Background and introduction:

Barrick Gold, the world's largest gold company, was looking for a way to install a vent shaft while continuing underground mining operations. Up till now, mining would cease while the shaft was drilled from the underground to the surface, so in order to install the vent shaft and mine simultaneously, the mine engineer devised a plan to drill a 14 foot diameter shaft from the surface to a depth adjacent to the end of the mine. This process has never been successfully attempted before. By drilling perpendicular to the mine, returns and cuttings removal could be maintained, and by not directly drilling into the mine, the fluid would not flood the mine at target depth. Once the hole was clean, the mine and vent shaft could then be connected by tunneling from the mine to the shaft.

For this project a proper operational design and fluid program was crucial to the success of the shaft. A collapse of the hole could damage or devastate under ground operations. Additionally, at a diameter of 14 feet, substantial subsurface area, approximately 44 ft^2, was exposed with each foot drilled. At this level, the effect of subsurface conditions (lithology and mineralogy) would be magnified. Subsurface conditions could be especially problematic in fractured zones as loss of whole fluid could be substantial as 6000 –6500 gallons per minute were required for drilling.

Although there were obvious unique challenges, the primary concerns for this project were similar to any exploration hole: retard swelling and erosion of reactive formations, minimize loss of circulation, stabilize the borehole, remove cuttings, and allow deposition of cuttings at the surface. Ultimately, although the magnitude and dynamics were different for the vent shaft, the functions of the drilling fluid were consistent with other vertical drilling applications.

The following outlines considerations discussed prior to commencing the project, summarizes fluid design and performance during the installation of the shaft, presents conclusions, and delineates lessons learned for continuous improvement of the application of drilling fluids in blind shaft drilling.

Fluid Considerations and Approach:

Ultimately, the fluid products, formulation, and application should aid in meeting the ultimate goal of safely and efficiently drilling and completing a 14 foot diameter vent shaft to a depth of 1500 feet with the blind or flooded reverse drilling method. While several criteria should be considered, it is important to remember that each individual criterion may be dependent upon several standards, good practices or beliefs.

Some criteria used for decision making were:

1. **HSE** compatibility with all Barrick, Cortez and MSHA rules, regulations and mandates.
2. **Contractor preference** based on experience with drill method, tooling, & rig design and contract obligations or restrictions
3. **Product environmental compatibility** with mine operators standards for usage on site

4. **Hole stability** or maintaining hole integrity during drilling and for the time required for the completion or shaft lining process.

5. **Fluid volume handling requirement** to help ensure adequate volume of fluid can be supplied to meet requirements for circulating and prevention of drilled solids accumulation. This includes pit size and design, surface tanks for mixing and storing fluids for drilling or loss of circulation treatments.

6. **Cost effectiveness** to ensure that the investment in fluid products is necessary for the drill method.

7. **Contamination** of the fluid by cement due to drilling of the grouted areas of the shaft bore or because loss of circulation has been treated with cement. Contamination will damage fluid properties and will be indicated by an increase in total hardness (calcium ions) and pH (possibly as high as 12 or 12.5).

8. **Loss of Circulation** or excessive seepage rates or loss of whole fluid to the formation.

9. **Weather** or effect of atmospheric and environmental conditions on men and machinery.

In regards to fluid loss, hole stability, and loss of circulation, rate of penetration was considered to be a key contributing factor. When encountering a loss zone, the fluid should be given time to fill the fractures in order to maintain returns, so excessive drilling rates and exposure of fractures could prevent the fluid from plugging those zones efficiently. Although this would not necessarily indicate that the amount of fluid lost could be different, maintaining returns is important for hole cleaning, therefore a slower penetration rate was considered most beneficial.

For volume handling and cost effectiveness, the amount of drilling fluid required (surface volume of ~4,000,000 gallons and hole volume at target depth of ~1,725,000 gallons) and application of loss circulation pills were key areas of focus. It was not the recommendation of Baroid IDP to fill the entire pond with drilling fluid prior to the drilling process. Instead, it was recommended that the newly mixed fluid be added directly to the hole as drilling was occurring. Also it was recommended that the pond volume be as low as possible prior to drilling (as long as the necessary minimum volume required for circulation was maintained). It was indicated that the first 500 feet of hole could have the most occurrences of seepage and loss of circulation. Since this was the case, a lower initial pit volume would facilitate more economical treatment of losses without jeopardizing the loss of product if the entire pond were initially filled with fluid.

Since gravity settling in the pits was the method for solids control, it was also crucial that the mixture and components of the fluid were designed to facilitate efficient solids settling without mechanical equipment. It was imperative that the fluid viscosity be kept at a minimum for settling, so velocity would primarily be relied upon for efficient cuttings transport from bit to surface.

Another factor in cost effectiveness is efficient mixing of drilling fluids and proper sizing of tanks for storage and LCM application. In order to address this concern, the use of four tanks of various sizes was recommended. For mixing, a 6300 gallon and 12,000 gallon tank equipped with a jet hopper and a mechanism for circulation within the tank were requested. For storage, two 18,000 gallon tanks were requested. These tanks and mixing set up would allow for efficient yield of products, proper storing capacity, and adequate mixing of fluids or blending of loss of circulation pills.

Ultimately, the fluid recommended varied based on the drilling conditions. Both high yield (QUIK-GEL® additive) and standard yield (AQUAGEL® bentonite) were used as well as regular viscosity (PAC™-R polymer) and low viscosity (QUIK-TROL® GOLD LV polymer filtration control polymer). Dispersive polymers (AQUA-CLEAR® PFD dispersant) to enhance surface cuttings deposition were also employed. Various loss circulation materials were used and applied on the backside as pills. This included chip bentonite (HOLEPLUG® additive), granular bentonite (CASING SEAL™ additive), spun mineral fiber (N-SEAL™ LCM), cellophane flakes (CELLOFLAKE LCM), and superabsorbent polymers (DIAMOND SEAL® LCM). Product usage can be best summarized in five distinct intervals and is outlined below.

Drilling Additives By Interval

Initial section (0-44 ft)
SODA ASH
AQUAGEL®
QUIK-GEL®
PAC™-R
QUIK-TROL® GOLD LV
CELLOFLAKE - mixed in the blending tank
N-SEAL™ LCM

Interval 1 (44-551 ft)
SODA ASH
AQUAGEL®
PAC™-R or QUIK-TROL GOLD LV
AQUA-CLEAR® PFD
CASING SEAL™ - back side after 209 ft
CELLOFLAKE - back side after 209 ft
CELLOFLAKE - mixed in the blending tank
DIAMOND SEAL® - at 179 and 274 ft
N-SEAL™ LCM
HOLEPLUG®- at 291-335 ft and 405-434 ft

Interval 2 (551-954 ft)
SODA ASH
AQUAGEL®
PAC™-R OR QUIK-TROL™ GOLD LV
AQUA-CLEAR® PFD - only when PAC™-R was used
CASING™ SEAL - backside
CELLOFLAKE - backside
N-SEAL™ - at 551-606 ft
HOLEPLUG® - at 871 929 ft

Interval 3 (955-1337 ft)
SODA ASH
AQUAGEL®
QUIK-TROL™ GOLD LV
AQUA-CLEAR® PFD - at 965-1168 ft
CASING™ SEAL- backside
CELLOFLAKE- backside
HOLEPLUG® - at 871 ft, 929 ft and 954 ft

Interval 4 (1337-1475.5 ft)
SODA ASH
AQUAGEL®
PAC™-R
AQUA-CLEAR® PFD at 1337-1433 ft
CELLOFLAKE - backside at 1433-1455 ft

Interval Discussion:

Interval One: 44'-551'

This interval was the longest drilled interval on the entire hole. An excessive seepage loss of fluid was experienced in this interval at 100,000 gallons per day. Some of the losses of whole fluid can be directly attributed to the increased drilling rate. That is, the large diameter bit will drill through some of the fracture zones faster than it would in a more solid competent rock that has fewer fractures. Consequently, more whole fluid is then lost to the fractured rock ahead of the bit. Only after the fracture areas are drilled, does the loss of circulation material (LCM) treat the fractures in the borehole face

For this interval, approximately 22,308 square feet of borehole face were in contact with fluid, with as much as 240 psi of hydrostatic pressure forcing the drilling fluid into any available space that would take fluid. It appeared that the rock ahead of the bit would continually take fluid, however once a 'ratty' or broken sections were drilled, the amount of those daily losses subsided. In other drilling disciplines, the loss of circulation occurs as the bit encounters the loss zone, and then most often directly healed at the bit by LCM additives. In our instance, the large diameter bit continually drilled up any healing of fractures that was taking place at the bit and most generally not after the hole is advanced. Also, in this hard rock large diameter environment, one can envision those fractures and cracks would stop taking fluid once filled. There was not anywhere for the majority of our whole fluid losses to go to, as the area of the NVS is not typically full of large never ending voids that would take enormously large amounts of volume (1150 gallons per foot) such as the drill was circulating with.

Interval Two: 551'-954'

For the most part, this section of the hole was uneventful in terms of problems or hazards associated with the drilling operation. In the preceding interval, an approximate total of 58,000 gallons per day of whole fluid was lost to the formation. In this interval, a substantially lesser amount of approximately 26,500 gallons of whole fluid per day was lost. This was achieved by making a few adjustments to the operation. First, as the drilling rate slowed slightly from the preceding section, the amount of AQUAGEL additive mixed in each batch was cut in half and the low viscosity filtration control agent QUIK-TROL GOLD LV polymer was increased extensively to lessen any overall increases in the fluid viscosity. Also, the amount of fluid mixed was lessened during this interval. Of the total of 37 days it took to drill the section, reduced fluid product additions were realized on 8 of them. The steady drill rate, competent formation and lessened amounts of whole fluid losses allowed for this savings to be realized.

The fluid cost for this interval was the smallest amount overall, the lowest cost of fluids per foot drilled and the 3rd lowest fluid cost per day. In fact, the fluid cost per foot drilled in this interval was less than half the fluid cost per foot for the preceding interval, $233 vs. $477. Normally one could attribute this fact to an increased penetration rate, but that wasn't the case, as this interval drilled slightly slower. However, approximately 100 feet less footage was drilled, and 8 less days were spent advancing the hole for this section.

Interval Discussion:

Interval Three: 955'-1337':

This interval length was the third shortest of the entire hole, and the lower part of the interval experienced some of the slowest penetration rate (ROP) on the entire hole. From 1140' to 1337', the penetration rate averaged slightly less than 8 feet per day. While from 955' to 1140', the average ROP was 13 feet per day. Obviously, the formation changed and became harder at or near 1140 feet to account for this slower ROP.

Holding true to form with the assumption that the faster the drilling rate, the more whole fluid will be lost to the formation in the form of excessive seepage, the average amount of fluid lost per day in the upper section of this interval was 34,100 gpd, and in the lower section an approximate total of 31,100 gpd were lost.

During the slower drilling in the lower portion of this interval, drilling fluids were mixed at a reduced rate for 10 of the 40 days this interval took to drill. Even though it was attempted to mix less fluid products, the fluid cost per foot and the fluid cost per day were very similar to that of the preceding interval. This is primarily because of the slower ROP, particularly in the bottom part of the interval.

The formation at the bottom of this interval, below 1140 feet, was considerably harder than that of the upper portion. As a result, it was necessary to increase the weight on the bit in order to maintain the ROP that averaged 8 feet/day. Even though the bottom hole assembly (BHA) is designed to prevent deviation of the hole from vertical, it is believed the deviated hole from approximately 1140 to 1337, was the reason that some of the formation caved into the hole while the BHA was tripped past it. From information gathered from personal conversation with rig personnel, it is believed that the amount of weight over the string weight that was necessary to pull the BHA from approximately 1240" to approximately 1080' was 850,000 lbs. It was believed that this process, however unavoidable, was the cause of the large amount of cave-in that was mucked from the bottom of the hole. The BHA and drill string was out of the hole from 4/21 through 5/25 for drill bit repair and rebuild, fishing of roller cone(s), and mucking of the hole cave-in. No fluids were mixed during the month long period of time.

Interval Four: 1337'-1475.5':

During the approximate month that the hole was not being drilled, fluid from the reserve pit was pumped to the collar to keep the hole full during fishing and mucking operations. Beginning on 5/25, whenever the rock and cobble on the bottom of the hole was drilled and ground up, through midday on 5/31, approximately $31,000 worth of fluid products were mixed to replenish the volume lost during the down time.

On the trip in the hole to ream cobble and fill, the bit took weight at approximately 1106' and then reaming commenced at approximately 1166' on 5/28.

Interval Discussion:

The reserve pit water was turned on and Jentech commenced to mix drilling fluids. From the morning of 5/27 through 5:30 am on 5/29, 575,000 gallons of water were run into the reserve pit. Also, during that time, Jentech mixed 207,000 gallons of drilling fluid and added it directly to the hole as the cobble and cave was cleaned from the hole. Then from 5/29 through 6/1, an additional 227,000 gallons of water were run for volume in the reserve pit.

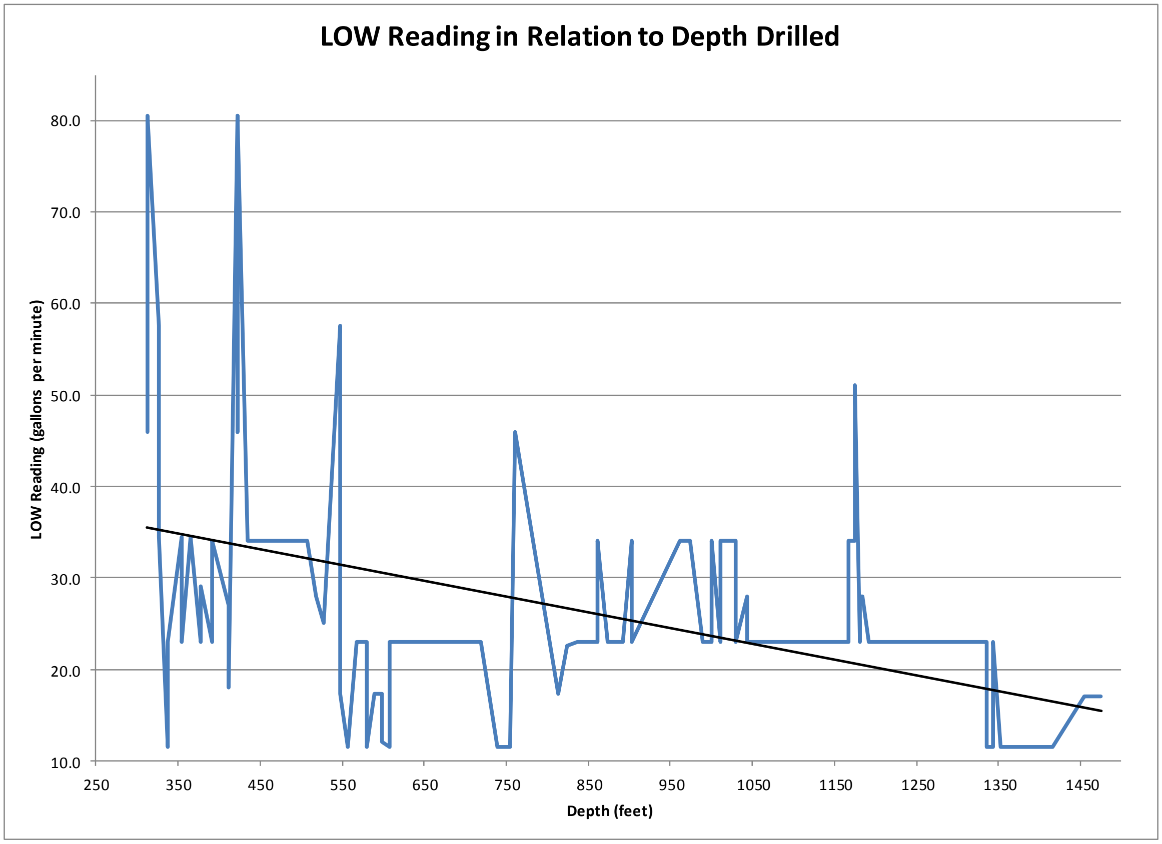
Approximately $63,000 of fluid products were mixed the last fifteen days of drilling to lower the filtration rate in preparation for the hole being open for an extended period of time while the rig was rigged down, gantry erected and the casing ran.

On nine separate days preceding the trip at 1337' on 4/21, the filtration rate of the drilling fluid in use averaged 20.2 cc/30 min. Surprisingly, the fluid that was in the hole for the entire month long period of fishing and mucking operations was 22.8 cc/30 min. Still quite good considering that no fluid products had been mixed in over 30 days and the fluid in the hole was not circulated during that time. From 5/30 through 6/15, the drilling fluid filtration rate averaged 16.4 cc/30 min. Jentech mixed approximately $63,000 worth of product to achieve the new lowered filtration rate and build approximately 800,000 gallons of circulating volume at the same time.

Summary and Discussion:

A summary of the effectiveness of the fluid solution must address several angles: loss of circulation, fluid properties, cost, time, and safety. The Frontier Kemper crews would often shut the drill down and monitor the amount of fluid losses in the collar. This was referred to as the LOW (loss of water) checks. Essentially, by monitoring the static fluid level in the hole for 10 min, the height the fluid dropped in the hole (inches) could be used to calculate fluid losses in gallons per minute. The table below indicates the scale of volume losses that could easily be experienced on a daily basis on a hole of this size. LOW losses were recorded several times a day and used to extrapolate loss for 24 hours.

Inches of Loss Per 10 min	GPM	Gals/HR	Gals/Day
1	11.5	690	16560
2	23	1380	33120
3	34.5	2070	49680
4	46	2760	66240
5	57.5	3450	82800
6	69	4140	99360
7	80.5	4830	115920
8	92	5520	132480
9	103.5	6210	149040
10	115	6900	165600



The results of the LOW checks displayed in the chart above, indicate that loss of whole fluid can be correlated to the rate of penetration which is related to the subsurface conditions. The depths with highest degrees of fractured and broken formation correlated directly to higher rates of penetration and whole fluid loss (see interval summaries above).

The question now exists then, did the LCM treatments for those days, aid in the stoppage of the whole fluid losses, or were the fractures just filled up, and there were no more noticeable losses? In order to answer that question, one would have to accept the losses as they are, and not mix LCM for several days. Then, mix LCM products after the fact to see if the amount of daily losses (the average amounts) can be lessened. Unfortunately, that could not be accomplished on this hole, but would be recommended for future projects. To determine cost effectiveness, the dollars spent on the LCM product need to be compared to the cost of the fluid lost to the formation. It should be kept in mind that there can be an added value cost savings as result of mixing LCM. If excessive amounts of fluid are lost and those losses jeopardize the hole stability, then spending the extra money on LCM may be justified without necessarily matching dollar-for-dollar as controlling the loss of whole fluid could be considered 'insurance' against some unforeseen possibility for hole failure.

For the entire hole, the mud weight was maintained at 8.6 lbs/gallon or less and funnel viscosity was between 28 and 31 seconds/quart at the flow line.

For the majority of the hole, fluid loss was maintained between 15.0 and 22.0 milliliters per 30 minutes. Overall, a low density and low viscosity were maintained throughout drilling. Fluid velocity generated by pumps and the drilling method, reverse circulation, was the primary mechanism for hole cleaning. Basically, effective drilling fluid properties were developed and maintained for ~1.7 million gallons in hole volume, ~3.3 million gallons of surface volume, and the volume lost to the formation while drilling. With the volumes required, it was evident that substantial product addition and time were required to effect changes. Thus, fluid alterations should be planned and implemented well before required to ensure desired properties are achieved based on subsurface conditions.

The total footage drilled, days to drill, and cost of the drilling fluid products are summarized in the Table below. If the cost for supporting the drilling fluids (supervision and rental of fluid handling equipment) are included, the total cost for the drilling fluid solution would be $831,328.31 or $3.66 per cubic foot drilled.

It is important that the fluid solution is properly managed to maintain desired properties at a reasonable cost and aid in an efficient drilling rate. Also in drilling of the North Vent Shaft, there were no safety incidents.

	FOOTAGE	DAYS TO DRILL	FEET/DAY	FLUID PRODUCT COST	COST PER FOOT	COST PER DAY
TOTAL	1431.5 ft	143	10.01	$528796.00	$370.44	$2827.70

Ultimately, at a the cost of $3.66 per cubic foot drilled with a rate of penetration of 10 feet per day, 0 safety incidents, and effective properties maintained over the millions of gallons required, the management of the fluid solution could be considered successful.

Conclusions, Key Lessons Learned, and Ideas for Future Projects:

Ultimately, casing was set at the desired depth of 1463’ the and the project was completed safely with **zero safety incidents**. Keys to success were: adequate tanks, adequate mixing equipment, control of fluid properties, and application of a fluid formulated to subsurface and drilling requirements. Key points for future projects of this magnitude are: fluid products were properly selected, substantial product addition and time are required to effect changes in fluid properties, rate of fluid loss and drilling rate could be correlated (faster drill rates corresponded to less competent formation), product usage could be reduced in more competent sections, fluid enhancement doses for unconsolidated sections need to be mixed and planned well in advance as the volume of fluid is substantial, slowing property adjustment. Overall, the fluid solution was cost effective in supporting completion of the 14 foot diameter shaft.