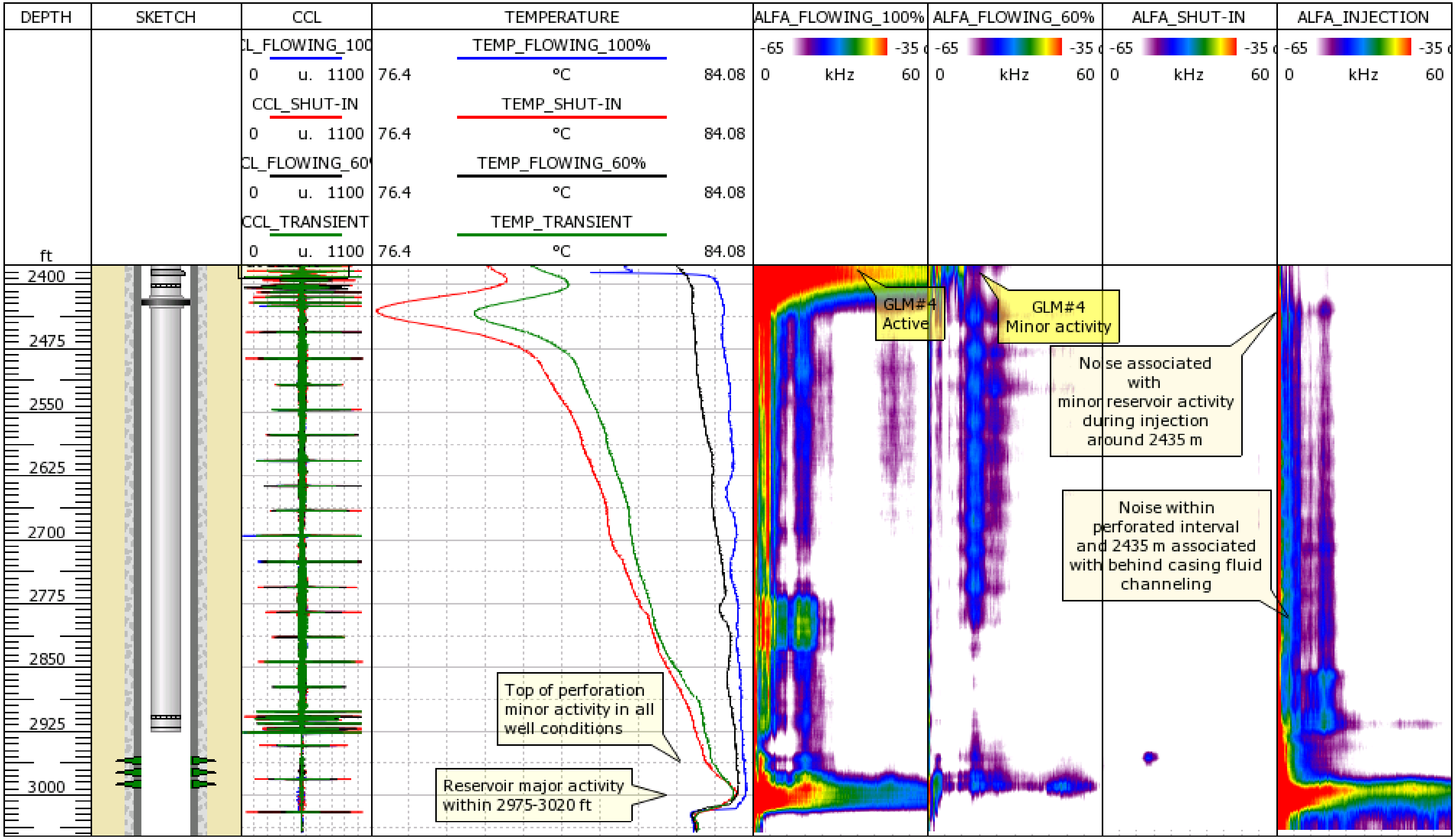

Figure 5 - ALFA-TEMP data Bottom section of the well.

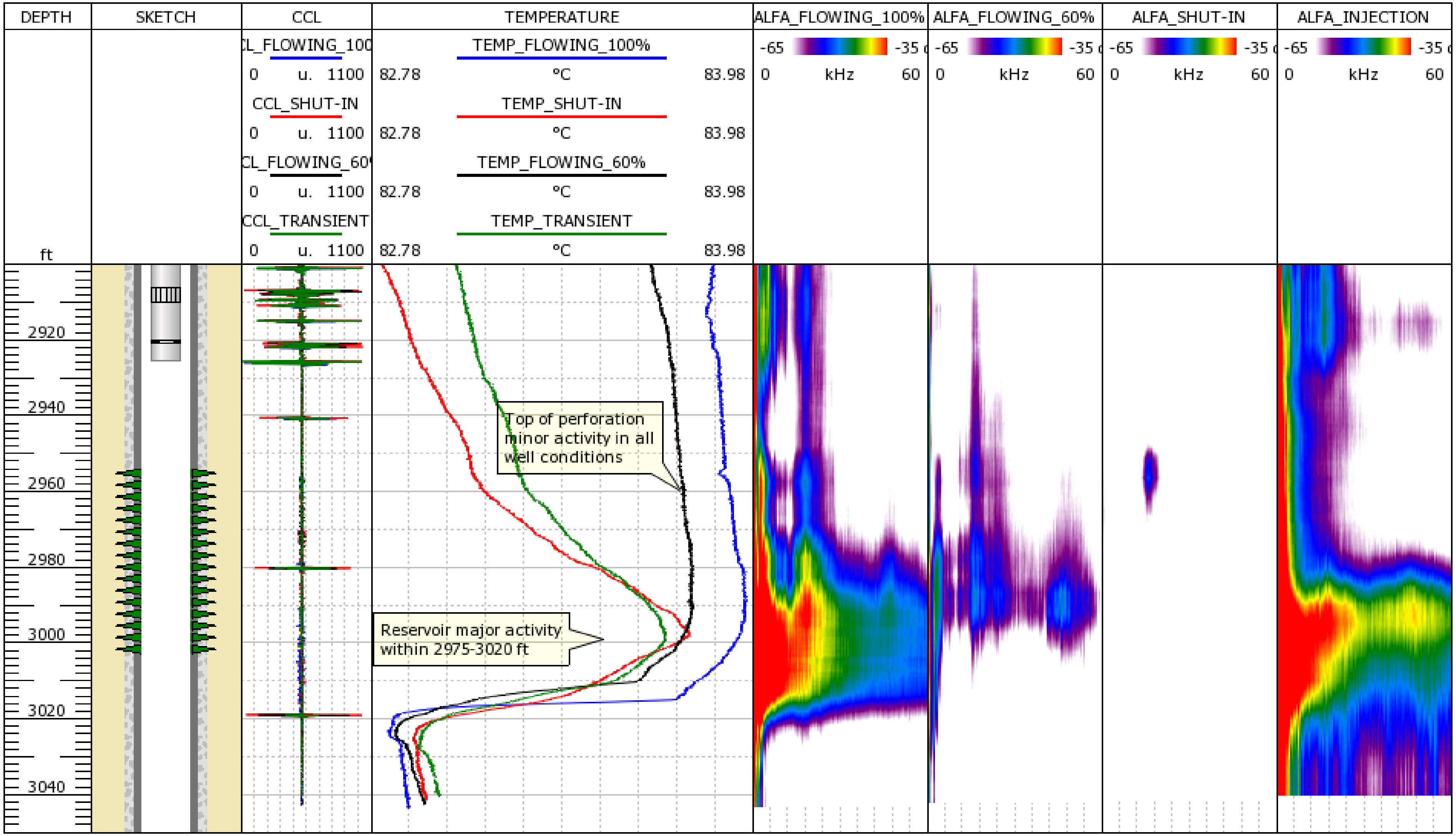

Figure 6 - ALFA-TEMP data around Perforation Zone.