A Question of Balance - dispelling the myth of 'boggy ground' and other spurious claims in coal seam drilling.

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Abstract

Directional drilling in Australian coal mining is a well-established technique for draining gas from coal, and rendering mining safe from the hazards of uncontrolled gas outbursts. A secondary use of the technique is for mine planning purposes as an exploration tool. Inseam drilling is now a $30M business in underground mining yet much of the reporting of drilling problems is qualitative at best and spurious at worst.

As effective and widespread as the methodology has become it still falls short in areas of difficult geology, the "boggy ground" of drilling legend. Boreholes that do not reach their target because of drilling difficulties add extra pressure to the mine development cycle and raise costs related to amelioration responses.

Boreholes that fail because of "conditions" reflect a usually untold geological or borehole management story. The information should be integrated into the geological model for mine planning purposes but seldom is, usually because of the vagueness of the reporting of the drilling problem and the subsequent long bow of interpretation that must be drawn. Many boreholes are terminated prematurely due to bad borehole conditioning practice.

This paper addresses some aspects of the failure of inseam directional drilling projects, and suggests developments for the future that may assist the management of inseam drilling projects.

Introduction

Australian underground coal mining has generally embraced directional drilling for the drainage of gas, and to a lesser extent as an exploration tool ahead of mine development. In-seam exploration drilling in Australian coal mining is dominated by directional techniques using a downhole motor and electronic survey tool. This has not always been the case; exploration work was commonly carried out

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by rotary drilling methods – with mixed success - during the 1980's. In the past decade directional drilling has predominated, mainly due to the exacting demands on steering and survey accuracy required in gas drainage programs. The spin-off from the drive to improve in-seam drilling for gas drainage has been geological exploration from in-seam directional boreholes, which has been generally successful, with some limitations.

Directional methods are effectively modified and adapted from conventional oilfield technologies. The US Bureau of Mines and some of the large US coal mining operations pioneered the early work in coalfield in-seam drilling. The demise of the USBM and structural changes to the US coal mining industry has effectively resulted in the baton passing to Australian coal companies, technology groups, and contract drilling operations. Today, Australian coal seam directional drilling techniques are equivalent to world standard practice. However, the science of underground directional drilling is a long way short of the norms of oilfield drill management, steering and logging.

Exploration of coal mining leases by directional drilling means has been carried out relatively consistently over the past ten years. The method has its adherents, and is generally utilised in a reactive manner according to specific mine planning requirements. Seldom is exploration drilling carried out on a routine, systematic basis. Often it is a by-product of gas drainage drilling - a consequence of surprising and adverse circumstances. The issue of 'boggy ground' appears in the gas drainage context but is particularly a common borehole terminator in exploration projects. Has the borehole failed due to geological conditions, or is it bad drill management? This is the main theme of the following discussion.

The equipment and reporting of underground directional drilling

Currently, all drilling contractors and in-house drilling crews are using the same equipment configuration (downhole component schematically represented in Figure 1). Therefore, there is a standardisation of reporting systems and procedures throughout the industry. Survey information (pitch, azimuth), pump water pressure and flow rate, and driller's comments are all recorded on hand written log sheets.

Most operators are using drilling rigs with a 75kW hydraulic power unit (operating at 1000V), and a 250 l/min water supply (with a 10 MPa high pressure pump). The rigs exhibit 135 KN thrust and pull, with 1500 to 2000 Nm torque.

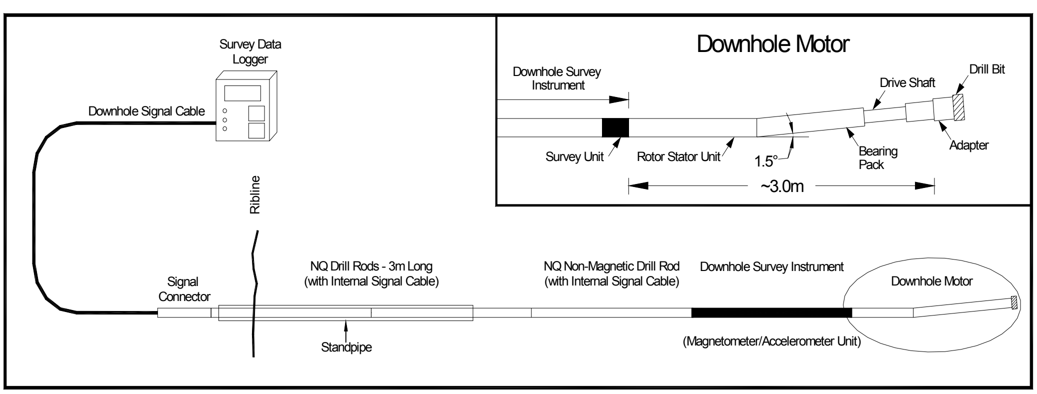


Figure 1. *Schematic representation of standard practice directional drilling downhole equipment*

An NQ, NRQ or CHD rod string is usual, and an electronic survey tool and downhole motor. Electronic survey tools have effectively replaced the use of single shot cameras due to the speed at which survey information can be processed and acted upon by the drill operator. Electronic survey tools are an integral component in the process of steering the drill. The increased reliability of the survey result has also had a favourable impact upon the geological interpretation process.

In an ideal environment, using current industry standard equipment, in-seam directional drilling is possible to distances of about 1500m. In reality, boreholes greater than 800m TD are rare in Australian (and international) coalfield drilling. In the majority of degasification drilling holes are drilled <300m. Exploration boreholes may be planned to 1000m+ but due to geological factors, rig performance limitations, borehole management issues, and time constraints do not always achieve the designated target.

The capital cost of the downhole component – rods, survey tool and downhole motor are always at risk on long exploration boreholes. The implications of a stuck drill string are extremely serious and the result is that drilling operators err on the side of caution. At the first sign of downhole drilling problems the rods will usually be withdrawn and the hole abandoned. The usual excuse is ‘bad geology’. Nobody wants the responsibility for $500,000 of lost equipment in a borehole.

With directional drilling there is no core, and cuttings from the borehole are not normally collected. The only formal record of the borehole is contained in the data from the electronic survey instrument and the written records of the driller. Current practice is for the driller to record changes in drill machine performance and ‘feel’ as the string advances. This is carried out in a subjective manner and recorded by the driller on log sheets. According to the skills of the operator, the notes can be quite detailed or basic in the extreme (usually the latter). The driller is mainly aware of hardness variation and the colour change of the drilling fluid exiting the borehole. Thus, in most cases geological interpretation is carried out post-drilling - from viewing the drill logs – and using intuition to resolve the true meaning of “hard”, “soft”, “sticky”, “white”, “boggy” etc.

Factors Limiting Inseam Drilling

The equipment limits the distance the hole can be drilled. The major limiting factor is the behavior of the drill pipe in the hole. Borehole geometry, wall roughness, cuttings accumulation and annular pressure all contribute to the overall drag force required to move the string in the hole. There is a limit to which a drill pipe can be pushed into a borehole. This limiting point is known as “lockup” and occurs when the axial force applied by the rig causes the pipe to buckle in the hole. Once this level of force is reached, pushing harder just increases the buckling. For NQ in a horizontal straight hole, the force sustained before lockup is around 12 tonnes. The specific maximum feed force for an LM75 is 12.5 tonnes. How much hole you drill before you accumulate 12 tonnes of drag will depend on the management of the contributing factors mentioned above. It is rare to reach lockup in cross block drilling. It usually requires longer holes to experience drill pipe lockup.

A typical scenario is for feed force to be steadily increased, and the thrust force transmitted to the bit. As the force increases the pipe begins to buckle, first in a sinusoidal fashion, then helically. A friction force between the helix and the wall is produced and this force will increase as the rig feed force increases. The transmitted force to the bit reaches a maximum as increasing rig feed force is entirely absorbed by the helix-wall friction – lockup point has been reached.

Once lockup is reached, the string cannot be further advanced into the hole unless rotated. From here, unless borehole conditioning can reduce drag, the hole has reached its conclusion. In some circumstances, the annular pressure may further limit the depth capacity of the directional-drilling project. The onset of lockup point can happen quite rapidly. The transition from “drilling well” to “can’t drill anymore”, “boggy ground” can be sudden. It can be due to the bit intersecting boggy ground but it can also be due to a change in borehole condition 100’s of metres away from the bit. ‘Boggy ground’ is a frequent cause of abandonment of a drilling exercise.

Inseam directional drilling currently involves the use of a downhole motor with a bent sub. The continual process of correcting the path of the borehole by modification of the orientation of the bend angle results in a borehole path that is not straight, more a series of subtle bends (the ‘flip flop’ effect), with a typical bend radii of 120-220m. Without rotating the drill pipe, cuttings fall to the low side of the hole and form a bed. This increases the surface area across which drag is transmitted to the drill string during movement across the borehole wall. This increases the thrust required to move the string forward, accelerating the onset of lockup.

Outside of the inseam drilling scene, this is ‘slide’ drilling. Australian underground directional drilling practice is almost exclusively ‘slide’ drilling. Elsewhere, the standard directional drilling method using down hole motors is ‘slide and rotate’. Here, the rods are turning whilst using a downhole motor and slide drilling is only carried out to get a deviated borehole to the desired attitude. Why is this technique most widely used? Because it delivers a smoother well bore and assists the borehole conditioning process.

‘Flip flop’ contributes to the accumulation of cuttings beds, tortuocity and the premature termination of inseam boreholes. A comparison of drilling long directional boreholes using slide / rotate and ‘flip flop’ methods is presented in Figure 2. Here the standard ‘flip flop’ technique has resulted in termination of the borehole at 864m. Drilling a parallel borehole in the same seam with the same equipment, but using slide / rotate (only from 450m onward), resulted in a borehole that reached a TD of 1302m.

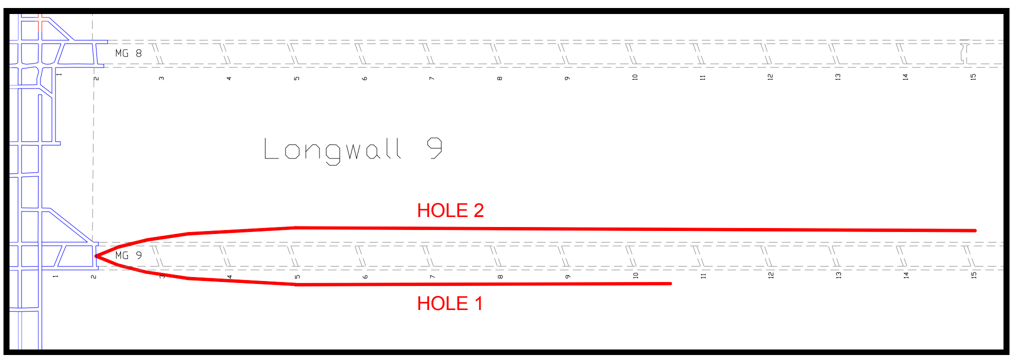


Figure 2. *Comparison of two parallel boreholes, one drilled entirely with the ‘flip flop’ method (Hole 1) and the other with mainly ‘slide / rotate’ (Hole 2), (Thomson, 2001).*

The ‘rotate/ slide’ method effectively reduces the dogleg severity of the borehole. For the example mentioned above, dogleg severity plotted versus borehole depth reveals a compelling case for ‘rotate / slide’ over ‘flip flop’. Dogleg severity is identical for the first borehole and the first 450m of the second borehole. After the ‘rotate / slide’ technique is introduced (beyond 450m in Hole 2), dogleg severity is markedly reduced (Figure 3), leading to the success of the second borehole. This example provides a good comparison as to the effect of borehole geometry. The shorter hole has an average dogleg severity of 10deg/30m, the longer hole 6.5deg/30m. Both were drilled to lockup point. It is important to note the borehole has been terminated due to physical limitations (borehole conditioning issues) rather than because of geological problems.

At the time, this adoption of ‘rotate / slide’ was resisted by the experienced inseam drillers on the project, and as a consequence, the client objectives were not adequately satisfied, leading to a negative commercial outcome. Attention to borehole conditioning issues has a quantifiable impact!

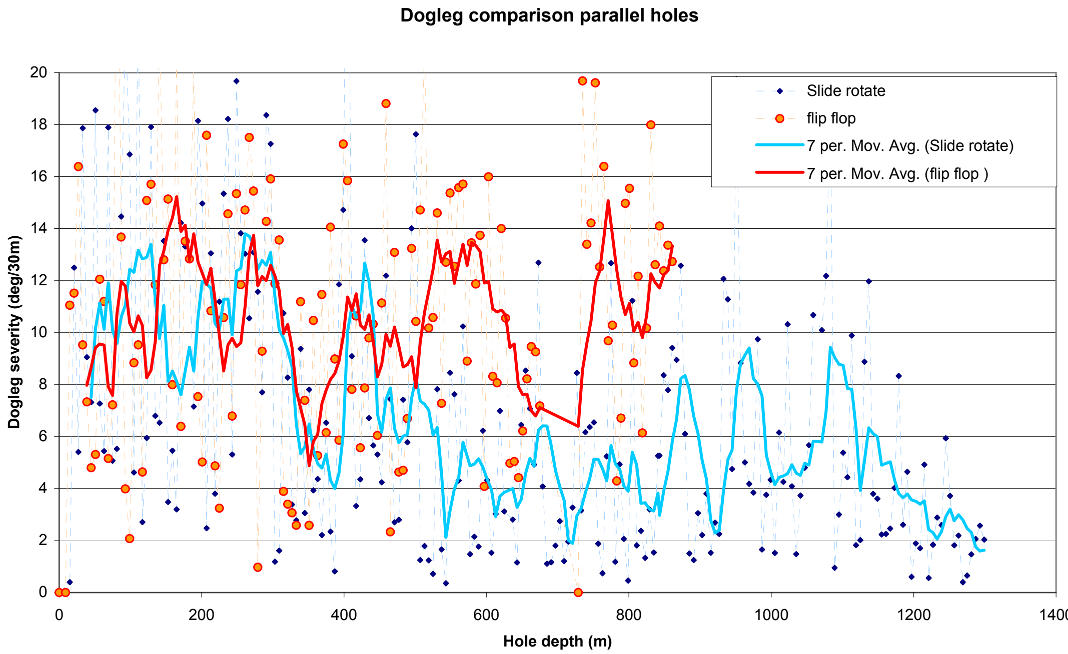


Figure 3. *Dogleg severity in two parallel boreholes, one drilled entirely with the 'flip flop' method (Hole 1) and the other with mainly 'slide / rotate' (Hole 2).*

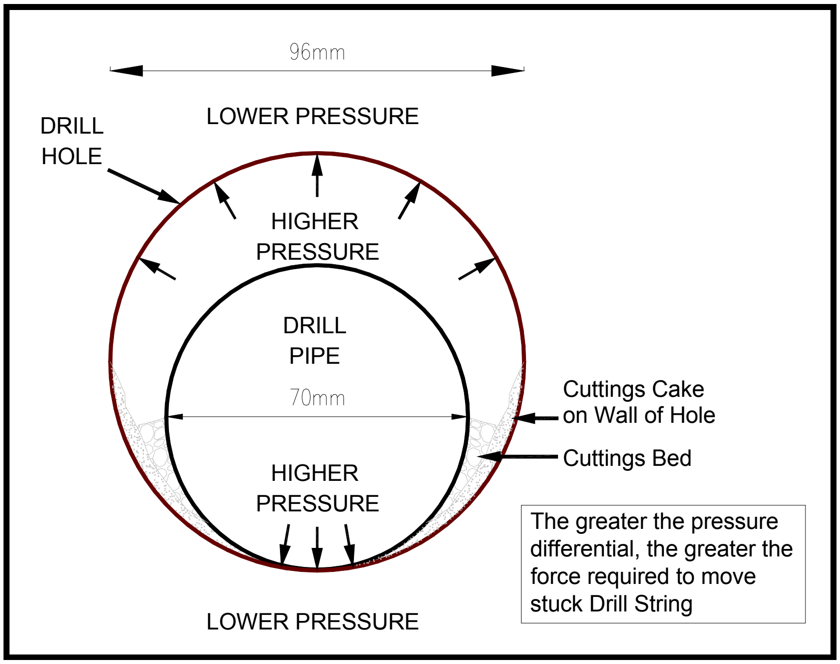
The 'Boggy Ground' myth

Poor cuttings removal leads to water circulation issues and possibly the beginning of differential sticking problems. The cuttings bed is swept up by a surge of fluid in the annulus and "packs off". This buildup of cuttings can effectively seal the annulus to the extent the water pumped through the drill string must be squeezed through the restriction under some pressure. This restriction may be related to a geological problem zone, or it may simply be a borehole conditioning issue.

When a blockage occurs the water may make its way through the formation – bypassing the restriction. The driller will observe high off bottom pump pressures and the returning water will be strangely clear (as it is filtered by passage through or around the restriction). The force required to move the drill string without rotating it will be unusually high due to the onset of "differential sticking". "Boggy ground" has appeared and the wrong conclusions may be drawn. The differential sticking phenomenon is also related to the issue of borehole 'balance' (to be discussed separately) and is presented in schematic form as Figure 4.

The geological interpretation of this borehole may then (erroneously) assign a structure to the interval where the string has become stuck – assumed to be at the bit position. Even if geology is a factor in the borehole not progressing, the problem may not be at the bit – it may well be further back along the drill string.

'Boggy ground' reporting needs to be treated with some scepticism and the assumption that its appearance is entirely related to geological structure should be questioned.



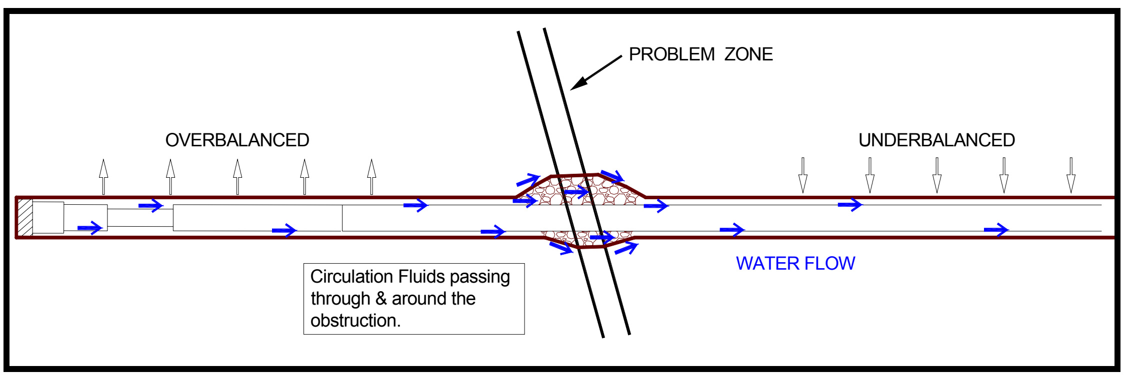


Figure 4. *Differential sticking is a leading cause of stuck drill pipe in underground inseam drilling.*

A Question of Balance

Underground directional drilling is 'underbalanced'; in other words, the formation pressures generally exceed the annular or circulating pressures. This because the borehole is drilled from near atmospheric pressure at the collar (~120kPa) and the formation is subject to its virgin in situ pressure state, which may be of the order of 1500kPa. This pressure differential will naturally allow for the gas and water in the formation to flow into the borehole, and out through the gas drainage network. This phenomenon underpins the success of inseam gas drainage in coal mining.

The success of inseam drilling depends also upon the ability of the annular wall to remain stable. In underbalanced drilling the risk is always that the borehole walls will collapse around the drill string, disrupt circulation, lead to pressure differentials, differential sticking, mechanical jamming and a failed borehole. This is why current Australian directional practice struggles in coals which are 'soft' (usually tectonically disturbed) such as the coals of China and New Zealand.

In Australia the coal tends to be strong, and underbalanced drilling is generally successful. One major contributor to this success is that the mined seams are shallow. This means the differential between annulus and formation pore pressure is generally low (1500 – 120 = 1380kPa (200psi)) underbalance. For coal of bulk strength above 5mPa this is likely to be no problem. In deeper seams with higher underbalance (for example, in parts of China, and noted in parts of the Sydney and Bowen Basins) the stability problem becomes a major issue, particularly when the coal is weakened by tectonic history.

The overbalanced drilling case occurs when the pressure of the annulus exceeds that of the fluid contained in the pore space of the formation. As a result, drilling fluids will tend to migrate into the surrounding geology and circulation may be lost. This also has the negative effect of damaging the borehole wall, leading to 'skin' effects – which may affect gas drainage performance. Although unusual in underground directional drilling, the overbalanced condition may occur when a borehole becomes locally blocked (disrupting circulation) or close to the collar where coal de-stressing occurs associated with the gas / water desorption process from the rib. It may also occur in areas of local high permeability associated with geological structures.

The place where overbalanced drilling is of the most concern is in surface to seam drilling in high permeability coals. Here, it is desirable to maintain borehole pressure above the gas desorption point, and below the local pore pressure average (Figure 5). In this example, taken from a surface to seam project in Queensland, off and on-bottom pressures are maintained in the desired window in order to minimise differential sticking and skin effects caused by drilling 'overbalanced' and avoid premature desorption by drilling too far 'underbalanced'.

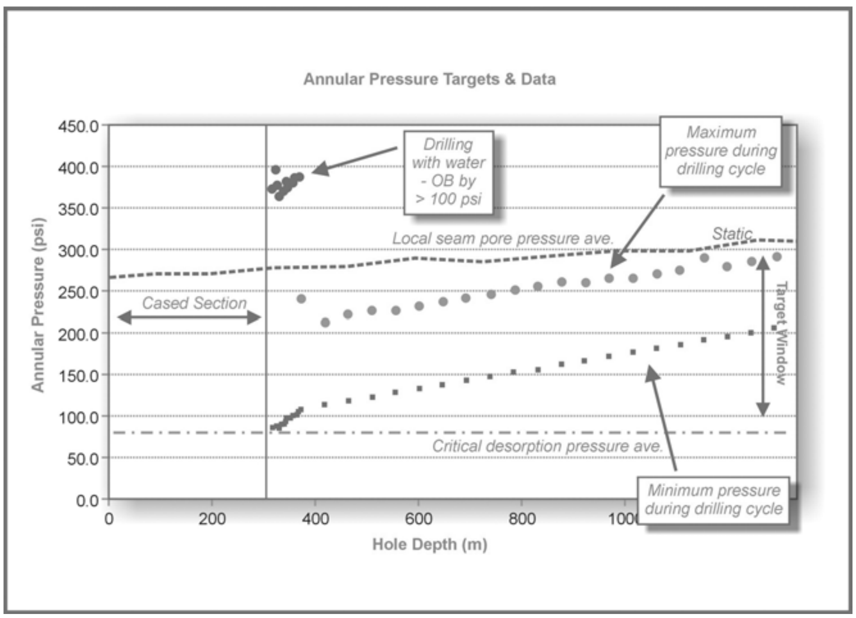


Figure 4. *The importance of maintaining balance in drilling is exemplified by this surface to seam example from Queensland (from Thomson & MacDonald, 2003).*

It is therefore theoretically desirable to maintain perfect balance in drilling boreholes, underground or otherwise. In underground drilling it is currently impossible to maintain this balance, however the subject has received some attention in the past. Gray (1998) noted the importance of maintaining borehole pressure to minimise the pressure differential between borehole wall and annulus, and developed a prototype borehole pressurisation device. The system was never trialed in an underground mine.

Seeking an improved understanding of downhole realities

The key questions to be answered when underground inseam drilling starts to experience problems include:

1. Is the problem at the bit or somewhere else in the borehole?
2. What are the limiting factors to progress? Are they related to equipment, borehole conditioning factors, or geology?

The tools required to record the answer to these questions are generally not carried on underground inseam drilling rigs. Tracking on bottom and off bottom forces and measuring pressure down hole would provide the information needed to make the correct decisions regarding reaction. In surface to seam drilling downhole pressure sensors and drill rig monitoring is used to assist the early diagnosis of drilling problems. This equipment could easily be modified for underground use; however acquiring intrinsic safety (IS) approvals is a formidable barrier to progress.

Given the existing underground inseam configuration, what can be done to assist the understanding of downhole conditions? The following suggestions apply:

1. Drillers should record forces, not rig pressures. Each rig is different. Typically drillers record drilling parameters in terms of hydraulic pressures. What does it mean if it is taking 2500psi to move the string? It only means something to the operator of that particular rig. In reality, a drill pipe of known weight can be used as a measuring tool for borehole properties if the force required to move the string is accurately recorded. This provides the basis for calculating the combined effects contributing to the drag and therefore the real causes of events registering as boggy ground.

2. The trip out after a hole is terminated can also yield important information. If the trip force is plotted against those recorded during drilling a problem at the bit face may be distinguished from a problem further back along the borehole (Figure 6).

3. Pump pressures are currently the most important records kept by inseam drillers. This is the only current objective record of a basic drilling parameter. The off bottom pressures become the basis for defining “normal” hole circulating condition (Figure 7 shows anomalous off bottom pressures in a borehole with conditioning problems). On bottom will differ from off due to torque generated by the downhole motor to keep the bit turning. An artificially high off bottom pressure signals borehole condition or equipment problems. The pattern of decline of off bottom pressure with string withdrawal will also provide an insight into the location of problem zones in the formation.

The reality is that given the current inseam drilling systems – and the IS barrier – the burden of resolving downhole issues rests with the skill of the individual operator. It is desirable for underground drilling rigs to employ the following technologies:

- A differential pressure gauge calibrated to provide thrust force information to the operator.
- Rig performance indicators measuring torque, penetration rate, weight on bit, annular and pump pressures.
- Geophysical sensors, in particular: borehole radar, dielectric, gamma, and conductivity (subject of a current ACARP project).
- A borehole pressurisation device to control balance, particularly relevant in soft or tectonically deformed coals.
- Utilise drilling fluid additives “mud” and mud recycling systems.

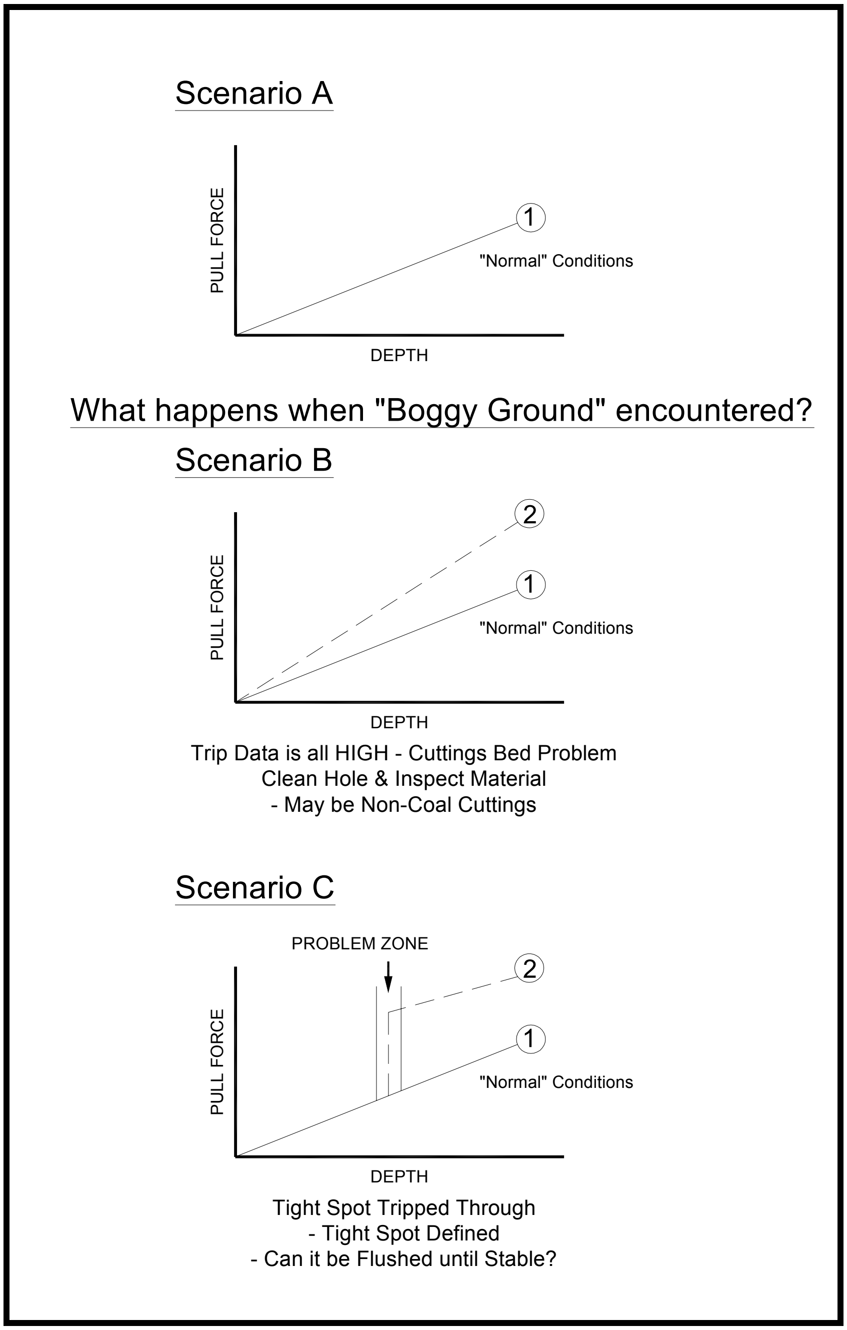


Figure 6. *During string withdrawal pull force may be monitored to determine the position of problem zones in the formation*

The borehole pressurisation prototype device developed in 1998 is worthy of further testing. Detailed rig performance analysis tools and geophysical sensors are unlikely to be developed in the short term due to the high cost and long lead time associated with mine approvals.

However, a simple but effective test – which is currently possible underground - is for the driller to record off-bottom water pump pressures for a given flow rate. A calculated increase in pump pressure with depth can be compared to actual, and anomalous zones identified. In Figure 7, taken from an inseam drilling borehole, high-pressure zones can easily be identified as peaks above the theoretically derived pressure gradient line. These peaks correspond to zones of poor circulation, which may be related to borehole wall collapse and geological structure. These zones may also continue to affect drilling even after the cuttings have been cleared and drilling recommences. Later borehole failure due to 'boggy ground' may be attributed to these zones, and not where the bit is currently located.

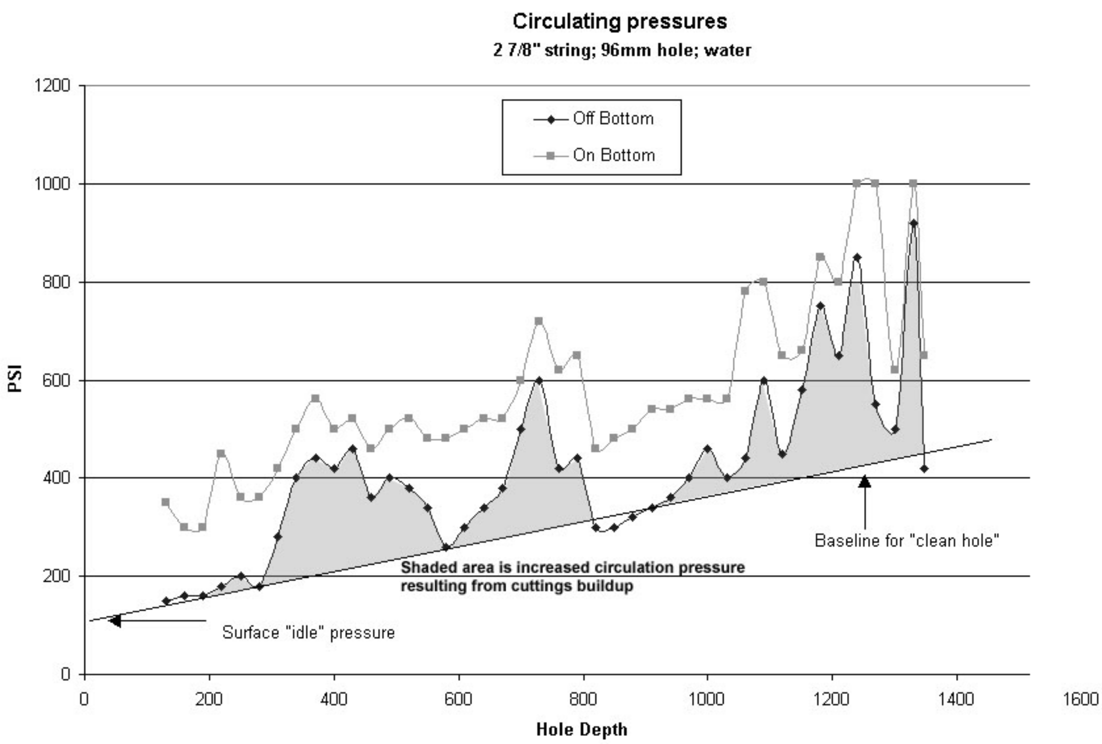


Figure 7. *Monitoring off-bottom pressure can improve the understanding of circulation issues and geological problem zones (from Thomson & MacDonald, 2002).*

A simple model can be proposed for an underground drilling system whereby off-bottom pump pressure (OBPP) is routinely monitored and drillers are instructed that should the OBPP exceed the baseline pressure, then drilling does not recommence until flushing and circulation is completed and the OBPP has returned to baseline levels (Figure 8). By comparing a theoretical pressure gradient increase for distance down hole, deviations to the norm can be identified and 'stuck' drill string avoided. In addition, the recognition of the pressure anomaly will pinpoint the position of failure in the borehole wall, and this may well be related to structure.

The important step is to identify when circulation pressure is abnormally high and take remedial steps before the problem ends the hole. Step 1 is to stop drilling & flush the restriction clear. What material is yielded – is it cuttings or cave? Have pressures retuned to normal? If not conduct a test during the trip out. They may come back into line after the bit is withdrawn through the problem zone – was the zone squeezing clay? The pressure may not return to normal at all – you have a problem with the drilling assembly. The systematic recording of accurate data will provide a lot of answers. These zones may also continue to affect drilling even after the cuttings have been cleared and drilling recommences. Later borehole failure due to 'boggy ground' may be attributed to these zones, and not where the bit is currently located.

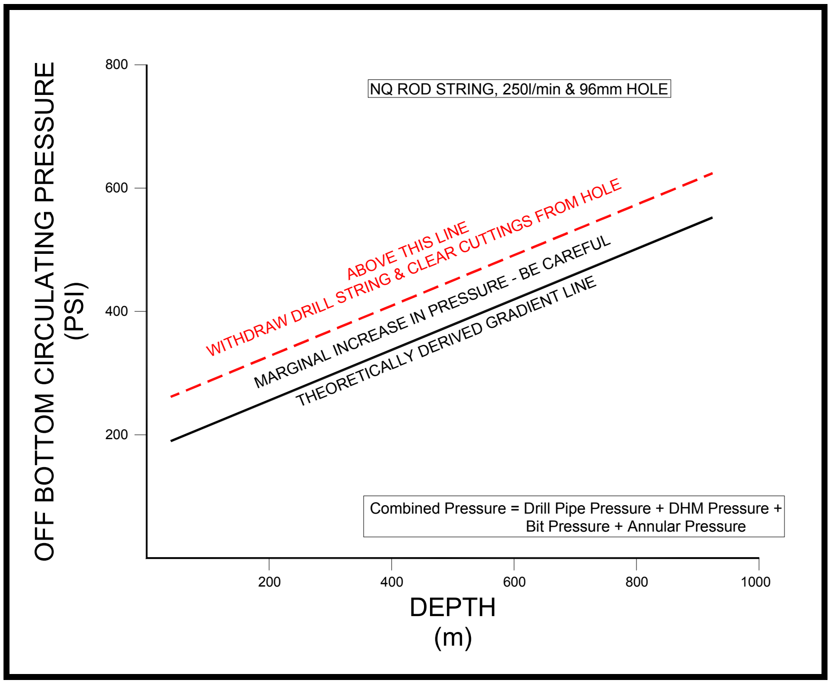


Figure 8. *Monitoring off-bottom pressure can be used as a guide to drilling practice.*

Conclusions

Further improvements to underground drilling performance can be achieved through developing an understanding of the contributing factors to differential sticking amongst the drilling fraternity. In particular, more routine application of slide / rotate rather than 'flip flop', and attention to off bottom pressures and regular flushing for cuttings removal is recommended.

It is also suggested that challenging the 'boggy ground' hypothesis is essential to improve underground drilling standards. Drillers need to be encouraged to show some quantitative analysis of downhole conditions and not to blame poor borehole conditioning on mysterious geological factors.

Although the tools to really understand downhole conditions are not as readily available to the underground driller as the surface driller, the following suggestions may improve the overall performance of inseam directional drilling:

1. Stuck drill pipe and the early termination of a borehole due to 'boggy ground' may be avoided by careful monitoring of off-bottom circulating pressures.
2. Diligent cuttings clearance and the deployment of the slide / rotate method can minimise the likelihood of differential sticking.
3. A differential pressure gauge should be developed for use with underground inseam drilling.
4. An education process is recommended for drillers and supervisors regarding the conditions that engender stuck drill pipe.
5. Further development of a borehole pressurisation device is recommended for underground drilling.

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