AADE-19-NTCE-020

Insights into Mechanical and Differential Pipe Sticking with Case Histories from Sindbad Field, Iraq

Abo Taleb T. Al-Hameedi, Husam H. Alkinani, and Shari Dunn-Norman, Missouri University of Science and Technology

Abstract

During drilling the Tanuma and Zubair formations in Sindbad field, Iraq, stuck pipe presents a significant wellbore instability problem for vertical and deviated wells, and it is the cause for the majority of the non-productive time (NPT) in field's development.

In this paper, two case histories of mechanical and differential stuck pipe in Sindbad field were reported and analyzed. The first case history is from Well-6, the Tanuma formation (mud shale), which is a mechanical stuck pipe problem. The crew tried to use many treatments to release the drill-string, and there was a significant NPT due to this problem. The crew first moved the drill string up and down to release the drill string but it didn't work. Then, the crew used a blend of water, caustic soda, sodium carbonate, and lignosulphonate pumped in front of the sticking area to try to release the drill-string. After using many treatments without successfully releasing the drill-string, the crew decided to use diesel oil and stuck breaker material which finally worked and released the drill-string.

The second case history is from Well-11, the Zubair formation (sandstone and productive zone), which is a differential stuck pipe problem. The differential stuck pipe problem happened after using high mud pressure to drill a high permeability formation (Zubair formation). The crew used the in-balance method (u-tube) and it worked and released the stuck pipe.

The objectives of this paper are to distinguish the reasons behind mechanical and differential stuck pipe, to show how each one can be diagnosed, and to provide the appropriate treatments for mechanical and differential stuck pipe.

Introduction

Wellbore instability is defined when the wellbore diameter does not stay the same as the diameter of the bit that drilled the hole due to shear failure, tensile failure, and mud cake building up. One of the wellbore instability problems which are the cause for the majority of the non-productive time and cost in the drilling operation developments is pipe sticking. The stuck pipe is defined as the inability of pulling the drill string out of the hole due to downhole obstacles even though the maximum over-pull has been applied. Stuck pipe problems are generally divided into two categories – mechanical sticking and differential sticking. The proportion of incidents classified in each category varies with the type of well and the geographical area (Basra Oil Company, 2011).

Starting with the mechanical stuck pipe, it usually occurs in shale formations due to sloughing, swelling, or collapse issues. The shale lithology represents the majority of the rock being drilled, and almost 85% of drilling problems are related to shale failures (Azar and Samuel, 2007; Chen, 2003a; Nygaard, 2002; Yan, 2013). Shale is defined as sedimentary rocks that contain a majority of clay minerals and/or clay-sized and laminated (Shaw and Weaver, 1989). Chen et al. (2002) showed that borehole instability in shale formation is associated with shear failure at the wellbore walls (i.e. the hoop stresses around well bore exceeds the compressive rock strength (C_0) since the mud pressure isn't sufficient to support the wellbore, due to the salinity differences between the drilling mud and the shale formation fluid, or when the mud pressure exceeds the tensile strength and creates tensile failure). According to Fjaer et al. (2008), there are multiple parameters that have a significant or minor impact on these two failure mechanisms such as high-stress contrast, shale mechanical properties, shale mineral composition, and shale anisotropy, bad design of the mud weight, mud properties, well trajectory design, and thermal issues.

Secondly, differential sticking which is related to pressure management was identified as significant problems for several wells over the world in the drilling operations, particularly in productive zones. Due to the over-balanced drilling phase, mud pressure acts on drill-string against filter cake deposited on permeable formations. Because of increasing drilling costs and non-productive time that is related to differential sticking, this issue is considered as one of the most serious drilling problems. It can range in severity from minor inconvenience to major complications, which can have significant negative unwanted consequences such as loss of the drill-string or abandon of the well. Differential sticking is required to be treated and should be freed as quickly as possible since the probability of freeing stuck pipe diminishes rapidly with time. Moreover, early identification of the reason for the differential sticking problem is essential, since each cause must be remedied with different measures. An improper reaction to the stuck pipe problem could easily make it worse (Basra Oil Company, 2016).

The Sindbad field is a super-giant field located in Southern Iraq. It covers approximately 800 km^2 area with an estimated

45 billion bbls STOIIP (stock tank oil in place) in multiple reservoirs. The field is currently in the first stages of commercial plan development, field assessment, and reservoir evaluation. Based on the data obtained from the vertical wildcat wells, several deviated wells have been drilled for long-term production. The majority of these deviated wells experienced severe wellbore instability issues in the drilling and completion stages, while only a few were completed without any wellbore instability issues. One of the most complicated problems in the Sindbad field is stuck pipe as mechanical due to shale issues and differential due to the over-balanced drilling and high permeability in the productive formations. Both of stuck pipe types are usually encountered during drilling the Tanuma and Zubair formations. The stratigraphic column of the Sindbad field is illustrated in **Figure A.1** (Appendix A) (Basra Oil Company, 2013).

The Tanuma formation is a shale formation with dark gray, brownish gray, black, slightly hard, fissile, occasionally sub blocky in place, no oil show, with a thickness between 92-160 meters. Many wells were lost or sidetracked due to the caving and swelling problem associated with shale penetration, particularly in directional wells. The Tanuma formation has all various types of shale, which are pressure shale, mud making shale-heaving, and stressed shale. To pass the Tanuma formation without any risk of instability, it is essential to monitor and design appropriate drilling fluid properties to avoid mechanical stuck pipe. While the Zubair formation is a sandstone formation with quartzes, very pale orange, pale yellowish orange, firm, very fine grain, subrounded, subspherical, well sorted, good visible porosity, good inferred porosity, good inferred permeability, and weak oil show. The Zubair formation is a productive zone with a thickness between 400-450 meters. The differential stuck pipe commonly happens in the Zubair formation due to the over-balanced drilling and high permeability (Basra Oil Company, 2013).

This paper is a combination of two case histories and analysis of successfulness of various techniques used to combat stuck pipe events in the Sindbad field. Data were gathered from drilling reports and analyzed to better understand both types of stuck pipe. Analysis of the case histories indicates a probable success rate with the "best" method varying by formation. The data presented in this paper are focused on the Sindbad field. However, this work can serve as a practical guide for developing stuck pipe mitigation and treatments strategies for formations with similar geological properties.

Mechanism of Mechanical Stuck Pipe and Identification

Because of physical restriction of the drill-string, the mechanical stuck pipe is usually experienced. Technically, there are various types of the mechanical stuck pipe, the first one is due to shale swelling and sloughing and it is related to chemical effect due to the salinity differences between the drilling mud and the shale formation. This type of mechanical stuck pipe will usually be encountered in mud making shale-heaving and stressed shale. The second type is drill pipe pack off due to the inefficient hole cleaning. Mechanical pipe sticking often called pack off when the cuttings and caving are wrapping around the drill string and prevent the movement. Warren et al. (1940) mentioned that pack off mechanical stuck pipe majorly occurs due to improper hole cleaning or formation degradation, and during pulling out the drill-string, the cuttings will fall by different sources such as hole washout (low flow rate), or inefficient fluid properties. As the hole over-gauges, the annulus velocity is minimized. Thus, the solid particles tend to settle down in the upper part of the drill-string tool joint because of hole restriction. The last type of mechanical stuck pipe is due to collapse issues when the stresses around the compact shale formation are higher than the compressive strength, and the mud pressure isn't sufficient to support the wellbore. The borehole potentially suffers from mechanical sticking pipe in shale formation if the chemical and physical properties react with the drilling fluid, forcing the shale to stick (or gummed) to the pipe (Devereux, 2012).

The mechanical stuck pipe can be identified by some indications such as initially having too much cutting on shale shaker, then the mud cycle will be lost and there are no cuttings over the shale shaker, the drill string can't be moved up, but it can be moved down only. **Figure A.2** (Appendix A) shows the mechanical stuck pipe due to the shale swelling **(Figure A.2a)**, compact shale **(Figure A.2b)**, tectonically stressed shale **(Figure A.2c)**, and fractured and faulted shale **(Figure A.2d)**.

Mechanism of Differential Stuck Pipe and Identification

''Differential sticking happens when the borehole pressure is substantially higher than the pore pressure in a permeable formation. Furthermore, the friction coefficient, inappropriate fluid loss controller as well as solid removing efficiency and BHA exposure time to the formation are intensified factors to the differential sticking'' (Rabia, 2010). According to Gray and Darley (1980), friction increases between the drill-string and the dehydrating and compacting cake, resulting in increased torque and drag. Once drag exceeds the power of the rig, the drill-string is stuck. The situation becomes worse with time as filter cake builds up around the stuck pipe section. Thus, increasing the area of contact between the drill string and filter cake, and most importantly, increasing the force required to pull the pipe out. The force required to free the pipe is a function of the differential pressure, the contact area, as well as the friction between cake and pipe and is given by Equation (1), **Figure A.3** (Appendix A) illustrates the differential stuck pipe (Basra Oil Company, 2016).

$$\boldsymbol{F = A \times (HP - P_f) \times f} \quad \textit{… (Eq. 1)}$$

Where F is a force to pull drill string free in Newton (N), A is filter cake contact area in cubic meters (m^2), HP is hydrostatic pressure in kilograms per squared centimeters (Kg/cm^2), P_f is formation pressure in Kg/cm^2, and f is friction coefficient.

The differential stuck pipe can be detected by some indications such as only one side stuck, mud cycle to the surface is available, and drill string can't be moved up or down.

Case Histories (General Considerations)

Mechanical and differential stuck pipes represent a major challenge for well designers. Many unwanted consequences are associated with drilling through shale formations such as fluid invasion, shale swelling, cuttings dispersion, and collapse issues. Also, drilling through permeable formation with over-balanced drilling phase causes differential stuck pipe. Thus, an appropriate selection of the drilling mud is required during drilling mud-heaving and stressed shale in order to avoid or at least mitigate the chemical interaction between the drilling fluid and the shale formation. Examples of these drilling fluids, which have to be used to drill mud making shale-heaving and stressed shale, including but not limited to, oil-based mud (OBM) and potassium chloride (KCL) mud. In addition, sufficient mud weight has to be used to drill compact shale (pressure shale). For high permeable formation, the mud weight has to be carefully designed, and it should be less than the mud weight that causes differential stuck pipe. The following case histories are from the Sindbad field.

Case 1. Using a Specific Chemical Pill to Stop Mechanical Stuck Pipe in the Tanuma Formation, Well-6, Sindbad Field

As mentioned earlier, the Tanuma formation has all various types of shale, which are pressure shale, mud making shale-heaving, and stressed shale. However, in this case history, mechanical stuck pipe has been presented due to swelling, sloughing, and pack off. At that time, fresh water-based mud was used to drill this formation, and due to the salinity differences and inefficient hole cleaning, mechanical stuck pipe was encountered. This problem was detected due to drag and over- pull during pulling out the drill string for new drill pipe connection. In addition, the mud cycle was lost over time, and there was no potential to move the drill-string up.

The first treatment that was prepared and implemented by the drilling crew is a washer chemical pill, and it consisted of the following chemical additives:

- 5 m^3 of water.
- 25 bag of caustic soda (NaOH), each bag had 25 kg.
- 5 bag of sodium carbonate (Na_2CO_3), each bag had 25 kg.
- 5 bag of Lignosulphonate, each bag had 25 kg.
- 3 bag of Chrome-lignosulphonate, each bag had 25 kg.

The total volume of this pill was 5 m^3, and it was a high alkalinity pill. It was pumped and displaced in front of the stuck area using normal drilling fluid. Most of the treatment was pumped and displaced in front of the bit and drill collar since the severity of this type of mechanical stuck pipe is usually associated with the bit and drill collar. The pill was pumped and displaced using low flow rate (Q) to provide sufficient exposure time to the stuck area to be effectively treated by this pill. The ultimate functions of this pill are to minimize the mud cake and the contact area between the wellbore and drill-string, to dissolve the accumulated cuttings around the stuck area, to lubricate the stuck area, and then to free the drill string. After pumping and displacing the pill in front the stuck area, one hour as waiting time was applied, and then workover the drill-string (move the drill string up and down) was used to release it every fifteen minutes, and this was repeated for five times. However, the above pill wasn't successful to free the stuck pipe (Basra Oil Company, 2016).

Due to the failure of the above treatment, another treatment was used to combat the mechanical stuck pipe, and it consisted of the 200 litters of stuck breaker and 6 m^3 of diesel oil. The new pill was pumped and displaced in front of the stuck area, and the waiting time was six hours to allow a sufficient time of interaction between the treatment and the stuck area. The same mechanism that was utilized in the first treatment was utilized in this treatment, but it wasn't efficient to release the drill-string. Then, an expert mud engineer suggested increasing the concentration of the second pill 400 litters of stuck breaker and 8 m^3 of diesel oil. He also proposed to pump and displace the pill gradually in front of the stuck pipe to provide effective interaction between the pill and the stuck area. The total volume of this treatment was 8 m^3, and it was pumped partially to the stuck area as 2 m^3 at each time and wait 2 hours, and then repeat the same procedure. This strategy was successful to free the drill-string from the stuck area, and then the drilling operation was resumed without any problems (Basra Oil Company, 2016).

Case 2. Using Various "U" Tube (In-Balance) Technique to Stop Differential Stuck Pipe in the Zubair Formation, Well-11, Sindbad Field

The Zubair formation is a productive zone with high permeability, the differential stuck pipe was experienced in this formation, the permeable layer was exposed to high overbalance drilling, the drill-string movement was very slow and was left stationary for a while, large contact area between drill string and the borehole walls was presented, and thick filter cake formed in the wellbore due to high mud weight. **Figure A.4** (Appendix A) illustrates the closest image for what happened when penetrating through the Zubair formation in Well-11.

Initially, 6 m^3 of crude oil was pumped and displaced in front of stuck area. The aims of this action were to lubricate stuck area, to reduce the surface tension, and also to minimize the mud pressure in the annulus. This was helpful in mitigating the differential stuck pipe, but didn't free the drill-string. Then, "U" tube (in-balance) method was applied to release the drill string from the stuck area. This technique was applied by pumping drilling mud in the drill-string with mud weight less than annulus. The purpose of pumping low mud weight in the drill string is to have flow-back from the annulus to the drill-string and reduce the mud pressure in the annulus. This approach was successful in reducing the mud pressure in the stuck area, and then the drill-string was released (Basra Oil Company, 2016).

Conclusion

Pipe sticking issue is very common and serious, and most fields in the world suffer from the stuck pipe during drilling operations. Hence, it is a challenging problem to be prevented or mitigated during drilling. This paper summarizes the experience of drilling wells using various methods to combat the mechanical and differential stuck pipe. The experience gained while drilling these wells has led to a better understanding of the advantages of using different techniques to free the stuck pipe.

Based on this study, the following conclusions were made:

- Summarize the real case history from drilling data with integrated analysis will provide a cohesive image for solving the challenging problems during penetrating troublesome problems. Thus, it is crucial to have more case histories to be developed as practical and substantial sources that will serve as reference material for controlling drilling operations problems at the well-site for drilling personnel.
- Stuck breaker and diesel oil pill can effectively be used to release the mechanical stuck pipe; however, this method should be implemented with the right and the accurate procedures to guarantee a high percentage of success.
- It is crucial to find alternative approaches if conventional treatments don't remedy the stuck pipe. In addition, a quick economic evaluation is desirable before doing any action. For instance, "U" tube (in-balance) technique was presented in this paper as an efficient way to release the differential stuck pipe in high permeability formation.

Acknowledgments

The authors would like to thank Basra Oil Company for providing us with various real field data about these case histories.

References

1. Basra oil Company. Various Daily Reports, Final Reports, and Tests for 2007, 2008, 2009 and 2010, 2013, 2016. Several Drilled Wells, Basra oil Fields, Iraq.
2. Azar, J. J., & Samuel, G. R. (2007). Drilling Engineering. PennWell Corporation.
3. Chen, G., Chenevert, M. E., Sharma, M. M., & Yu, M. (2003). A study of wellbore stability in shales including poroelastic, chemical, and thermal effects. Journal of Petroleum Science and Engineering, 38(3-4), 167–176. http://doi.org/10.1016/S0920-4105(03)00030-5.
4. Nygaard, R., Hareland, G., D., Budiningsih, Y., Terjesen, H. E., and Stene, F. (2002). Eight Years Experience with a Drilling Optimization Simulator in the North Sea. Presented at SPE/IADC Asian Conference, Jakarta, Indonesia, 9-11 September. SPE-77247.
5. Yan, C., Deng, J., & Yu, B. (2013). Wellbore stability in oil and gas drilling with chemical-mechanical coupling. The Scientific World Journal, 2013(1993). http://doi.org/10.1155/2013/720271.
6. Shaw, D. B., & Weaver, C. E. (1989). The mineralogical composition of shales, 35(1), 213–222.
7. Chen, X., Tan, C. P., Petroleum, C., & Haberfield, C. M. (2002). A Comprehensive, Practical Approach for Wellbore Instability Management, (December).
8. Fjar, E., Holt, R. M., Raaen, A. M., Risnes, R., & Horsrud, P. (2008). Petroleum Related Rock Mechanics: 2nd Edition. Elsevier Science.
9. Al-Ameri, K.T., Jafar, M.S.A., Pitman, J. 2011. Modeling Hydrocarbon Generations of the Basrah Oil Fields, Southern Iraq, Based on Petromod with Palynofacies Evidences. AAPG Search and Discovery Article #90124 © 2011 AAPG Annual Convention and Exhibition, April 10-13, 2011, Houston, Texas.
10. Warren, J. E. (1940, January 1). Causes, Preventions, and Recovery of Stuck Drill Pipe. American Petroleum Institute.
11. Devereux. (2012). Devereux, Steve. Drilling Technology in Nontechnical Language (2nd Edition). Tulsa, OK, USA: PennWell, 2012. ProQuest ebrary. Web. 28 December 2015. Copyright © 2012. PennWell. All rights reserved. (December).
12. Schlumberger Company. 2016. Prevention and Control of Stuck Pipe Best Practices.
13. Rabia, H. (2010). Well Engineering & Construction, 248.
14. Gray, G. R., Darley, H. C. H. (1980): Composition and Properties of Well Drilling Fluids, Gulf Publishing Co., Houston-London-Paris-Tokyo, 1980.

Appendix A

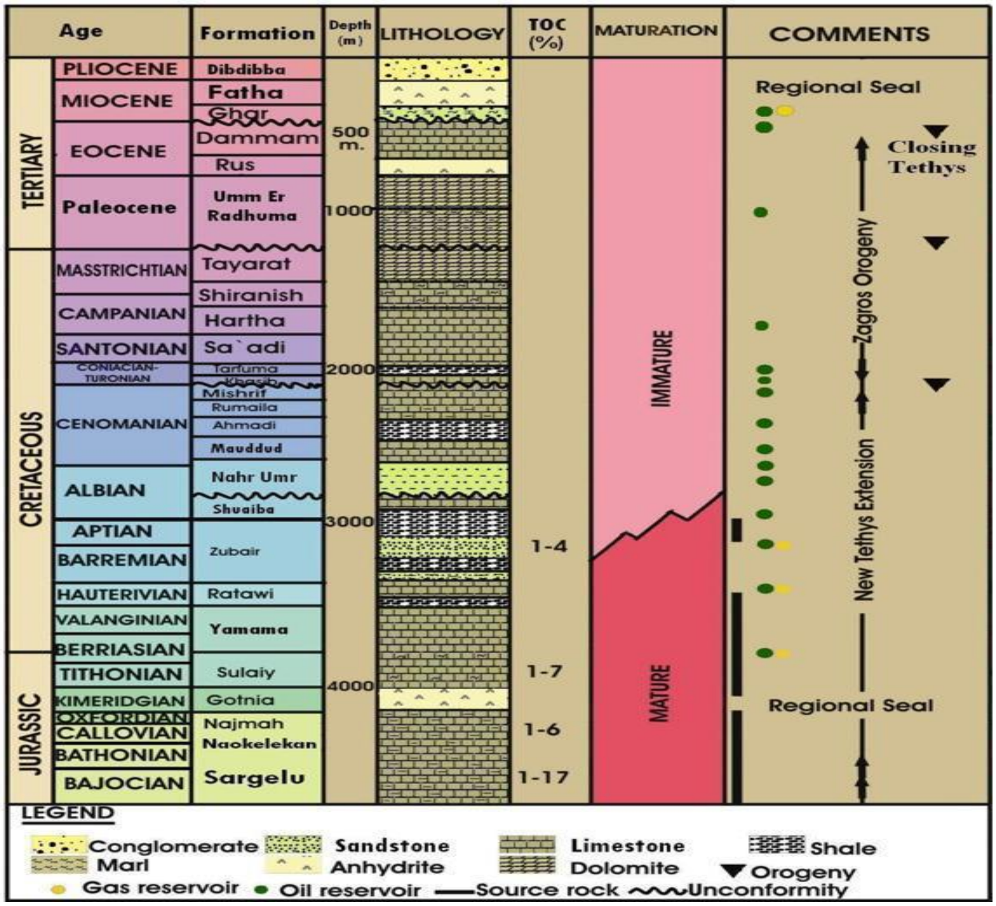
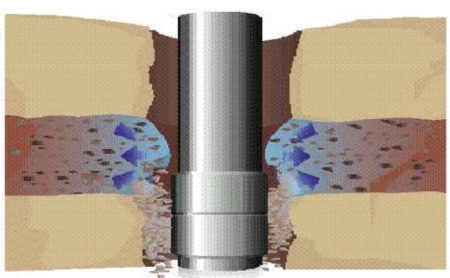
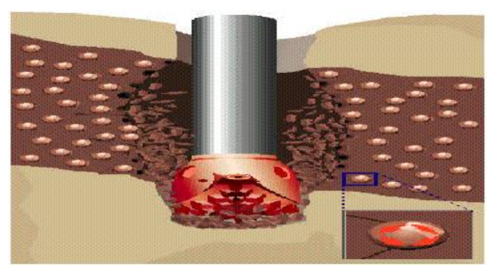


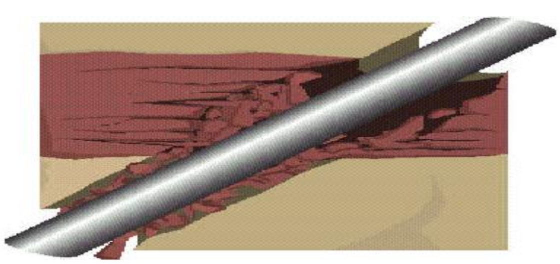
Figure A.1. Stratigraphic Column of Sindbad Field (Al-Ameri et al., 2011)



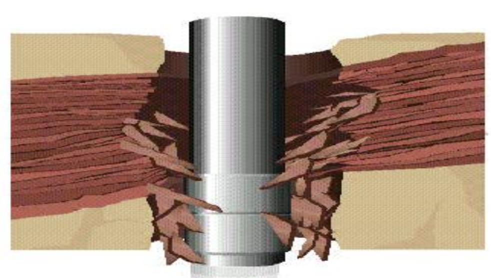
(a) Mud Shale Swelling



(b) Compact Shale



(c) Tectonically Stressed Shale



(d) Fractured and Faulted Shale

Figure A.2. Mechanical Stuck Pipe with All Various Types of Shale (Schlumberger, 2016)

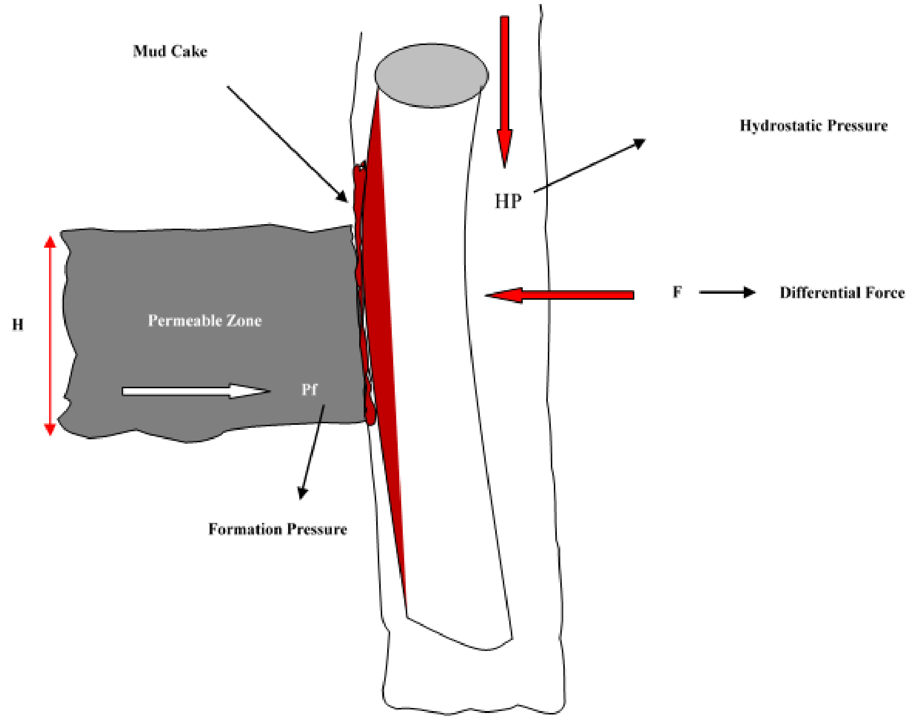


Figure A.3. The Differential Stuck Pipe (Basra Oil Company, 2016)

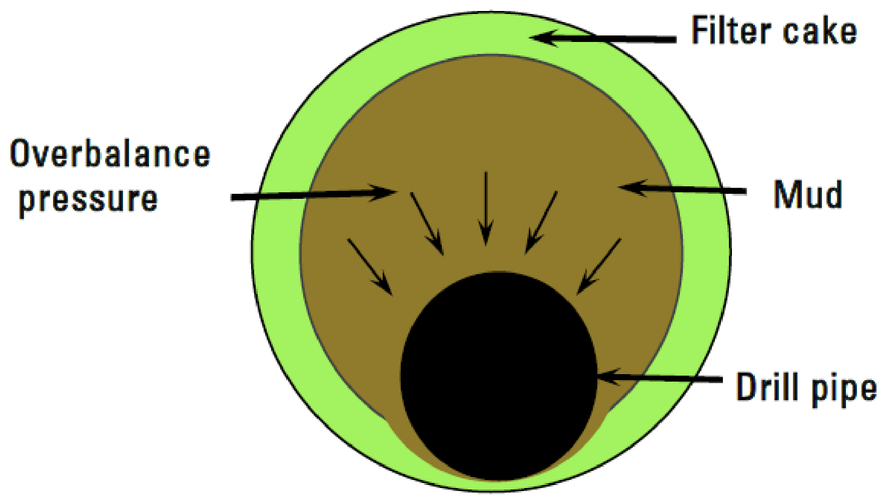


Figure A.4. Illustration of what happened in the Zubair Formation (Schlumberger, 2016).