GEO India 2018

PaperID **AU366**

Author **Nitin Bhardwaj , Reliance Industries , India**

Co-Authors **Ashutosh Kumar, Karthikeyan Gunasekaran, Jayanta Dutta**

G&G Perspective on Well Integrity Risks and Mitigation Strategies in Deepwater Petroleum Operations

Abstract

Globally, the approach towards well integrity in petroleum operations are commonly built around the development of engineering solutions to provide structural barriers in the well. However, apart from the loss of physical or mechanical barriers there are various geological characteristics of the subsurface, which if not understood properly can lead to situations where control on the well could be lost or compromised. In this paper, authors provides a geological perspective and overview on the key subsurface risk and hazards which can potentially lead to well integrity issues during drilling and production phases. We have classified the key geological risks into 5 broad categories. Each of the risk category if not mitigated suitably can lead to Non-Productive Time (NPT) in least case or to a catastrophic wellbore failure which can jeopardize the well control in the worst case. The paper also proposes key effective multi-disciplinary strategies for better classification and mitigation of such geological hazards, thereby reducing well integrity risks.

Introduction

Well integrity and loss of well control has always remained a critical issue in the development of oil and gas fields. Such events can not only effect the safety of personals, it also negatively affect the project economics and can potentially pose danger to environment. Globally, in exploration and production sector the scope of well Integrity is commonly seen through the prism of engineering applications and solutions. .They are primarily focused towards the installation of robust barrier system which can reduce the risk of uncontrolled release of formation fluids throughout the life cycle of the well. Though this approach and strategies is built around the development of engineering solution to provide physical structural barriers in the well, it is also imperative to first understand various geological characteristics of the subsurface, which if not characterized and defined accurately will invariably lead to well integrity issues. An improved understanding of key subsurface geological hazards can not only leads to better identification of Risks and Challenges towards Well Integrity, it also facilitates in providing optimum engineering solutions.

Though the hazards associated with loss of well integrity are present in all the operating conditions, however risks and challenges in Deepwater Operations are far greater as Cost, Time, Equipment, Logistics, and Expertise needed to solve them are many folds greater than in the case of onshore or shallow waters operations. In this paper, authors provide a geological perspective and overview on the key subsurface risks and hazards which can potentially lead to well integrity issues during drilling and production phases. The paper also proposes the key effective multi-disciplinary strategies for better classification and mitigation of such geological hazards.

Key G&G Risk and Challenges

We believe that in a comprehensive well integrity management system, before we start looking at the engineering solutions, we should first undertake the classification of key risks present in the subsurface. The risk classification should cover the whole life cycle of well from drilling to abandonment. This process needs to be an integrated approach involving all the key stake holders, i.e. Drilling and Completion, G&G Operations, Pore Pressure and Geomechanics, Asset and Subsurface plus reservoir and production engineering teams.

We have classified the key G&G risks into 5 broad categories **(Figure 1)**. These risk categories are: 1) Shallow hazards, 2) Overpressured Subsurface Formation, 3) Formations having high in-situ stresses and low mechanical strength, 4) Faults and Fractures intersecting wellbore trajectories and 5) Depletion induced differential stresses. The first 3 risks are likely to be encountered during drilling and completion phase of operations, while 4 and 5 are usually come across during the production phase of Petroleum operations. Each one of these 5 categories possess considerable risk and may lead to number of well events, highlighted in the **Figure 1**.

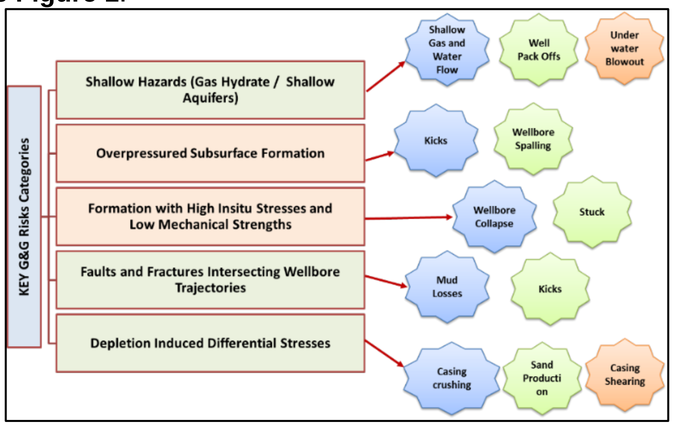

Figure 1. Key G&G Subsurface Risks and associated Well Integrity Events

If not mitigated, Shallow hazards can cause Well pack offs, shallow gas and water flows, sunken well heads, and underwater blowout in worst case. Overpressured subsurface formation can trigger kicks and wellbore spalling and even lead to blowouts in worst cases. Formation with high in-situ stresses combined with low mechanical strength are regularly candidates of wellbore collapse and stuck situations. Faults and fractures intersecting wellbores are often zones of mud losses to even unexpected kicks. Depletion induced differential stresses are repeatedly the prime reasons for sand production and crushing or shearing of lower completion equipment.

Key G&G Well Integrity Risks during Drilling

Drilling and completion phases of petroleum operations in deep water operations involves large amount of capital investments, where daily operational rates may range from 0.2 Million USD / Day to 0.5 Million USD. With such high amount at stake, high NPT associated with well integrity issues can potentially derail the project. Hence issues of well integrity should be taken with an integrated, systematic, detailed and robust approach with all the contingencies covered.

Shallow Hazards

Shallow hazard are generally referred to as the "Adverse Subsurface conditions that may be encountered prior to the setting surface casing and emplacement of BOP (Blow out Preventer) onto the well". In offshore deepwaters, shallow hazards are often located within the top 600-700m of sediment from the seabed. This shallow zone of sediments is usually drilled without BOP in place, this necessitates that all risk and hazards within this zone should be carefully identified and mitigated**. Figure 2**, shows the major shallow hazards in deepwater operations. Seabed anomalies, such as Mud Volcanoes, Gas vent, Gas Hydrates, and unstable slope poses high risk towards well head integrity at seabed. Drilling underbalanced into Bright Amplitude bodies can lead to shallow water and gas flows, while soft sediments and reactive clays can cause pack off situations. Following are few strategies that can be employed to mitigate the above shallow hazard risks:

- Wherever possible, high resolution seismic data should be used to identify and delineate the high amplitude shallow bodies. Once identified they should be thoroughly characterized and classified based on their seismic response and log behavior (if penetrated earlier by offset wells).

- In case of high risk classification, pilot holes should be drilled before the main hole to ascertain the risk. Detailed drilling plan to be prepared for such shallow hazard pilot holes with contingencies covered. One of the key aspect of this is to have proper logistic support as PAD (pump and dump) mud requirement for such pilot holes may exceed the rig storage capacity.
- Another important element is to have Real time monitoring through ROVs (Remotely Operated Vehicles) at wellhead for any sign of water or gas flow.
- Inclusion of Pressure and Logging While Drilling (PWD / LWD) Tools during drilling of Tophole sections provides valuable data for real time decision making. PWD tools can give early signs of impending stuck situations due to reactive clays.

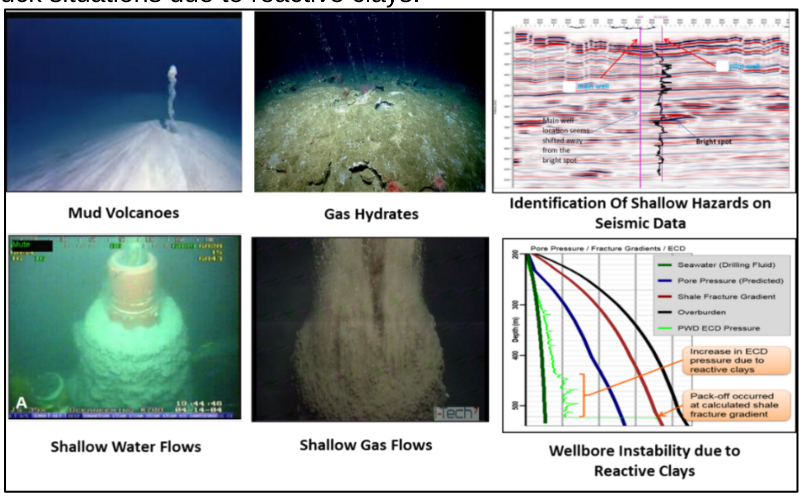

Figure 2. Major Shallow Hazards Risks in Deepwater Settings (courtesy @ References1, 5, and 6)

Overpressured Formations

Overpressured formation, i.e. formations having pressure higher than the hydrostatic pressure poses a serious threat and risk during drilling operations. Drilling into unexpected high pressure permeable formations can lead to a “kick” (influx of fluids into the wellbore) which if ignored or not mitigated can turn into a blowout. Even if the formations are not permeable i.e. shales but have high pore pressure in them can lead to wellbore instability if drilled underbalance due to wellbore spalling issues. Hence, identification of high pressure formation and estimation of pressure magnitude in them is of critical importance in delivering Safe Wells.

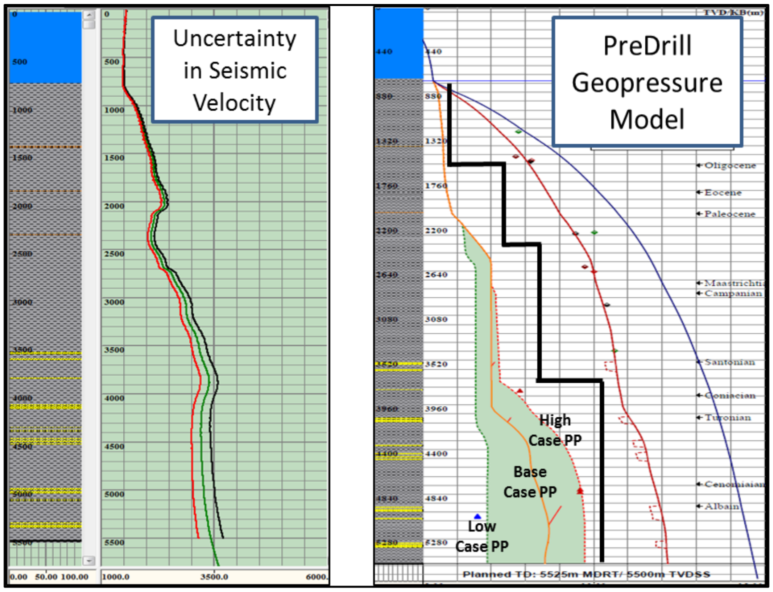

Figure 3. Velocity Uncertainty and Predrill GeoPressure Model with Low, Base and High Cases

An integrated and robust Pore Pressure Modelling process during Well Planning stage can greatly mitigate the risks of encountering kicks. The critical factor in this process is to properly define the uncertainty range in the pore pressure model **(Figure 3).** Following are few strategies that can be employed to mitigate the above overpressure formation risks:

- Employ integrated modelling process, which include multi domain approach of combining offset well analog models with the seismic velocity and basin modelling based pressure outputs.
- Perform uncertainty analysis in the input dataset i.e. seismic velocities, as well in the process, i.e. defining normal compaction trend (NCT).
- Generation of Low, Base and High case pressure models instead of single model.
- Have contingency plans ready for the high case pressure scenario.
- Utilization of Logging While Drilling (LWD) tool for real time monitoring and optimization.

Formation having high In-situ Stresses and Low Mechanical Strength

Subsurface formations through the process of sediment deposition accumulate both vertical as well horizontal stresses over geological time. These stresses are primarily generated due to combined weight of overlying rocks and fluid in them. If the effective subsurface stresses become excessive than the rock strength, they can lead to rock failure which creates wellbore instability and wellbore collapse **(Figure 4).** If not mitigated quickly, then excessive wellbore collapse can create drilling string stuck problems to even full loss of wellbore. This problem is more pronounced in case of deviated, high angle and horizontal wells, which experience higher differential stresses than the vertical wells. The critical factor to avoid such wellbore instability issues is to have a robust and carefully designed mud weight and mud properties. The pre-requisite in achieving a robust mud weight design is it to have well calibrated and integrated geomechanical earth model, which describes both subsurface stresses as well as rock mechanical properties.

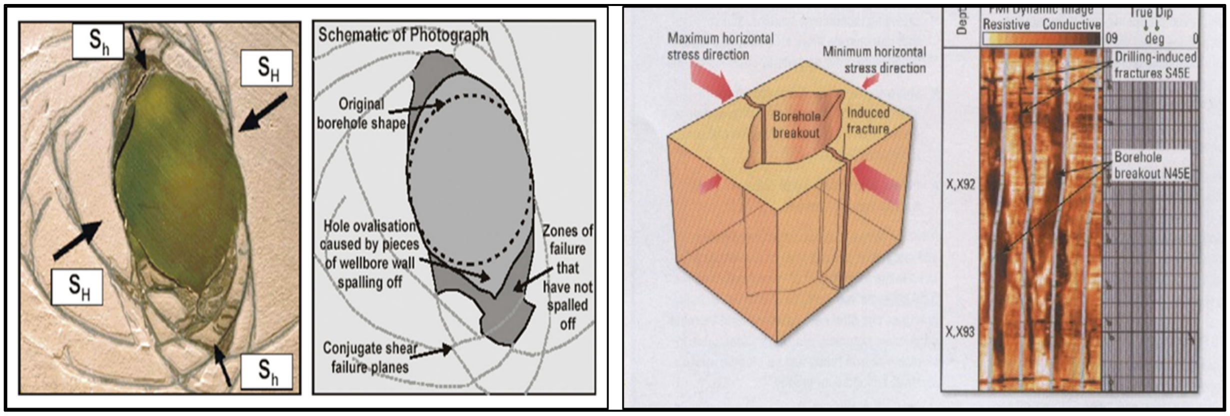

Figure 4. Wellbore Instability and wellbore breakouts due to high In-situ Stressres. (Courtesy @ Reference 4)

Following are few strategies that can be employed to mitigate risks of wellbore instability due to high insitu stresses and low mechanical strength:

- Utilize calibrated Geomechanical Earth models to identify the zones susceptible of wellbore breakout failure and wellbore breakouts.
- If possible use Real Time Image data (Density or Sonic Images) from Advance LWD (Logging While Drilling) tools for monitoring and early identification of wellbore breakouts.
- Employ trained Mud logging service personnel to identify caving associated with wellbore failure at rigsite.
- Utilize advance mud logging equipment like cutting flow meters, which can give early indication of excessive cuttings or caving's generated in the hole. This is especially useful in case of horizontal or extended reach wells.
- Have contingency plans ready in case of excessive wellbore breakouts.
- If breakout does occur and mitigated successful, carry out detailed data acquisition and analysis for optimization in future wells.

Faults and Fractures Intersecting Well Trajectories

Planning well trajectories through faults and major fractures **(Figure 5)** always carries risk of heavy mud losses, hole pack offs and stuck situations. The risk associated with them is primarily governed by the nature of fault as a fluid conduit, i.e. whether faults are likely to be sealing or leaking in nature. Leaking faults will carry far more risk than the sealing faults if well trajectories are passing through them. If the faults are critically stressed i.e. in-situ stresses acting on fault plane are strong enough to cause it to slip then the fault are much likely to be leaking than sealing. 3D geomechanical analysis are required to ascertain which faults in the area of interest are critically stressed and which are not. Apart from heavy mud losses, leaking faults also carries risk of transmitting high pressure from deeper formation to shallower depths.

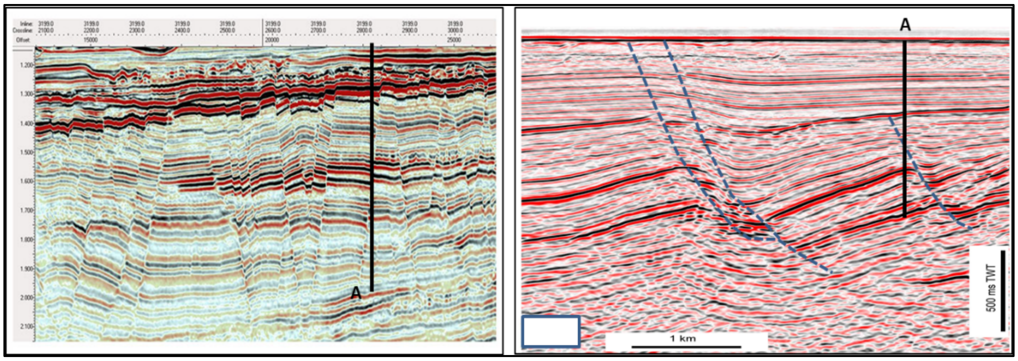

Figure 5. Typical situation of well trajectory intersecting with faults (Courtesy @ References 7 and 8)

Following are few strategies that can be employed to mitigate well integrity risks associated with fault and fractures intersecting well trajectories:

- Utilize high resolution Seismic data and specific seismic attribute such as coherency volumes to identify the faults and fracture on a field scale.
- Employ 3D Geomechanical stress analysis to identify the critically stressed faults.
- In case, high risk is associated with certain faults, it is best to avoid them by altering the well trajectories. If unavoidable, reduce the wellbore exposure to the fault zone.
- Have contingency plans ready in case of heavy mud losses.

Key G&G Well Integrity Risks during Production

Hydrocarbon production from subsurface reservoirs induces pressure change them, this in turn changes the in-situ stress field within the reservoir. These stress change can have adverse impacts such as compaction of the reservoir, sand production in the wells and fault reactivation. All of which can compromise the well completion integrity. In extreme cases it can lead to loss of well control.

Depletion induced differential stresses

Differential stresses in the reservoir start developing as soon as we start production from any reservoir. These are mainly generated due to unequal increase in vertical and horizontal effective stresses within the reservoir as a consequence of reduction in reservoir pressure. Since the pressure reduction is more near the wellbore area, excessive increase in differential stresses near the wellbore area may lead to rock deformation which can cause sand production issues in weakly consolidated reservoirs if sand exclusion strategies are not employed **(Figure 6)**. With production, depletion effect reaches away from near wellbore area which in turn can cause compaction process at field scale. If compaction magnitude is high, it may in turn induce faulting within the reservoir or re-activate pre-existing faults. Both, sever compaction and faulting or reactivation of faults can lead to damage of production casing or lower completion equipment's **(Figure 6)** if not accounted during project planning phase. Following are few strategies that can be employed to mitigate well integrity risks associated with depletion induced differential stresses:

- Acquire high quality data for geomechanical analysis during the appraisal phase before the start of development.
- Employ 3D-4D Geomechanical analysis in understanding reservoir behavior during depletion phase.
- If sanding risk is high, employ sand exclusion in the completion strategy. If risk is low and surface or production facilities are capable of handling solid production then go for sand management strategy.
- In case of high compaction risk, employ compaction joints in the completion strategy.
- Avoid well trajectories through intra reservoir faults and fractured zones.

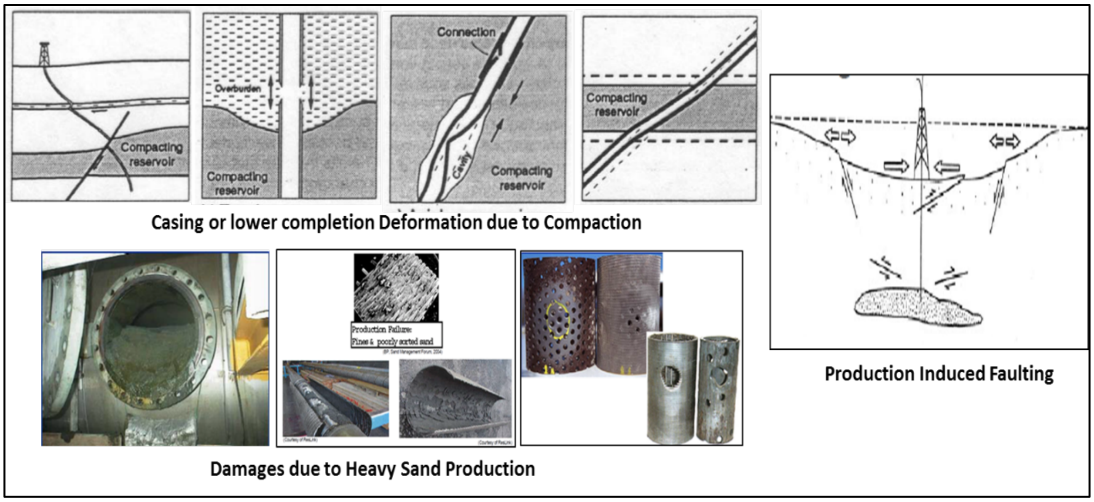

Figure 6. Key Hazards and Risks associated with Depletion (Courtesy @ References 2 and 3)

Summary and Conclusion

An in-depth and improved understanding of key subsurface geological hazards not only leads to better identification of Risks and Challenges towards Well Integrity, it also facilitates in providing optimum engineering solutions through the project life cycle. The key success factor in achieving robust well integrity practices is to employ multi-disciplinary and integrated approach and to have the worst case contingency plan ready.

Acknowledgement

We thank and appreciate the critical inputs received from Suraj P. Sharma and Nishikanta Kundu which helped us to improve the overall contents of the paper. We would like to thanks Reliance Industries Ltd., (E & P) Petroleum Business for giving us the permission to publish this paper.

References

1. Mannaerts, et.al, (2005). Atlantis, The Quest for Its Stray Shallow Water Flow Sands, OTC 17658.
2. Maurice B.D, et.a, (2001). Casing Shear: Causes, Cases, Cures, SPE 72060.
3. Segall, P, et.al, (1996). A note on induced stress changes in hydrocarbon and geothermal reservoirs, Techtonophysics, 298.
4. Wikel, K, (2011). Geomechanics: Bridging the Gap from Geophysics to Engineering in Unconventional Reservoirs, CSEG Recorder, 05.
5. https://flowergarden.noaa.gov/image_library/volcanoimages.html
6. https://www.usgs.gov/news/atlantic-methane-seeps-surprise-scientists
7. https://ihsmarkit.com/research-analysis/fault-enhancements-with-3d-log-gabor-filter-array.html
8. http://www.seismicatlas.org/entity?id=987bd642-cc8a-4f7b-9ac9-360abdf9cff1