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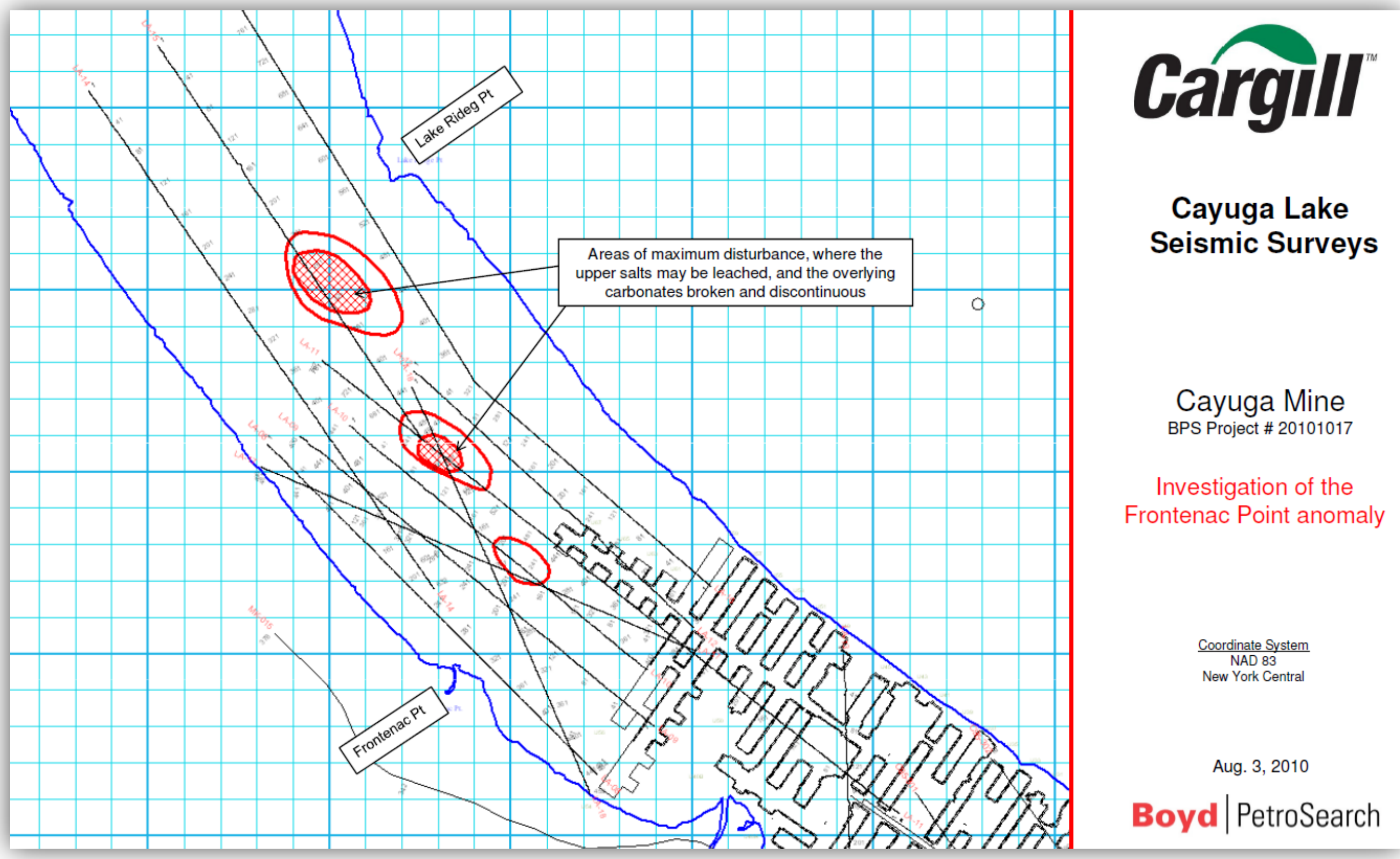
CARGILL DEICING TECHNOLOGY
CAYUGA MINE
THOUGHTS ON MINING THE NORTHERN RESERVES



Gary Petersen, Principal Engineer/Consultant

August 27, 2016

Dave Plumeau
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Dear Dave,

Due to the recent theorizing that the abnormal closure in U12, U40B and perhaps U24 could be due to hydraulic pressure within the de-stressed zone of the yield pillar panel design, it was wisely decided not to use the YPP design to mine the northern reserves where the potential for high pressure/high volume aquiferic water in conjunction with large geological anomalies could bring water too close to the mining horizon. The concern being that the YPP design creates a low stress (destressed) zone above that panel that attracts higher pressure fluids in the rock strata, which given a geological conduit will flow into the de-stressed zone resulting in abnormal panel closure. It was this scenario that resulted in the leak at Cleveland and a very large inflow of water at the Retsof Mine causing it to flood. The hydrology above the Northern reserves is very similar to that of the Retsof Mine.

The big pillar design doesn't create a de-stressed zone above the panel, making it a much better design for potential water pressure situations. The challenge now becomes how to mine the Northern reserves using the conventional big pillar design that gave us so much ground control problems on the east end of the mine. East end mining is about 700 feet deeper than the Northern reserves, but doesn't have the high pressure aquiferic water above the mining horizon. I'm not sure what affect this might have on the big pillar design. Although the potential for developing a leak is much lower, it may exert additional pressure (load) over the panel. I guess this is a good question for the hydro guys.

We know from experience that the big pillar design is prone to shear the roof along the roof/pillar contact out over the room and in some cases results in a rather large roof fall. Roof falls in East-1 (big pillar design) went as high as 12 feet that went hundreds of feet in length in the worst case. The rate of roof failure is in direct correlation with the rate of pillar creep. Pillar creep is primarily a function of mining depth, room height, and mining extraction.

<u>Thoughts on Big Pillar Design</u>

We have two approaches to use to come up with a design. On the computational side we have Leo's salt equations, and on the applied side we have the results of Cleveland's North Mains. RESPEC did the Cleveland North Main design using Leo's pillar equation. The approach was to assign a tunnel life for the "old" big pillar design of [redacted] years and, based on Leo's equation, to calculate a pillar creep rate that would be ten times slower, which would extend the tunnel life to [redacted] years. The North Mains were mined in 2003 or 13 years ago using this design method. Roof conditions are still pretty good with some fracturing in the shale bed between A and B salts, which was somewhat expected. I think we can say the design performance is on track with the [redacted] year design life.

RESPEC has used the same design concept for the Northern reserves using the "old" big pillar design as a baseline. The challenge is to determine a reasonable tunnel life for that design. This is a bit more complicated than at Cleveland because the mining depth changed going east and there was the influence of 4-Level mining. Roof conditions directly below 4-Level mining were much better than mining where there was no 4-Level. Roof conditions directly below the edge of 4-Level mining were the worst. It is surmised that 4-Level acted like a yield pillar panel stress relieving the panel and transferring the load to the adjacent solid. Roof conditions were the worst when mining beneath the abutment load. The other problem is you and I were not around when E-1 was mined; however, we did have firsthand experience with tunnel conditions in the E-1 and S-1 beltlines as shown in Figure 1, which was used until 1984.

East-1 was mining approximately from 1971 to 1974 as shown in Figure 1. I came to Cayuga in June of 1975 and you came a year later. I think the demise of E-1 was due to increasing the mining extraction at the end of the panel from [redacted]% to [redacted]% at a mining depth of nearly 2700'. This resulted in pillar creep rates significantly increasing and roof conditions rapidly deteriorating resulting in the abandoning of the panel. Mining was then relocated to S-1 just before I came and tunnel conditions in S-1 were quite good mostly because of 4-Level protection. However that came to an end on the south end of the panel as 4-Level workings no longer existed and then we hit the fault.

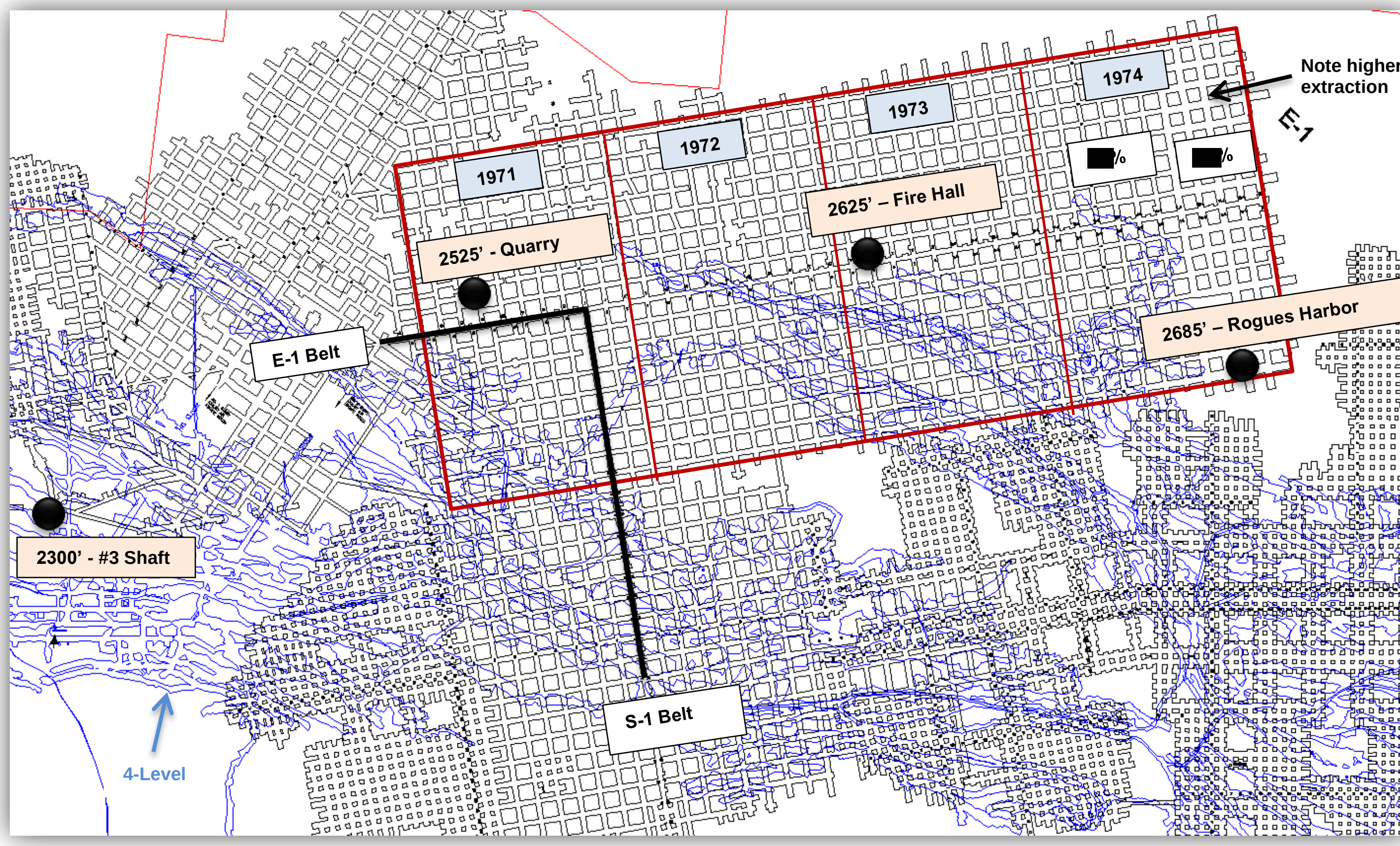

Figure 1 – Map showing the mining sequence of E-1 and mining depths.

I think the quadrant mined in 1971 is our best area to try to determine a tunnel life for the old design. Much of it was out from under the 4-Level and we used the beltline tunnel for about [redacted] years. When I started in 1975 I don't recall the E-1 Belt tunnel roof conditions being that bad. At that time it would have been around 4 years old. As I recall we eventually shot the roof down in the northern half of S-1 because tunnel conditions had deteriorated as such (maybe due to higher stress at the edge of 4-Level), but I don't recall shooting the roof down in E-1. In 1975 I mapped all the roof conditions in E-1 and I'm wondering if those maps are hidden away someplace.

The paper we wrote and published in EM&J in 1979 indicates the tunnel life was [redacted] to [redacted] years, but that could have been based on conditions toward the east end of E-1 where the mining depth was approaching 2700 feet. E-1 in the 1971 Quadrant was used for 13 years and tunnels in the Old Shop near the bottom of #1 Slope are still open and they were mined around 45 years ago, albeit the roof has been repaired several times. On the other hand, what was acceptable back then is probably not acceptable today. The new generation of miners is used to excellent roof conditions, and roof shears along the top of the pillars may not be acceptable. For this analysis I will define tunnel life as the time it takes for the roof to need significant rehab bolting with a longer heavy-duty support system. This was the basis of the Cleveland analysis as well. Based on this, I would put the tunnel life of the old design at a mining depth on 2500' at [redacted] to [redacted] years. To be on the conservative side I will use [redacted] year as the baseline. Utilizing the spreadsheet Leo provided and using [redacted] year tunnel life in the E-1 mining at 2500' I get the following tunnel life for varying extractions.

Mine	Location	Extraction (%)	Pillar size (Square)	Room width	Mining depth	Mining ht.	Tunnel Life (yrs)	Tunnel Life (yrs)
Cayuga	E-1	[redacted]	88'	32'	2500'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	100'	42'	1820'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	110'	42'	1820'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	120'	42'	1820'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	130'	42'	1820'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	140'	42'	1820'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	150'	42'	1820'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	160'	42'	1820'	11'	[redacted]	[redacted]
Cleveland	North Mains (as mined)	[redacted]	140' x 170'	35'	1750'	16'	[redacted]	[redacted]
Cleveland	North Mains (if mined 11' high)	[redacted]	140' x 170'	35'	1750'	11'	[redacted]	[redacted]
Cayuga	Northern reserves	[redacted]	180'	42'	1820'	11'	[redacted]	[redacted]
Cleveland	Old big pillar design	[redacted]	105'	45'	1750	19'	[redacted]	

Figure 2 – Chart showing calculated tunnel life based on Leo's salt pillar equation.

Using the applied approach I did a reality check by comparing these results with Cleveland's North Main design. As I mentioned above, Cleveland's North Mains were designed using Leo's salt pillar equation and it appears to be on track so far after 13 years. Since the creep rate of the pillar is sensitive to the width-to-height ratio of the pillar, if the North Mains at Cleveland were mined at Cayuga's height of 11' the calculated life expectancy would be [redacted] years. The mining depth at Cleveland is nearly the same as the Northern reserves (1750' vs 1820') so we can make a ballpark comparison of the two. Matching extraction percentages of [redacted]% and using the same mining heights (11') the calculated life expectancy at Cayuga is only [redacted] years as compared to [redacted] years at Cleveland as shown in Figure 2. Although there are some differences between the mines, there should not be this kind of discrepancy. Since the Cleveland results are better verified I have to think my assumption of a [redacted] year life of E-1 is too low. If I assume a life of [redacted] years the comparison is much closer ([redacted] vs [redacted]). If I assume a life of [redacted] years the comparison is very close ([redacted] vs [redacted]). To stay on the conservative side I will lean more toward the [redacted] year life. These results are shown in Figure 2 as well.

Leo's spreadsheet calculates pillar shortening rates for 3 different depths (2005' for near the shore, 1820' for between the shore and center of the lake, and 1570' for the middle of the lake). Below are the results for [redacted]% and [redacted]% extractions using an assumed [redacted] year life for E-1 in the 1971 quadrant (2500' deep):

Mining Depth	Life @ [redacted]% Extraction (years)	Life @ [redacted]% Extraction (years)
1570'	[redacted]	[redacted]
1820'		
2005'		

Figure 3 – Calculated tunnel life expectancy based on an assumed life of [redacted] years in E-1

According to Leo's salt pillar calculations and an assumed life expectancy of [redacted] years in E-1, a [redacted]% extraction (pillars 100' x 100') would provide the life you are looking for ([redacted] yrs). If you want to start off conservatively, consider an extraction of [redacted]% (pillars 120' x 120'). This gives a calculated life of [redacted] to [redacted] year life.

<u>Thoughts on Your Proposed Design</u>

Based on the above analysis the proposed big pillar design is very conservative with extractions ranging from [redacted] to [redacted] percent (not including the YPP 3-entry system). As a side note, including the YPP as part of the overall extraction isn't accurate as the load distribution of the YPP is not evenly distributed over the area. It is concentrated over a relatively small area. Here wherein lies the problem. The load transfer from the YPP initially goes to the edge of the adjacent big pillar and creates a relatively high peak load along the edge of the pillar in the area shown in Figure 4, which can cause roof shears to develop rather quickly. Over time, this peak load dissipates as the transferred load spreads out a bit, but by then the damage to the roof is already done. This may or may not be a serious problem in the short-term, but it certainly is a vulnerable weakness in the design.

The other vulnerability of the design is the de-stressed zone that's generated above the YPP. Albeit it is 74% smaller than the 500' wide YPP production design, but it still exists. In other words, the narrower YPP lowers the risk, but does not eliminate it. Some might think water will never get that low in the rock strata, but that's what we thought about Unit 12. Where high pressure water and geological anomalies exist, the unexpected can happen. The idea is to get away from the YPP concept in the Northern reserves so my thought is to see if you can meet your operational needs without relying on the YPP portion of your design.

As I understand it, the reason for the YPP is for operational real estate for infrastructure and long-term stability for the beltline. The second part of this reasoning is simple to address because with the right extraction (say [redacted]%) the beltline tunnel should be stable well beyond the expected life of the panel. The operational real estate issue is harder for me to comment on as I don't know the exact needs, but let me dust off my operational hat and I will throw out some ideas.

[redacted]

Figure 4 – Proposed design concept by Cargill. Peak pillar stress highlighted in red.

Thoughts for an Alternative Design

[redacted]

Figure 5 – Notched beltline concept.

[redacted]

Thoughts on Roof Support and Monitoring

The failure mode with the big pillar design is much different than the YPP design. The YPP design de-stresses the immediate roof and the big pillar design puts additional stress in the roof. As a result the failure mode with the big pillars is shearing along the top of the pillars as shown in Figure 6. If the roof starts to fail shearing will start along the pillar and work its way toward the center of the tunnel along a stress arch. At some point during the progression, the immediate roof detaches and a roof fall develops. If this does occur there is a lot of physical evidence that the miners should be able to observe such as the roof shearing, offsets in observation holes, and most likely broken roof bolts. And, in actuality, the rock tech guys will see it prior to anybody else during their routine roof evaluations.

With the YPP design room closure is the bread and butter of monitoring. With the big pillar design room closure doesn't tell us a lot as it usually is difficult to interpret because of floor heave, which is prevalent with the big pillar design. The focus should be on the condition of the immediate roof. This could be done by having three inspection holes drilled in the roof at each drill round as shown in Figure 6. A hole 5' off each rib and one in the center would do nicely. These are inspection holes where the miners can look up the holes with a light looking for offsets, and the rock tech guys will be running a camera up the hole looking for cracks. Obviously the rock tech guys will see cracks developing with the camera before offsetting shows up. If cracks do show up then roof monitors could be installed. What drives the roof deterioration is the expansion of the pillar so the main rock mechanics instrumentation might be pillar extensometers. With each variation of extraction ratios the pillar expansion will be different. The higher the extraction the higher the rate of pillar expansion and vice versa. This technical data could be valuable in dialing in the correct extraction ratio for the design.

I'm assuming you are going to stay with your existing roof support system, which is fine unless significant roof shears develop. Hopefully it won't get to that, but if it does you need to be prepared to install a more robust system which will be able to support the failing arch. The size and shape of the failing arch will be determined by scoping holes, but I would say something along the lines of a 12' long #8 Dywidag bolt will be needed.

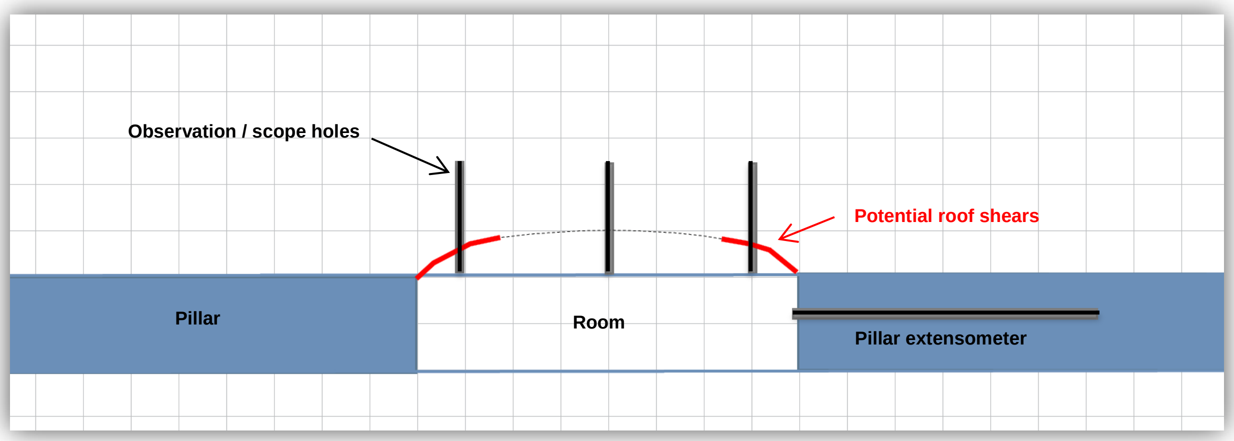

Figure 6 – Sketch of roof failure mechanism and monitoring plan.

This is a draft report and can be a basis for stirring discussion during the evolution of the Northern reserve design. Using Leo's salt pillar equation is only as good as defining the life of the E-1 design, which is what everything is based on. I think Cleveland's North Mains is a good comparison to use for giving us a basis to work from and a real life situation to learn from. I have no problems leaning heavily on Cleveland's results and see it as a confidence builder.

Let me know if you have any questions about this report.

Sincerely yours,

Gary Petersen
RockTec Solutions

CC: Shawn Wilczynski
Adam Skrobialowski