

Mitigating the Risks Associated With the Acquisition of Formation Evaluation Data

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Abstract

Acquiring formation evaluation data is a critical element in the drilling of any well regardless of the location, well type, or well geometry. Risks associated in acquiring data can be classified as follows:

1. Lost rig time due to the inability of logging tools getting to bottom (bridging).
2. Lost rig time due to delays associated with making last minute arrangements for alternative logging methods when bridging problems become too severe.
3. Lost in hole charges associated with permanently sticking logging tools due to bad hole conditions.
4. Unsound decision making throughout the life of the well, because bad hole conditions, made the acquisition of formation evaluation data impossible.

The risks outlined above increase as wells are drilled at faster rates, with higher geometric complexity. Advanced drilling technologies allowing for access to difficult to reach petroleum resources will increase as the industry exploits unconventional resources and increasingly complex reservoirs.

Recent advances in formation evaluation technology and conveyance techniques allow for the acquisition of high quality petrophysical measurements regardless of borehole conditions or geometry.

Logging systems conveyed in the drill string, or through the drill string, have a 100% chance of getting to bottom on the first attempt. With the logging tools securely attached to the drill pipe, the risk of the logging tools getting stuck is also reduced.

The non-traditional conveyance techniques discussed in this paper bring operational optimization to formation evaluation.

Introduction

Throughout the history of the oil and gas industry, new techniques to locate and access oil and gas resources have been developed constantly. Improvements in materials, electronics, chemicals, and engineering techniques, to name a few, have allowed for the development of oilfield equipment that has improved the efficiencies of oilfield operations.

In addition, the need to develop harder to access oil and gas reserves, have led to many creative solutions in a number of disciplines engaged in oilfield activity. Techniques that increase well productivity, reduce damage to the formation,

and reduce the time to drill a well have all gained acceptance anywhere oilfield operations are conducted. This paper discusses the evolution of how new drilling and formation evaluation techniques have led to the need for complimentary solutions. Techniques which mitigate the risks involved in the drilling and formation evaluation process, and improve the efficiencies of oilfield operations will be presented.

The Development of New Drilling Techniques

To satisfy the demands of the oil and gas industry, drilling techniques have evolved in response to the need to drill increasingly more complex wells. Examples of these types of wells are:

- Wells drilled in deep, high temperature, high pressure formations.
- Wells drilled in remote locations.
- Wells drilled in offshore locations.
- Wells drilled with high deviations and complex geometries.
- Wells drilled horizontally in extended reach situations.
- Wells drilled to maximize formation productivity.
- Wells drilled that minimize formation damage.

Drilling techniques that will accomplish these items are directional drilling, horizontal drilling, coiled tubing drilling, and under-balanced drilling. The effectiveness of these techniques can vary from one region of the world to another; but generally, the popularity of these techniques continues to grow. Figure 1 illustrates the growth of horizontal and directional drilling.

Figure 2 illustrates the growth of coiled tubing drilling.

The Development of New Formation Evaluation Techniques

The development of formation evaluation techniques have focused on creating a broader range of measurement types to measure a wider range of formation properties. The need for improved knowledge of the formation, and wellbore environment has driven this evolution which has continued to the present day. Examples of this include the use of nuclear devices to measure porosity and lithology, the use of acoustic devices to measure rock strength, and the use of high resolution electrical devices to measure the orientation and stratigraphic features of rock units.

Formation evaluation techniques have also evolved with advancements in materials and computer technology. These

advancements have allowed for the development of equipment that has increased the well site efficiency of logging operations. Such developments include smaller and combinable logging tools, improved data handling capabilities, and high speed data transmission from down-hole to the office.

The need to acquire formation evaluation data in boreholes regardless of how they are drilled, well geometry, or location, has also created new approaches to formation evaluation techniques. Techniques such as LWD, MWD, various forms of drill pipe conveyed logging, and a few non-traditional wireline techniques, have all been developed to meet the challenges posed by the development in drilling technology. All of these techniques allow for the acquisition of formation evaluation data in challenging situations, and mitigate or eliminate the associated data acquisition risks.

Risks Involved in the Data Acquisition Process

Formation evaluation data acquisition is a critical element in the drilling of any well regardless of the geometry, location, or how it was drilled. Difficulties acquiring this data can pose financial risk for the operator which can vary from a few thousand dollars to millions of dollars. The following is an outline of the key risks associated in acquiring data.

1. Lost rig time due to the inability of wireline logging tools getting to bottom (bridging).

On the vast majority of wells drilled, formation evaluation is performed at the end of the drilling operation prior to running production casing.

Table 1 is a summary of the results of a study performed by Weatherford on the frequency of bridging. The study, undertaken between January 1997 and March 2005 in Canada, shows that on average, logging tools “bridge off” or are unable to get to bottom on the first attempt 7.4% of the time. It also shows that logging tools with a small diameter have a 50% greater chance of getting to bottom compared to conventional (larger) diameter tools.

The lost time related to bridging has also been investigated, and on average 15.6 hours of NPT are associated with each bridging event. The cost of this NPT has also been investigated and each bridging event, on average costs \$22.5K. Table 2 summarizes the lost time and costs associated with bridging.

In addition to the cost of the NPT, wellbore deterioration increases as the well remains open while formation evaluation efforts are attempted.

2. Lost rig time due to delays associated with making last minute arrangements for alternative logging methods when bridging problems become too severe.

When log data cannot be acquired using traditional wireline techniques, and the requirement for formation evaluation data still exists, alternative methods must be employed. Unless a strategy to effectively deal with this situation was planned as a contingency, the following financial risks begin to present themselves:

- a. Rig time charges while alternative arrangements are researched and sourced. Alternate equipment must be

compatible with existing equipment at the rig such as drill pipe, etc. In addition alternative logging suites are quite often not as comprehensive as traditional wireline suites.

- b. Mobilization, set-up, and operational charges to deliver alternate equipment to the well site.

The financial risks associated with this scenario can increase the formation evaluation costs by a factor of four and can result in compromises in the data that is ultimately acquired.

3. Fishing and lost in hole charges associated with permanently sticking logging tools due to bad hole conditions.

Occasionally, borehole conditions are such that wireline logging tools cannot be removed from the borehole without the aid of an intervention technique such as fishing. The financial risks associated with this scenario include the following:

- a. Rig time to work a stuck logging tool.
- b. Rig and equipment standby charges while intervention equipment is sourced and dispatched to the location.
- c. Damages to equipment that is successfully fished from the wellbore.
- d. Lost in hole charges if logging equipment cannot be recovered from the well.
- e. Costs to permanently abandon equipment lost down hole and to re-drill the portion of the well where the logging tool has been abandoned.
- f. Costs associated with abandonment of the well and the lost opportunity of production from that location.

4. Unsound decision making throughout the life of the well, because of bad hole conditions, made the acquisition of formation evaluation data impossible.

While not generally regarded as the worst case scenario (see point 3f), this scenario presents considerable risk throughout the life of the asset. When accurate information about formation depth, porosity, lithology, water saturation, etc, is not available, accurate determination of hydrocarbon reserves is not possible. The risks that arise from this include:

- a. Risks involved in the over or under assessment of the asset value.
- b. Risk in not knowing how to proceed when well performance changes.
- c. Lost production from wells that were abandoned prematurely due to lack of information about the reservoir.

Conveyance

Solutions to eliminate or mitigate the risks described above can be found in the study of conveyance. Conveyance is a developing body of knowledge that allows for the classification and development of techniques to allow for data acquisition regardless of borehole conditions or geometry. Table 3 is a summary of the conveyance techniques that are currently employed in formation evaluation operations throughout the world.

The conveyance techniques summarized in Table 3 present

solutions to most types of oil field operations, well types, and data acquisition scenarios. The following is a brief summary of each technique.

1. Logging While Drilling

Logging While Drilling system is a conveyance technique that combines open-hole data acquisition and drilling. Equipment employed in this system is designed with specifications to withstand the demands of the drilling environment. Measurement sensors powered by down-hole batteries or mud turbines located in the drill string, produce data about the borehole environment and formation. This data is transmitted to the surface while drilling using mud pulse or electro-magnetic telemetry. Alternatively, data can be recorded in down-hole memory subs for data acquisition during tripping operations.

Typical Applications

- Geo-Steering applications in horizontal wells and wells with complex well paths.
- Monitoring bore and annular conditions down-hole.
- Used as an alternative to wireline evaluation in high cost drilling areas.
- Applications in wells (vertical or deviated) where wireline logging is problematic.
- Underbalanced drilling.
- Directional wells utilizing MWD.

Benefits

- Geological sidetracks (without incurring wireline logging costs in dry holes)
- Pore pressure determination.
- Early hydrocarbon detection.
- Acquire log data while performing conditioning trips.
- Insurance – to ensure that a basic set of log data is obtained from an expensive exploration well, even if subsequent hole problems prevent wireline logging.
- Acquisition of data before the effects of formation wash out or excessive invasion impairs the measurement ability of wireline tools.

2. Wireline

Wireline was first used as a method of conveying logging tools in 1927, and today it is still the most versatile and widely used method of conveyance. Wireline serves four important functions in this conveyance technique:

- a. **Power Transmission:**
Electric power required to operate the down-hole tools is transmitted via conductors in the wireline.
- b. **Data Communication:**
 - i. Data commands necessary for down-hole tool function.
 - ii. Formation data acquired from tool measurements is transmitted via conductors in the wireline to the surface.
- c. **Depth Measurement:**
Wireline cables are marked and depth calibrated for depth determination of each measurement.
- d. **Conveyance:**
Logging tools are attached to cable heads constructed on the down-hole end of the wireline. The wireline and

cable head coupling allow for controlled pulling and breaking of the cable if excessive sticking should occur.

Typical Applications

- Logging vertical wells.
- Logging deviated wells where wellbore deviation does not impede the ability of gravity to facilitate tool descent.
- Used to convey both standard sized and small diameter logging tools.
- Used in open-hole and cased-hole applications.
- Can be used in rig and rig-less operations.

Benefits

- Most cost effective means of conveyance in low and medium cost drilling operations.
- Real time monitoring during the down-hole data acquisition process.
- Allows for interaction with down-hole pressure tools.
- Quickest method of deploying logging tools.
- Can be used to deploy any down-hole measurement device including third party devices.

3. Well Shuttle

The Well Shuttle is a conveyance method where a string of small diameter logging tools are conveyed to TD inside the safety of a drill pipe garage. Upon reaching TD, the logging tools are deployed into the open-hole by activation of the release mechanism. Activation can be done by a mechanical messenger or by a mud pulse. The logging tools are powered by down-hole battery packs and log data is recorded and stored in down-hole memory subs. Log data is recorded while tripping, and downloaded when the logging tools reach surface.

Typical Applications

- Logging horizontal wells.
- Logging vertical or high angle wells where wellbore conditions cause high incidence of bridging with wireline conveyance.
- Logging wells in locations where there are no wireline logging units.

Benefits

- No risk of bridging with logging tools.
- Circulate, rotate, and reciprocate pipe while logging.
- Reduce rig time while acquiring log data.
- Acquire log data regardless of well condition or geometry.
- Low lost in hole costs.
- Wireline quality data.
- Broad range of logging measurements.
- Helicopter deployment in locations not accessible by wireline units.

4. Through Drill Pipe Logging

Through Drill Pipe Logging is a conveyance technique that can be used when well restrictions, caused by sloughing formations, ledges, and other obstructions, make open-hole wireline conveyance problematic or impossible. With this technique, open ended drill pipe is lowered into the well below the zone(s) of restriction. Small diameter logging tools conveyed on wireline are then run through the drill pipe and

out into the open-hole below the drill string. Log data is acquired over the zones of interest, below the zones of restrictions, and transmitted real time to the surface unit. In wells with multiple zones of restriction, the drill pipe can be re-positioned in different locations in the well until full open-hole log coverage is attained. Figure 3 illustrates the operation in Through Drill Pipe Logging.

Typical Applications

- Used in wells to acquire open-hole data in zones below restrictions caused by sloughing formations, ledges, and other obstructions.
- Can be used as the primary conveyance method in anticipation of poor borehole conditions.

Benefits

- Saves rig time used for incomplete logging operations (bridging events).
- Saves rig time used for clean out and conditioning trips.
- Increased certainty of open-hole data acquisition.

5. Coiled Tubing

Coiled Tubing conveyance employs coiled tubing to convey small diameter logging tools into difficult-to-access wells. Two options are available in Coiled Tubing Conveyance:

a. Impulse Shuttle:

Small diameter logging tools can be conveyed safely inside a drill pipe garage attached to the end of the coiled tubing. Logging tools are released into the open-hole via mud pulse. Log data is recorded by the small diameter logging tools and stored into a down-hole memory sub. Log data is recorded while tripping, and downloaded when the logging tools reach surface.

b. Down-hole tension compression deployment:

Small diameter logging tools are attached to the end of the coiled tubing string and conveyed into the well. Down-hole tension and compression forces exerted on the logging string are monitored on the surface during the trip into and out of the well. Log data is recorded and stored into a down-hole memory sub. Log data is recorded while tripping, and downloaded when the logging tools reach surface. On coiled tubing units with embedded wireline, data can be transmitted to the surface while the tools are being tripped into or out of the well.

Typical Applications

- Used on wells drilled with coiled tubing units where hole conditions make for difficult wireline conveyance.
- Used in situations where coiled tubing units are employed to perform workover and remedial work.
- Used in small diameter holes (<4.75”).

Benefits

- Provides a solution for the conveying of logging tools into difficult wells.
- Provides a method of conveying open-hole logging tools into horizontal wells.
- Can acquire data in small diameter wells.

6. Slick-line

Small diameter logging tools can be deployed on Slick-line by attaching the tools directly to the end of the line. Deployment of the tools must be in memory mode and can be run on any slick-line, regardless of provider. Slick-line operations with small diameter tools are performed with pressure control equipment.

Typical Applications

- Used on wells in remote or difficult to access locations where slick-line is available on the location.
- Used on wells where high pressure or sour conditions exist.

Benefits

- Open-hole logging operations can be performed without the need for a braided cable logging unit.
- Provides a method of acquisition of open-hole logging data in high pressure sour conditions with the use of slick-line pressure control equipment.

7. Wireline Drop-off

Wireline Drop-off is a conveyance system that allows for open-hole data acquisition while tripping. In this technique, small diameter logging tools in memory mode are conveyed down-hole by wireline through the drill pipe conduit. The logging tools pass through the open ended drill pipe, and hang into the open-hole on a no-go at the bottom of the drill string. The wireline drop-off system is activated by mechanical or electrical means, and after release, the wireline is removed from the well. Drill pipe is tripped from the well and log data is recovered from the memory sub at the surface upon tripping out of the hole.

Typical Applications

- Vertical or deviated wells where hole conditions create a high risk of bridging.
- Used on wells where conventional wireline units are not available.
- Used on wells where third party wireline units are available.

Benefits

- No risk of bridging with logging tools.
- Acquire log data while performing conditioning trips.
- Reduce rig time while acquiring log data.
- Acquire log data regardless of well condition or geometry.
- Low lost in hole costs.
- Wireline quality data.
- Broad range of measurements.
- Helicopter deployment in locations not accessible by wireline units.
- Can be used with third party wireline units.

8. Wireline Tractor

Wireline Tractor conveyance is a conveyance technique where logging tools are conveyed into highly deviated or horizontal wells on wireline with the aid of tractors to pull them. Tractors are mechanical devices powered with electricity transmitted through the wireline from the surface. Standard sized or small diameter logging tools are attached to the tractor and conveyed with the aid of the tractor past the

point where gravity allows for natural descent. After the logging string and tractor have reached TD, or a predetermined depth, acquisition of log data is made in real time mode as the tool string and tractor are extracted from the well.

Typical Applications

- Used in horizontal or deviated wells as an aid to get logging tools to total depth.
- Used as a means of acquiring wireline pressure data in highly deviated or horizontal wells.
- Can be used on rig or in rig-less situations.

Benefits

- Efficient means of acquiring real time pressure measurements in highly deviated or horizontal wells.
- Broad range of measurements.
- Does not require a rig on the well.

9. Through the Bit

Through the Bit logging allows for logging to take place as quickly after drilling or coring as possible. In this method, small diameter logging tools are conveyed through the drill pipe conduit, through specially designed drill bits with removable central inserts. Logging tools can be dropped off, with a wireline drop off tool, and log data can be recorded in memory mode as drill pipe is tripped from the well. Alternatively, logging tools can be conveyed by wireline and log data can be recorded in real time. Figure 4 is a picture of a two piece bit.

Typical Applications

- Logging vertical or high angle wells where wellbore conditions cause high incidence of bridging with wireline conveyance.
- Used in wells to acquire open-hole data without having to trip entire strings of drill pipe.
- Used to log zones or test zones immediately after penetration.

Benefits

- No risk of bridging with logging tools.
- Acquire log data while performing conditioning trips.
- Reduce rig time while acquiring log data.
- Low lost in hole costs.
- Wireline quality data.
- Broad range of measurements.
- Can acquire log data before the effects of invasion and mechanical formation damage.

10. Continuous Rod

Co-Rod is a conveyance method where small diameter logging tools in memory mode, are conveyed on the end of specially designed strings of continuous sucker rods. The Co-Rod is 1 1/8 inches in diameter, and is capable of conveying logging tools into highly deviated and horizontal wells. Log data is acquired as the Co-Rod is pulled from the well.

Typical Applications

- Logging highly deviated and horizontal wells in remedial situations.
- Used in situation where pressure control is required during the logging process.

Benefits

- Logging can be done without the need for a drilling rig or service rig on location.
- Low lost in hole costs.
- Wireline quality data.
- Broad range of measurements.
- Acquisition of log data in horizontal wells.

11. Drill Pipe Conveyed Logging

Drill Pipe Conveyed Logging is a conveyance method where logging tools are attached to the end of drill pipe and pushed to the bottom of the well. The logging tools can be operated in memory mode and also with real time wireline connected to a logging unit on the surface. With wireline applications, the wireline is introduced into the drill pipe through a side door sub in the drill string when the logging tools enter the highly deviated, or horizontal section of the well. After pumping the wireline to the top of the logging tools, it is connected to the logging tools with a wet connect latch. When the logging and drill strings are at TD, data acquisition is ready to begin with the trip out of the well.

Typical Applications

- Logging horizontal wells.
- Logging vertical or high angle wells where wellbore conditions cause high incidence of bridging with wireline conveyance.
- Used to acquire measurements where a wireline connection to the surface is necessary.

Benefits

- Log data can be acquired in highly deviated or horizontal wells.
- Full range of measurements.
- Log data can be monitored during acquisition with wireline method.

Case Study 1: Rainbow Lake, Canada September 1999

To access the remaining oil reserves in the Keg River formation in Western Canada, horizontal wells are drilled along the top of the formation. These horizontal legs can be drilled from the existing vertical well, using small diameter drilling equipment.

Figure 5 illustrates how a horizontal well started in the Keg River dolomite reservoir was drilled at the top of the formation, but exited into the overlying non reservoir dolomites and anhydrites of the muskeg formation, only occasionally intersecting the reservoir.

Due to the small diameter hole nature of the well, LWD equipment could not be employed at the time of drilling, and pipe conveyed logging with wireline was judged to be too risky. As production did not meet expectations, a strategy to resolve the problem involved acquiring formation evaluation data, and performing remedial work.

This horizontal leg was logged with a new technique using a wireless coiled tubing unit and a new generation of small diameter logging tools. The logging tools were deployed in memory mode and a tension-compression device was used to ensure safety of the down-hole logging equipment. Log data

was acquired during the trip out of the well, and upon review of the data, it became apparent that not enough of the reservoir was intersected with the horizontal leg. A decision was made to re-drill this leg in a lower position that would intersect more of the reservoir. This second leg was also logged in memory on coiled tubing and is illustrated in Figure 5.

This case study illustrates how small diameter horizontal drilling technologies can drill wells that can enhance production. It also shows however; that if efficient means to gather formation evaluation data are not available, production enhancement may not be achieved. Therefore, the risk of not having data due to wellbore challenges, can lead to the waste of drilling funds and the loss of production.

Case Study 2: Jiba 10 well, CANO LIMON FIELD Cravo Norte Area, Colombia, May 2006

Acquisition of formation evaluation data in the Cano Limon field can be difficult due to a series of thin laminations of contrasting hardness that are located above the zones of interest. Soft shale laminations between hard sandstone laminations wash out creating ledges of hard sandstone. In deviated wells, these ledges can interfere with the descent of logging tools on wireline. In order to convey logging tools past these obstructions oil companies have employed the following techniques:

1. Conventional Wireline:

This option is the lowest risk if wells are vertical. As wellbore deviation increases, the risk increases; and this method can become ineffective.

2. Pipe Conveyed Logging:

This method allows for a better success in getting tools to bottom compared to wireline; however, the risk of tool damage is greater. In addition, more rig time is required to perform this operation.

3. LWD:

Although this option has a 100% chance of getting logging tools to bottom, this method involves higher costs as specialized drilling equipment needs to be sourced for this type of work.

4. Through Drill Pipe Logging:

This option is the least risky as it allows for a 100% chance of getting logging tools to bottom. All equipment necessary to do this type of work is already at the drilling site and can be employed before a bridging event occurs. This technique can be as efficient as conventional wireline conveyance in vertical wells where no bridging would be expected.

The through drill pipe method was employed on the Jiba 10 well and resulted in savings of up to 3 days compared to data acquisition operations on other wells in the area where alternative conveyance techniques were used. Figure 7 illustrates the time savings that can be achieved when conveyance type is factored into the formation evaluation operation.

This case study illustrates that quality formation evaluation data can be acquired in difficult wellbore conditions. There is

however a need for pre-job planning on what conveyance option is to be employed based upon the criticality of obtaining formation evaluation data and the sourcing of the required equipment to perform the operation.

Conclusions

The risks associated with the formation evaluation process have become the subject of increased study. This study has demonstrated the following.

- The continuous search for new sources of hydrocarbons, has necessitated the development of new types of drilling technology that allow for access to difficult-to-produce reserves.
- This new drilling technology can drill wells that require alternative methods of formation evaluation from traditional wireline methods.
- These new methods encompass the growing body of knowledge of conveyance that considers not only conveyance type but also measurement type and measurement device type in the strategy to acquire formation evaluation data.
- Choosing the most appropriate conveyance technique, can mitigate the risk that is associated with the evaluation process.
- Employing these new methods can eliminate the risks ranging from lost rig time due to bridging, to the risks of critical formation evaluation data not being acquired in wells all over the world.

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Nomenclature

NPT = Non Productive Time

TD = Total Depth

References

1. Elkington, P.A.S., Spencer, M.C., and Spratt, D.L., J.: "An Openhole Memory Logging System for High Angle Wells and Bad Hole Conditions" *SPE Reservoir Evaluation and Engineering*, February 23, 2004.
2. Spencer, M.C., Ash, S.C. and Elkington, P.A.S.: "Pressure Activated Deployment of Openhole Memory Logging Tools Into Directional Wells and past Bad Hole Conditions," SPE-88635, SPE Asia Pacific Oil and Gas Conference and Exhibition, Perth, Australia, October 18-20, 2004.
3. Petroleum Services Association of Canada, 2004 PSAC Well Cost Study, October 23, 2003.
4. Blount, C.M., Mooney, M.B., Behenna, F.R., Stephens, R.K., Smith, R.D.: "Well Intervention Challenges To Service Wells That "Can Be Drilled"" SPE 100172, SPE /IcoTA Coiled Tubing and Well Intervention Conference and Exhibition, The Woodlands TX, U.S.A., April 4-5, 2006.

Table 1. - Frequency of bridging in Canada with wireline conveyed logging tools.

Small Diameter Logging Tools				Conventional Sized Logging Tools				Combined
PSAC Area	Wells Bridged	Wells Logged	Bridging Frequency	PSAC Area	Wells Bridged	Wells Logged	Bridging Frequency	Bridging Frequency
1	4	63	6.3%	1	0	8	0.0%	5.6%
2	102	1169	8.7%	2	139	709	19.6%	12.8%
3	230	3574	6.4%	3	82	863	9.5%	7.0%
4	67	1673	4.0%	4	40	661	6.1%	4.6%
5	161	1709	9.4%	5	147	1052	14.0%	11.2%
6	23	1133	2.0%	6	32	233	13.7%	4.0%
7	82	1572	5.2%	7	110	808	13.6%	8.1%
8	9	192	4.7%	8	7	80	8.8%	5.9%
9	20	1030	1.9%	9	25	426	5.9%	3.1%
10	18	572	3.1%	10	17	322	5.3%	3.9%
Total	716	12687	5.6%	Total	599	5162	11.6%	7.4%

Table 2. – Summary of NPT (Non Productive Time) and costs associated with bridging in Canada.

PSAC Area	Wells Bridged	Wells Logged	Bridging Frequency	Bridging Hours	Clean-Out Hours	NPT per Bridging Event	Rig Cost per Hour	Logging Unit Cost per Hour	Average Cost of Bridging Event
1	4	71	5.6%	18.5	51	17.4	\$1244.01	\$400.00	\$28,391.01
2	241	1878	12.8%	1089.2	4309	22.4	\$1260.04	\$400.00	\$37,183.13
3	312	4437	7.0%	978.7	3334.4	13.8	\$869.07	\$400.00	\$17,543.70
4	107	2334	4.6%	284.9	875.8	10.8	\$997.87	\$400.00	\$15,163.63
5	308	2716	11.2%	971.6	3411.9	14.2	\$1000.00	\$400.00	\$19,924.55
6	55	1366	4.0%	162.3	604.3	13.9	\$884.40	\$400.00	\$17,900.98
7	192	2380	8.1%	700.5	2574.8	17.1	\$988.20	\$400.00	\$23,681.11
8	16	272	5.9%	56.3	280.8	21.1	\$1579.73	\$400.00	\$41,704.25
9	45	1456	3.1%	130.8	298.8	9.5	\$922.49	\$400.00	\$12,623.90
10	35	894	3.9%	93.2	303.3	11.3	\$940.97	\$400.00	\$15,189.38
Total	1315	17849		4485.7	16044.1				
Average			7.4%			15.6			\$22,513.99

Table 3. - Summary of the conveyance techniques currently employed in formation evaluation operations throughout the world.

Conveyance Technique	High Angle/Hz Wells	Rig less Operations	Drilling Rig Operations	Real Time Acquisition	Memory Acquisition
LWD	•		•	•	•
Wireline		•	•	•	
Well Shuttle	•		•		•
Through Drill Pipe	•		•	•	•
Coiled Tubing	•	•		•	•
Slickline		•	•		•
Wireline Drop Off	•		•		•
Well Tractor	•	•	•	•	
Through the Bit	•		•	•	•
Continuous-Rod	•	•	•		•
Pipe Conveyed Logging	•		•	•	

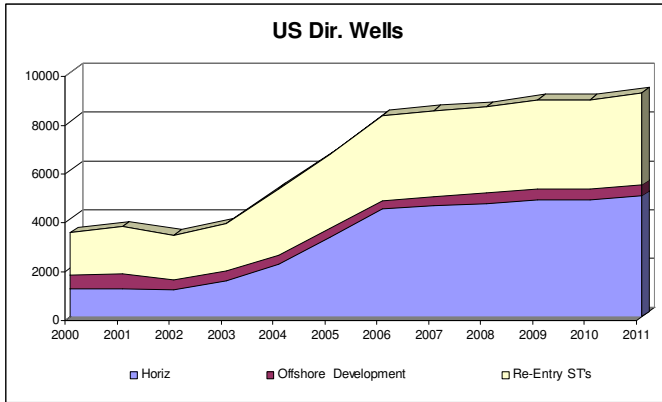


Figure 1. – Historical review of growth of Horizontal Drilling.

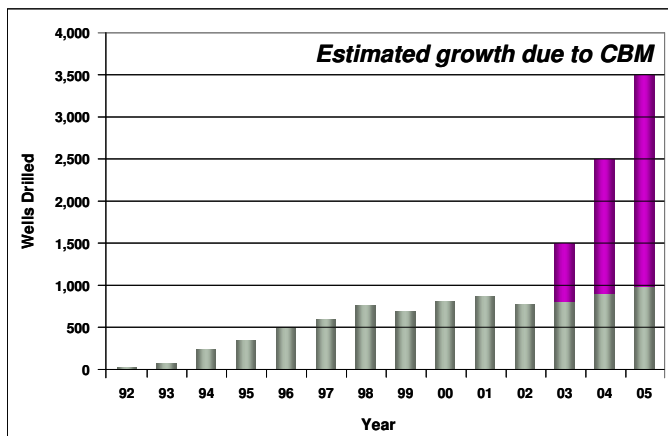


Figure 2. – Historical review of growth of Coiled Tubing Drilling.

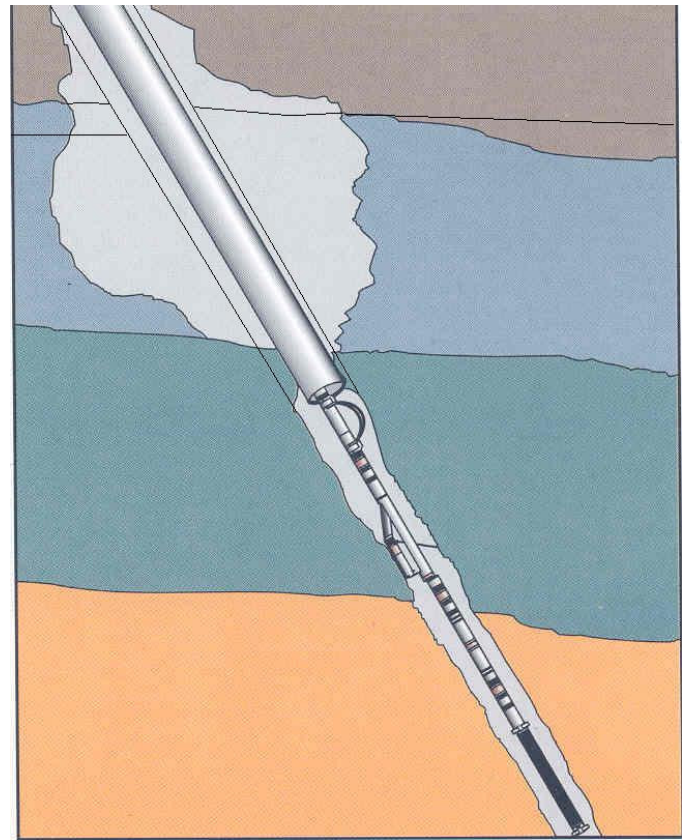


Figure 3. – Illustration of Through Drill Pipe Operation.



Figure 4. –Two piece drilling bit.



Figure 6. – Time saving potential when conveyance type is factored into the formation evaluation operation.

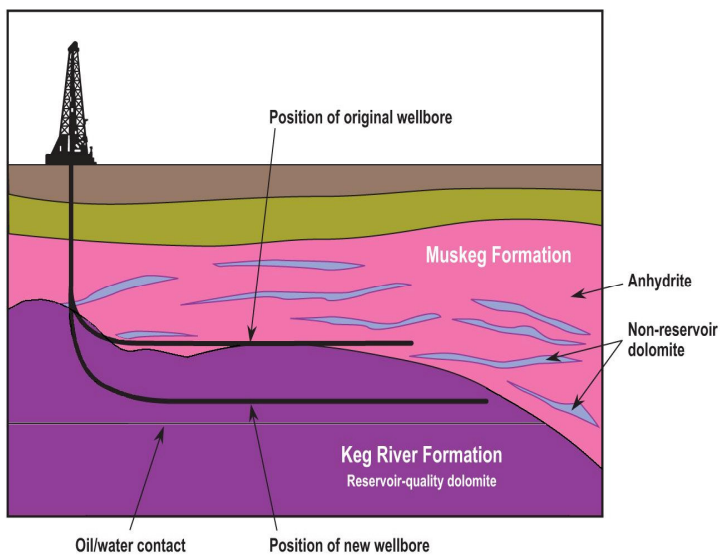


Figure 5. – Illustration of horizontal wells drilled in the Keg River formation in Canada.