

## Rotary Steerable System Technology Case Studies in the Canadian Foothills: A Challenging Drilling Environment

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### Abstract

The Canadian foothills are situated in a challenging drilling environment with deep wells in hard, abrasive formations that lead to extended drilling times. There is a real concern of casing wear in the upper sections and special care must be taken to ensure the integrity of the casing throughout the life of the well. Studies have shown that even slight doglegs in this vertical section lead to localized “hot spots” where erosion of the casing is focused. Keeping the well straight in this highly dipping formation has been a priority for directional drilling companies and operators.

Rotary Steerable Systems (RSSs) have greatly assisted in drilling these wells. From a “closed loop” feature, which automatically seeks a vertical profile in an openhole sidetrack with a carefully controlled dogleg severity (DLS), the rotary steerable tool is proving invaluable in drilling these complex wells and in reducing risks.

This paper describes the use of the RSS in different drilling applications and the procedures that have been developed in Western Canada. Case studies illustrate the benefits now being realized.

### Introduction

A quick look at western Canada drilling environments leads us to operation segmentation from low- to high-cost operation. This paper concentrates in the foothills drilling operation which is considered high cost related to many factors: surface locations at the top of mountains; high formation dip, especially in the surface holes; highly faulted areas which lead to geological uncertainty; and harsh drilling environments related to abrasive formation, shock and vibration, and slow penetration rate.

After the introduction of Rotary Steerable System (RSS) technology in many parts of the world, it proved to be the perfect match for high-to-medium-drilling-cost environments. Recently, RSS tools have been introduced to the high-cost rig-drilling operations in Western Canada, specifically targeting the foothills where the RSS tool aids the operator to reduce drilling costs.

Drilling in the foothills is subject to high levels of drilling shock and vibration, which cause premature failure to downhole equipment and drillstring components and lead to bottomhole assembly (BHA) failures. In addition to this, the

abrasive formation limits the number of hours for every bit run before a dedicated trip to change the bit. Drilling with the RSS adds more power to the drillstring as will be demonstrated herein.

### Geological Background for Canadian Rocky Mountain Foothills

The Rocky Mountain foothills in Alberta are located between the Western Canadian Sedimentary Basin (WCSB) and the Rocky Mountains. This fold and thrust belt was formed by shortening of the Paleozoic and the Mesozoic rocks in late Jurassic to Eocene as terrain accretion occurred on the western margin of North America. Within the foothills, thrust faulting has assisted structural shortening.

The Rocky Mountain foothills are the focus of ongoing hydrocarbon exploration in Western Canada. To date, most geophysical exploration in the Rocky Mountain foothills has used seismic exploration and has yielded clear images of 3D structures. However, the complicated geology and rugged terrain in the Rocky Mountain foothills presents some challenges. (See Figure 1.)

The western margin of the WCSB has had a long tectonic history. This was dominated by extension from the Proterozoic to the Triassic and compressive deformation from the Middle Jurassic to the Eocene.<sup>1</sup>

The compressive tectonic movements caused significant shortening of the western margin of the WCSB and created both the Rocky Mountains and the foothills.<sup>1</sup>

The tectonic setting has controlled the stratigraphy of the Rocky Mountain foothills. The Paleozoic succession is composed mainly of marine carbonate sediments. Clastic sediments, such as shales, siltstones, and sandstones dominate the Mesozoic succession.<sup>1</sup> As a consequence of the intense compressive deformation, overthrust faults and folds developed in the Rocky Mountain foothills. The structures in the foothills are very complex, and different structural styles have developed in response to varying lithology. Generally, a northward change in structural style from thrust-dominated in the south to fold-dominated in the north can be observed.<sup>1</sup> This is consistent with the general trend of a northward decrease in the competency of the entire Phanerozoic sedimentary sequence in the foothills.

The geological formations exposed in the foothills range in

age from the Mississippian to the Paleocene, and from wells it is known that in the subsurface there are rocks of Devonian to Cambrian age. These formations have been described in detail in many publications, and the stratigraphic succession is well established (Table 1). Generally, the formations in the western foothills are thicker than those in the east. The maximum aggregate thickness represented above the Proterozoic basement is about 9000 m.<sup>2</sup> (See Table 1.)

### Traditional Drilling Approach

For the last decades, steerable positive displacement motors (PDM) have been used for the majority of directional drilling work in the Canadian foothills area. Steerable motor drilling is a relatively inefficient process, with associated problems in the area ranging from trajectory control in unstable formations, high-dip formations, slow penetration rates, pipe sticking, and slide drilling.

Steerable motor drilling requires sliding of the bottomhole assembly in order to steer the wellpath; therefore, drilling becomes slower and potentially more problematic. Rate of penetration (ROP) is impacted as a result of wellbore friction, and BHA and drillstring components hang up. Hole cleaning without drillstring rotation has an adverse effect—cuttings will drop out of suspension to the low side of the hole. The transition from slide back to rotate requires rotating the motor bend through the section steered.

To steer an orient a motor requires that we maintain the orientation of the bend in the desired toolface setting. Reactive torque from the motor itself works against good toolface control, with the force turning the string in a counterclockwise direction. The magnitude of reactive torque will depend on the torque being generated at the bit, which itself is a function of bit aggression, motor torque output, and the formation being drilled. As a result, a compromise on bit selection is frequently made for steerable motor drilling.

Microtortuosity associated with a slide-and-rotate sequence is of particular significance in many regional reservoirs. Coiled-tubing accessibility can be severely impacted by a tortuous wellpath in the reservoir. In a 6-in. hole, today's extended power motors are susceptible to formation effects and can be difficult to stabilize, and a highly tortuous wellpath can result in the reservoir.

### RSS Technology

Exploration and production (E&P) companies plan exotic wellbore trajectories that push the limits of directional-drilling technology. Companies simultaneously seek cost savings and improved operational quality.

Rotary steerable drilling technology made a dramatic entry into the market in the late 1990s. The technology has advanced considerably since then, offering increased flexibility, greater reliability, and higher rates of penetration. These high-performance systems facilitate the drilling of complicated wellbore trajectories in harsh environments. With industry costs for nonproductive drilling time estimated at US\$ 5 billion per year, RSSs are one of the keys to preventing

or reducing these significant losses.

Engineering service contractors have developed distinct rotary steerable systems for many different applications. These systems share several features, including the continuous rotation of all external components at the same speed as the bit.

The RSS family can be divided into two principal technologies: "Push-the-bit" and "Point-the-bit".

In push-the-bit technology (side forces), the RSS tool relies on the application of force outwards against the wellbore to push the bit and deflect the BHA to the opposite or resultant direction.

In point-the-bit technology (bit tilt), the RSS tool achieves wellbore deflection by actually bending a shaft or using a tilted device within the tool itself. The benefit is that the RSS tool does not have to rely on the wellbore condition; also, the tool requires less reaction from the formation.

Ultimately, "shoe-to-shoe" rotary steerable drilling will allow companies to drill out the casing shoe and continue drilling to the next casing point in a single run. With industry costs for nonproductive drilling time estimated at US\$ 5 billion per year, the RSS can be a key factor in the prevention or reduction of these significant losses.

This paper discusses the deployment of RSS technology in the Canadian foothills. RSS technology has achieved the benefits of better directional control with the subsequent mitigation of drilling-associated problems through the prevention of cuttings accumulation around the BHA, thus minimizing the possibility of getting stuck, and by providing the ability to back ream, thus eliminating the need for dedicated wiper trip. The final value is the remarkable penetration rate enhancement, better hole quality, and safer and more efficient drilling operations—hence, early production.

### Canadian Operators' Drivers and Needs

The main incentives to use RSS technology are to improve the operational efficiency through the mitigation of drilling risks and to optimize drilling performance by applying the new technology that will add value to the operation and reduce the drilling time compared to conventional drilling. Through close monitoring of historical wells drilled with the conventional motor system in the Canadian foothills, most challenges were found in the directional profile, sliding-related hole problems, and bit selection, among others.

The challenges were

- Casing wear
- Hole cleaning
- Stuck pipes
- Low ROP
- Number of BHAs
- Excessive torque and drag due to the microdoglegs created with the frequent slides.

## Case History and Success Stories

The following cases discuss different applications of RSS technology in the Canadian foothills drilling environment in Alberta.

### Case #1 – Operator with Vertical Drilling Application

Operators drilling in the Alberta foothills area face the following drilling challenges:

- Maintain vertical hole through high-dip formation.
- Endure slow drilling related to very hard, abrasive formations.
- Minimize the number of BHAs to drill the surface hole sections and avoid correction runs to bring the well back to vertical.
- Avoid casing wear—a drilling risk in this sour gas environment.
- Minimize doglegs severity. Doglegs present in wellbore will create hot spots in the casing where the casing is forced to bend. The severity of the hot spots can be reduced with dedicated reaming runs prior to running casing, which will be extra time and cost. In addition, dogleg locations must be recorded to allow for reference and monitoring when inspecting casing.
- Minimize torque and drag (T&D). High doglegs in the top part of the wells created by correction slides in high-dip intervals cause excess torque and drag. The length of the [spell out HZ] (HZ) lateral is affected by the high T&D, and expensive torque reducers (e.g., lubricants, beads, and agitators) are required to achieve the geological objectives.

On the basis of the drilling design in that area, the objective was to maintain the well close to vertical and to drill as deep as possible—2000–3500 m—before starting the kickoff point (KOP). It was important to minimize doglegs in order to run casing to bottom without creating hot spots, which could create casing wear and affect well integrity in the future. Most of these wells were planned as deep wells with final total depths (TD) at 4000–6500 m with a step out of 1.8–2.8 km.

The execution phase used the RSS in a 16-in., 12 1/4-in. and 8 3/4-in. (406-mm, 311-mm, 222-mm) hole.

### Case #1 Evaluation Phase

Significant time/cost savings were achieved compared to the offset wells drilled with PDM; the drilling maintained inclination and DLS below 2 degrees, which had been agreed to be the threshold. Figure 3 shows the wireline dip logs from the well; this demonstrates how the RSS makes a difference compared to the old PDM approach. With this kind of log data, we can quantify how the RSS performs against the formation dip. However, in some cases, the formation evaluation program did not run logs. In this case, we were able to compare data with the offset wells drilled by PDM, as this was the only resource available for comparison.

### Case #2 – Operator with Directional Drilling Application

In Case #2, the operator used the RSS plus a motor with inclination-hold function to drill the 8 3/4-in. (222-mm) hole section building to 35 degrees inclination, then drilled the long tangent section  $\pm 2000$  m as smooth as possible, kept the trajectory through steeply dipping beds, and kept surface rotations between 30 and 60 rpm to minimize the casing wear caused by rotation.

The RSS demonstrated excellent performance to finish the section four days ahead of schedule with excellent hole condition, thus eliminating planned wiper trip in-ream and back-ream time. Time saved was 5 days. For more details, refer to Figure 4, which highlights the comparison to offset wells.

### Case #3 – Operator with Sidetracking Application

An active operator currently has six rigs drilling in the Alberta foothills area with the following drilling challenges:

- High-density fault area with wellbore instability issues related to different drilling hazards such as shale and coal.
- Slow drilling operations related to very abrasive formation.
- Minimize doglegs and DLS to minimize the future occurrence of casing wear hot spots where the casing is forced to bend. This is a drilling risk in this sour gas drilling environment. The severity of the hot spots can be reduced with dedicated reaming runs prior to running casing. The location of the doglegs should be recorded to allow for reference and monitoring when inspecting casing.

Operator objectives were to sidetrack the well after getting stuck in the 12 1/4-in (311-mm) hole and to minimize doglegs in order to run casing to bottom without creating hot spots while maintaining the well integrity to the final well TD at approximately 6800 m.

Execution phase used the RSS. The sidetrack took place in the 12 1/4-in. intermediate hole at 2130 m. After dressing the openhole cement plug, the RSS drilled a 12 1/4-in. hole from 2130 m with a smooth DLS (2°/30 m) to 2246 m, while building angle from 0.2° to 6.93° in the right azimuth direction of 268°. Then, 9 5/8-in. (244.5-mm) casing was run to the bottom with no problems.

**Case #3 Evaluation of the RSS Performance**

- Significant time/cost savings were achieved compared to the offsets wells drilled and sidetracked with PDM.
- Excellent hole quality was maintained to allow casing to be run to bottom.
- Operator's drilling project manager indicated that an After Casing Wear log run after 30 days showed minimal casing wear.

Note that there was minimal wear at the sidetrack point. Production Casing 244.5 mm has sufficient burst integrity to continue drilling with no drillpipe protectors. (See Figure 5.)

**Conclusions**

RSS technology is becoming the ultimate choice for all drilling applications that start from vertical drilling to maintain well verticality with minimal inclination and DLS, which could affect the entire well integrity. This eliminates any need for correction runs; in addition, it improves drilling efficiency in deviated and horizontal drilling by eliminating sliding intervals. The results are a faster rate of penetration and smoother boreholes with better hole cleaning, which eliminates the need for dedicated wiper trips and yields subsequent economic benefits related to cost reduction in the overall drilling operation and to the shortened time to early well production.

**Acknowledgments**

First, I acknowledge the Canadian operators who were willing to try new technology as the way forward to improve drilling operations. I also thank the Schlumberger Drilling and Measurements Canada Team, who worked hard and put forth a great effort and provided quality service to achieve this success.

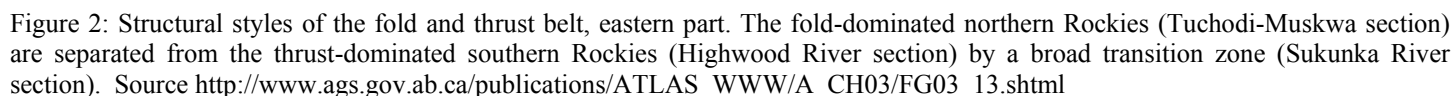
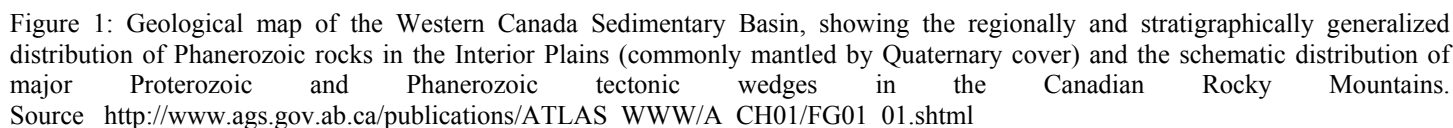
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2. Geological Atlas of the Western Canada Sedimentary Basin [http://www.ag.gov.ab.ca/publications/ATLAS\\_WWW/ATLAS.shtml](http://www.ag.gov.ab.ca/publications/ATLAS_WWW/ATLAS.shtml)
3. Magnetotelluric Exploration in the Rocky Mountain Foothills, Alberta, Wen Xiao UNIVERSITY OF ALBERTA
4. Foothills' Stratigraphy (modified from Fox, 1959)

Table 1: Foothills' Stratigraphy (modified from Fox, 1959)

**Table 1-1** Foothills' Stratigraphy (modified from Fox, 1959)

System	Formation	Thickness (m)	Lithological Description
Tertiary Paleocene	Paskapoo- Porcupine Hills	610	Sandstone, shale, mudstone, thin coal seams, cobble bed at base
	Willow Creek	30—250	Sandstone, shale, mudstone
Cretaceous Upper	Edmonton	300—460	Sandstone, shale, and coal, conglomeratic at base in places
	Bearpaw	0—180	Shale, siltstone, with thin sandstone beds
	Belly River	70—1220	Sandstone, shale, some coal, basal sandstone very massive in places
	Wapiabi	30—550	Siltstone and shale
	Bighorn (Cardium)	10—140	Sandstone, arenaceous shale, lentils of chert conglomerate
	Blackstone	140—300	Siltstone and shale
	Crowsnest	0—550	Agglomerate, tuff, essentially confined to Crowsnest area
Lower	Blairmore	300—700	Sandstone, shale, some thin limestone, bentonitic, and tuffaceous beds
Cretaceous	Kootenay	15—210	Sandstone, Carbonaceous shale, and coal
Jurassic	Fernie	30—270	Siltstone, shale, and fine- grained sandstone
Triassic	Spray River	0—15	Dolomite and limestone
Permian	Rocky Mountain	0—120	Arenaceous dolomite, limestone, quartzitic sandstone, siltstone, basal conglomerate in some places.
Carboniferous Mississippian	Rundle group	270—610	Limestone, dolomite, some calcareous shale, commonly cherty, in places anhydritic
	Banff	150—270	Silty dark limestone, calcareous shale
	Exshaw	3—10	Black shale
Devonian	Palliser	200—350	Limestone, dolomite, characteristically Massive
	Alexo	30—60	Dolomite, silty to arenaceous
	Fairholme	410—530	Dolomite, limestone, argillaceous and silty limestone, anhydrite
	Ghost River	80+	Variegated shale, dense dolomite, edgewise conglomerate
Cambrian		780+	Limestone, dolomite, argillaceous limestone, with sandstone or quartzite at base
Proterozoic		3050+	Limestone, dolomite, argillite, quartzite, shale. Known only in Lewis overthrust sheet



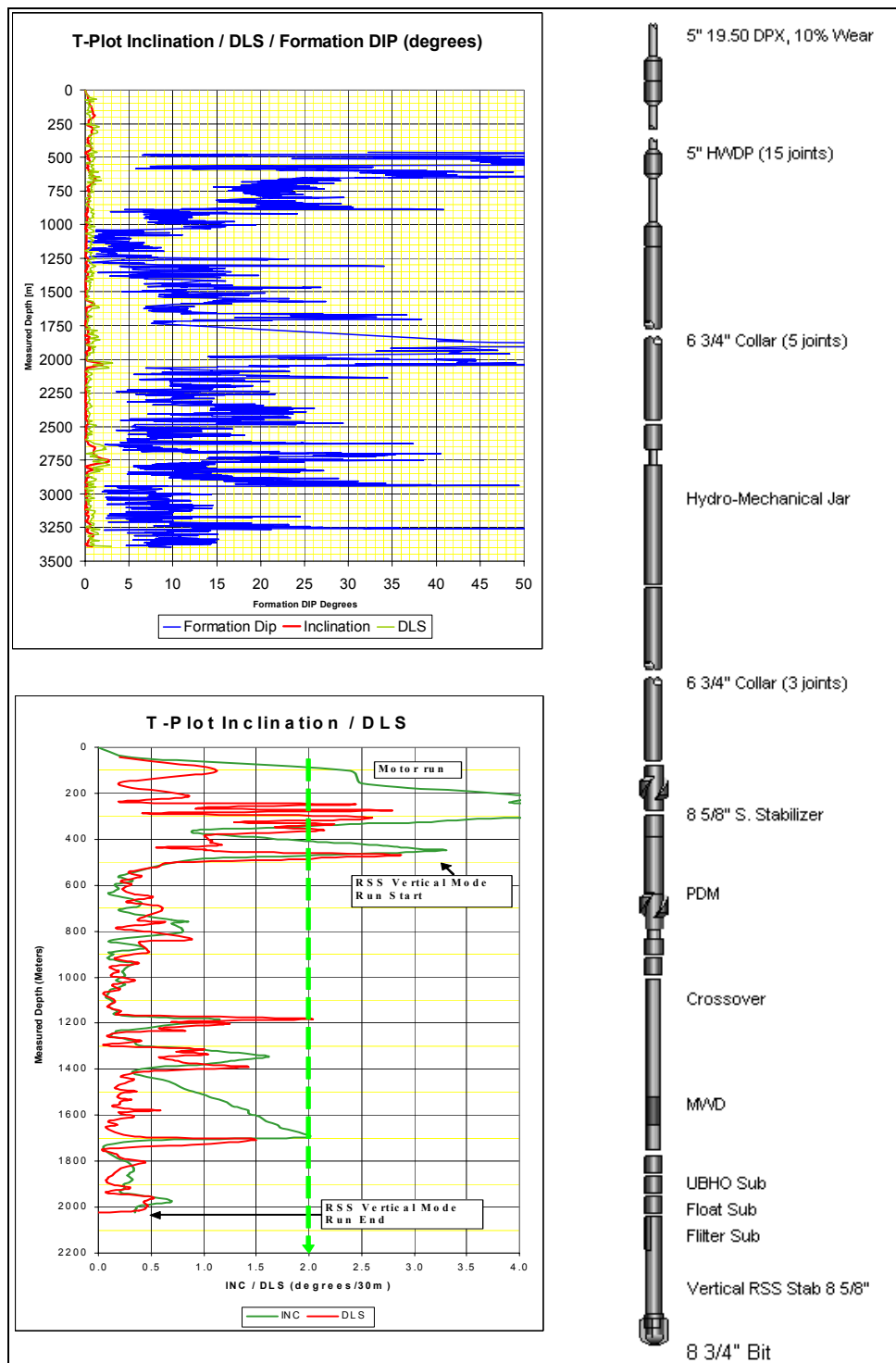


Figure 3: Case #1 –Vertical drilling application of RSS technology.

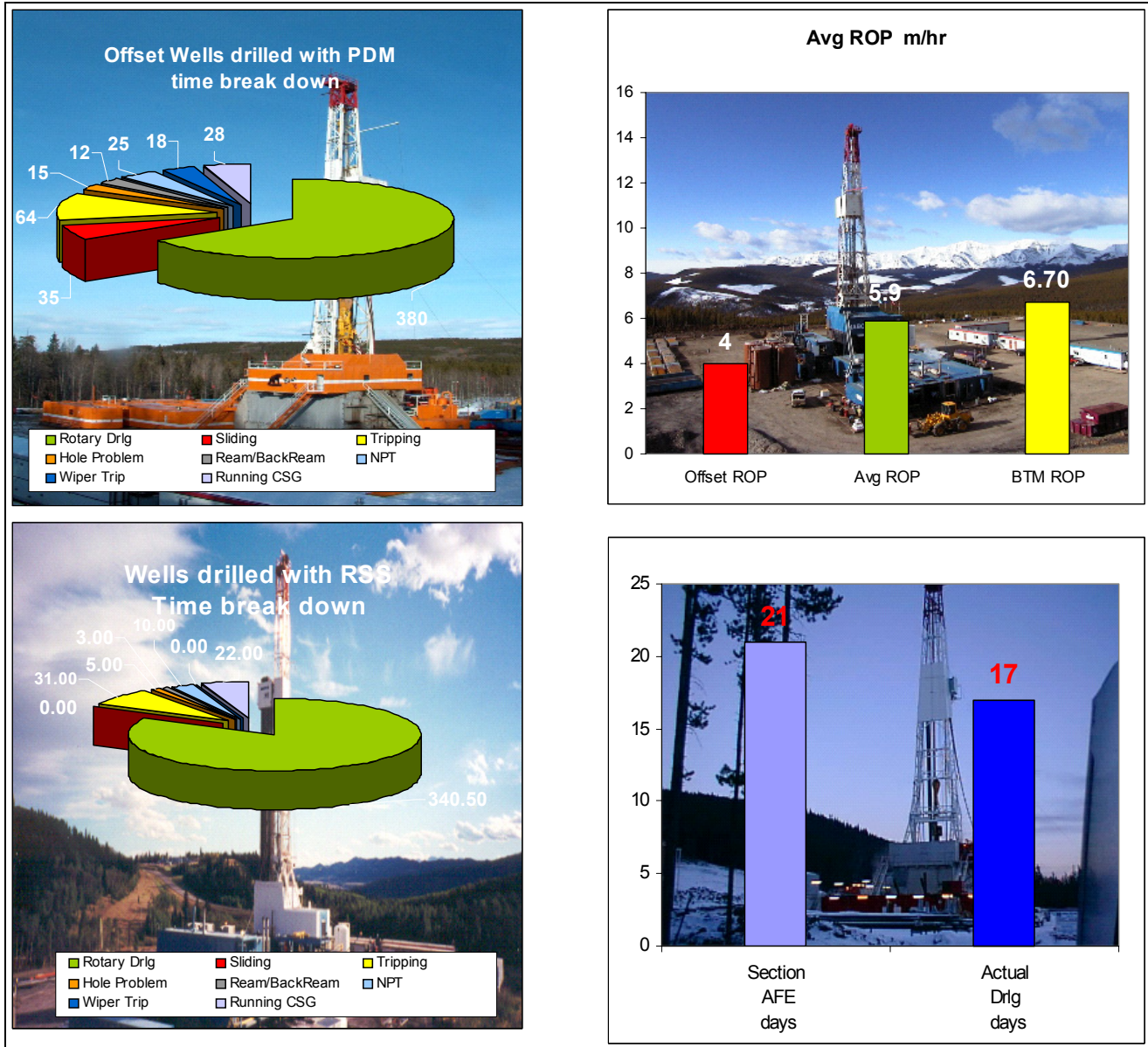


Figure 4: Case #2 – Highlights of the comparison of RSS-drilled wells to offset wells. (Directional drilling application of the RSS.)

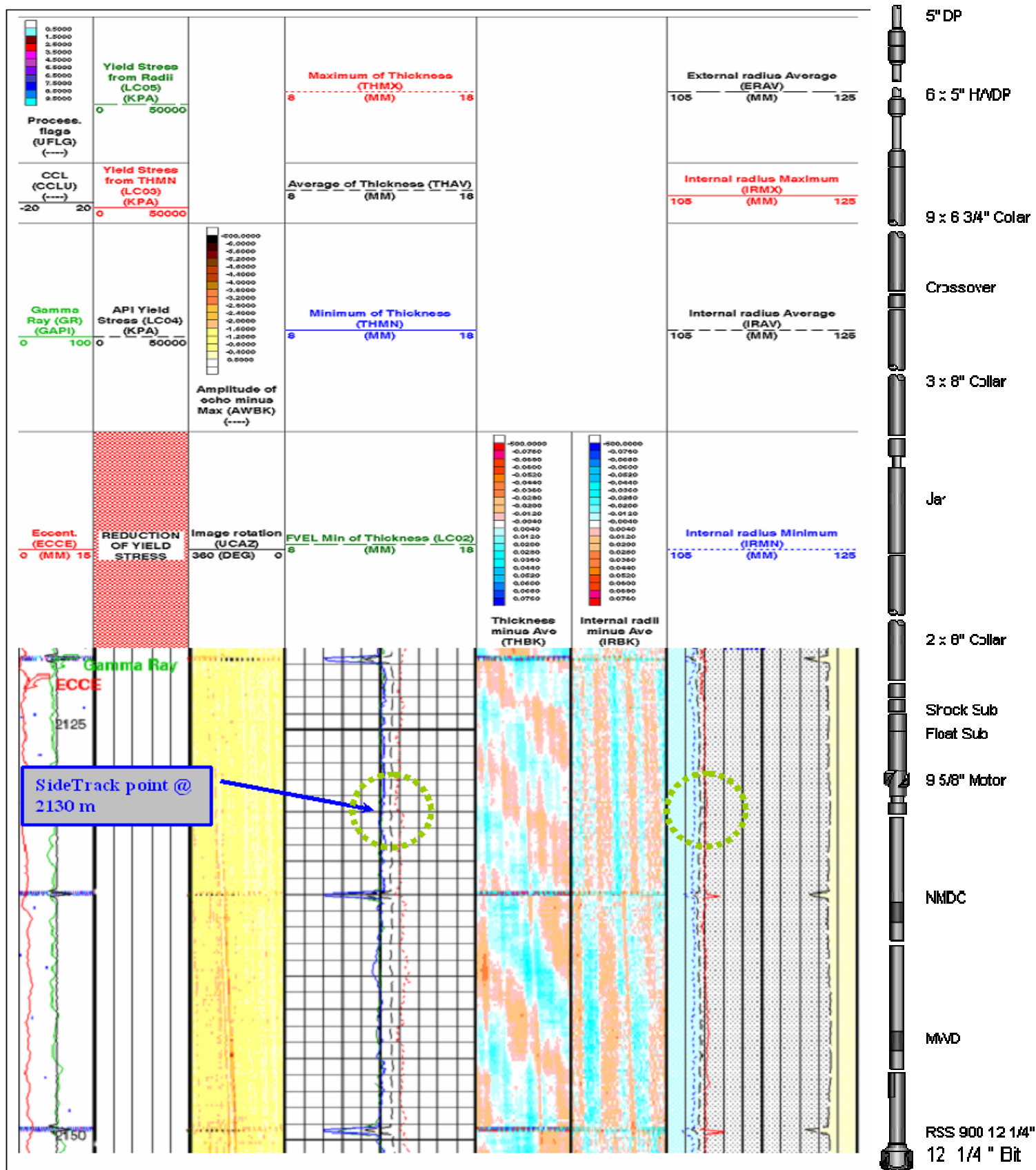


Figure 5: Case #3 – Sidetrack application of the RSS. (Casing wear log ran after 30 days and sidetrack BHA )