AADE-24-FTCE-100

Navigating the Complex Structure of Hassi Messaoud: Challenges and Innovations in Hydrocarbon Exploration

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Abstract

Hassi Messaoud, situated in the heart of Algeria, stands as one of the world's richest hydrocarbon fields, boasting vast reserves of oil and natural gas. However, drilling and exploration within the Hassi Messaoud region present a unique set of geological, environmental, and logistical challenges. In this paper, the authors provide an exhaustive analysis of the intricate complexities and innovative strategies involved in hydrocarbon exploration in the Hassi Messaoud territory.

When drilling in Hassi Messaoud, once past the main salt body known as the Lias salt, the drillers face geological intricacies including intricate fault systems. Known as G35, this sub-salt section with its unique geological complexities adds layers of difficulty to drilling operations, demanding precise wellbore placement to mitigate structural risks, while penetrating the reservoir section, to ensure optimal hydrocarbon recovery.

This article delves into the challenges and innovations required for managing the damaged sub-salt formations, which can cause wellbore instability and formation damage. Innovative techniques to address these concerns, including drilling fluid formulation and wellbore strengthening methods, are discussed in detail in the paper.

Real-time monitoring and data analysis play a crucial role in making informed drilling decisions, and ensuring well integrity, particularly in this challenging section. Drilling in the Hassi Messaoud demands a comprehensive approach, involving geology, engineering, technology, and environmental conservation. By tackling these chronic challenges, the operator can maximize hydrocarbon potential while ensuring well integrity and contributing to the socio-economic development of the field.

Introduction

The drilling performance curve for the Ghadamiss Basin had reached a point of reliable performance apart from the lost circulation experienced in the recurring rubble zone. Loss of circulation typically occurs while penetrating the Trias Argileux Greseux (TAG) formation in the lower section of the 8½-in. interval (Fig. 1). Vertical well profiles indicate the thief zone is below a high-pressure interval, which is commonly drilled using salt-saturated water-based fluid with a density in the range of 1.98 to 2.1 sg (16.5 to 17.5 lb/gal). The losses are thought to be induced due to a severe pressure transition once the main salt section has been drilled, exposing the TAG formation to an excessive annular hydrostatic pressure (>9,000 psi). This over-pressure induces fractures and causes severe losses to the formation.

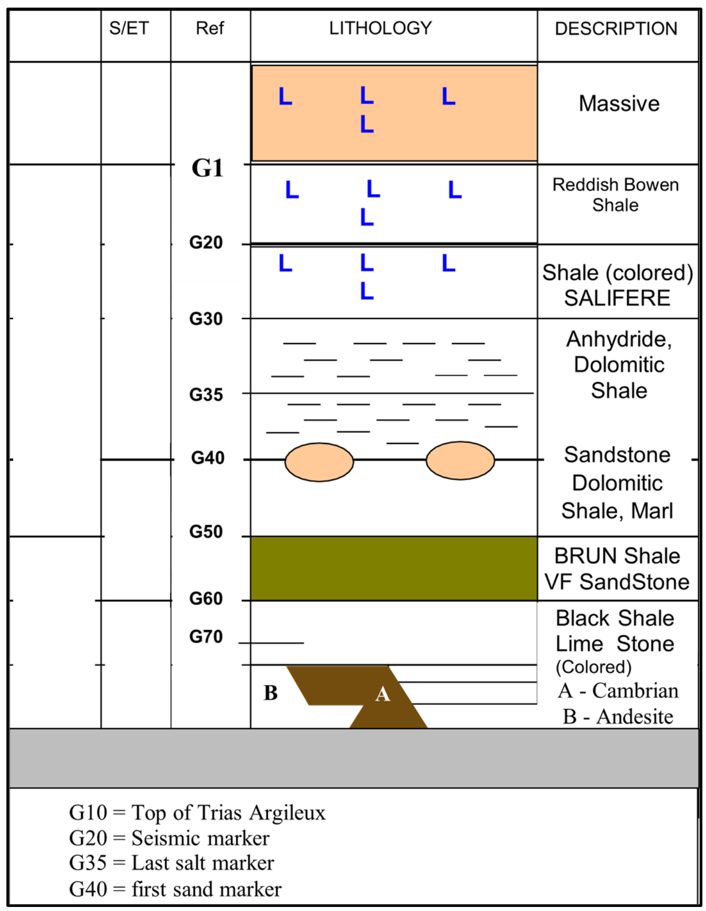

Fig. 1 – Formation of Trias Argileux Greseux (TAG).

The shape and structure of induced formation fractures is always subject to the nature of the formation and mechanical effects of drilling operations, as well as geological influences over time.

Table 1 - Ghadamiss Basin Messaoud Historical Offset Well Data (Examples)					
Well	Offset 1	Offset 2	Offset 3	Offset 4	Offset 5
Depth of Losses (ft)	11000-11056	10997	10991	11171	11037-11043
Fluid Density (lb/gal)	17.5	17.2	16.9	17.0	16.9
Top of G 35	10932	10974	10968	10984	10925
Top of Cambrian Ri	11142	11207	11158	11280	11211
Top of Cambrian Ra	11260	11289	11230	11414	11293
Cement Plugs pumped	6 + 2 LCM	1	1	2	9
7-in. Casing Depth	11155	11217	11165	11273	11224

The Ghadamiss Basin is considered to be divided into many separate blocks, and subsequently each block appears to exhibit unique geological characteristics. The basin can best be described as unified single units referencing specific geology and stratigraphy.

With the experience gained developing the Ghadamiss Basin Field, the operator was able to predict the depth and severity of the losses with a relatively high degree of accuracy. Typical historical offset data are given in Table 1.

The challenge remained to develop an effective solution to prevent or cure the severe losses encountered below the salt formation. Extensive investigations were carried out, involving modification of drilling practices and testing of a wide range of lost circulation materials (LCM). According to operational data, squeezed cement slurries across the thief zone were successful at sealing off the losses, but always involved a negative effect on performance due to the non-productive time associated with repetitive trips involved with the squeeze job.

A new chemically thermally activated crosslinking pill (CTACP) was proposed to the operator to shut-off losses, should they occur, below the salt zone. Strict operational procedures were also developed, giving clear directions as to the timing and method of applying the CTACP.

Performance improvement was the target of this proposal to the operator, with the performance improvements being directed not at the drilling fluid, but the large gap existing between conventional LCM and cement squeezes contributing to severe loss of circulation. The CTACP proposed to the operator had the following properties.

- A simple fluid that can be pumped through the bit nozzles and bottomhole assembly (BHA)
- Adjustable particle-size distribution to fit formation specific requirements (squeezable into micro-size fractures)
- Forms a semi-ridged gel structure as a filling material for the loss zone
- Chemically active to properly bond with the formation.

A time breakdown was conducted on several offset wells in the Ghadamiss Basin Field. The results of this analysis suggested that if the sub-salt lost circulation problems could be eliminated, a drastic enhancement of the drilling performance was possible. The following example illustrates the time and cost benefits available through eliminating the non-productive time (NPT) associated with the sub-salt losses.

The CTACP technique was proposed as a lost circulation solution in the TAG formation with the specific requirements to cure losses with maximum possible sealing efficiency and increase formation integrity across the weak sections.

Additionally, the process of applying the CTACP was recommended to involve less time than what was currently associated with applying the cement squeezes. The new technique was applied successfully, sealing the TAG formation without any lost tripping time, and allowing drilling to continue with no further losses.

Ghadamiss Basin

The following section describes the typical formation properties and drilling conditions for a Ghadamiss Basin well. The sub-salt sections are typically drilled with a 1.98 to 2.1 sg (16.5 to 17.5-lb/gal) salt-saturated drilling fluid system. Higher drilling fluid density is required for the Jurassic Dogger, Lias, and Trias-Salifere formations, which typically require pressures of 10,000 psi to maintain overbalance pressure (Fig. 2).

Once the Trias Argileux had been penetrated, a pressure reduction is encountered. This interval contains weak formations, highlighted in Fig. 3, which are readily broken down by the high hydrostatic pressure in the annulus. The mechanically induced fractures subsequently lead to total loss of returns. Severity of

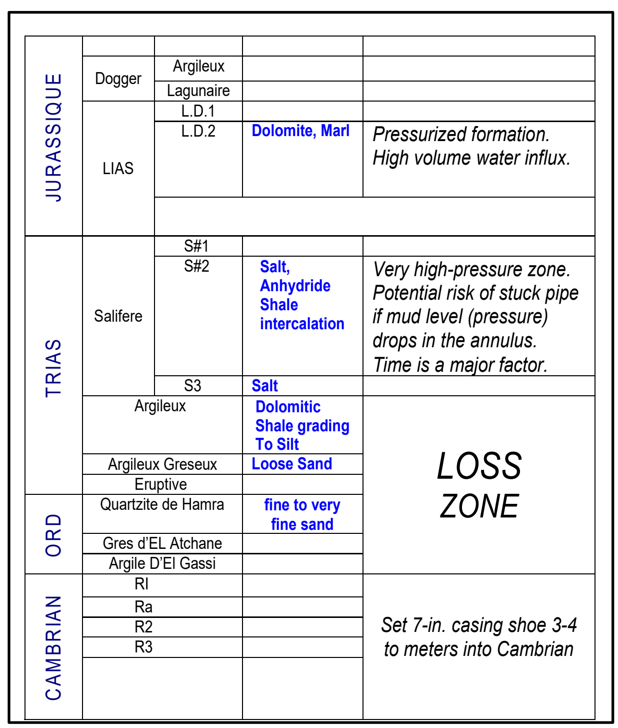

Fig. 2 – Chart showing formation, typical composition, and anticipated problems in drilling the formation.

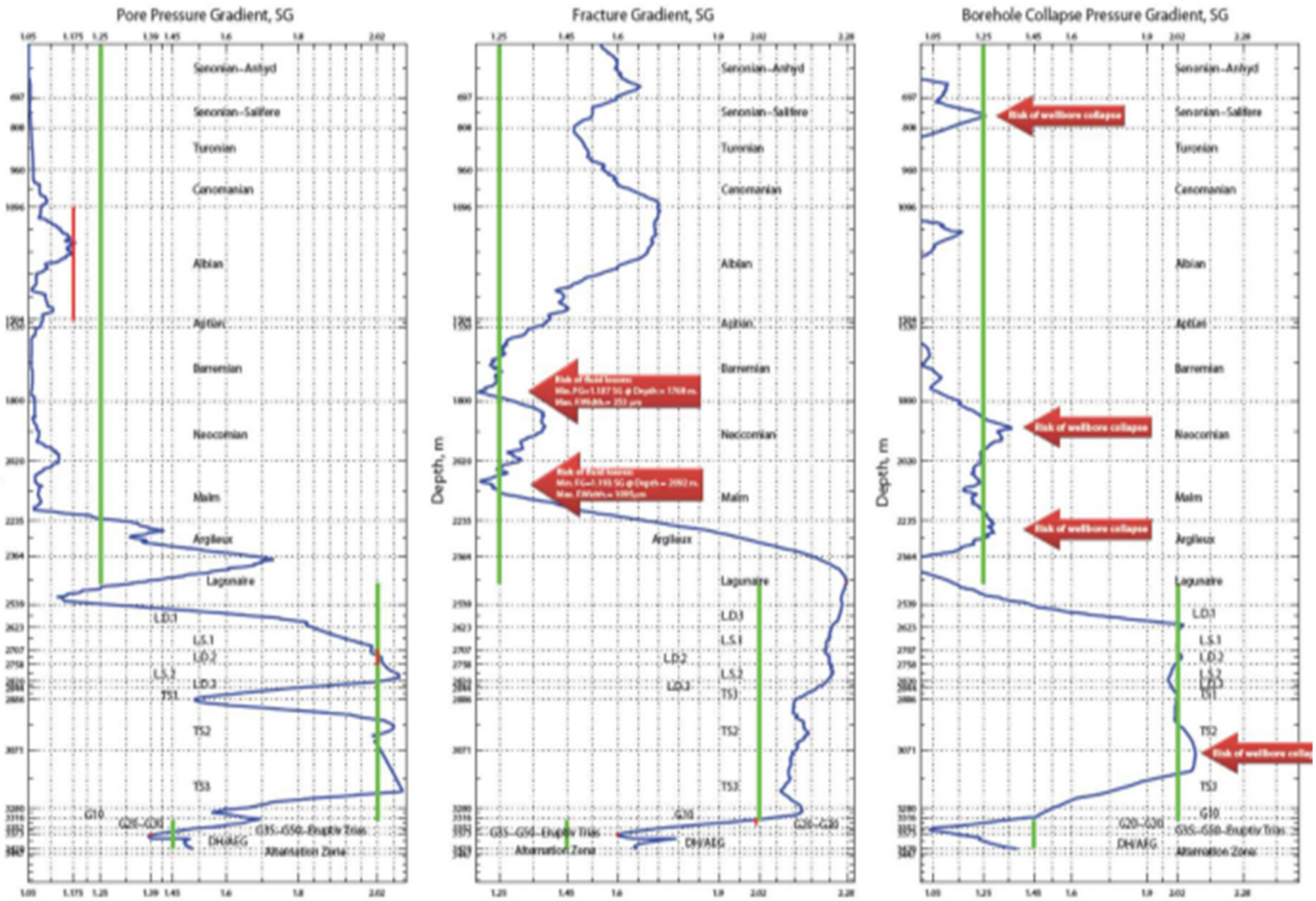

Fig. 3 – E logs displaying the sealing of the used techniques.

the losses varies from block to block due to the variation in formation integrity common to the Ghadamiss Basin and the mechanical forces applied while drilling each section.

The above scenario was encountered numerous times in the Ghadamiss Basin while drilling the troublesome sections. It must be stated that changing the casing design is not an option. If the 7-in. casing is set higher, the situation becomes worse due to the resulting reservoir depletion which leads to a greater pressure transition problem and added cost of non-productive time. Furthermore, establishing a link between the TAG and Cambrian formations (reservoir section) is not an appropriate completion strategy for the wells.

Numerous attempts had been made to attack the sub-salt thief zone using different solutions suggested by cement and drilling fluids companies. Results varied from total failure to partial success. The most common practice to cure the massive losses on the offset wells was to spot and squeeze cement into the induced fractures. The aim of the cement squeeze was to reconsolidate the formation to allow drilling to continue without further losses. Depending on the severity of the losses, this process often had to be repeated several times on some wells. Prior to application of the CTACP, no other remedy was able to satisfactorily solve the fluid loss problem.

Drilling through salt formations can be troublesome for a number of reasons. Typically, the formations immediately below the salt are either mechanically weaker or fractured, introducing a greater risk for loss of returns. The time lost in treating severe sub-salt losses can be up to several weeks, with obvious cost implications, especially for deepwater drilling operations.

Though not the case in the extensively developed Ghadamiss Basin Field, often on exploration wells, little information regarding pore pressure and fracture gradient is available. Gulf of Mexico sub-salt wells often encounter higher pore pressures below the salt, creating challenging well control issues. In this instance, the higher densities required to balance the pore pressure place even greater stress on the weakened sub-salt formations. However, in the case of the Ghadamiss Basin, the pore pressure, and subsequent required drilling fluid density, was significantly lower than that required in the actual salt formation. As such, the formations directly below the salt are drilled in a high overbalance environment.

Losses in the formations directly below the thick salt zones of the Ghadamiss Basin are typically severe, ranging from 16 m^3/hr (100 bbl/hr) up to total loss of returns and the inability to maintain a full annulus. A wide variety of LCM have been applied in sub-salt thief zones, in an effort to control losses. Pills containing sized solids, gunk squeezes, conventional cement squeezes, and foamed cement have all been proposed as solutions to sub-salt lost circulation. While the cement squeezes were able to reduce losses in the Ghadamiss Basin Field, the associated non-productive time remained a costly factor.

Chemically Thermally Activated Crosslinking Pill

The CTACP proposed for the sub-salt lost circulation problem in the Ghadamiss Basin was a blend of crosslinking polymers and fibrous material. The material was designed to plug deep fractures, faults, and vugular formations. The material can be blended with a biopolymer to enhance the viscosity of the material to suspend barite while pumping. The crosslinking process is chemically activated. After setting, the material forms a firm, rubbery, ductile plug in the fractures and voids that it has been squeezed into, preventing further loss of fluid.

The CTACP can be mixed in freshwater, seawater, or saltwater and applied in wells drilled with water-based, oil-based and synthetic-based drilling fluid systems. One major advantage of the CTACP is that it can be pre-mixed ahead of time. This allowed for significant time savings on the Ghadamiss Basin field. The anticipated volume of CTACP required was pre-mixed and kept on standby.

When drilling below the salt formation, once severe losses were encountered, the crosslinking agent was added to the pill and the CTACP was immediately pumped into the thief zone. Though not necessary for the Ghadamiss Basin drilling, the CTACP can be used to cure losses and at the same time shut off zones producing water or gas. This would suggest that the CTACP might be an ideal material for attacking Gulf of Mexico sub-salt thief zones.

Variations of the CTACP are available that can be tailored to specific applications. Depending on the formation properties and the characteristics of the loss zone, higher polymer loadings can be selected, higher fiber loading, or a CTACP with coarse calcium carbonate can be used. The CTACP is not recommended for producing zones as the material does not degrade and is not acid soluble.

The proposal developed to counter the chronic lost circulation problems in the Ghadamiss Basin had not previously been proven successful in this type of situation. As such, the potential risks were identified and reviewed in the context of applying the CTACP once losses occurred.

Since the pressure profile for the openhole section is very complicated with a large pressure reduction and weak formations, there is always potential for wellbore instability to develop once formation losses occur. The massive losses that occur can reduce the annular hydrostatic pressure to levels that cannot support the upper sections of the wellbore, introducing the potential for borehole collapse. Once loss of returns has occurred, any delay in curing the losses introduces the risk of losing the well. For this reason, it was imperative to develop a lost circulation solution that could be deployed rapidly and become effective as soon as possible. The CTACP involved minimal downtime between the onset of the losses and placement of the pill across the loss zone.

In order to minimize the potential for stuck pipe, the safest practice after pumping the pill required pulling the drillstring above the high-pressure formation immediately after placing the pill across the loss zone. If the borehole did collapse due to reduced annular pressure being insufficient to support the borehole, any potential for stuck pipe would be reduced. Typically, 9,000-psi equivalent fluid density is required to stabilize the formation. Once the string is located above the loss zone, the CTACP is squeezed into the induced fractures to reconsolidate the section and allow drilling to continue. The operation can be repeated to seal additional weak zones that may be encountered drilling to interval TD.

CTACP Field Test

The well that was selected to apply the first CTACP lost circulation pill was located in one of the most challenging blocks in Ghadamiss Basin Field. This scenario provided an opportunity to aggressively test the approach against severe loss conditions and a high level of borehole instability.

The section to be drilled would require a 2.02-sg (16.9-lb/gal) salt-saturated system. It would be necessary for the CTACP to be designed with consideration for the following surface and downhole conditions:

- The effect of high concentrations of barite on both the slurry rheology and thickening time
- The compatibility of the CTACP with the drilling fluid system when drilling through the plug
- The effect of formation salt contamination while pumping and squeezing the pill
- Mixing time and temperature effects.

The slurry design was based on 90 minutes of pumping time and a total of 5 hours setting time, which would be sufficient to allow for mixing, pumping, squeezing and pulling the drillstring above the pill to 3,000-meters (9,834-ft) measured depth. Table 2 displays the increase in the viscosity of the material 120 minutes after crosslinking has been initiated.

Table 2 – Viscosity profile of CTACP

Rheology	Initial	45 min.	90 min.	120 min.
600rpm Reading	95-115	95-115	120-130	130-140
300 rpm Reading	75-85	75-85	80-90	90-100
200rpm Reading	60-70	60-70	70-80	70-80
100 rpm Reading	45-55	45-55	50-60	50-60
6rpm Reading	15-20	15-20	20-25	25-30
3 rpm Reading	15-20	15-20	20-25	25-30
PV (cP)	30-40	30-40	35-45	35-45
YP (lb/100 ft^2)	45-55	45-55	50-60	50-60

Based on the potential risks and the pill design criteria, a spotting and squeeze procedure was designed that would minimize any operational risks. For the initial trial, 8 m^3 (50 bbl) of the CTACP was mixed prior to drilling into the trouble zone. Once the thief zone had been drilled into and only if losses occurred, the following procedure was utilized. The following steps illustrate the stages involved with spotting and squeezing the CTACP.

1. Pull out of hole to the top of TS#2.
2. Add the chemical activator and immediately pump the CTACP, displacing all of the CTACP from the drillstring.
3. Two options available:
   a) If only partial returns are observed while spotting the pill, pull up 10 stands to ensure the drillstring is

completely above the top of the pill.

b) If no returns are observed, it is not necessary to pull 10 stands.

4. Close annular preventer and squeeze the 8-m^3 (50-bbl) pill into the formation at no more than 320 L/min (2 bbl/min).
5. Hold pressure on the pill until 5 hours have passed since initial pumping.
6. Ream through plug and continue drilling ahead. If losses are again encountered, an additional pill can be mixed, and the procedure repeated.

After the initial and highly successful trial, the procedure described in this paper was continued to ensure the procedure was in fact a feasible solution to the sub-salt thief zone problems. The procedure has since been adopted as standard practice for the Hassi Messaoud field. Some of the definitive advantages of the CTACP procedure include:

- Reduced non-productive time by eliminating tripping time associated with cement squeezes, resulting in fewer days to TD with production brought on line faster for an average time saving of 7.5 days per well.
- NPT minimized with mixing and storage of CTACP slurry prior to drilling into loss zone.
- The procedure does not require water-based spacers ahead of and behind the pill. Thus, reduced washout across the salt sections and less cement volume required for casing.
- Reduced risk of borehole instability in the formations due to the reduced exposure time and underbalanced static periods.
- CTACP is very effective at increasing formation integrity. The drilling progress after each CTACP has been better than previously recorded in offset wells.
- The CTACP is easy to mix and pump. A cement pump is not required (on the initial trial a cement pump was used).
- No additional drilling fluid treatment was required after each plug. Previously, after each cement squeeze, treatment was necessary.
- The CTACP is compatible with the drilling fluids typically utilized on the Ghadamiss Basin Field.

Conclusions

Based on the highly successful application of the CTACP in the sub-salt thief zone of Ghadamiss Basin Field, several conclusions can be drawn.

- A well-defined and engineered strategy for managing the onset of lost circulation below the salt formations was critical to improving the drilling efficiency in the Ghadamiss Basin Field.
- Strict adherence to the agreed upon decision tree ensured the successful implementation of the CTACP methodology.
- Significant reductions in non-productive time were possible through elimination of trips associated with cement squeezes.
- Production came online earlier than planned.
- Application of the CTACP technology eliminated the lost time associated with preparation of alternative pills. The CTACP slurry is prepared prior to the onset of lost circulation.
- Reduced NPT by eliminating tripping time for cement squeezes saving an average time of 7.5 days per well.
- A higher quality wellbore was available for cementing due to reduced washouts typically associated with placing cement plugs.
- After spotting and squeezing the CTACP, fluid losses were eliminated, and full circulation was maintained while drilling to TD.
- The CTACP approach has been adopted as standard practice on the Ghadamiss Basin when encountering severe losses in the sub-salt thief zone.
- The CTACP is NOT recommended for producing zones as the material does not degrade and is not acid soluble.
- Success in the Ghadamiss Basin suggests that the CTACP might be an ideal material for attacking Gulf of Mexico sub-salt thief zones.

Acknowledgments

The authors thank the Operator for the real-time monitoring and data analysis critical to making informed decisions while drilling these challenging wells.

Nomenclature

BHA = Bottomhole Assembly
CTACP = Chemically Thermally Activated Crosslinking Pill
LCM = Lost Circulation Material
NPT = Non-Productive Time
TAG = Trias Argileux Greseux Formation
TD = Total Depth

References

Bruton, J.R., Ivan, C.D., and Heinz, T.J. 2001. “Lost Circulation Control: Evolving Techniques and Strategies to Reduce Downhole Mud Losses.” SPE/IADC Drilling Conference, Amsterdam, The Netherlands, February 27 – March 1, 2001. SPE/IADC 67735-MS. www.doi.org/10.2118/67735-MS

Sweatman, R., Faul, R., and Ballew, C. 1999. “New Solutions for Subsalt-Well Lost Circulation and Optimized Primary Cementing.” SPE Annual Technical Conference, Houston, Texas, October 3 - 6, 1999. SPE-56499-MS. www.doi.org/10.2118/56499-MS