



## A Novel Application: Automated Vertical Drilling System Saves Time and Money in Salt Dome Gas Storage Drilling

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This paper was prepared for presentation at the AADE 2005 National Technical Conference and Exhibition, held at the Wyndam Greenspoint in Houston, Texas, April 5-7, 2005. This conference was sponsored by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.

### Abstract

Wellbores with less than 6° of inclination are generally considered vertical in the oil and gas drilling industry. When drilling into a salt dome for use as a gas storage container, however, the definition of a vertical hole differs significantly. The hole needs to be as vertical as possible (~ 0°) so that unwarranted stress is not induced in the wellbore that may compromise the cavern's integrity during the leaching process. Drilling precisely straight holes has been a challenge using conventional rotary drilling assemblies. An Automated/Self-correcting Vertical Drilling System (VDS) was selected based on these conditions, which helped drill with near-vertical accuracy and resulted in a 25% to 75% time savings. The VDS discussed in this paper is an integrated drilling tool, combining the latest rib steering, downhole motor, and MWD technologies. The VDS is a simplified automated steering tool specifically for drilling vertical, quality wellbores, and has been used successfully in several well drilling applications. However, using this tool for the storage application described above is unique. The technology application was on EnCana's first-ever salt dome brine replacement well for its Starks Gas Storage Project (Starks Project) in Calcasieu Parish, Louisiana. In this paper, the authors share the drilling details of this unique application opportunity with the industry.

### Introduction

Maintaining a vertical wellbore with a conventional drilling assembly is achieved typically by adjusting drilling parameters such as string RPM and WOB, resulting in a reduction of the penetration rate. If these measures are not sufficient, the use of steerable motors becomes a requirement. This, by nature, will lead to a tortuous wellbore, as switching back and forth between rotary drilling and slide drilling is required to optimize performance and to steer the wellbore back to vertical. Maintaining a stable toolface orientation in salt is a challenging and time consuming operation due to the mechanical properties of salt. Small changes in WOB result in large changes in TOB.

Hole deviation is a major problem when drilling a salt cavern well, particularly in the highly fractured and vugular caprock overlying the salt. Verticality is also critical in the salt section because if the final well is off vertical, the leaching strings suspended from the wellhead will move to vertical as leaching progresses, resulting in an asymmetrical cavern. A conventional drilling assembly requires several correction runs to ensure true verticality. Using a self-correcting/automated VDS for the above drilling application provided promising results with significant cost savings.<sup>1</sup> While the VDS is technically similar to a 3-D rotary steerable system in areas such as steering head, down-hole power supply and bi-directional communication, it differs significantly in other areas.<sup>2</sup> It is a much simplified, vertical seeking straight hole drilling device and is substantially less expensive to run than a 3-D rotary steerable system. EnCana Gas Storage Inc, a leader in the natural gas storage industry, decided to run the VDS technology in this novel application in return for the opportunity for reduced costs and improved quality.

### Vertical Drilling System Development

The VertiTrak<sup>®</sup> System (referred to as VDS in this paper) is expected to reach its 2,000,000<sup>th</sup> foot of drilled depth in January of 2005. The first VDS was introduced more than a decade ago for a scientific drilling project in Germany. Only 600,000 ft were drilled during the first few years of its use. There has been a 230% increase in automated vertical drilling footage in the last year and half. The challenges of drilling soft, hard, permeable, and semi-permeable formations have led to a series of redesigns and development of the automatic drilling tool with increased reliability, reduced cost and simplified tool maintenance. These capabilities have been realized while maintaining quality wellbore geometry and full steering capability. The latest addition to the VDS technology is the development in 2004 of a system to drill a kick off after drilling the vertical hole. The VertiTrak<sup>®</sup> Plus System is designed to eliminate a bit run for creating a kick off from vertical.

In a VDS system, the automated rib steering process

does not require the operator to sacrifice optimal drilling parameters or make time-consuming correction runs to maintain a vertical wellbore.<sup>1, 2, 3</sup> Today, drilling gun barrel quality boreholes without offsets and ledges is possible since there is no bend on the VDS to create oversize sections nor any string rotation that could damage the borehole walls. Furthermore, eliminating string rotation protects the drill string and the casing from wear. Non rotation does not impact hole cleaning, as vertical hole cleaning depends primarily on the viscosity, density and flow rate of the mud system as opposed to deviated holes, which rely heavily on string rotation and turbulence.

### Vertical Drilling System Description

The VDS discussed in this paper is an integrated drilling tool, which incorporates pad steering, drilling motor, and integrated MWD closed loop technologies. As shown in Fig. 1, the VDS can be broken down into three main components: (1) MWD Control Package, (2) Power Section and (3) Steering Head.

The MWD Control Package provides precise inclination measurements ( $0.01^\circ$ ) and two-way communication with the surface. The turbine-driven generator and hydraulic pump generate steering pressure to each pad to maintain verticality through continuous downhole corrections. A full LWD suite can be incorporated within the BHA to provide comprehensive, real-time formation evaluation.

The Power Section, which helps the bit rotate, uses a pre-contoured stator tube coated with a thin layer of elastomer, rather than a round steel tube coated with a lot more elastomer to create stator ridges (Fig. 1). This design helps provide more power to the bit with improvements ranging from 60% to 100%, depending upon the application.

The Steering Head is comprised of three expandable steering pads that deliver a powerful side force. The spring-loaded pads are activated hydraulically to deliver continual course control independent of drilling parameters and formation tendencies. Hydraulic lines extend through the entire power section and are connected to the control valve in the steering unit. Based on the system's near-bit inclination measurements, hydraulic force is applied to the appropriate pad to steer the wellpath back to vertical (Fig. 2). Detailed tool description and functionality were provided by M.Reich et al.<sup>2</sup> in SPE 84451.

### Automated Vertical Drilling Mechanism

In normal drilling operations, the tool is employed in the slide mode and the internal hydraulic pump (Fig. 1) is continually operating, providing rib steering pressure as required. Bit rotation is a function of flow rate through

the power section. Integrated, near-bit sensors measure hole inclination and transmit the data continuously to the surface. Whenever the system's near-bit inclinometers detect the well path beginning to deviate from vertical, the system's control sub applies the required pressure to the pads to achieve the necessary steering force to counteract any deviation tendencies and push the wellbore back to  $0^\circ$  inclination. This process is described in Fig. 2. The system's closed loop control, as shown in Fig. 3, provides continuous course corrections, ensuring that the wellpath remains straight with as little tortuosity as possible. The closed loop control mechanism feeds near-bit inclination data (Input) continuously to the steering control logic (Controller). The Controller automatically adjusts the steering mechanism (Process) to maintain a precisely vertical well path. Deflection of the wellbore from formation influences (Random Events) is, therefore, countered continuously for precise wellbore positioning control (Optimized Output).

As the VDS tool seeks the low side, no time is spent for orienting the tool face. The WOB can be optimized for high ROP, as the tool compensates for any build tendencies that would occur with a conventional assembly. The continuous steering results in improved wellbore quality, thus reducing weight transfer problems and harmful high local dogleg severities. As the VDS is utilizing a mud motor to provide the required power to the bit, no drill string rotation is required, which reduces the risk of vibration related drill string failures in vertical wellbores.

### Starks Project Area Salt Dome Geology

The Starks Project area's geology in southern Louisiana is characterized by southerly dipping and thickening sedimentary strata displaced by diapiric salt structures, thus forming shallow growth faults with the strata. Salt domes are formed by the loading of sediments and density contrast between the sediments and underlying salt. The Starks Project salt dome is one in a series of large salt domes that extend west-southwest into Texas and to the east-southeast toward the Mississippi River Delta. A simple representative schematic of a salt dome is presented in Fig. 4.

The dome's subsurface is composed predominantly of Pleistocene Age terrace sediments that are characterized by clays and silty-clays intersected by discontinuous layers of silts and sands. This interbedded sand/shale formation contains three major water producing zones typically used in the project area by industries and agriculture as sources of fresh water. Below the interbedded formation is a sealing structure called caprock formed by insoluble impurities of limestone, gypsum and anhydrite that are left behind as the salt dissolves with underground freshwater. This

caprock is found at about 1,400 ft below ground level. The thickness of the caprock ranges from less than 50 ft on the flanks of the dome, to as much as 700 ft over the dome. The top of salt in the area is encountered at about 2,025 ft below the ground level. The salt dome is an oval shaped piercement structure below the caprock with the longer axis orientated approximately north to south. The flanks of the dome dip approximately 60° to 70° on the northern and southern sides and approximately 75° to 80° on the eastern and western sides. At about 2,100 ft, the salt elevation contours toward the northeast. The size of the dome is more than 1 mile long measuring from north to south and 0.5 mile wide measuring from east to west. At about 4,100 ft, the salt contours change again with the dome size changing to approximately 1.5 miles long measuring from north to south and 1 mile wide measuring from east to west. The composition and thickness of the caprock over the salt dome, combined with the depth of the salt dome beneath the caprock, is what makes the cavern suitable for containing the storage gas and preventing the migration of gas out of the storage cavern.

#### Creation of a Salt Cavern for Gas Storage

Salt cavern wells are drilled for brine production or to create caverns for underground storage or disposal. Salt has significant mechanical strength that permits large caverns to be constructed that will remain stable over time and low permeability makes it ideal for storage and waste disposal. To form a salt cavern, a well is drilled through the overlying strata and through the caprock into the salt. A final casing is set in the salt above the intended cavern roof and the well is then drilled to total depth. Two leaching strings are suspended from the wellhead to near total depth. The leaching is done in stages from the bottom up and a "blanket" material, generally diesel oil or an LPG, lighter than water, is used in the annulus between the last casing and the outer leaching string to control the upward leaching. As leaching progresses, the setting depths of the leaching strings are raised and the blanket material positioned higher in the wellbore. Cavern construction is a dissolution process where water dissolves the salt, producing saturated or near-saturated brine.

Two leaching methods are used: direct and indirect. With direct leaching, water is injected down the center leaching string and brine is produced through the annulus between the two hanging strings (Fig. 5). This process is used initially to create a "sump" to contain any insoluble materials entrained in the salt. This step is required as Gulf Coast salt domes may contain 5% or more of insoluble materials. With indirect leaching, water is injected between the two hanging strings and brine is produced from the center string. This technique is used to control the diameter and shape of the cavern.

Caverns can be over a thousand feet tall and have diameters of 400 ft so controlling the size and shape is critical to stability, spacing between caverns, and a long productive life.

The leaching strings are hung in the wellhead. If they are not vertical, as the salt borehole enlarges with time, gravity will pull them to vertical like a pendulum. The result will be an asymmetrical cavern that could reduce overall extraction ratios during brine recovery. Additionally, the spacing between adjacent caverns could be affected, which could result in a cavern being a poor candidate for conversion to hydrocarbon storage. While specifications vary, operators typically prefer wells that have no more than 1°/100 ft deviation.

#### Drilling Operations

The well design for the Starks Well is represented by the casing program (Fig. 6). As part of the drilling program, the Starks well was essentially divided into two sections for describing the directional program. Down to the 16-in. casing point, inclinations as high as 1½° were permitted; however, the overall departure from vertical could not exceed a wellbore averaging 0.5°. This specification resulted in a 26-ft radius target at 3,000 ft, the 16-in. setting depth. From the 16-in. casing point to a depth of 6,500 ft, the intended TD, the wellbore could not exceed the 0.5° inclination at any point in the trajectory, resulting in a 57-ft radius target at that depth.

A 42-in. conductor pipe was driven into the upper interbedded formation to case off the unconsolidated sediments to a depth of 155 ft. RKB for this rig was 32 ft. The plan was to drill a 17½-in. pilot hole with a 9½-in. VDS (17½-in. steering ribs) into the caprock. The borehole would then be opened in two hole opener runs to 36 in. to run 30-in. casing. The large hole was drilled to so that a contingency string of casing could be run if required to control a catastrophic lost circulation zone and to allow for a good cement sheath to seal off the freshwater aquifers. The BHA used (Table 1) performed with a ROP of 99.7 ft/hour in this interval. The final depth for the interval was 1,494 ft with an average inclination of 0.4°.

Upon completion of casing and cementing operations, the 17½-in. BHA that was racked on the derrick floor was picked up to drill the next pilot hole prior to opening it to a 22-in. hole to run 16-in. casing. This section of hole penetrated about 600 ft of caprock to the top of salt at about 2040 ft, and continued to a casing depth of 3,035 ft. The average rate of penetration in the salt was 34 ft/hour with controlled drilling because cuttings could not be controlled due to limitation of shakers and screen sizes. The objective to keep the well vertical was fulfilled up to this casing depth with average inclination of 0.1°. The casing was run to bottom without problems and

cemented as planned.

The next section was drilled with a 9½-in. VDS, as before, but now with 14¾-in. steering ribs to drill a 14¾-in. pilot hole size (Table 2). The interval was started by drilling the shoe track through the planned salt interval to a final depth of 7,035 ft. No dogleg was induced during the entire interval as VDS further reduced the inclination to an average value of 0.04°. VDS drilled the interval with a ROP of 48 ft/hour. The interval was then enlarged to 22-in. minimum diameter, the 13-3/8-in. leaching casing was set at 6,627 ft and the 8-5/8-in. leaching casing was set at 6,985 ft.

### Application Benefits

The drilling benefits delivered by the VDS for the salt dome included a smooth, vertical borehole, ease of running different sizes of casing, and significant time saved compared to similar wells drilled in the Starks Project area.

Drilling through the salt dome for gas storage poses more stringent challenges as opposed to conventional salt drilling for E&P wells. Fig. 7 shows typical inclination measurements from an E&P salt well. The typical salt section has a lot of build tendency and when drilled with a conventional drilling assembly, inclination control is a challenge. Inclination correction is possible with an adjustable downhole motor; however, micro and macro doglegs in the well trajectory are introduced when making severe corrections. An average of inclination measurements from conventionally drilled wells in the salt dome area are also shown in Fig. 7. Owing to the 1½° maximum limitation, most wells are either control drilled or corrected to achieve this target. Sometimes, this target was not achievable as reflected from the average measurements provided in the figure. The application of VDS in the subject well showed a near-zero inclination up to a final depth of 7,035 ft. VDS was also employed in another salt cavern application in the area, producing similar results with an average inclination of 0.2°.

The use of VDS also increased the ROP in this salt dome application. The ROP comparisons of subject well to typical salt well and offset wells in the salt dome are shown in Figure 8. Typical salt wells in the coast line of the Gulf of Mexico region are known to be drilled with an average ROP of 17 ft/hr with conventional packed or rotary assembly. The offset wells in the Starks Project area with the same design were drilled with an average ROP of 10 ft/hr. However, the subject well drilled with VDS showed an average drilling ROP of 42 ft/hr. This is a significant improvement compared to both a typical salt well and offset salt dome wells.

The history of offset wells drilled with conventional

packed assembly or rotary assembly in the Starks Project area revealed that it took more time to control deviation tendencies. This is evidenced with Well #1 drilled to a total depth of 4,050 ft in 98 days with packed assembly (Fig. 9). Well #2 with a depth of 5,090 ft was drilled in 73 days. Both wells utilized similar packed assemblies, but with some changes in drilling program. Well #3 had some improvement with 59 days of drilling at the same total depth as Well #2. Wells #4 and #5 also showed some improvement. Well #6 was drilled in 104 days to a total depth of 6,400 ft. There was a great improvement in the VDS – Starks Well that was drilled to a total depth of 7,035 ft compared to all other offset wells as the entire sections were drilled in 33 days plus eight days to perform all the leaching processes and equipment installation for brine production. In addition to the ROP improvement, the subject well took less days for the drilling program (Fig. 10) than to run casings, an indication of good borehole quality. After the success of the subject well, another salt dome well was drilled in the area with VDS from the caprock to final depth of 7,050 ft. in 20 days.

The use of VDS in the subject well saved a total of 14 days from the projected drilling time of 47 days (Fig. 10). The well was also drilled a little deeper than the expected footage. Typical well costs for domal salt gas storage drilling operations are in the range of U.S. \$5 million. It was estimated that VDS provided cost savings of approx. 15%.

### Conclusions

The objective of keeping the wellbore vertical in the drilling of the EnCana Starks Well was achieved with higher rates of penetration in the sandstone, caprock and salt formations. The VDS controlled deviation and maintained verticality in real time. An average inclination of 0.18° was achieved. The ability to control the hole angle in real time resulted in significant rig time savings.

Additionally, higher rates of penetration significantly reduced the number of days and the associated rig cost. VDS provided 25% to 75% time savings when compared to offset wells in the area. When compared to the proposed program costs, a 15% savings was achieved. The analysis of the offset wells in the Starks Project area showed that not only was quality vertical wellbore delivered, but it was done efficiently. Borehole quality was demonstrated with the ease of running casing that aids in upward movement of the pipes during the leaching process to ensure that large cavern is created without causing any form of leakage under normal operating conditions. Borehole integrity is improved as the risk of a seal loss is eliminated.

This application outside of the E&P industry opens the door for other outside industry vertical drilling applications such as construction drilling and mining,

which also require near-vertical bores.

### Acknowledgments

We appreciate the managements of EnCana Gas Storage Inc, Essex Storage Services and Baker Hughes Inc for support, review and permitting us to publish this paper. We also appreciate the editorial help of Pramod Kulkarni with Baker Hughes Incorporated and Jamie Craddock with EnCana Gas Storage Inc.

### Nomenclature

*BHA* = Bottomhole assembly  
*BOP* = Blowout preventer  
*ECD* = Equivalent circulation density  
*EMW* = Equivalent mud weight  
*LWD* = Logging while drilling  
*MWD* = Measurement while drilling  
*RKB* = Rig floor kelly bushing elevation  
*ROP* = Drilling rate of penetration  
*RPM* = Revolutions per minute  
*TD* = Total depth  
*TVD* = True vertical depth  
*TOB* = Torque on bit  
*WOB* = Weight on bit

### SI Metric Conversion Factors

°F            (°F – 32)/1.8 = °C  
ft            x 3.048\*     E - 01 = m  
in.           x 2.54\*     E + 00 = cm

\*Conversion factor is exact

### References

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3. Chur, C., Oppelt, J.: “Vertical Drilling Technology: A Milestone in Directional Drilling,” paper SPE 25759 presented at the SPE/IADC Drilling Conference, Amsterdam, Mar 11-14, 1993.












	6 5/8" Drill pipe
	6 5/8" HWDP
	8" Sub - X/O
	8" Drill collar
	9 1/2" Sub - X/O
	9 1/2" Drill collar
	9 1/2" Drilling Jar
	9 1/2" Drill collar
	17 1/4" Nortrak Stab (w/float)
	9 1/2" VDS w/17 1/2" ribs
	17 1/2" Rock Bit (3x18 jets)

Table 1. 9 1/2 inch VDS BHA for drilling 17 1/2 inch Pilot Hole






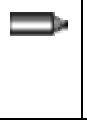
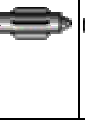
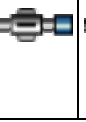

	6 5/8" Drill pipe
	8" Sub - X/O
	8" Drill collar
	9 1/2" Sub - X/O
	9 1/2" Drill collar
	9 1/2" Filter sub
	14 1/2" Nortrak Stab
	9 1/2" VDS w/14 3/4" ribs
	14 3/4" Rock Bit (2x18/1x20 jets)

Table 2. 9 1/2 inch VDS BHA for drilling 14 3/4 inch Pilot Hole

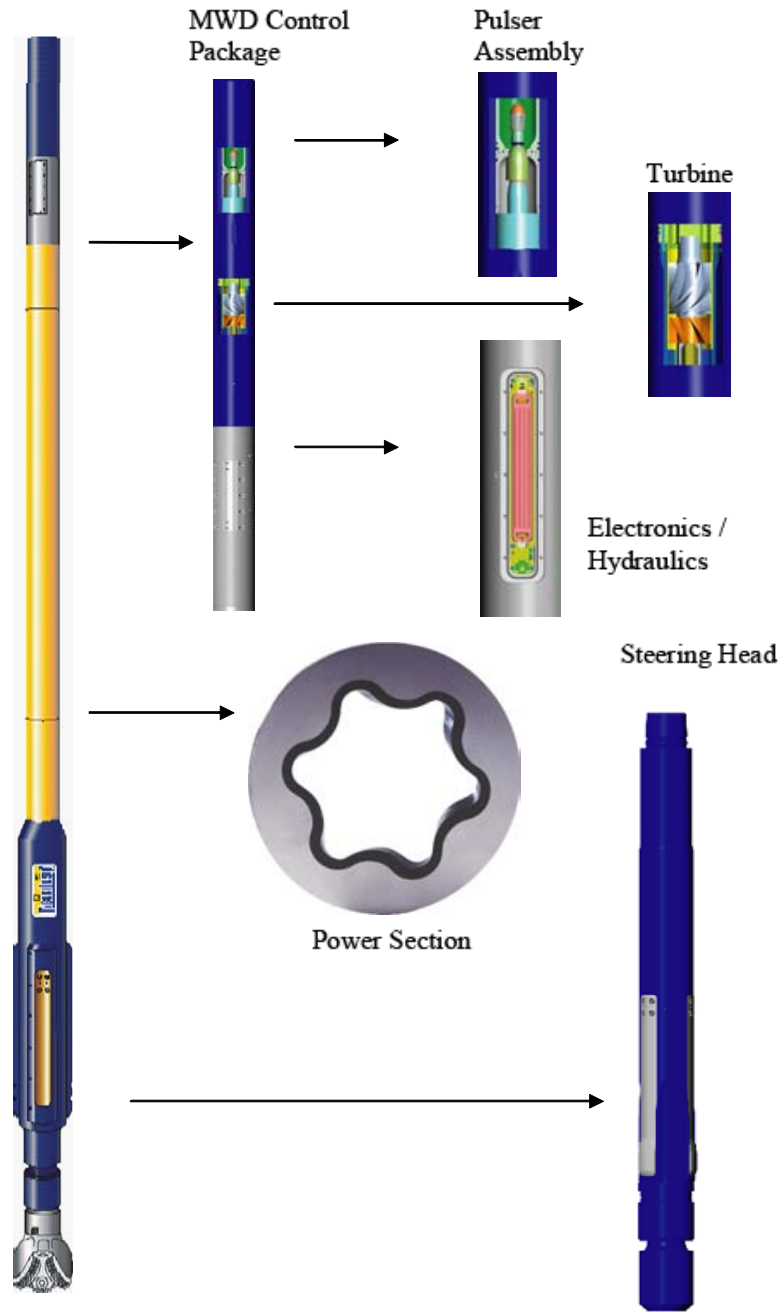


Figure 1. VertiTrak® System

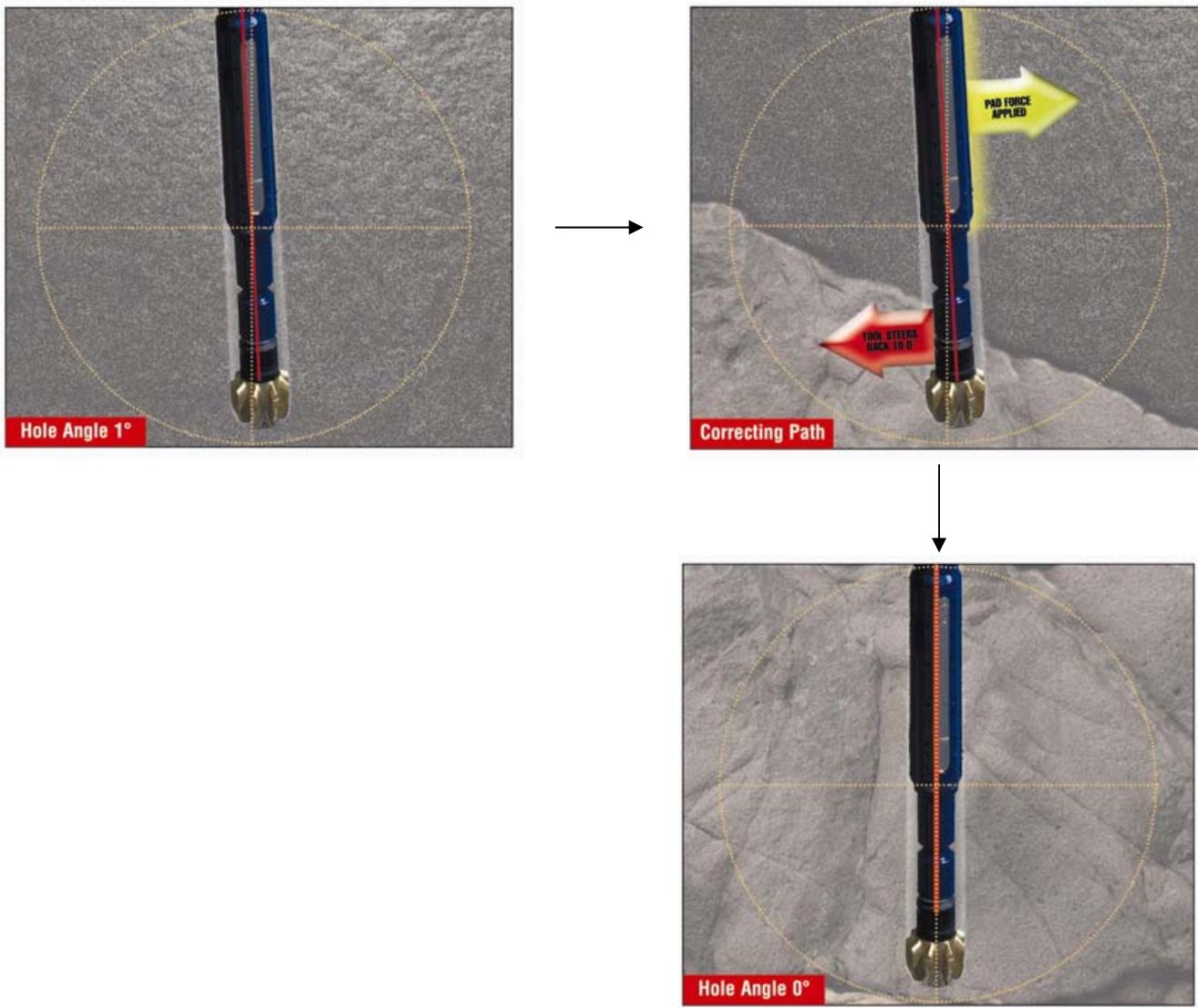


Figure 2. Self Correcting Automated Vertical Drilling Mechanism

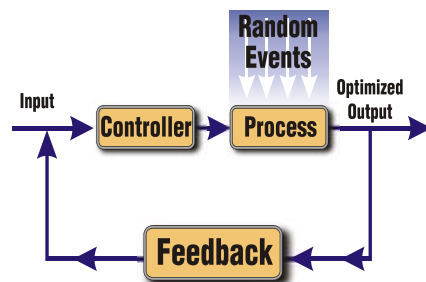


Figure 3. Downhole Closed Loop Control

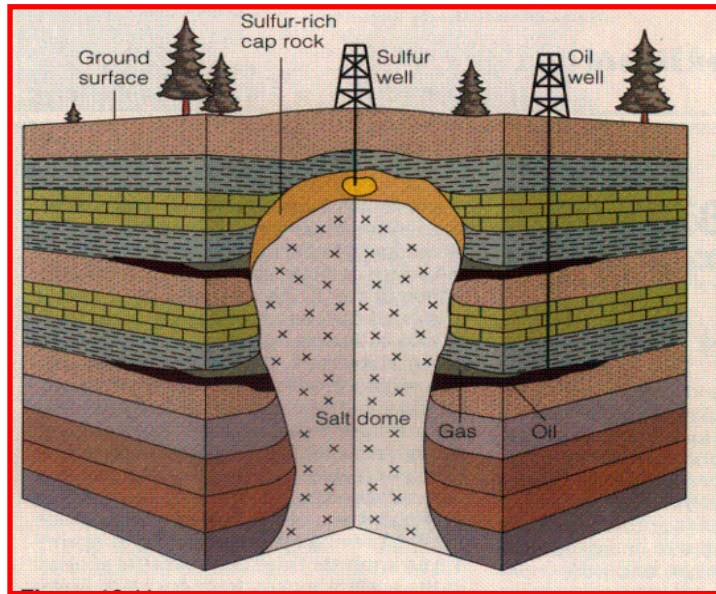


Figure 4. Representative Geology of a Salt Dome

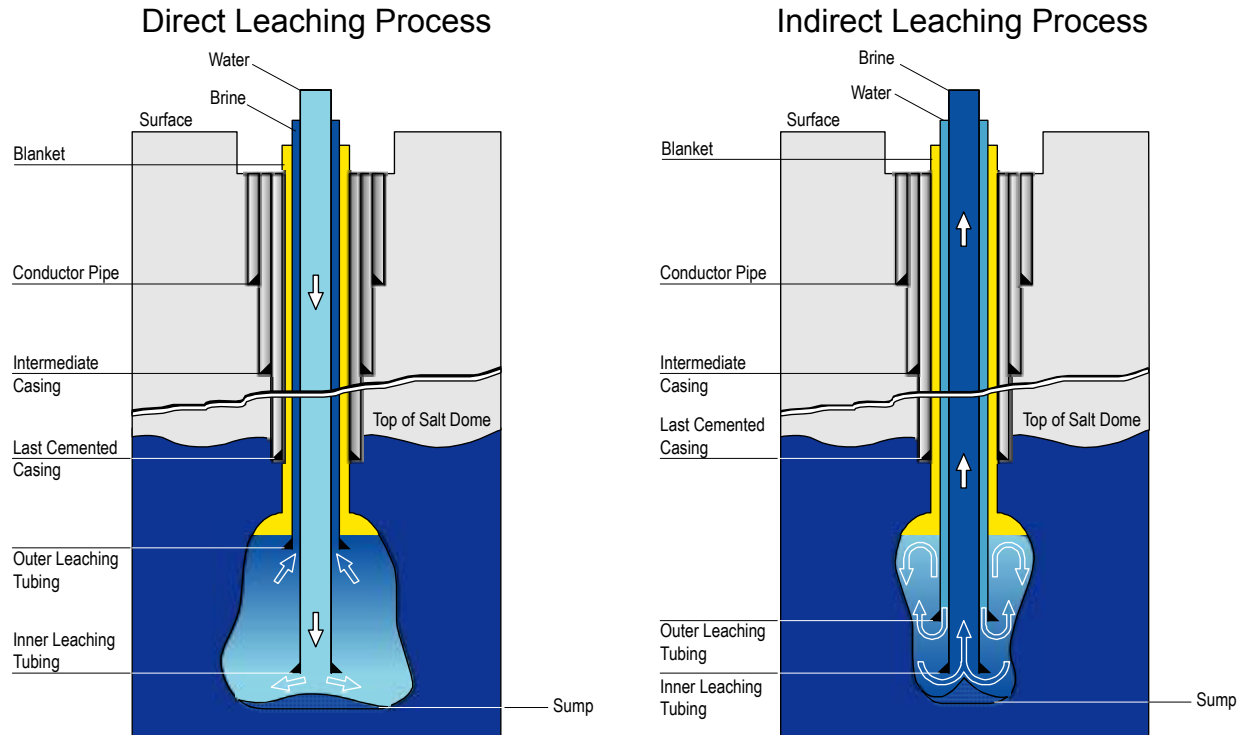


Figure 5. Leaching Process

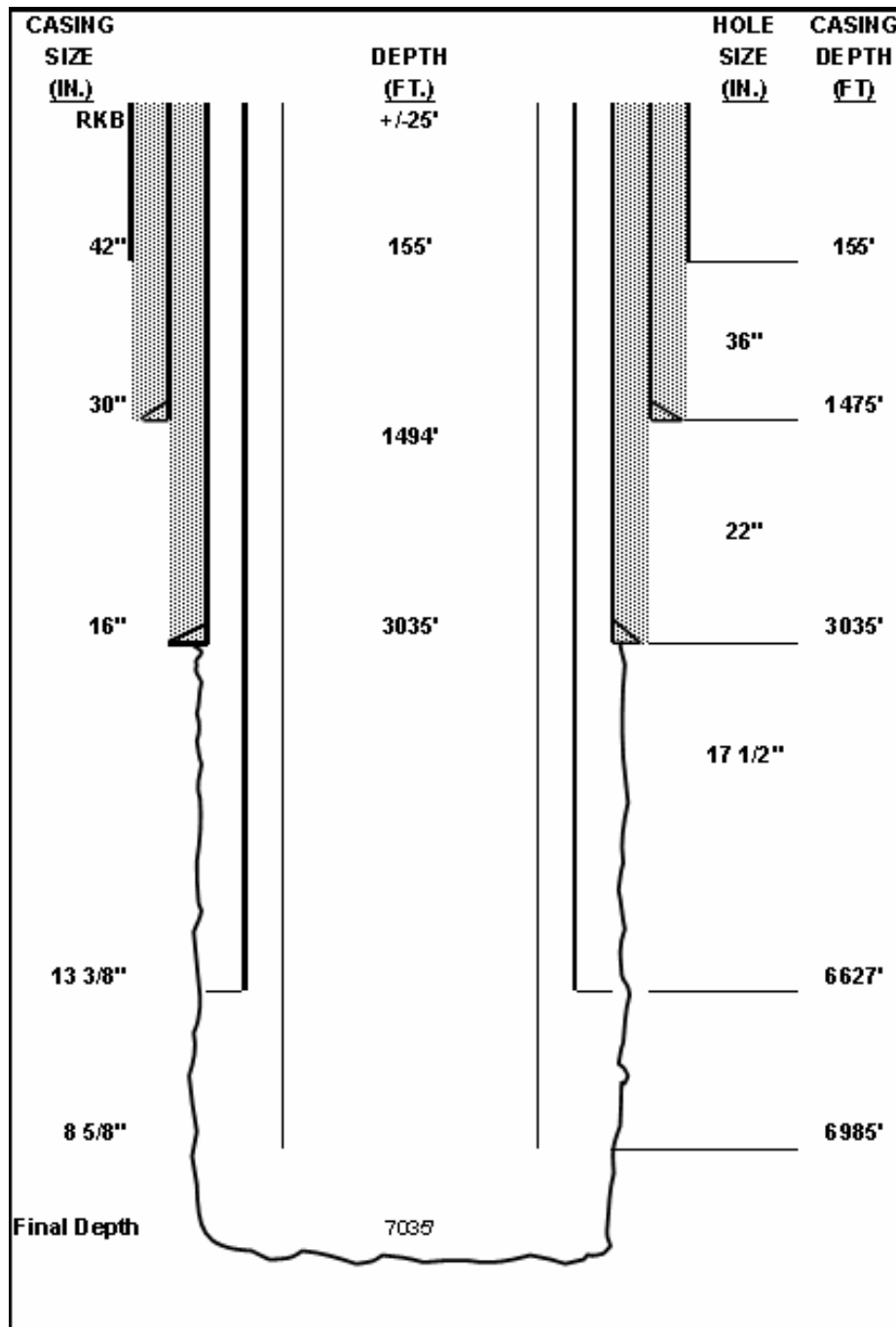


Figure 6. Subject Well Casing Program

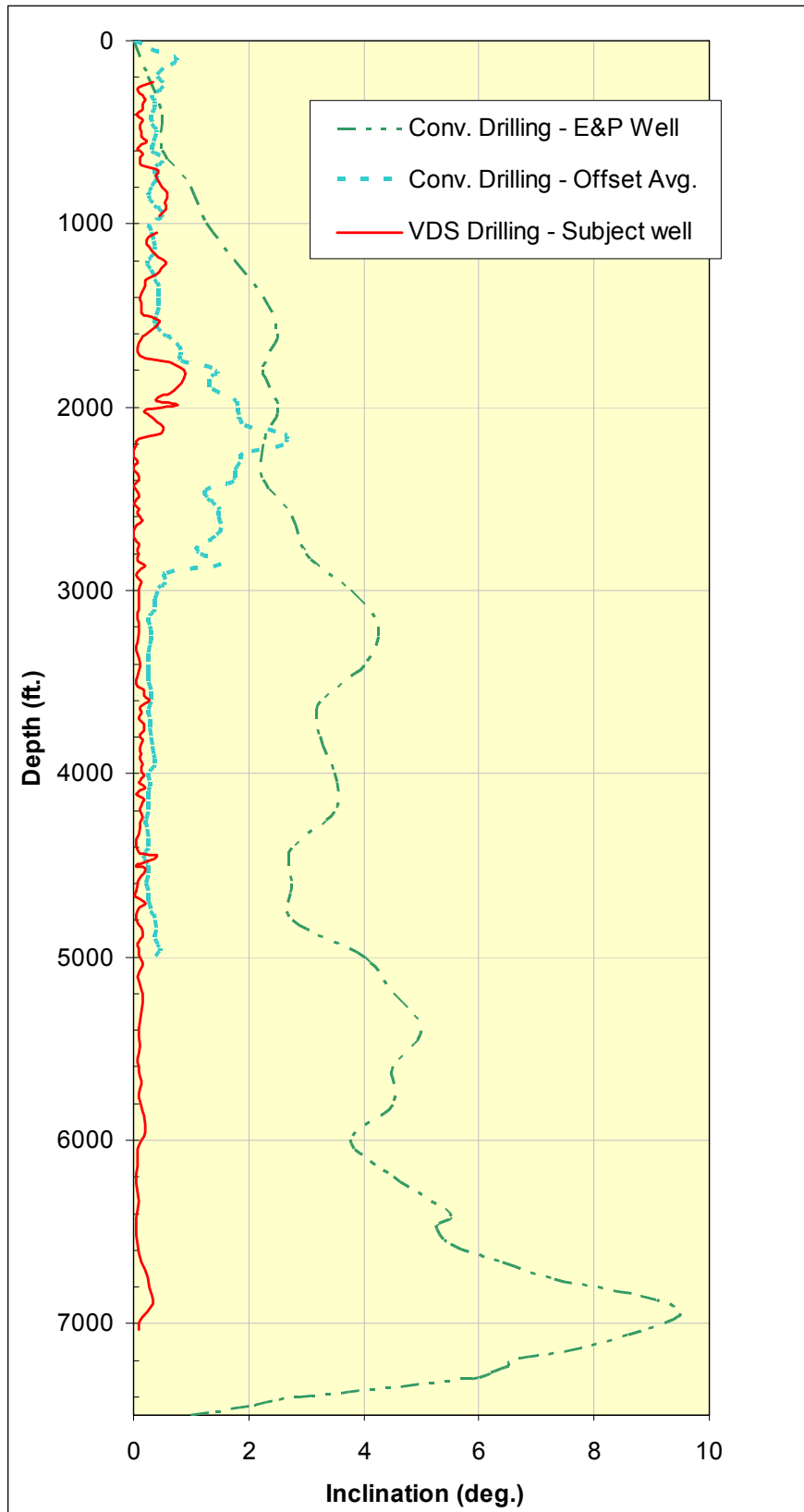


Figure 7. Comparing Vertical Drilling deviations in Salt

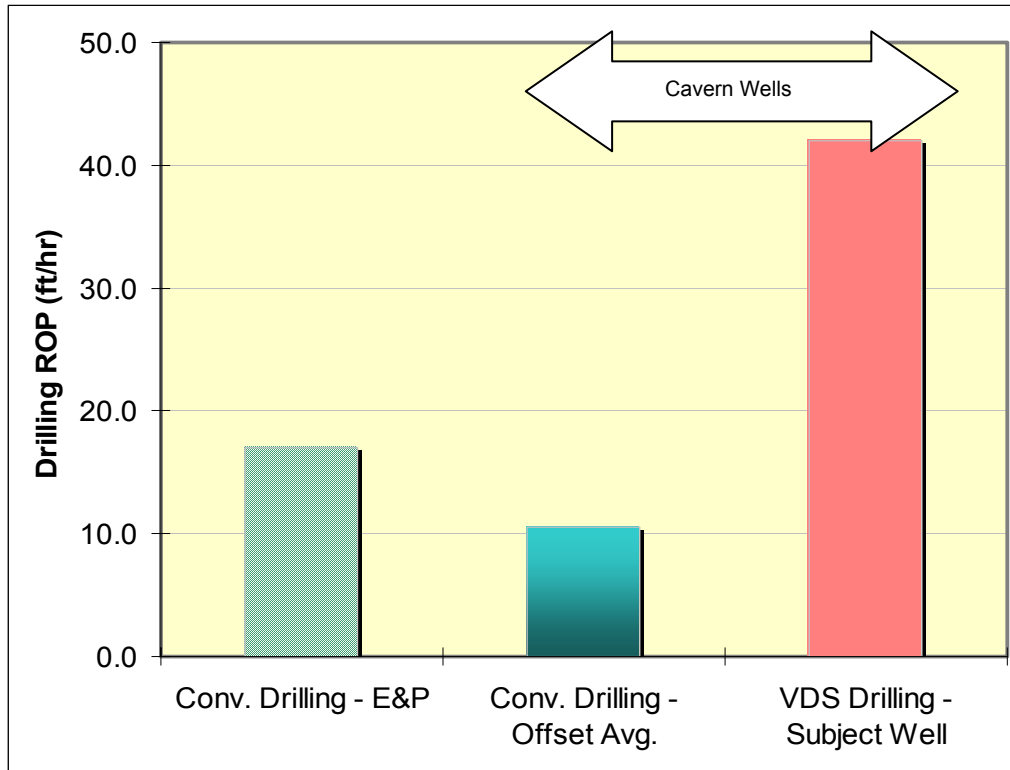


Figure 8. Rate of Penetration (ROP) Comparison in Salt

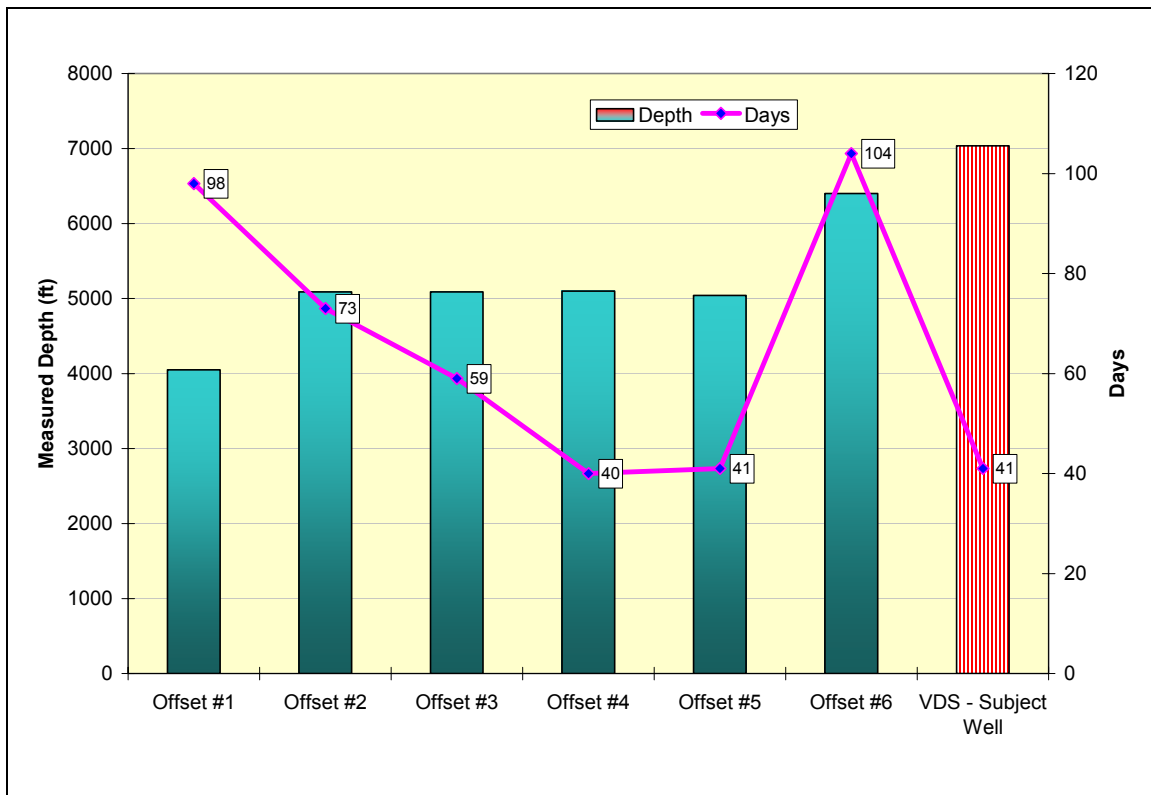


Figure 9: VDS Drilled Deeper and Faster than all the Conventional Drilled Offset Wells

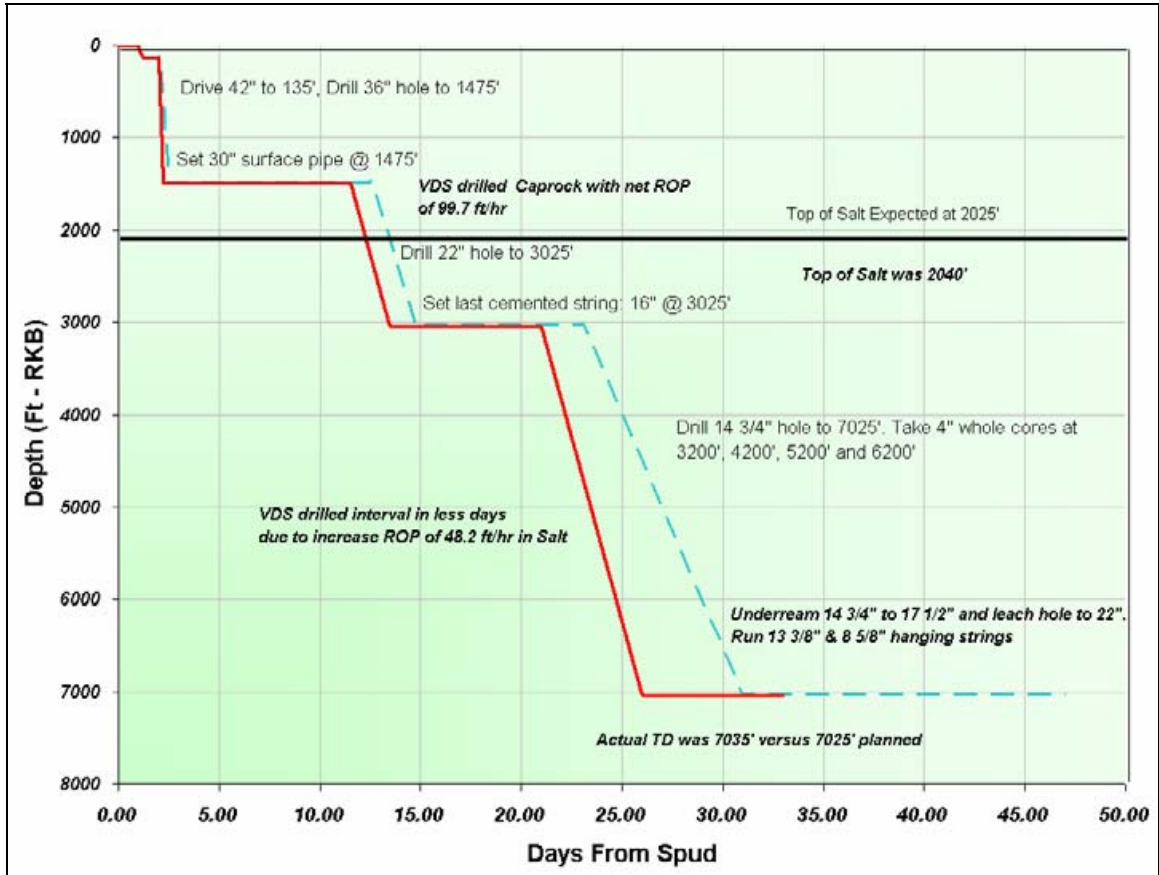


Figure 10: VDS saved 14 days from plan