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Restore Flowing Annulus with PWC

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Karina Sari, Yoga Nuryanto, Alif Aulia Risatrio, Arif Setiaji Wibowo, Gitani Tsalitsah Dahnil, Herfran Rhama Priwanza, Arief Dirgantoro, Tomi Sugiarto
Pertamina Hulu Mahakam

Abstract

Well TN-XX was drilled with swamp barge rig Hibiscus. 24" CP has been driven to 124 m. Well was spudded on October 6th, 2003. 17-1/2" hole was drilled to 1644 mMD/ 1238 mTVD with 1.16 SG mud. 13-3/8" casing was then run to 1639 m, cemented and tested to 2500 psi. No losses and back flow was reported during the cementing operation. Some operations performed while Waiting-On-Cement were rig down the cement head, lay down the diverter and installing gate valves on the wellhead. Gas influx was flowing from the 13-3/8" x 24" annulus. ERT was activated, followed by mustering for all non essential personnel. The Rig was demobilized on October 12th.

As prevention, the production flow line was depressurized and well intervention barge was mobilized to secure all adjacent wells. The Well Intervention barge was then performing CBL, temperature log, USIT, noise and RST logs on TN-XX. The logging interpretation identified that possible flowing zones were at 1250, 1150, 675 and 350 m. Perforations and cement plugs were performed over these intervals to regain the integrity of the annulus. Additional shallow interval was chosen to establish circulation to the surface thru annulus at 279 – 291 m based on USIT log. 13.5 bbls of 1.2 SG mud was pumped into the perforations and the well flow suddenly stopped. Hesitation squeeze was performed at 183 – 380 m interval. The Well was secured.

The drilling was continued on December 14th 2003 by the same rig on and completed on January 30th 2004. The well was then put on production till fully shut-in condition later in May 2015. No sustain casing pressure was reported on Annulus C (annulus between 24" CP to 13-3/8" surface casing). The perforation and cement plug were successfully restoring the integrity of the well.

Poor annular cement led to sustain casing pressure. A section milling will be required to regain the integrity on the annulus. The perforation, wash and cement (PWC) technology then was introduced later by Hydrawell in North Sea in 2011 to replace section milling activity. The concept was to punch casing to access to poor cement section and established circulation thru annulus prior to perform cementation to restore the integrity of the annulus – similar to what we've done back in 2003. The technology has been proven with more than 95% success rate over 213 plugs. The solution will be adopted for securing wells with leak on open type CP and/or sustain casing pressure on outermost annulus.

Keywords: Sustain Casing Pressure, PWC, Well Integrity, Well Abandonment

1. Introduction

Pertamina Hulu Mahakam has more than 2000+ wells spread over swamp and offshore environment. The wells are developed with various well architecture and completion type – due to continuous development since 1967 until now. Mahakam field is prone to shallow gas environment (except on Tambora). During the time of writing, 368 wells of 2191 wells have been reported with sustain casing pressure and/or leaking on the open type CP (bubbling). 236 wells out of 368 reported wells are having sustain casing pressure in the outermost annulus and/or bubbling on the open type CP. Sustain casing pressure on outermost annulus and bubbling on the open type CP is considered as leak – risking the well integrity. In some cases, the pressure might reached the threshold value which may risk the fracture of previous casing shoe (fracture gradient of the CP will be so low) or may collapse the CP itself. Regular bleed-off might be required and this practice might lead to introduce bigger leak path. Several wells have been flagged with red well integrity status, and therefore no hot work permit will be allowed in the platform.

Several attempts have been taking into consideration to reduce the risk of sustain casing pressure on the outermost annulus: usage of gas tight slurry, reduction of the CP size, good centralization and cementing up to surface. The development of recent gas tight slurry has been proven to reduce the risk of sustains casing pressure. Reductions of the CP size and good centralization have increased the confidence – this will help create the turbulence flow and removal of the mud. Cementing the surface casing to surface has always considered as good practice of cementing in the shallow gas prone areas, however then no more intervention can be done to well with sustain casing pressure (i.e. injecting the brine in the annulus).

Since it was impossible to restore the annulus by injecting heavy brine and regular bleed off may lead to bigger leak path, another approach was tested including resin injection. Several attempts have been tried in the wells to mitigate the sustain casing pressure in outermost annulus with different procedures, however none come as success result.

However in 2003, during shallow gas incident, a flowing annulus can be restored with perforation, circulation between annulus and cementing. This paper will provide brief chronology, result and comparison with more recent technology including noise log and Hydrawell PWC.

2. Basic Theory

There will be two separate theories to be discussed here. The flowing annulus – in this case refer to well with sustain casing pressure. And second, the PWC is an effort to restore the annulus and then developed to replace section milling in permanent abandoned wells.

Sustain casing pressure, later mentioned as SCP, is an excessive casing pressure in wells that persistently rebuilds after bleed down. ISO 16530 stated that SCP is a particular concern as it can be indicative of a failure of one or more barrier elements which enables communication between a pressure source within the well and an annulus. This, by definition, means that there is a loss of integrity in the well that can ultimately lead to an uncontrolled release of fluids, which in turn can lead to unacceptable safety and environmental consequences.

SCP on the outermost annulus, or bubbling on the open type CP (leak was detected, however was unable to identify the fluid and or the pressure since it was disposed directly to atmospheric condition) were migration of shallow gas to the annulus and/or communication between the outermost annulus with inner annulus due to leak on the casing and/or fracture from the shoe. Refer to Fig. 1, leak path 6, 7 and 11.

The SCP on the outermost annulus that has been discussed in this paper is limited to SCP above 7 bar (~100 psi). This was decided due to most pressure gauges installed within 500 psi range.

Wells identified with sustain casing pressure must be operated and followed-up carefully, refer to MHK-ENTY-SOP-FOP-GEN-0011. It was advised that the annulus should be maintained full of fluid when possible, however this will be difficult for the outermost casing since it is cemented up to surface. For wells with sustain casing pressure, a monthly leak test is recommended to check the evolution of the leak. It should be kept in mind that systematic and excessive annulus pressure bleed-off is not advisable and might increases the leak. Consequently, it is not recommended to exceed a frequency of more than one bleed-off per month and/or one leak test per month. It is to be understand that if sustain casing pressure is confirmed, one barrier is considered to be lost and remedial actions to be taken.

Plug and Abandonment (P&A) is an integral part of a well's lifecycle. When a well has been in unacceptable condition due to degradation of system, or it has become unproductive or uneconomical to produce, it must be permanently sealed in order to remove its associated threat to environment.

MHK-COMP-RUL-EP-FP 424 defines that a permanent well envelope shall achieve a permanent obstruction to any flow of effluent from and into any IZI (Identified Zone to be individually Isolated) by ensuring a full lateral coverage of the well cross section (from the wellbore to the center) and vertical isolation (along the wellbore axis) over a 50 mMD minimum length. Refer to Fig. 2. IZI itself is defined as a formation or a series of formations naturally isolated from the environment and from other IZI before the well was drilled and containing any kind of fluid (water or hydrocarbon). It is required that all IZI to be isolated from each other by two validated and independent permanent well envelopes. The abandonment of a well aims to isolate all of the IZI on the very long term. The only material considered acceptable by D&W entity to fulfill this requirement is plain cement.

A permanent well envelope shall composed by one or several of the following permanent barriers:

a. Competent wellbore formation strong enough to withstand the load conditions generated by the IZI;
b. Validated annular cement of 50 mMD minimum length;
c. Validated inside cement plug of 50 mMD minimum length.

Refer to Fig. 3 for examples of barriers of two permanent well envelopes.

Similar to previous reference, NORSOK D-010 r.04 required for an external well barrier envelope of 50 m with formation integrity at the base of the interval. If the casing cement is verified by logging, a minimum of 30 m interval with acceptable bonding is required to act as a permanent external WBE. An internal WBE (e.g. cement plug) shall be position over minimum 50 m interval. Refer to Fig. 4.

Poor cementing has always been accused of being the cause of sustain casing pressure on the outermost annulus. It will be difficult to achieve turbulence on a very large size annulus (most common architecture in Tunu field is Light Architecture which comprises of 24" CP, 9-5/8" production casing and 3-1/2" tubing). Both MHK-COMP-RUL-EP-FP-424 and NORSOK D-010 requires validated annular cement to establish permanent well barrier envelope. Section milling might required to establish such envelope. Refer to Fig. 5.

3. Methodology

Perf-Wash-Cement or known as PWC is develop as an alternative to section milling in situations where the permanent wellbore barrier needs to be placed across a section of un-cemented casing. Section milling is time consuming and results in exposing the BOP to swarf.

Later, PWC are introduced not only as a solution to replace section milling for plug and abandonment but as a intervention for annulus pressure remediation and stabilizing casing exit to sidetrack the well. The concepts are to perforate the troubled area identified with cement log, jet and wash the interval and create communication between annulus prior to spot and squeeze cement over the interval.

From bottom up, the PWC system consists of 50 m of drill pipe conveyed perforating guns which drop on firing. Above the guns is an opposed cup wash tool which is left in hole as a base for the cement job. On top of the wash tool is a cement stinger. Instead of milling the casing, PWC provide access to the annulus without creating any metal debris (known as swarf).

On earlier SPE paper in 2011, SPE-148640-MS, the PWC system and procedures creates an abandonment plug that can be verified in the annulus, unlike plugs set with the traditional section milling method. After placing cement, it is possible to drill out the plug and log the cement bond in the annulus to provide competency verification. The paper itself concludes that PWC has been successfully replace the section milling since it can place an abandonment plug as an effective bridge which is formed across the wellbore section both vertically and horizontally. The success of PWC is determined by:

1. Annulus evaluation prior to running a PWC system by the availability of the annulus data from cement bond log to decide placement of cement plug.
2. Creating the annulus communication – effective washing behind casing will need to be engineered by designing the perforation diameter, number of exposed perforations between opposing wash cups and confined backpressure adjusted by pumping rate.

During the first phase of the Valhall DP P&A campaign, Hydrawell, working with Aker BP and Statoil, performed PWC over several wells to validate the system effectiveness. Refer to SPE-185938-MS, Valhall is an overpressured, high porosity Upper Cretaceous fractured chalk field located on the Norwegian continental shef that has already produced over I billion barrels of oil since 1982. The gas cloud known as DPZ #7 typically sits in the 9-5/8" casing x 12-1/4" hole section of the well and experience has shown that the cement very rarely covers above this DPZ during 9-5/8" primary cementing. The PWC is chosen to create a minimum 50 m single barrier over the DPZ, the annulus cement needs to be verified by log and the internal part of the cement plug need to be pressure tested. 31 wells then carefully selected (all of them need to be permanently abandoned and most of them are lacking annular barriers behind the 9-5/8" casing across DPZ #7). The result is on Fig. 6 and 7.

4. Case Study

Unfortunately no PWC practice has been done in any of PHM wells. However similar practice has been taken into account in real flowing wells in early 2003. The basic idea of perforating the casing to gain access to the problematic annulus, create circulation – communication between annulus and create a cement plug to cover the both annulus was done in TN-XX. To make it convincing, the well was even flow from the outermost annulus due to shallow gas incident.

TN-XX was a gas producer well, drilled in Tunu field, shallow gas prone area - adjacent to the existing TN-XX1 well. Refer to Fig. 8 for the platform layout. The well had S-shape trajectory and will be completed with tubingless completion. The architecture will be 24" CP (has already driven to 127 m during platform installation), 13-3/8" surface casing, tapered 9-5/8" to 7" production casing and then 4-1/2" tubing.

Rig Hibiscus was arrived on the platform, the well was spud on October 7th, 2003. The 17-1/2" surface section was drilled to TD at 1644 mMD/ 1238 mTVD. Cement job was performed: no losses and no gain was reported. By 16:00 PM October 11th, 2003 observed gas influx coming out from 24" x 13-3/8" annulus. Complete chronology is available on Table 1. Refer to Fig. 9 for the wellhead schematic during event.

The Well Control Plan was created, including strategy to determine the source of the gas and water flow. This included running a number of logs including CBL, USIT, RST, noise and temperature logs inside the 13-3/8" casing. A perforate and circulate kill was believed to be possible once the source of the flow was known. Cement would then be placed to permanently prevent any flow from resuming.

Sequence can be seen on Fig. 10:

1. Cold cut the platform structural beams to gain unrestricted access to flow,
2. Install a diverter line over 3" valve to direct the flow away from the structure,
3. Install a BOP stack on top of the compact wellhead,
4. R/U high pressure pump spread and kill the well,
5. Perforate the 13-3/8" casing at selected intervals,
6. Perform killing operation,
7. Secure the inside of the 13-3/8" casing and the 24" x 13-3/8" annulus so the well can be safely entered with a drilling rig.

The result of the logging were not conclusive about the source of the flow, but the information gained led to the identification of four zones that were initially picked to be perforated in an attempt to stop the blowout. These were chosen as possible flow zones and it was agreed that the prudent course of action would be to attempt the kill operation at each zone.

Zone 1 at 1250 mMD and zone 2 at 1150 mMD were selected since the USIT log showed gas across the annulus, additionally the noise log confirmed noise at this depth.

Zone 3 at 675 mMD was selected as the LWD confirmed this depth as large gas sand and USIT showed poor cement in this interval.

The uppermost zone 4 was selected at 350 mMD. USIT indicated a channel in the cement job from this depth to surface. It is believe that circulation to surface thru 24" x 13-3/8" annulus could be gained in this depth.

Kill operations were started on October 31st. See Table 2 for summary of the actual perforations and cement plug placement. No circulation was established and no change in the blowout flow rate was observed from any zone. A cement plug was placed across each zone via 2" coiled tubing and tested to 2500 psi. It was not possible to establish circulation thru 24" x 13-3/8" annulus to surface at selected upper most interval. Therefore additional depth was chosen from USIT at 279 – 291 m depth. After perforating this interval, 13.5 bbls of 1.2 SG mud was pumped at 0.6 BPN with 200 psi into the perforations and well flow suddenly stop. Refer to Fig 11 for Wellbore Diagram after completed intervention.

5. Result and Discussion

A post kill operation was done by tagging top of cement inside of the 13-3/8" casing at 106 mMD with coiled tubing. Attempt to perform top job inside of the annulus but failed – the maximum depth of 1-1/4" tubing is limited to 5 m below wellhead. Several lesson learned taken such as:

1. The exact source of flow was never accurately determined. Noise log was

unable to confirm noise from shallow depth. The flow from the blowout made so much noise that it was difficult to get reliable readings. The temperature log was also cannot confirm the source of flow.

2. Lack of coil tubing depth control might resulted difference in measurement from wireline. Some of the perforations were near other sets of perforations and it was difficult to space out coiled tubing to circulate out at the proper depth.
3. Cementing through coiled tubing in a large hole 13-3/8" casing ID led to poor cement jobs.

Drilling was able to continue on this well. Re-entry operation was done on December 15th, 2003. No flow was reported from the 8" diverter line. The cement plug was drilled and integrity test was performed. Leak was observed and cement squeeze job was performed prior to continue drill the 12-1/4" intermediate section. The well then completed with tubingless architecture on January 30th, 2004. Well was then PoP on March 12th, 2004. Well was fully shut-in since April 26th, 2015. No flow from Ann-C was reported during production and/or well intervention. Refer to Fig. 12 for the final well schematic.

These success leads into the acceptance of PWC to overcome sustain casing pressure in Mahakam field. Study was ongoing at the moment and it has been started by running a newer technology of noise logs to confirm the source of flow. USIT and/or CBL to quantify the quality of casing, especially due to multiple casing deployed on the wells. Spectral Noise Log (a services from TGT) has been run inside the production tubing over various architecture to detect the source of flow in the outermost annulus to confirm the flow behind the cemented annulus. As a trial, TN-M58 was selected. The well has been reported with sustain casing pressure on Ann-C (24" CP x 10-3/4" surface casing). The noise log was required to be run in stationary position in shut-in condition and Ann-C bleed-off condition. Together with temperature log, the noise log was able to predict the possible source of leak and flow direction. Refer to Fig. 13 for the noise log interpretation on TN-M58.

As the successful run in TN-M58, it was decided to run the noise log on a well with multiple sustain casing pressure (including bubbling on the open type CP). TN-C1 was selected since the well has been reported with sustain casing pressure on Ann-B (9-5/8" production casing x 13-3/8" intermediate casing), Ann-C (13-3/8" intermediate casing x 20" surface casing) and bubbling on Ann-D (open type CP). Three runs were required, one in shut-in condition, second with bleed off Ann-B and third with bleed off Ann-C. The noise log has been proven powerful enough to confirm the possible source of leak of multiple sustain casing pressure and bubbling on open type CP. The tool even was not disturbed by the uncontrolled noise due to bubbling on the open type CP. Refer to Fig. 14 for the noise log interpretation on TN-C1.

As we know the sources of flow, now we can identified the cement plug position to restore the integrity of the annulus.

6. Recommendation

It was proposed to performed trial PWC on wells with multiple sustain casing pressure with zero stakes – ready to be abandoned. TN-C1 therefore was chosen. The well was drilled and completed in 1993. No more stakes are identified in this well and it has been in fully shut-in condition since 2012. The well has been reported with various case of sustain casing pressure and require regular bleed-off on Ann-C (this annulus is cemented to surface and therefore brine injection will not be possible). Noise log has identified several possible source of leak over Ann-B, C and D. In zoom, refer to Fig. 15x and 16 for possible source of leak on these annulus. More thorough investigation will be required prior to draft the program and decide the PWC interval. Furthermore SKK Migas approval will be required to perform propose well securing. If proven, PWC might be the answer to restore well integrity due to sustain casing pressure over aging wells in Mahakam field.

7. Acknowledgement

The writer would like to say thank you to WLC/WIN PHM team for the support over times spent for noise log trials, sustain casing pressure investigation and possible abandonment project.

8. References

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Internal References:

MHK-ENTY-SOP-FOP-GEN-0011: Wellhead Annulus Pressure Monitoring, Diagnostic and Follow-Up

External References:

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ISO /TS 16530-2: 2013 (E) Well Integrity – Part 2 Well integrity for the operational phase, page 32, 63

NORSOK Standard D-010 Rev.4, June 2013: Well Integrity in Drilling & Well Operations, page 104, 107

Paper:

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TN-A37: Daily Drilling Report, Final Well Report (Suryadi JS, January 2004), Dossier Puits TN-A37 Well Control Historique

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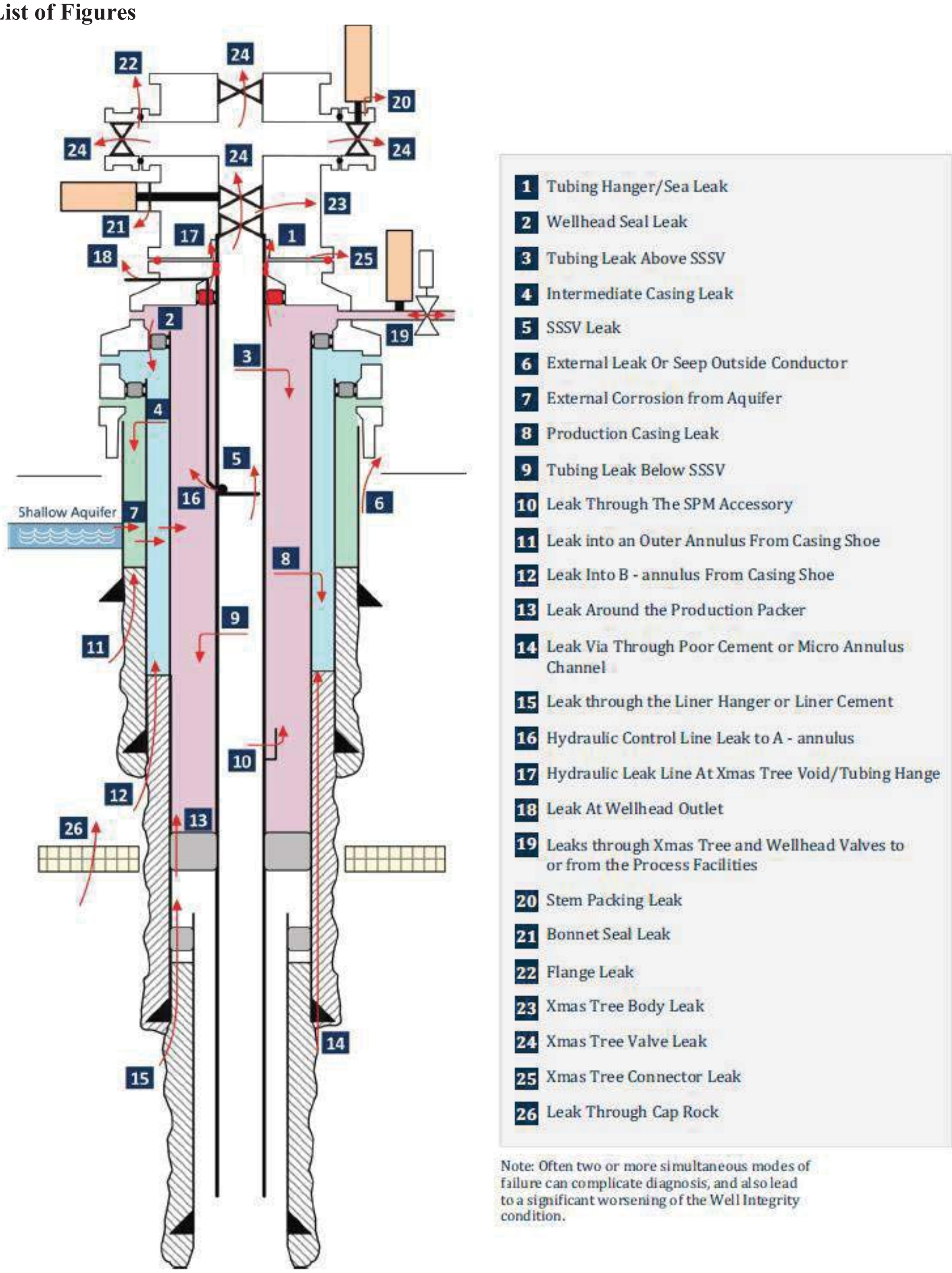


Figure 1. Potential Leak Path

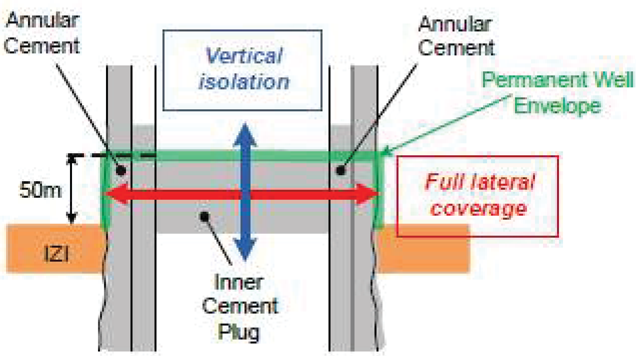


Figure 2. Full Lateral Coverage as per MHK-CR-EP-FP-424

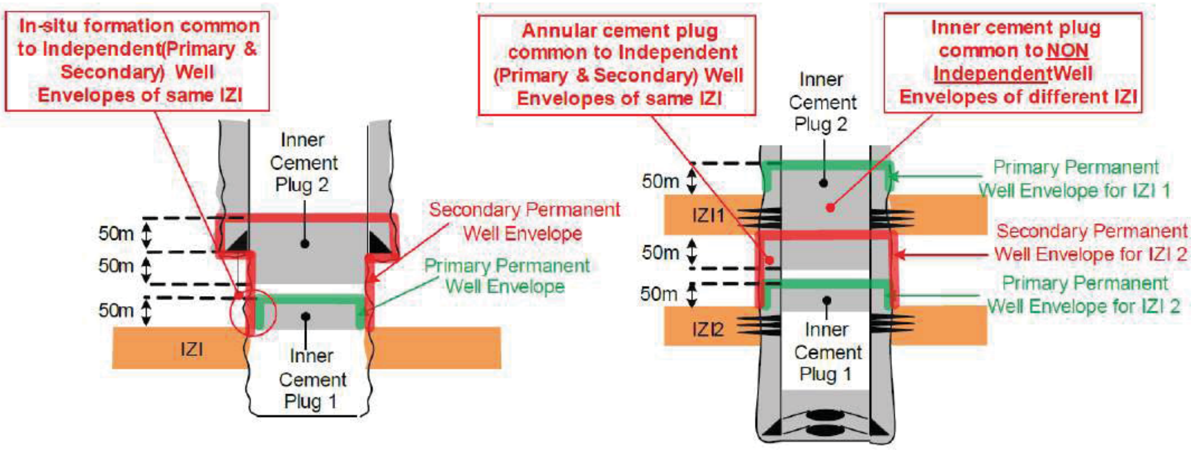


Figure 3. Examples of Barriers common to two PWE as per MHK-CR-EP-FP-424

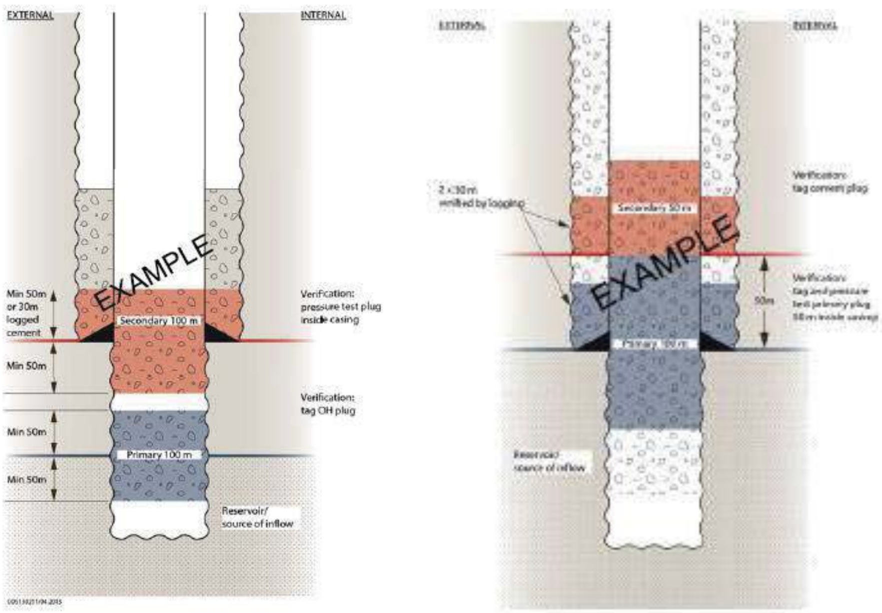


Figure 4. Examples of WBE as per Norsok D-010

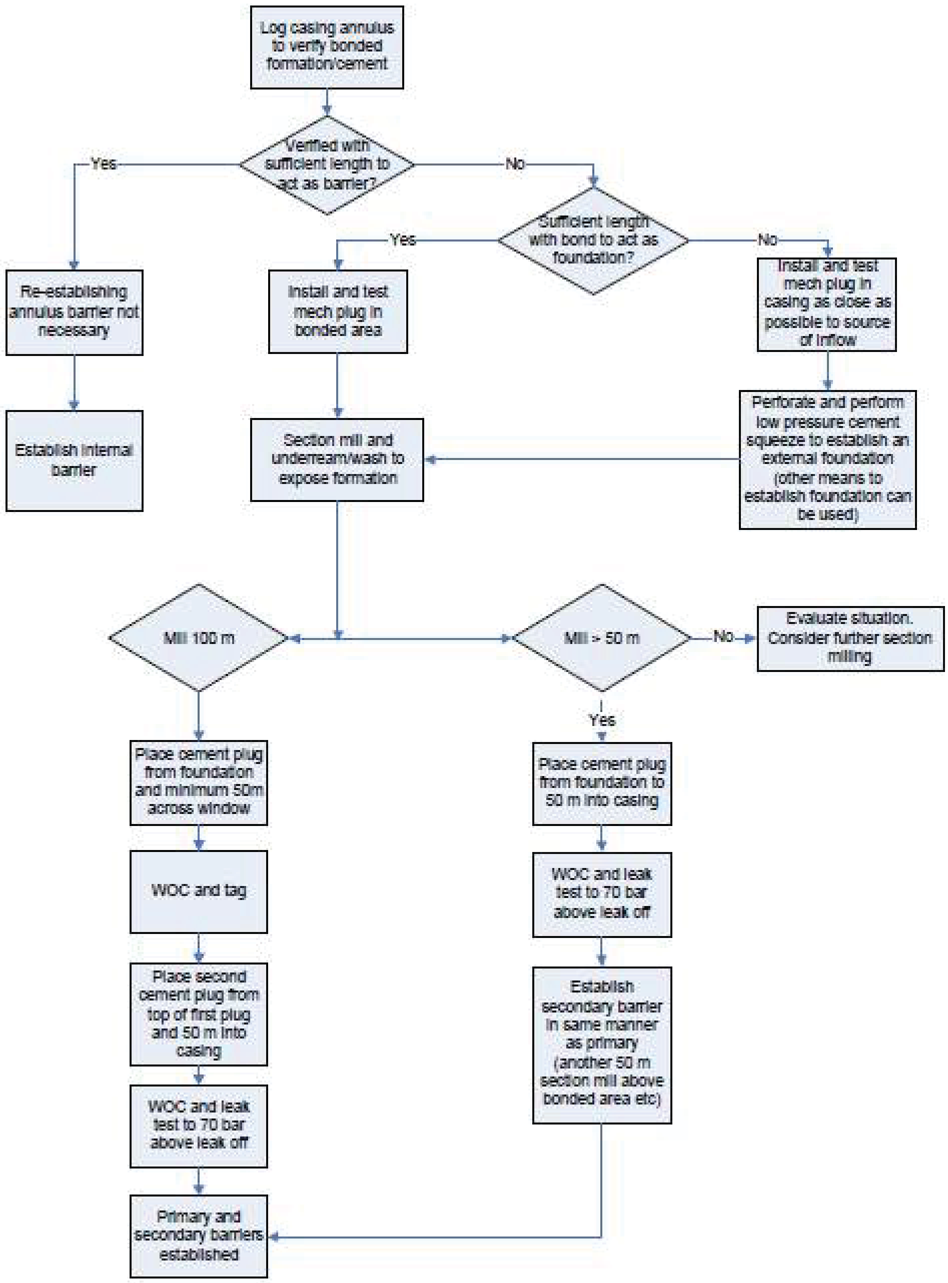
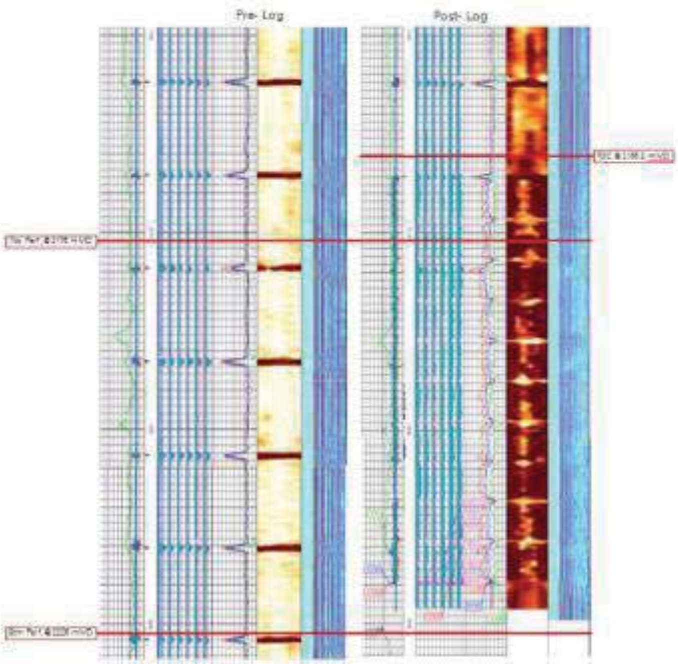


Figure 5. Section milling to establish cement plug as per Norsok D-010

Well - Valhall DP	A-25 B T3 (Secondary)	A-4 B (Primary)	A-4 B (Secondary)	A-10 B T3
Length of Perforated interval (MD)	50 m	50 m	50 m	50 m
Length of logged circumferential cement (MD)	46.3 m	36.6 m	37.1 m	74 m
% of perforated interval with circumferential cement verified via log	93%	73%	74%	148%
Internal base	Cement	Internal Cement Foundation	Cement	Internal Cement Foundation
Annular base	Cement	Expanded Casing	Cement	Expanded Casing
Well Inclination	62-63°	50°	50°	40-43°

Figure 6. Result of the PWC campaign on Valhall DP – presented during SPE Bergen One Day Seminar held in Bergen, Norway, 5 April 2017



Circumferential Cement verified via log

Top [mMD]	Base [mMD]	Thickness[mMD]
2165.3	2172.7	7.4
2174.0	2177.4	3.4
2178.5	2183.6	5.1
2184.3	2188.5	4.2
2189.5	2193.3	3.8
2194.0	2199.1	5.1
2199.8	2204.0	4.2
2205.1	2213.8	8.7
2214.8	2217.1	2.3
2217.3	2219.4	2.1
Total circumferential bonding (>2 m) [mMD]		46.3
Total circumferential bonding (>2 m) [%]		92.6%

Figure 7. Pre and Post PWC CBL result on A-25 B T3 well of the PWC campaign on Valhall DP – presented during SPE Bergen One Day Seminar held in Bergen, Norway, 5 April 2017

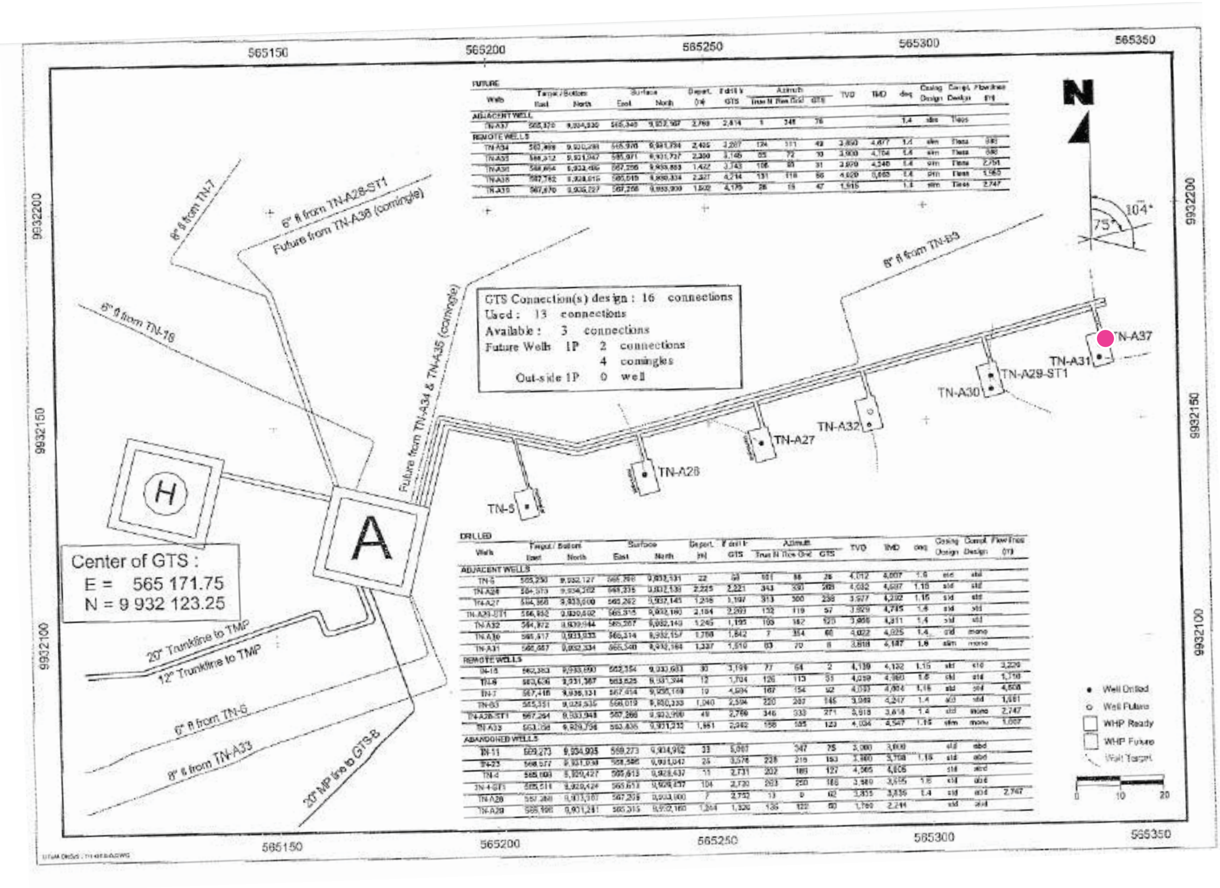


Figure 8. GTS-A Platform Layout

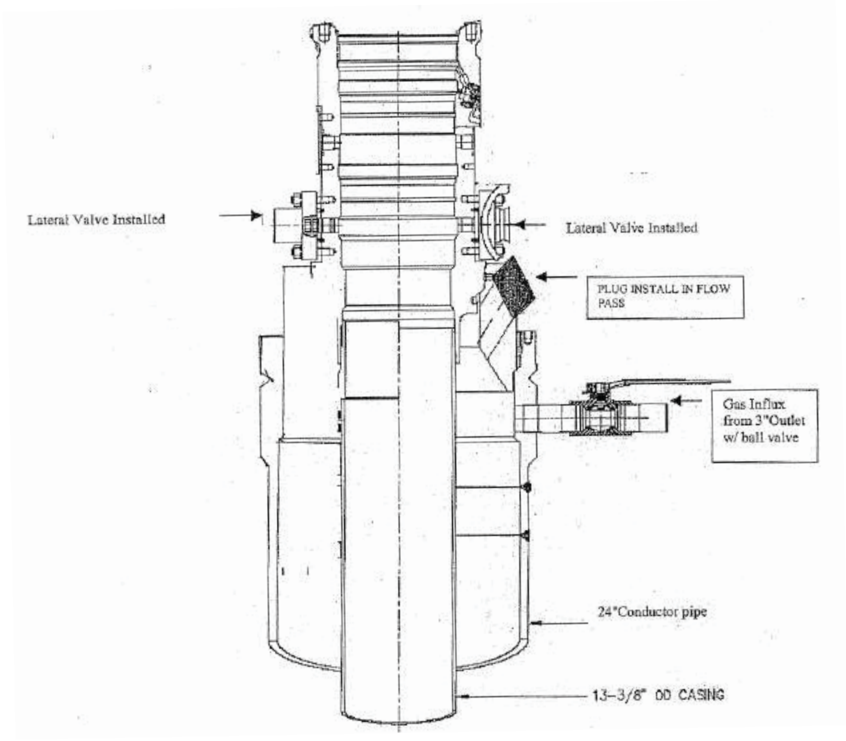


Figure 9. Hibiscus TN-XX Wellhead Schematic

Sequence 1: Removal of Platform Structure	Sequence 2: Installation of Diverter Line
	
Sequence 3: Installation of BOP Stack	Sequence 4-7: Securing the Well
	

Figure 10. TN-XX Well Securing Sequences

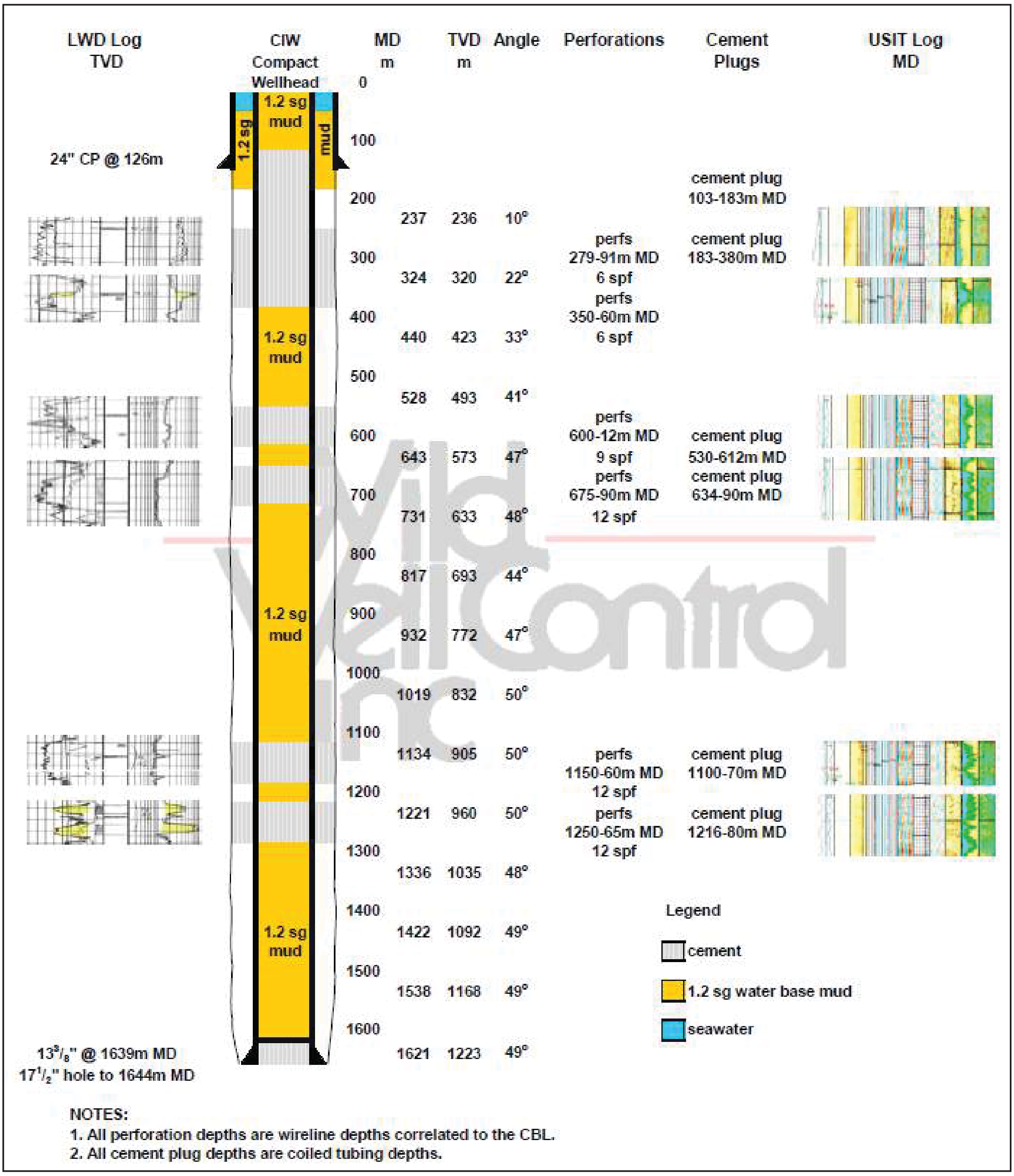


Figure 11. Wellbore Diagram after Completing Well Intervention

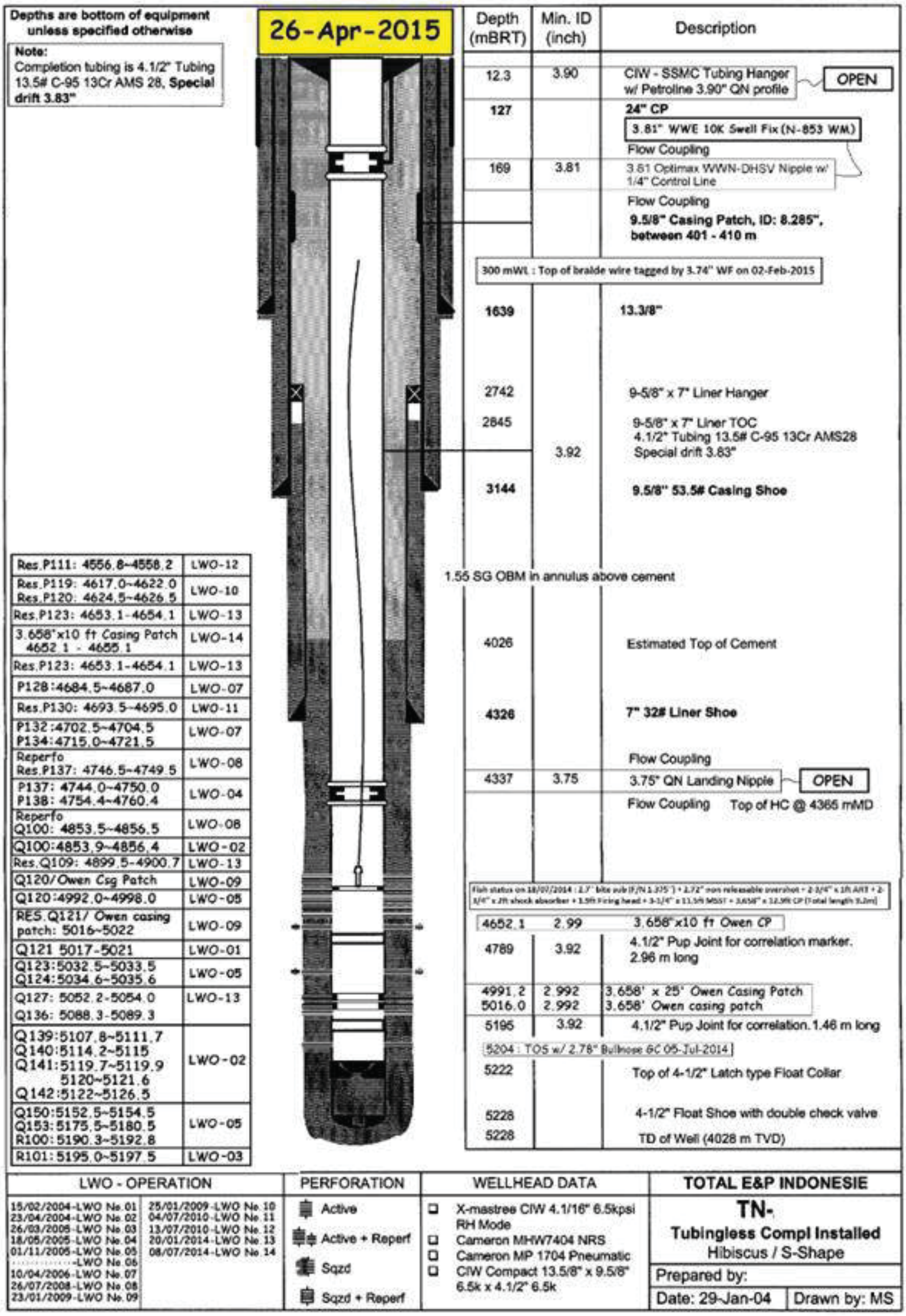


Figure 12. Well Schematic of TN-XX

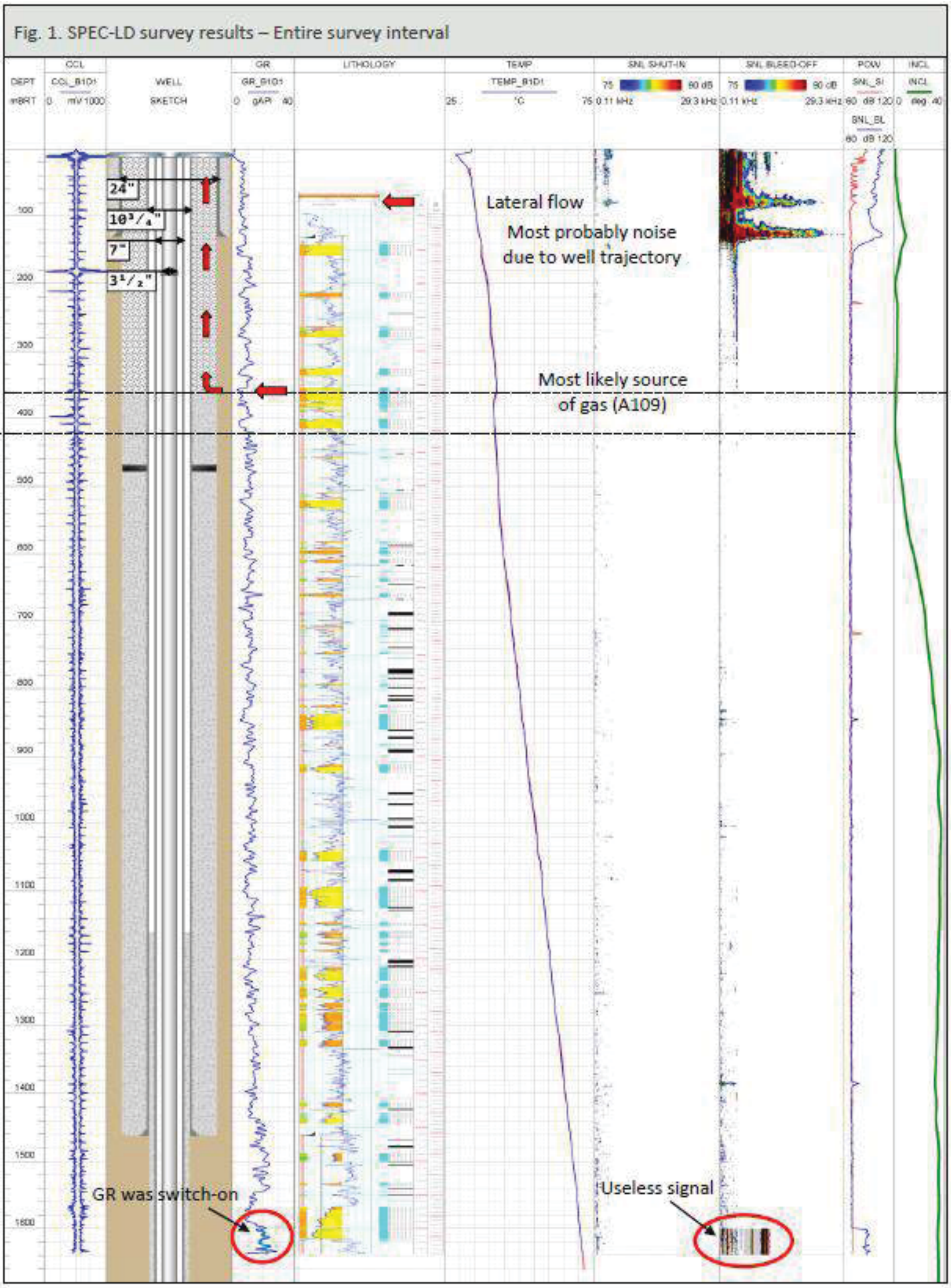


Figure 13. Result of Noise Log TN-XX2

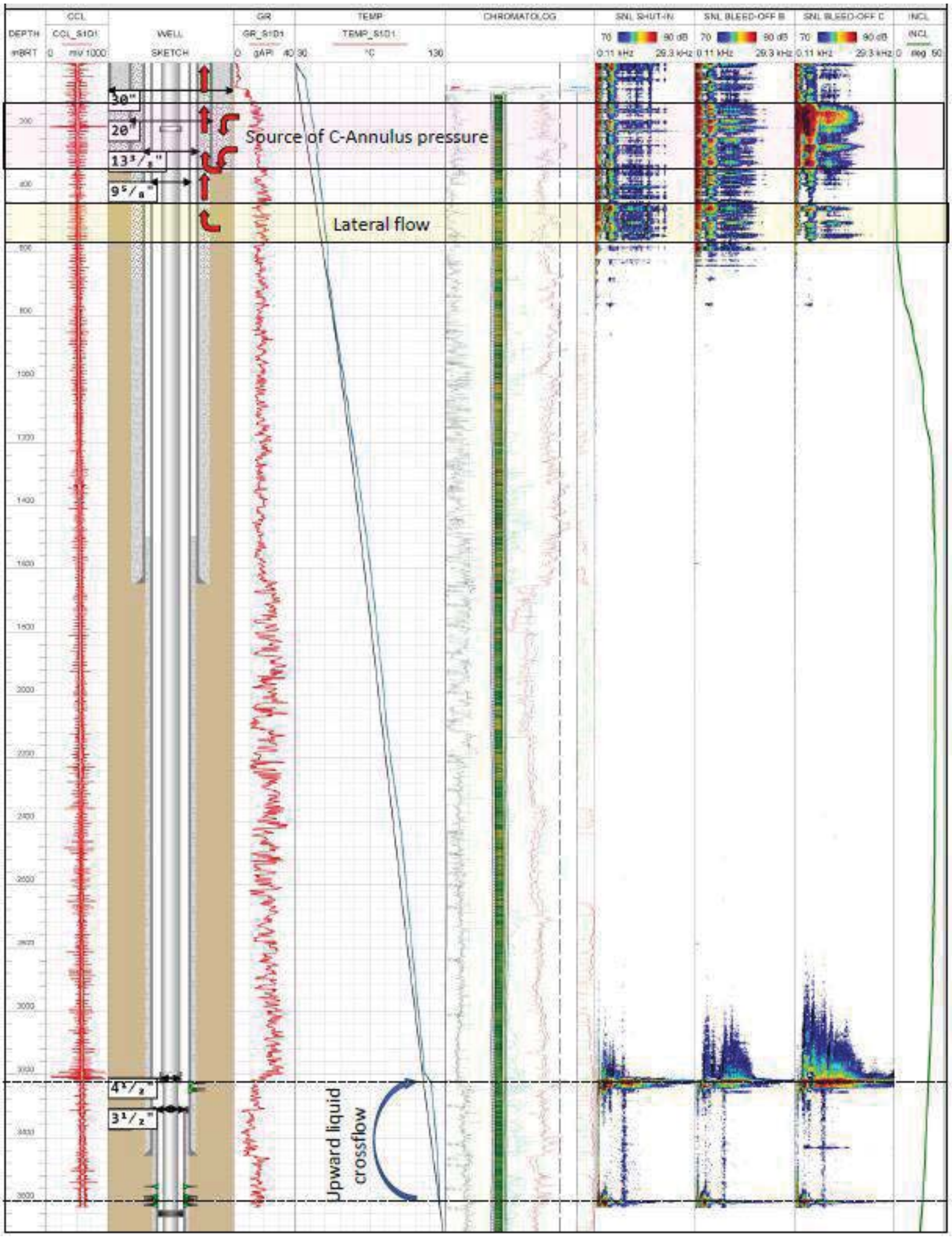


Figure 14. Result of Noise Log TN-XX3

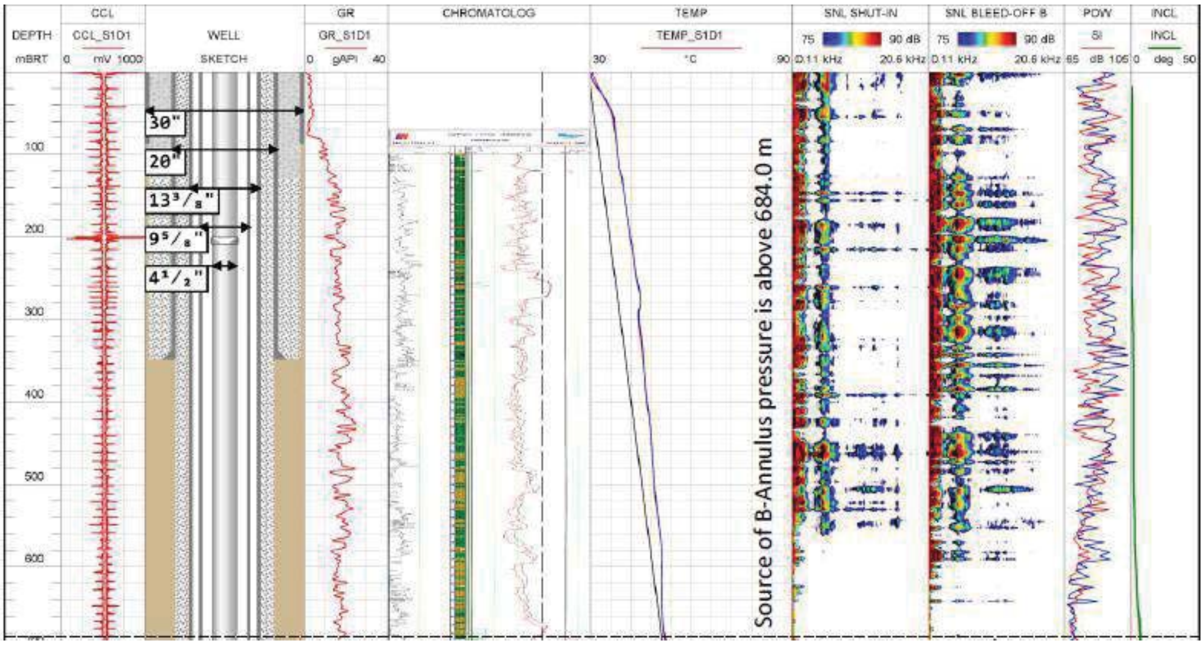


Figure 15. (Zoom) Source of Leak on Ann-B TN-XX3

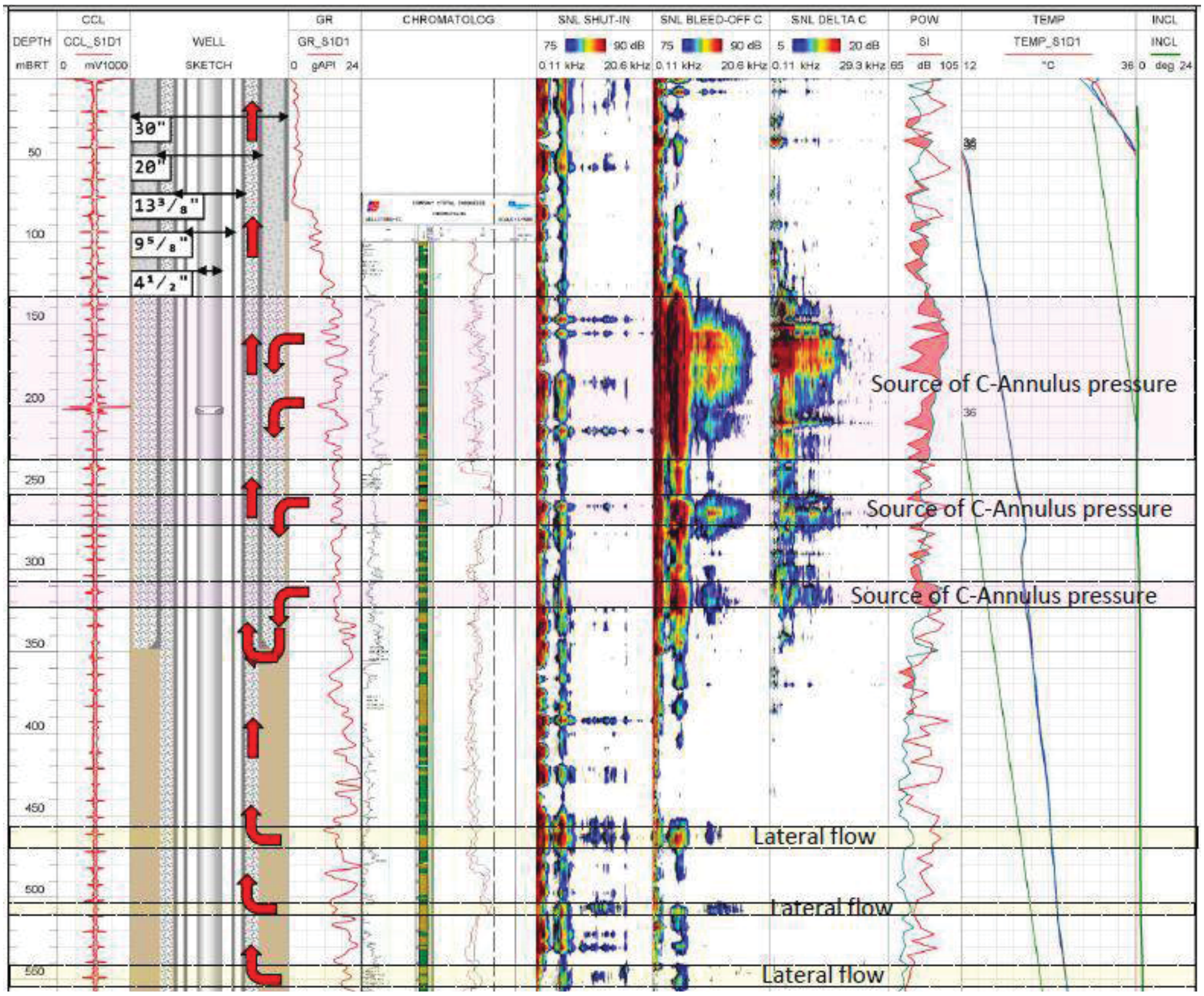


Figure 16. (Zoom) Source of Leak on Ann-C and D TN-XX3

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Table 1. Chronological Order of TN-XX Shallow Gas Event

Date	Time	Description of Event
2-Oct-2003	12:00	Rig arrive at the location, start R/U
6-Oct-2003	05:00	N/U 29-1/2” diverter with 2 overboard lines
6-Oct-2003	19:30	M/U 17-1/2” Clean Out assy, RIH and tag @ 28 m
7-Oct-2003	00:00	Clean out 24” CP to 127 mMD
7-Oct-2003	00:00	Clean out 24” CP to 127 mmD
7-Oct-2003	02:00	Flow check, run multi shot gyro, POOH 17-1/2” clean out BHA
7-Oct-2003	08:00	Start P/U & RIH 17-1/2” motor BHA, shallow test
7-Oct-2003	15:30	Spud TN-A37, start drilling from 127 mMD
9-Oct-2003	16:30	Reach section TD @ 1644 mMD/ 1238 mTVD, circ hole clean
9-Oct-2003	20:00	Start backream to kick-off point at 600 mMD
10-Oct-2003	07:00	Clear tight spot at 402 mMD, cont POOH to surface
10-Oct-2003	12:30	BHA on surface
10-Oct-2003	15:30	Start RIH 13-3/8”, 68#, K55, BTC casing
11-Oct-2003	01:30	M/U and land multi bowl @ 12.82 m, set shoe @ 1639 mMD/ 1234 mTVD
11-Oct-2003	03:30	Start conditioning mud, PJSM
11-Oct-2003	06:30	Start cementing job: Drop bottom pump, pump $168m^3$ of 1.50 SG gas tight cement slurry, drop top plug and displace the well with $126.9m^3$ of 1.17 SG water based mud. Bump plug and P/T system to 2500 psi.
11-Oct-2003	10:30	Complete cementing job, clean out diverter, R/D cementing head
11-Oct-2003	15:00	Start install Cameron gate valve 2-1/16” 5k on wellhead
11-Oct-2003	16:00	Gas influx coming from 24” x 13-3/8” annulus, remove gate valve from wellhead, N/U diverter, installed 4 x 4” flow thru outlet on landing ring and divert flow thru 3” x 500 psi ball valve on 24” pin connector. Switch on deluge system around moonpool
11-Oct-2003	16:45	Shut down rig operation due to uncontrolled gas influx, mustered all non essential personnel
11-Oct-2003	17:20	Notified CPU RSES then activate ESD-1 of GTS-A (est production 60 MMscfd).
11-Oct-2003	17:30	Launch evacuation of non essential personnel, calculate of moving variable loads prior to rig move out, skid in cantilever. Start backload excess equipment and 70 tones barite. Move out nearby support barges
12-Oct-2003	00:00	Start rig Hibiscus deballast
12-Oct-2003	06:30	Rig Hibiscus move out from location
12-Oct-2003	19:00	Rig arrive on safe location

Table 2. Perforations and Cement Plugs Interval

Interval	Depth	Shots per foot	Cement Plug Depth MD
1	1250 – 1260 m	12	1216 – 1280 m
2	1150 – 1160 m	12	1100 – 1170 m
3	675 – 680 m	12	643 – 690 m
4	600 – 612 m	9	530 – 612 m
5	350 – 360 m	6	
6	279 – 291 m	6	183 – 380 m
			103 – 183 m