A Case Study of a Low Overburden Longwall Recovery With Pre-Developed Recovery Entries

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Abstract

The Signal Peak pre-developed longwall recovery entry was designed to move a longwall safely and efficiently in abnormal roof conditions. The design originates from the individuals at the mine who battled through two very tough longwall moves. Our vision was to eliminate hazards experienced during the previous longwall moves. Shallow cover in combination with roof geology constitute unique ground movement when the longwall advances into the recovery room. These conditions required a system that didn't exist anywhere else. Some mines in the U.S. and Australia had used pre-developed recovery rooms with some success, but also plenty of failures. Our system would be engineered by the best and overdesigned . Failure was not an option.

The recovery system design needed to eliminate stopping to install support. A pre-developed recovery room that was completely backfilled was designed. The 3 Right recovery entry was 42ft wide and developed in two stages, 21ft wide in each stage. we installed "the beef" roof support The entry roof was reinforced with steel wire mesh/Huesker recovery mesh, high-capacity primary bolts and Sumo cables. After all the support was installed, the entry was completely backfilled with specially designed, cuttable, low-density cement. In January 2014 we successfully mined into the 3 Right pre-developed entry. Since then a few tweaks were made, during March 2015 we completed a second longwall move with the same success by mining into the 4 Right pre-developed entry. The following presentations is based on actual observance and practices of the 3 Right and 4 Right recovery entries.

Acknowledgements

1. My Team at SPE
2. Art Craven (JennMar)
3. Golder Associates PTY. LTD.

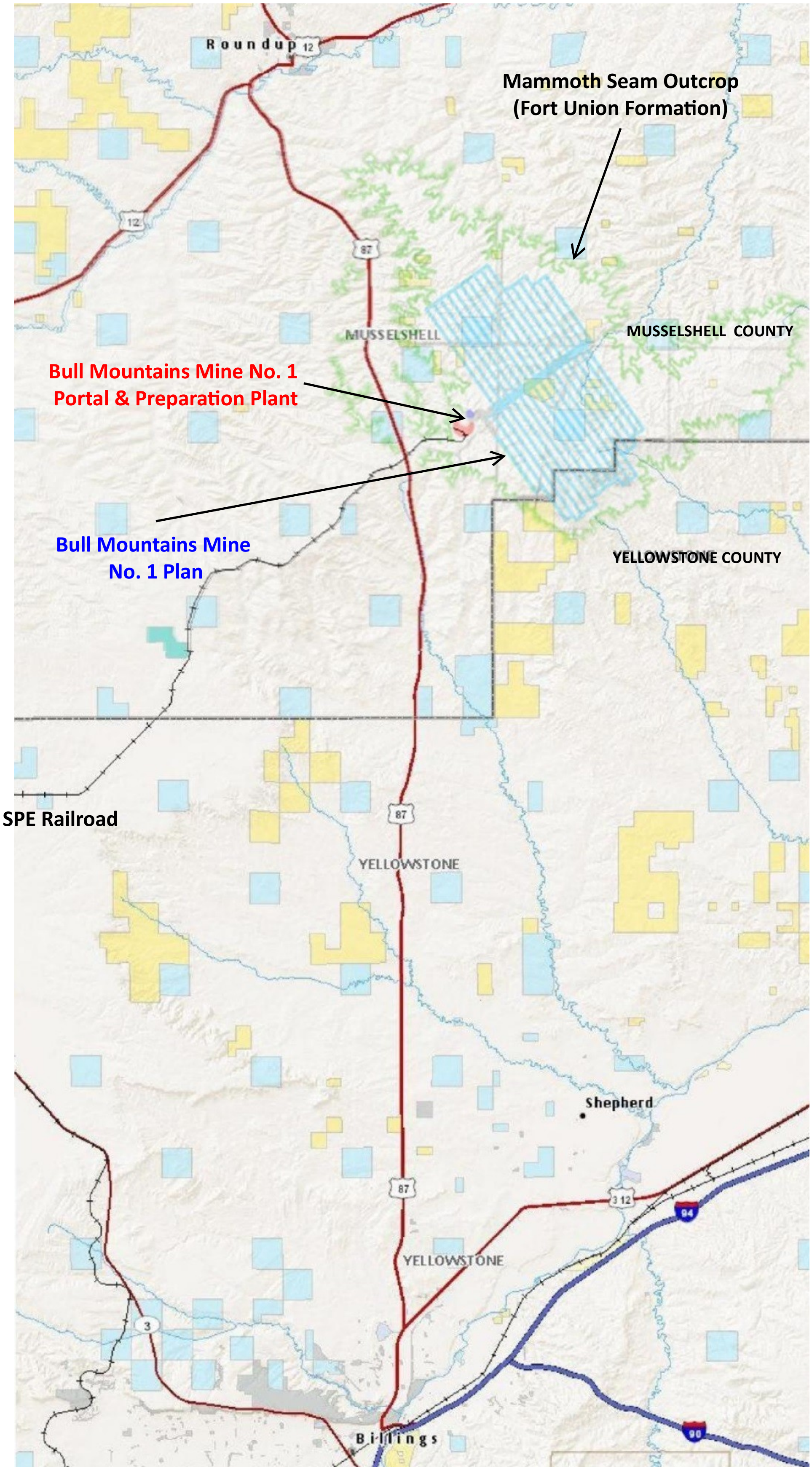
Introduction

- Brad Hanson President /CEO
  - Started my 38th year in the coal business
  - All but a short stint in Australia have been in the western united states.
  - Have 23 years experience moving longwalls in all types of conditions.
  - Made the move to SPE in August of 2010.
  - At this time they were currently mining with the longwall in the 1 Right panel.

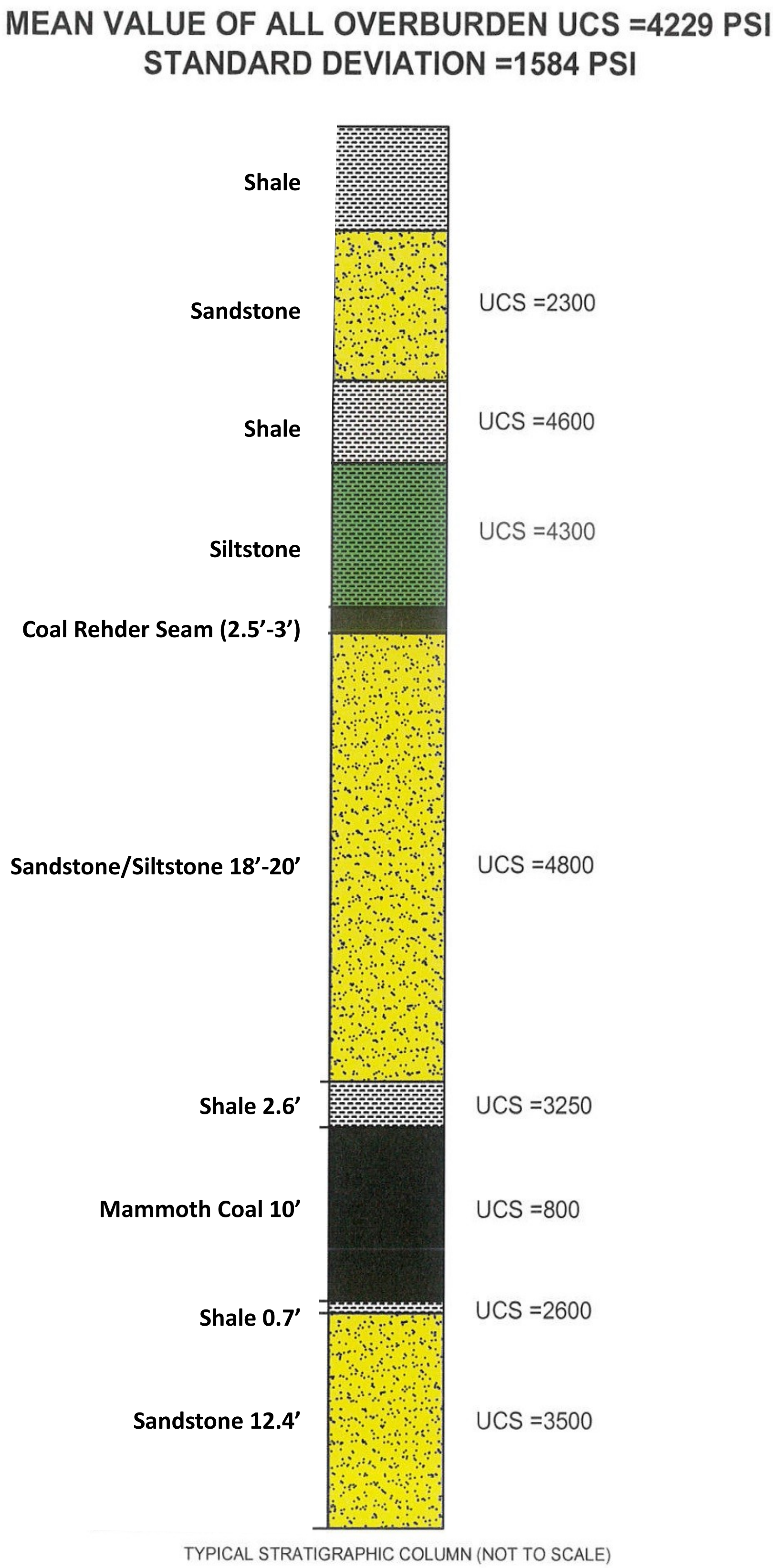
- Robert Ochsner/Chief Engineer
  - South Dakota School of Mines and Technology graduate, Mining Engineer.
  - Over 30 years underground coal experience including exploration, mine design, permitting, and operations.

Vicinity / Location Map

Roundup, Montana

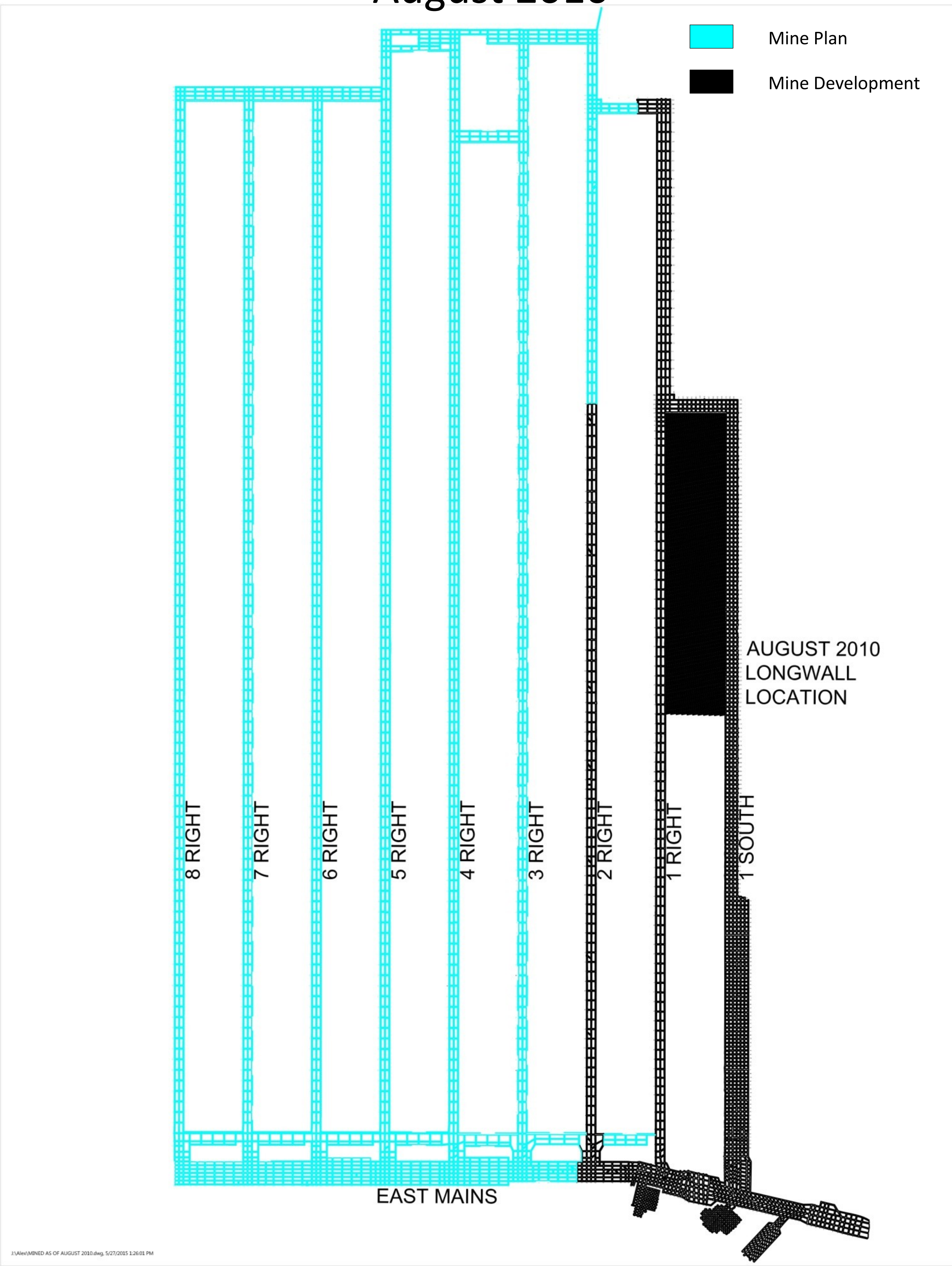


Lithology
Uniaxial Compressive Strength (UCS)

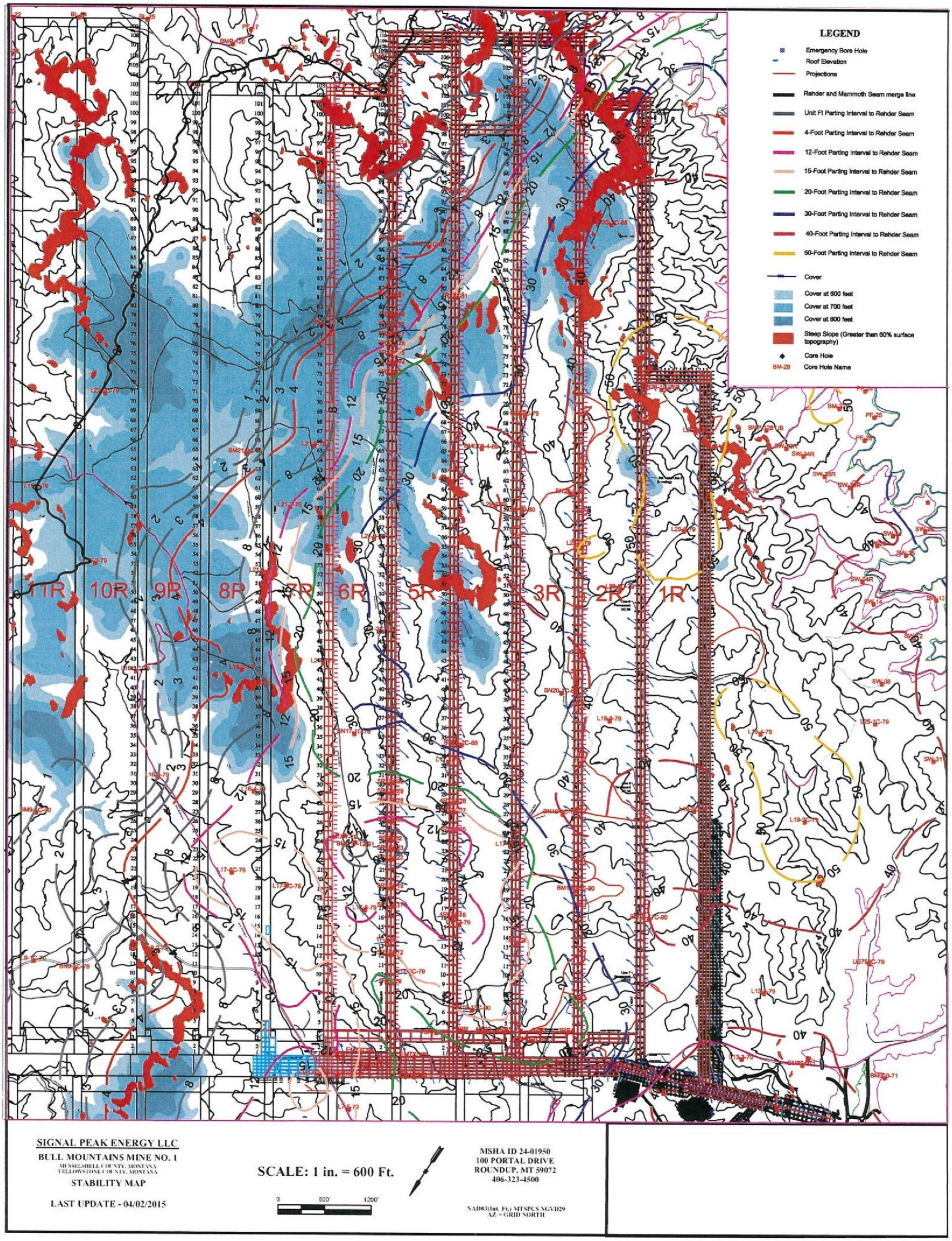


Mine Development Map

August 2010



Stability Map



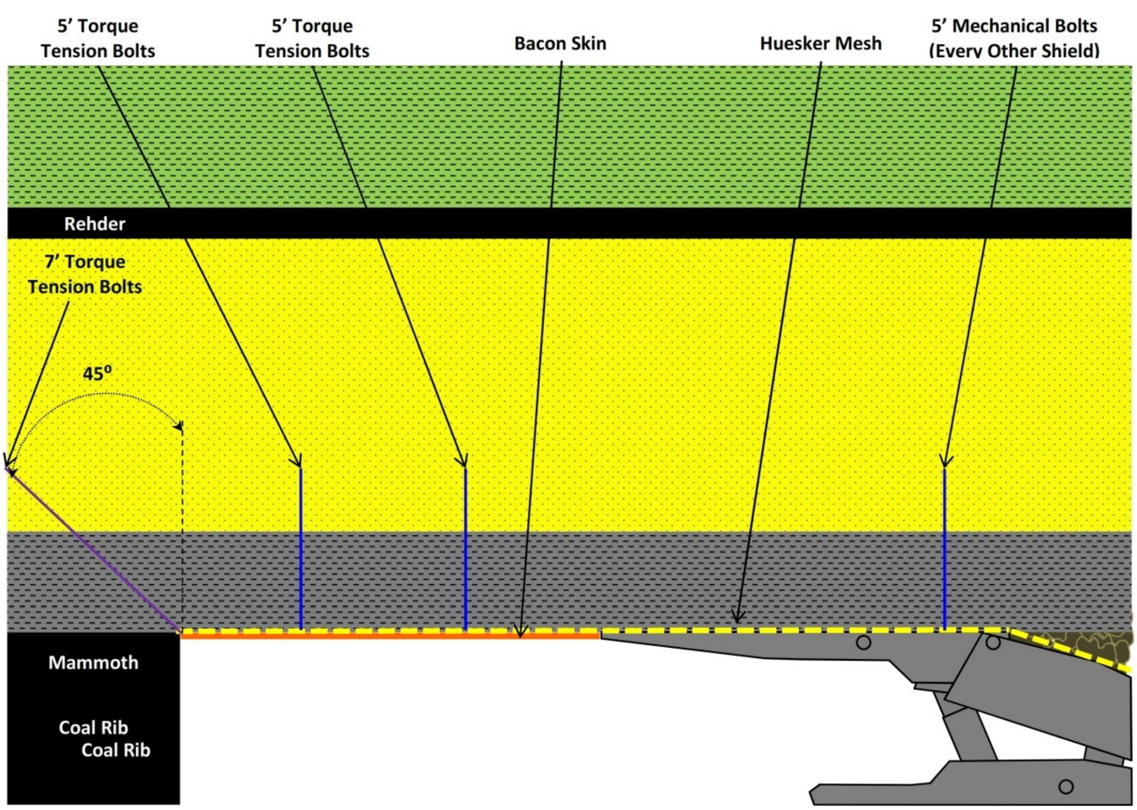
Mine Info
August 2010

- Mine Conditions
  - Low cover (200-800 ft)
  - No Methane
  - Competent roof/ no faults
  - Thick coal (10-17 ft)
  - Level seam
  - Mammoth Coal Seam has large reserve (+278M tons)
- Longwall Equipment
  - 1250ft face (189 shields).
  - Unique, longest panels in USA 23,500 feet.
  - Cat AFC, drives, crusher, stage loader and tailpiece (5000 tph).
  - 7LS Joy shearer.
  - Joy shields 2 meter, 1130 ton.
  - Switched from exhausting ventilation to blowing ventilation May 2013.
  - Bleederless ventilation system, progressive HG seal installation, 2 entry TG return with back around T-Split.
- Longwall commissioned December 2009.
- Production 10-11M Raw Tons, 7-8.5M Clean Tons.

1R Conventional Move

- Completed mining the 1 Right panel in March 2011.
- 1 Right Conventional Conditions
  - Shallow cover (200’ Overburden).
  - Normal lithology (Sandstone Top).
  - Normal mining height (10’).
  - Interburden between the Mammoth and Rehder Seams greater than 20’.
- Huesker Meshing was planned at 10 passes with a finished tip to face distance of 10 feet.
- As we started the meshing process we experienced some cap rock issues which slowed the bolt installation.
- As the meshing process continued we experienced serious convergence on the shields (old style yield valves). The yield valves were yielding well below their limit causing shield leg loss at a rapid rate; making it tougher to mesh and bolt.
- During this time frame every step of the conventional move became a challenge.
- Along with continued convergence on the shields we had several shield tips down.

1Right Conventional Move
Roof/Supplemental Support



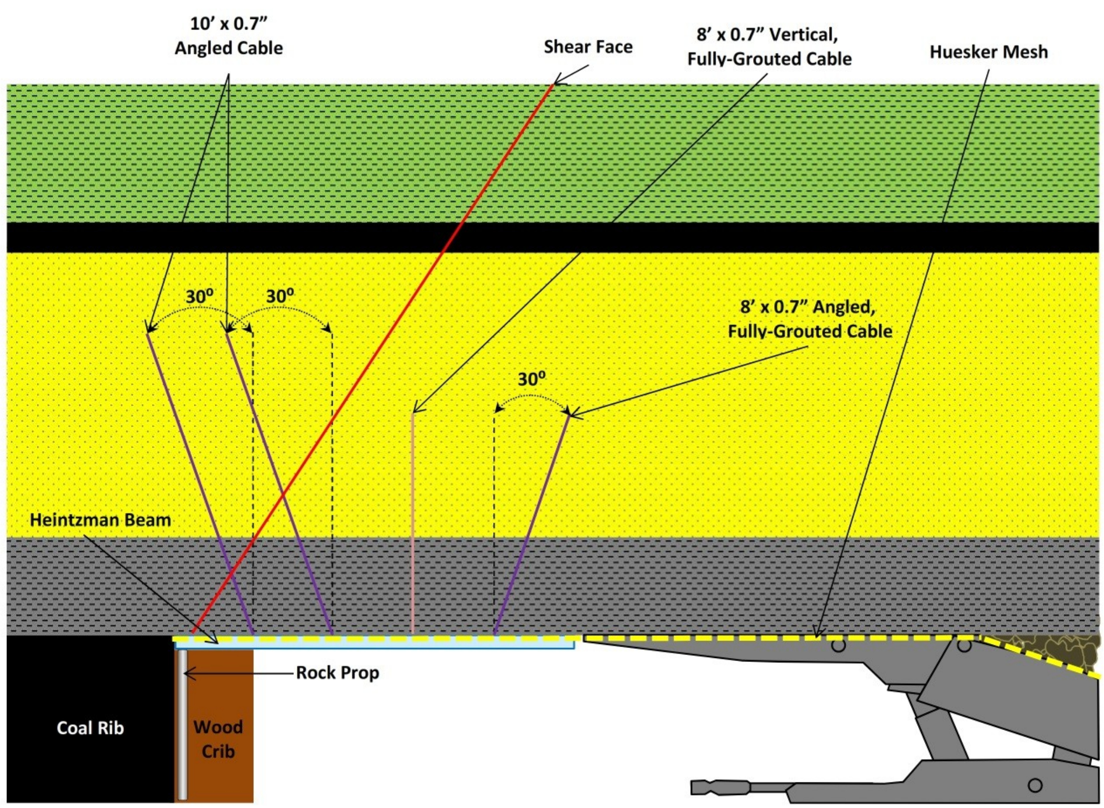
1R Conventional Move

- During extraction of the AFC, headgate and tailgate we started to develop a cutter on the solid rib line.
- It was decided at this time to bring in the Fletcher roof bolter and spend the time to bolt the face with a denser and more substantial support .
- The cutter continued to worsen and the roof was displaced.
- A continuous miner was brought in to grade head to tail to gain height and expedite the shield extraction. This made it easier to shoot the floor out from under the iron bound shields.
- We started building 2ft X 4ft cribs along the solid face. Heintzman beams were placed on top of the cribs and staggered and placed over the shield tips.
- With everything out of the way and the additional roof support added we began shield extraction. Pulled from HG to TG with no problems with the first 40 shields.
- Then weighting event occurred, and shields 40 to 130 were collared, it was a fight with each and every one.
- The longwall extraction took 55 days (hanging mesh to final shield pulled).

1Right Conventional Move

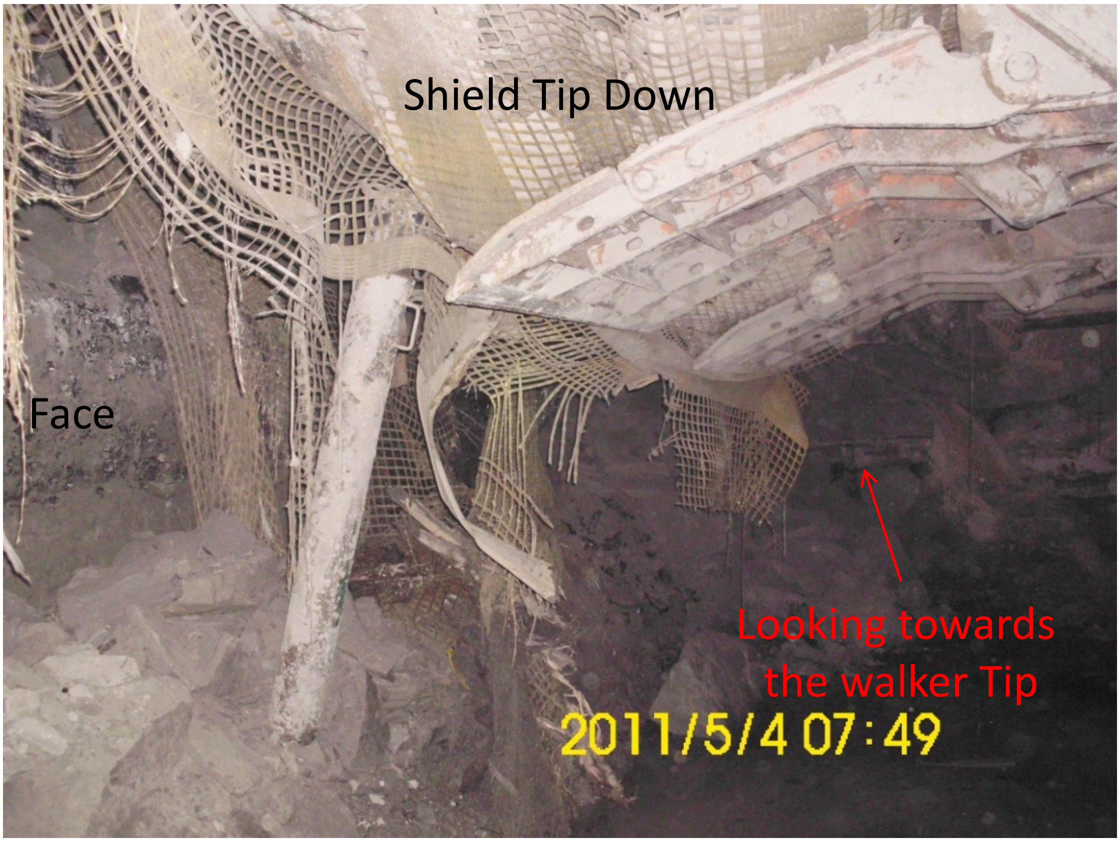
Post Event Roof/Supplemental Support

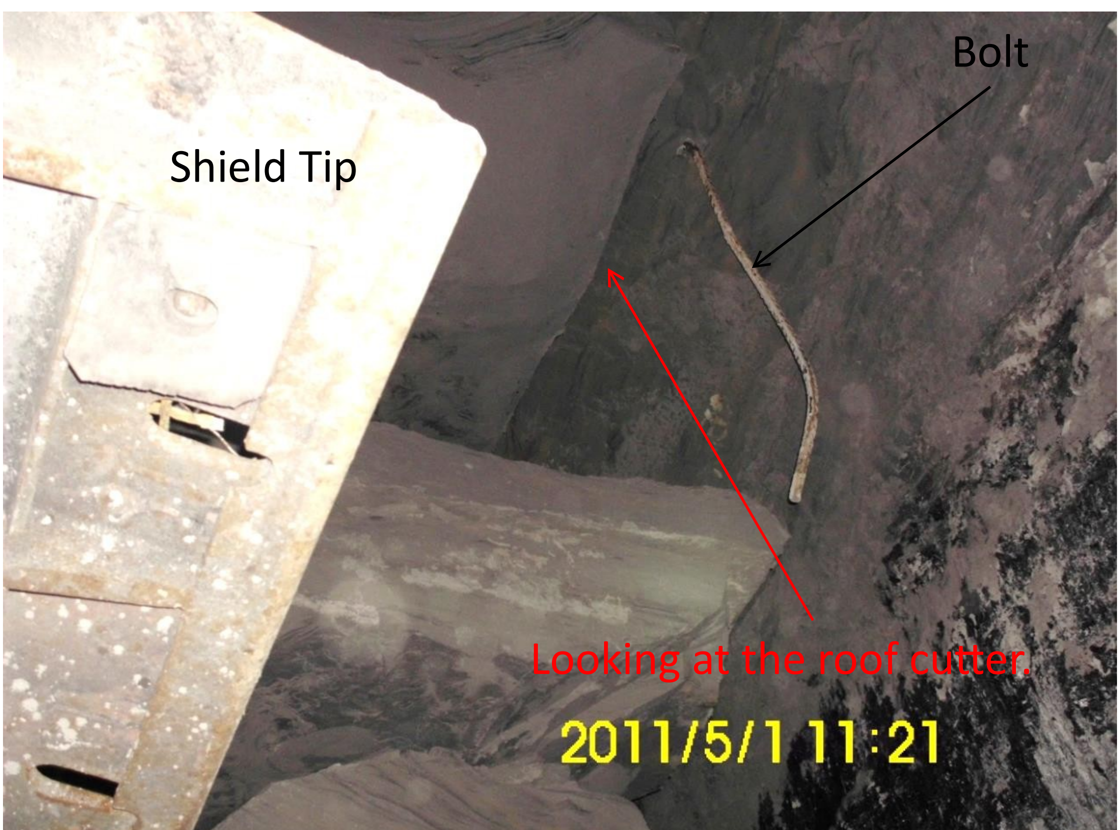
Installed with “Fletcher Bolter” after AFC removed



1R Conventional Move

After Shield 40 Event



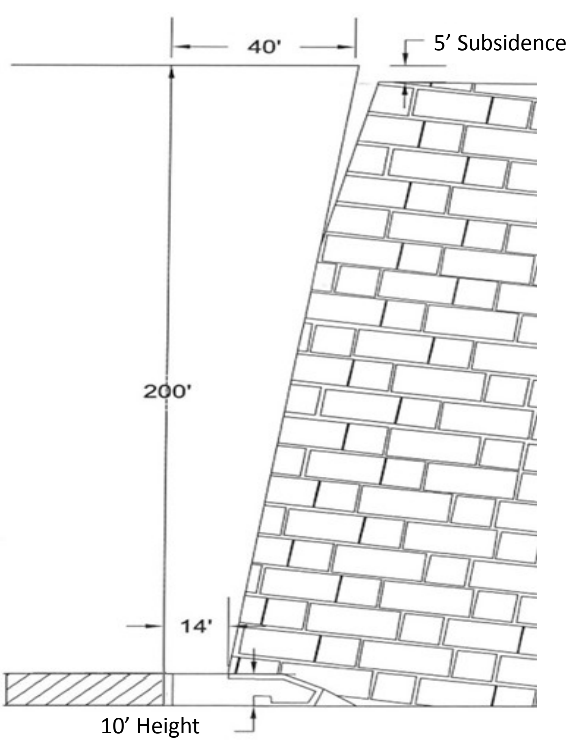


Post 1 Right Evaluation

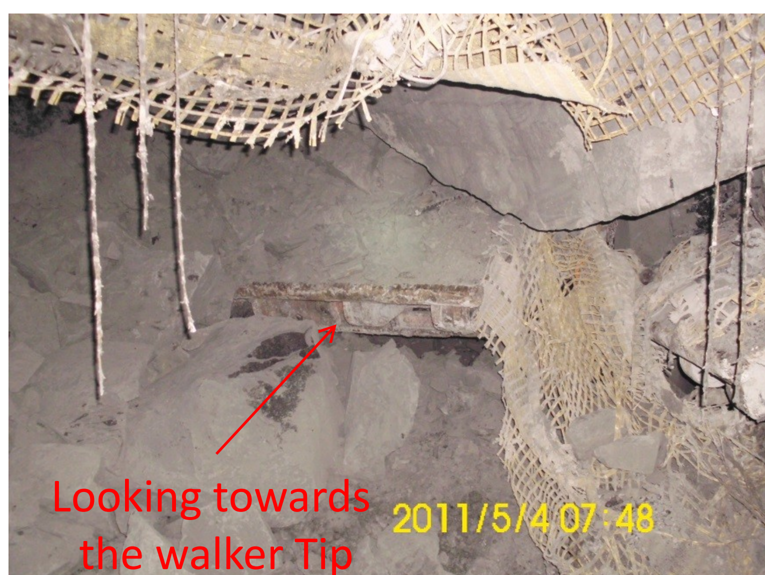
- Analysis of the 1 Right Recovery Room showed a significant angle shear with subsidence expressions from the recovery room to the surface.
- Its determined that the roof failure included both the immediate roof and the overburden rocks.
- SPE key managers were involved.
- The focus was on method of moving the longwall that would speed up the meshing cycle and allow us to install a support to prevent the cutter on the solid rib / face side.
- We were also convinced that we needed a support plan including standing support that would hold up to a large dead load due to the weak strata and shallow cover.
- The pre developed entry came into play.
- SPE Management and Engineering developed a recovery entry system.
- Keystone was contacted and participated in the final design.
- Design was based on what had worked and what didn't work at other coal mines in all parts of the world.
- This was submitted to MSHA for approval.

1 Right Conventional Cave Observation

No Forward Abutment

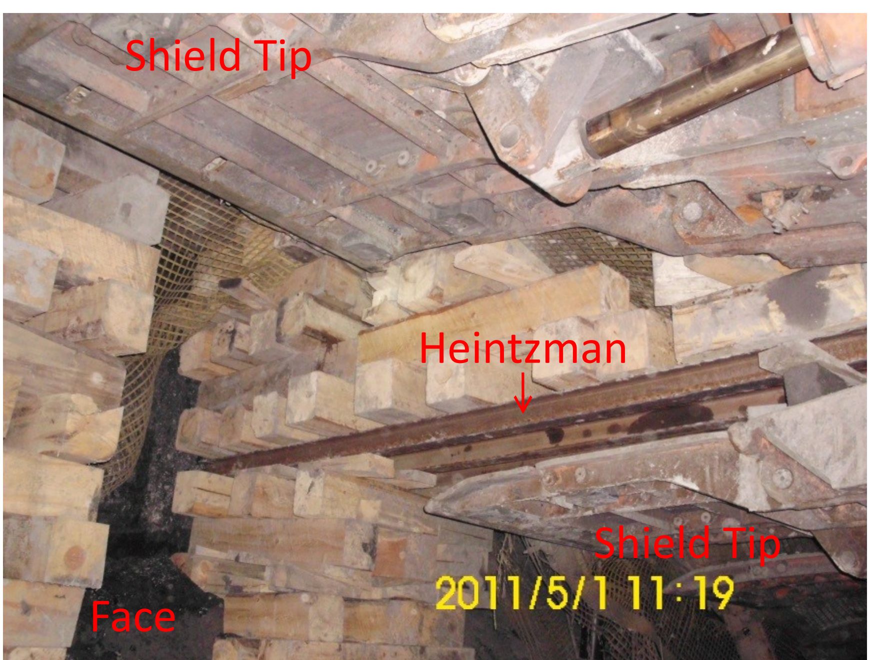


1 Right Conventional Buried Walker

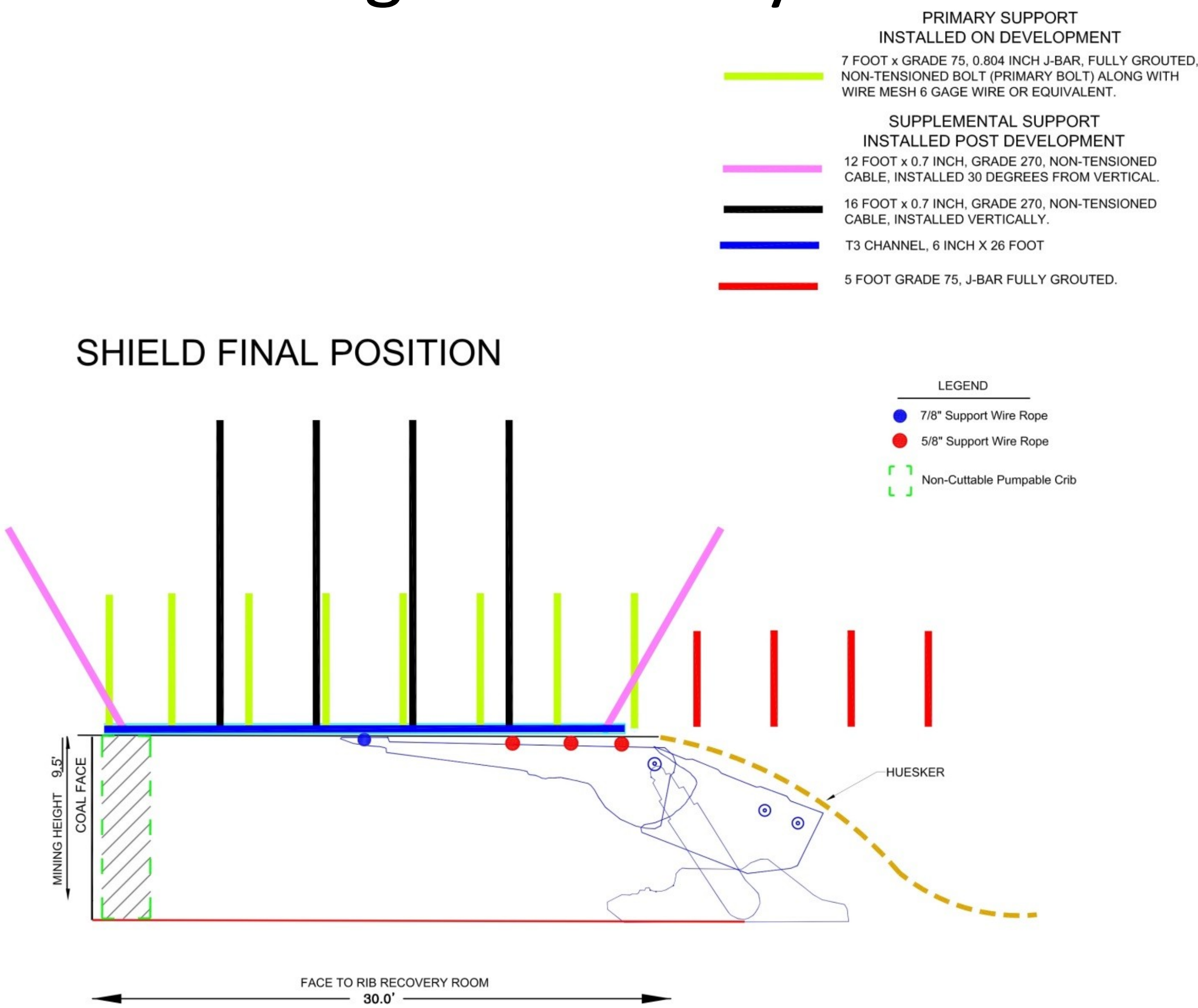


Post 1 Right Evaluation

- Supplemental support was successful in stabilizing the roof to minimize hazards associated with exposure of miners to bad roof.
- For the next panel plans are to develop a safer and efficient way to move the longwall.



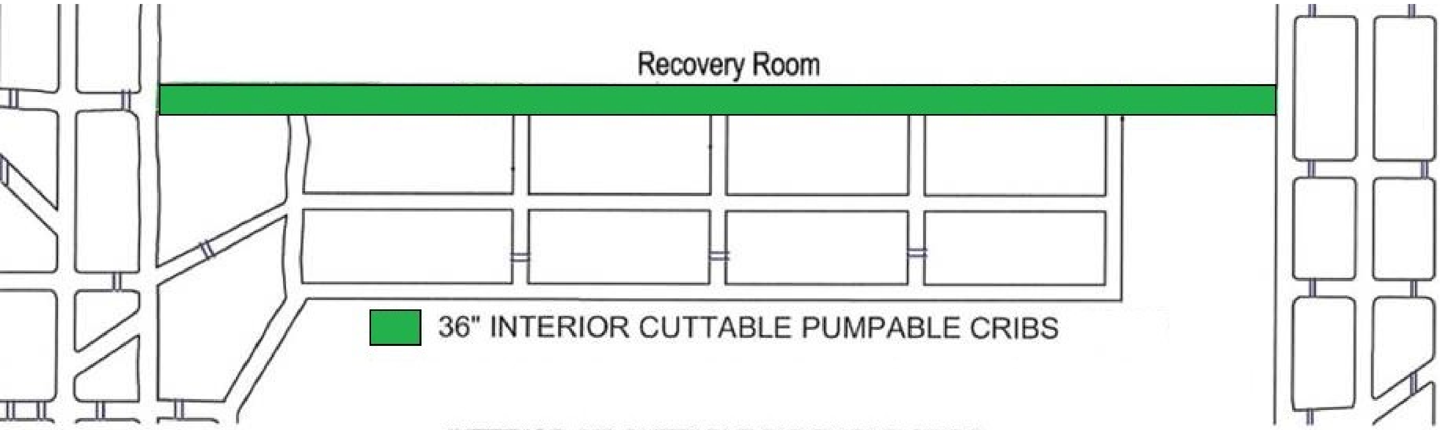
2 Right Recovery Plan

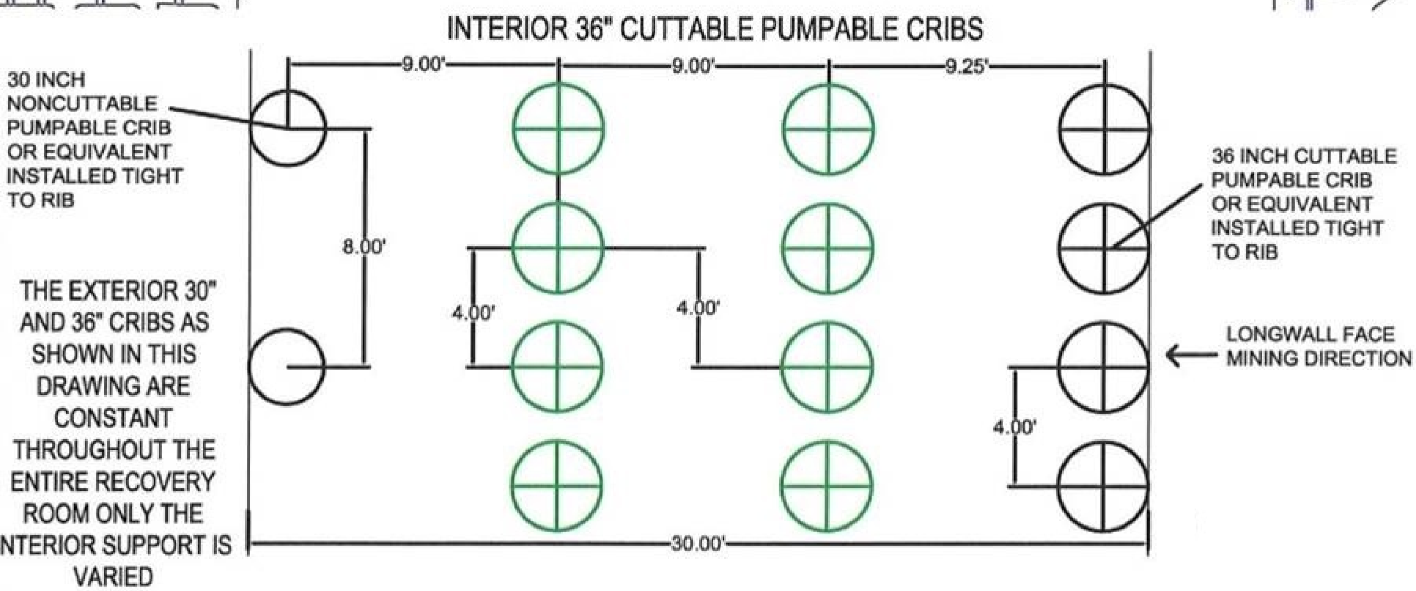


- **30 Foot Wide Recovery Room.**
  - Cut 20’ wide, then slab cut 10’.
  - Primary support installed on cycle.
  - Supplemental support installed after development.
- **Primary & Supplemental Support**
  - Primary: 7’ Grade 75, 0.804 J-Bar, non-tensioned, fully grouted bolts on 4’ centers with wire mesh.
  - Supplemental:
    - 12’, grade 270, 0.7 inch non-tensioned cable bolts installed 30 degrees from vertical.
    - 12’, grade 270, 0.7 inch non-tensioned cable bolts installed vertical.
    - 16’, grade 270, 0.7 inch non-tensioned cable bolts installed vertical.
    - T3 Channel 6” by 23”.
    - Bytm Truss system, 8’ by grade 75, 0.804 J-Bar Super Twist Plus. 84” 45degree angled bolt for the Bytm Truss.
  - Chutes Support:
    - Roof: 7’ Grade 75, 0.804 J-Bar, non-tensioned, fully grouted bolts on 5’ centers with wire mesh.
    - 12’, grade 270, 0.7 inch non-tensioned cable bolts installed vertical.
    - Bytm Truss system, 8’ by grade 75, 0.804 J-Bar Super Twist Plus. 84” 45degree angled bolt for the Bytm Truss.

2 Right Recovery Plan

Supplemental Support



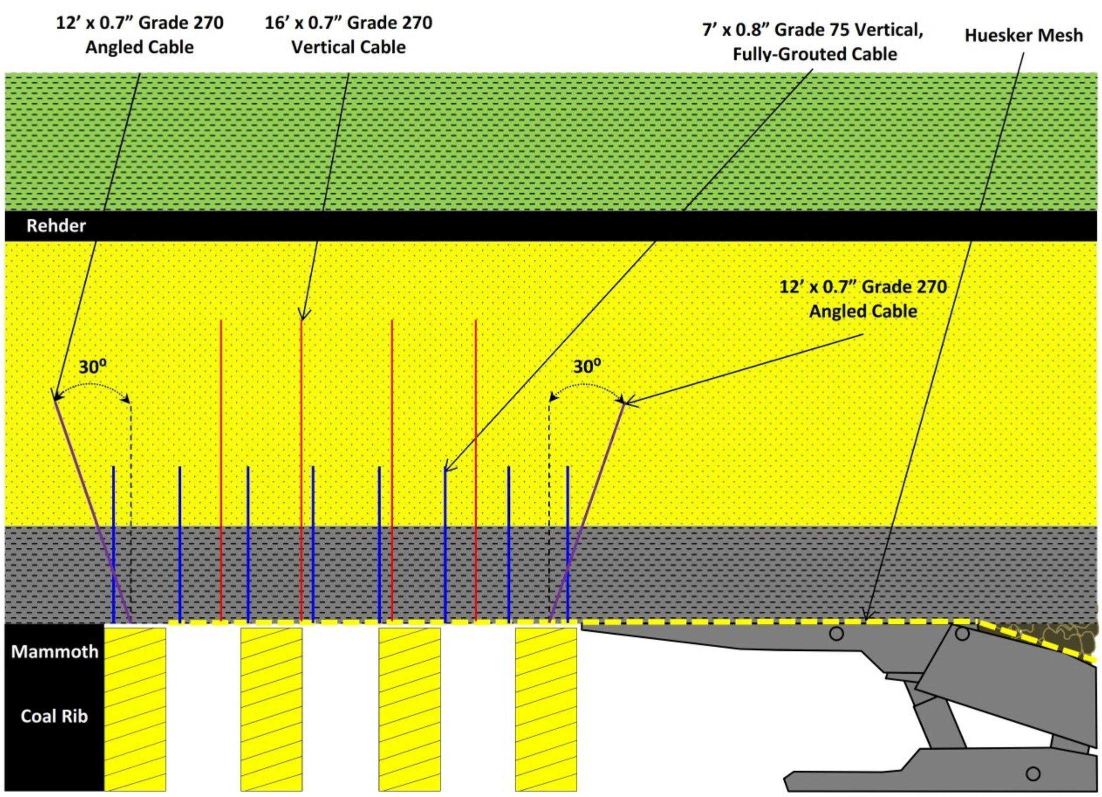


Parameter	Overburden Depth m (ft)	CMRR	RDI, MPa·m	SSD, Mpa	Shield Capacity, Metric Ton
2 Right Recovery Room	67 (220)	59	0.99	0.34	1,025 (line shield) of 1,143 (gate shield)

2 Right Recovery

- Finished the mining of 2 right panel in August 2012.
- 2 Right Recovery Room Conditions
  - Shallow cover (220’ Overburden).
  - Normal lithology (Sandstone Top).
  - Normal mining height (10’).
  - Interburden between the Mammoth and Rehder Seams greater than 20’.
- Normal mining proceeded. More Huesker Mesh than needed due to delayed MSHA approval. Mesh was pulled onto the face (conventional style), pinned in place and was bolted on the ends.
- Meshing was slow due to cap rock and uneven roof. We had thought the cap rock issues would not be present due to the supported recovery room ahead of us, not true. Installation of the roof mesh slowed the advance rate, and face roof conditions did deteriorate.

2 Right Recovery Room
Roof/Supplemental Support



2 Right Recovery

- When the fender pillar was approximately 15 feet at the tailgate and 18 feet at the headgate a weight transfer occurred. Both the shields and the standing support were immediately converged approximately 24 inches. After the weight transfer event many of the shields were ironbound.
- Shield toes were blasted and recovery work continued. The sudden convergence damaged the yield valves. The yield valves were replaced with rock burst valves .
- Damage was found at the chutes at the rib line in two of the chutes, #4 being the worst. Several of the pumpable crib in the recovery room had failed.
- We had District 9 MSHA roof control and ventilation managers on the face 24/7 during this move.
- Due to the partial fender and shields not being in final position we could not repair or replace cribs in the recovery entry.
- MSHA did allow us to build cribs in specific areas of the chutes.
- Again every inch of shield advancement and meshing was a battle.

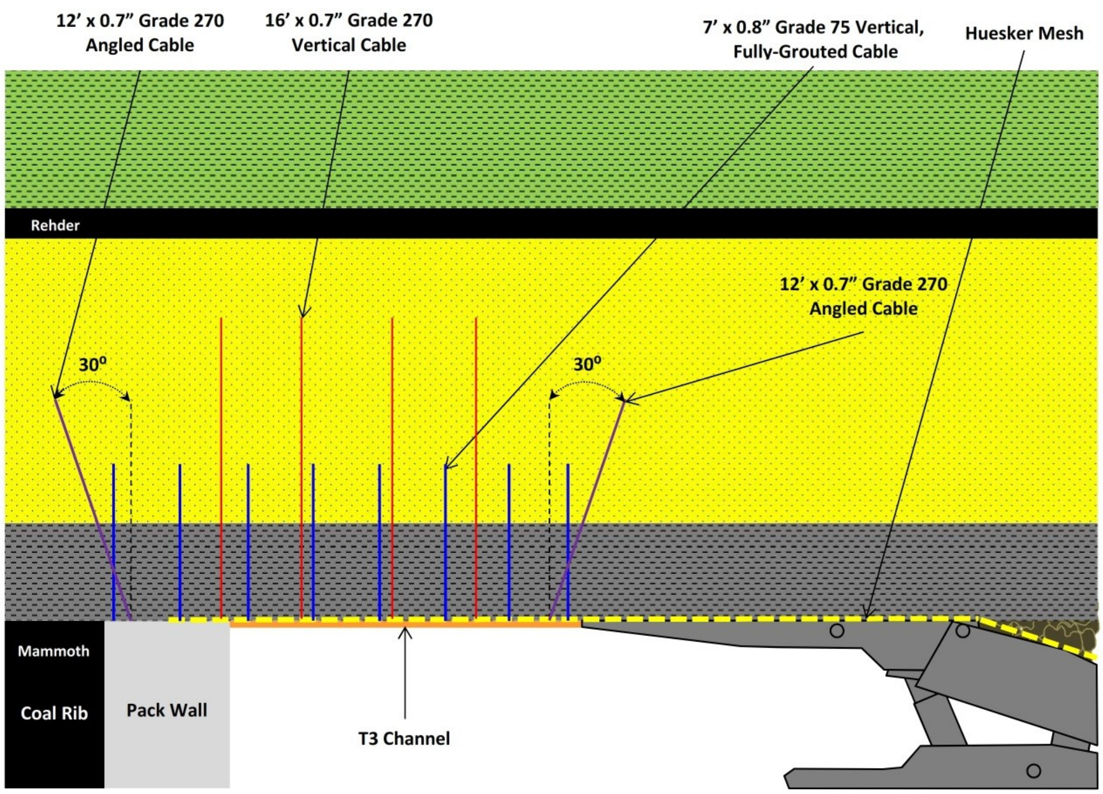
2 Right Recovery

- Shield legs were iron bound and shield tips were down bad enough to prevent mining with the shearer.
- We installed standing support (water props and prop-setters in the recovery room in all intersections of the chutes in line with the solid rib line.
- Then we continued to set the same support along the solid face / rib where the pumpable cribs had and were failing.
- Once again we were developing a major cutter along the face / rib line.
- On the face side we decided to park the shields where they set and started to extract the AFC, headgate drive and tailgate drive.
- We then brought the continuous miner in and graded head to tail for extraction of the iron bound shields.
- Back to the recovery room solid pillar side we strung out brattice for a form along the new standing support that had been installed. (8 foot average thickness)

2 Right Recovery

- Tech-seal was pumped into this void to create a pack wall matching a 900 psi coal strength. With the pack wall completed and a minimal cure time all convergence slowed.
- Shields were extracted at a slow pace due to the majority being iron bound and the Huesker mesh not being in the desired or proper position.
- The longwall extraction took 60 days (hanging mesh to final shield pulled).

2 Right Recovery Room
Roof/Supplemental Support



2 Right Post Evaluation

- Prior to the weighting transfer the normal mining rate was reduced due to the meshing installation.
- When the fender pillar yielded the shields converged, and the standing support failed.
- The standing support density of 0.34 was underestimated.

Fender Intact

Fender Failure

2 Right Post Evaluation

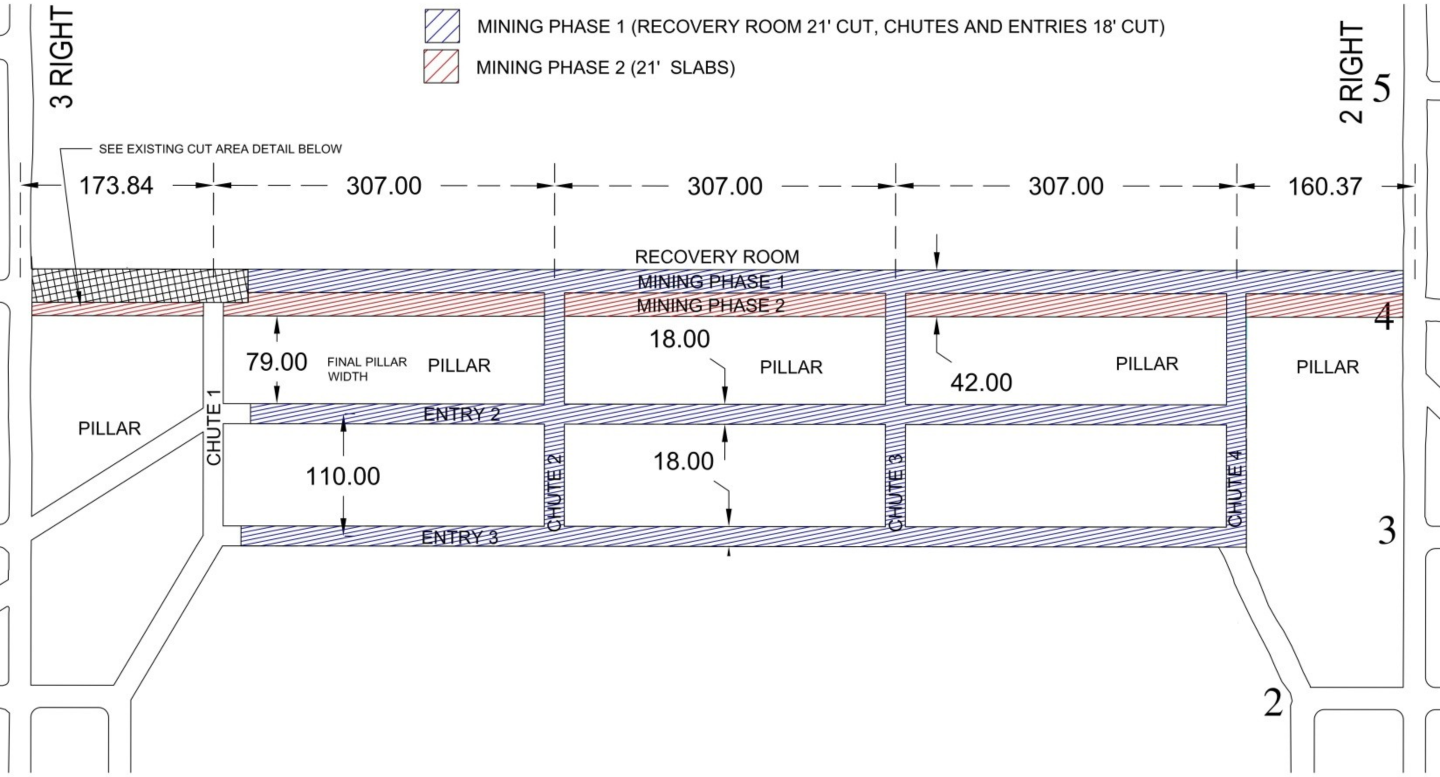
- Yield valves were damaged when the weight transfer occurred, and the shields yielded. The damaged yield valves were replaced with burst valves that are designed for high volume discharge.
- Shields had to be blasted to gain ram extension (Leg)
- Convergence continued as the shields were being advanced
- 8’ thick 900 psi pack walls were constructed, the roof stabilized and roof convergence decreased.
- Shield recovery was completed.
- The installed roof support bought us time until the packwall was completed.

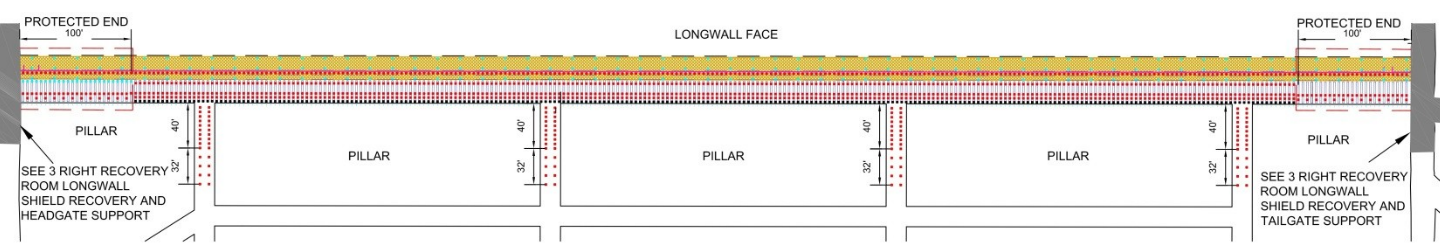
Back to the Drawing Board

- **POST MOVE MEETING**
  - SPE managers, myself and the engineering team met.
  - During 70+ day longwall moves you have the opportunity to do a lot of thinking.
  - We needed a safe/quicker/more efficient way of moving the longwall.
  - With the low cover, weak sandstone, heavily jointed strata and wide face moving the longwall at SPE is a challenge.
  - Our vision was to design a recovery room with the Huesker mesh already installed to eliminate valuable and critical time.
  - This same recovery room would have bolts that I had used in Australia (Mega 63 ton) to anchor above the Rehder seam which was needed in controlling the solid rib cutter.
  - This recovery room would have a better method to prevent the cutter on the solid rib/face side.
  - This recovery room would be completely filled with a 800PSI concrete or equivalent.
  - We went to work and put together a great plan with all of our ideas and presented the plan to Keystone.
  - Keystone thought the new plan had some merit and they made a few modifications.

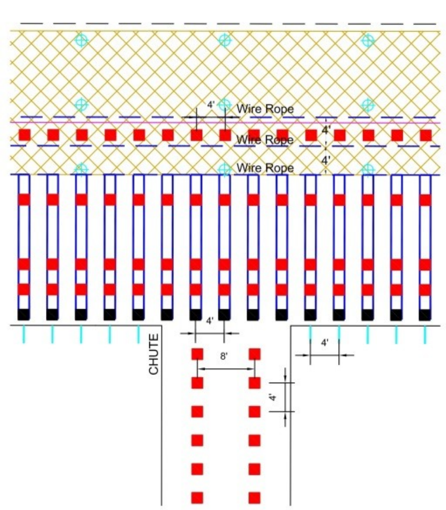
- **VISIT AUSTRALIA**
  - We made a trip to Australia to look at the JennMar equivalent to the Mega bolt.
  - We talked to BHP about their history with recovery rooms (success and failure)
  - We shared our idea of having the huesker installed ahead of time with BHP and they were excited about the idea.
  - We visited Golder and ran the plan by them.
  - Golder convinced us to move the location of one of the 63 ton "Sumo" bolts. (above the shield leg)
  - Golder also suggested we use fiberglass dowels on the fender for stability reasons.

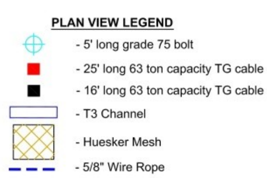
3 Right Recovery Plan





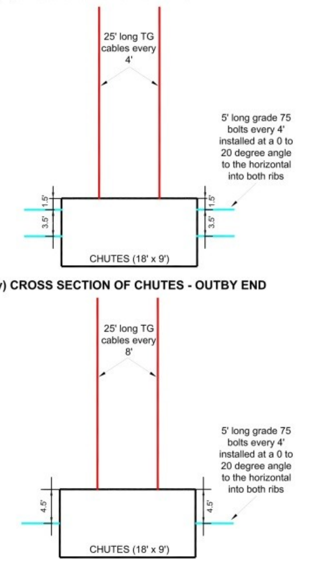
(i) PLAN VIEW OF RECOVERY ROOM MID-FACE



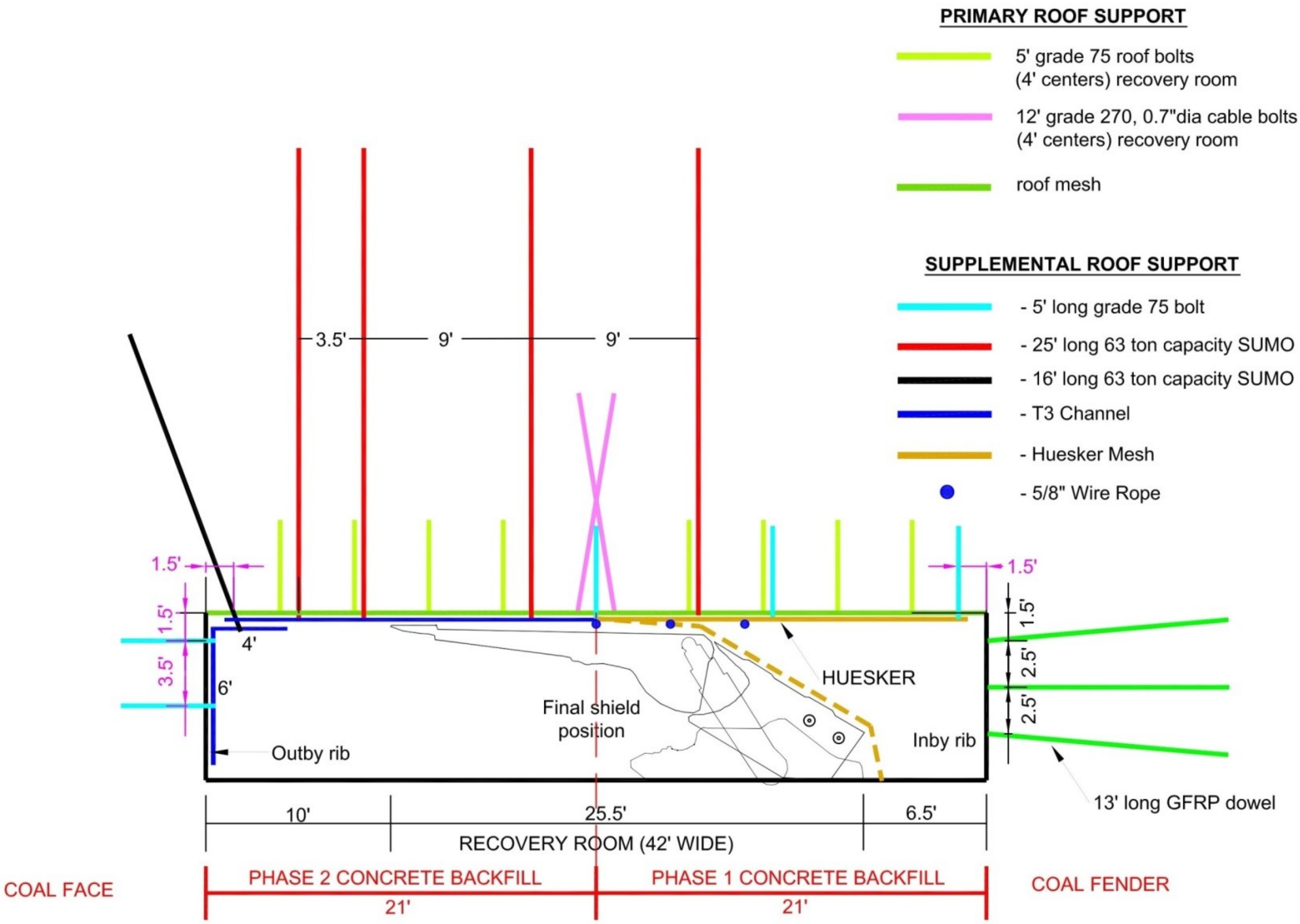


(iii) CROSS SECTION OF CHUTES - INBY END

(iv) CROSS SECTION OF CHUTES - OUTBY END

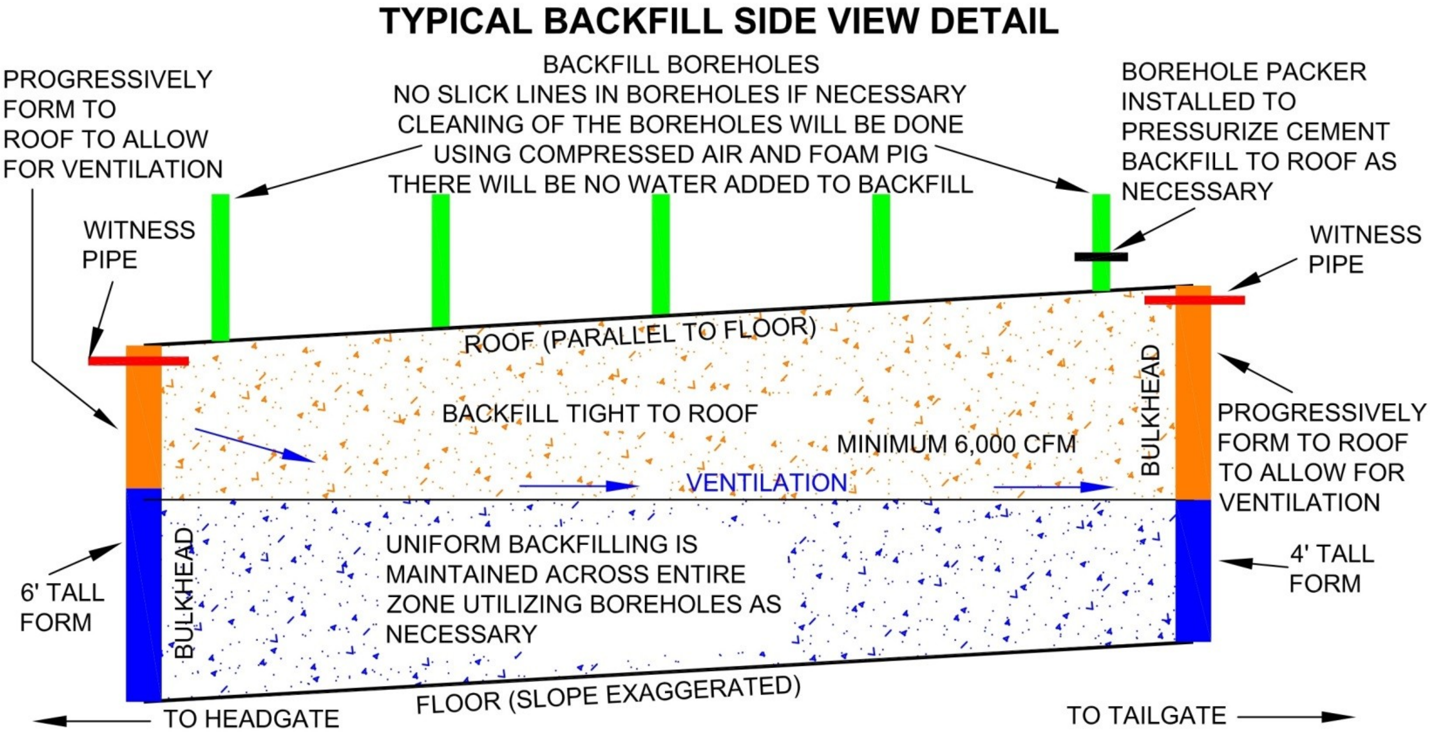


3 Right Recovery Plan



- 42ft wide recovery room developed in 2 stages.
  - Phase 1: 21 ft wide. Bolted with wire mesh and huesker mesh. Then backfilled with low density concrete.
  - Phase 2: 21 ft wide. Bolted with wire mesh and backfilled.
- Primary & Supplemental Support
  - Primary: 5’ Grade, 75 J-Bar, non-tensioned, fully grouted bolts on 4’ centers with wire mesh.
  - Supplemental: 16’ and 25’, 62 ton capacity, fully grouted SUMO cable bolts with 20’ T-Channel.
  - Outby Rib: Two 5’ Grade, 75 J-Bar, non-tensioned, fully grouted bolts on 4’ centers with angled channel.
  - Transition Between Phase 1 & 2: Two 12’, grade 270, 0.7 inch cable bolts were cross installed.
  - Chutes: Two Rows of 25’ SUMO, 62 ton capacity, cable bolts with 30 ton cable truss system.

3 Right Recovery Plan



- **3 Right Recovery plan was MSHA approved July 2013.**
- **Low-Density Concrete Backfill**
  - Concrete was pumped from the surface to the recovery room through boreholes (approximately 120 foot spacing).
  - Backfill rates were maintained at 800 cubic yards or less, and no more than 2’ thick increments.
  - Brattice cloth used as barrier to protect roof support.
  - Backfill density was continuously monitored, and samples were taken every hour. Later tested for unconfined compressive strength greater than 800 psi.
  - Inspections to confirm full roof to floor cement contact were performed with borehole cameras, top of form witness pipes and vent pipes at high points.
    - Any voids found while developing phase 2 were filled with polyurethane or J-CRIB material.
  - Ventilation (6K CFM min) was provided across the top of the backfill until the final lift was poured.

Parameter	Overburden Depth m (ft)	CMRR	RDI, MPa·m	SSD, Mpa	Shield Capacity, Metric Ton
2 Right Recovery Room	67 (220)	59	0.99	0.34	1,025 (line shield) of 1,143 (gate shield)
3 Right Recovery Room	61 (200)	59	1.62	5.5	1,025 (line shield) of 1,143 (gate shield)

3 Right Recovery Plan

Backfilling 3 Right recovery room

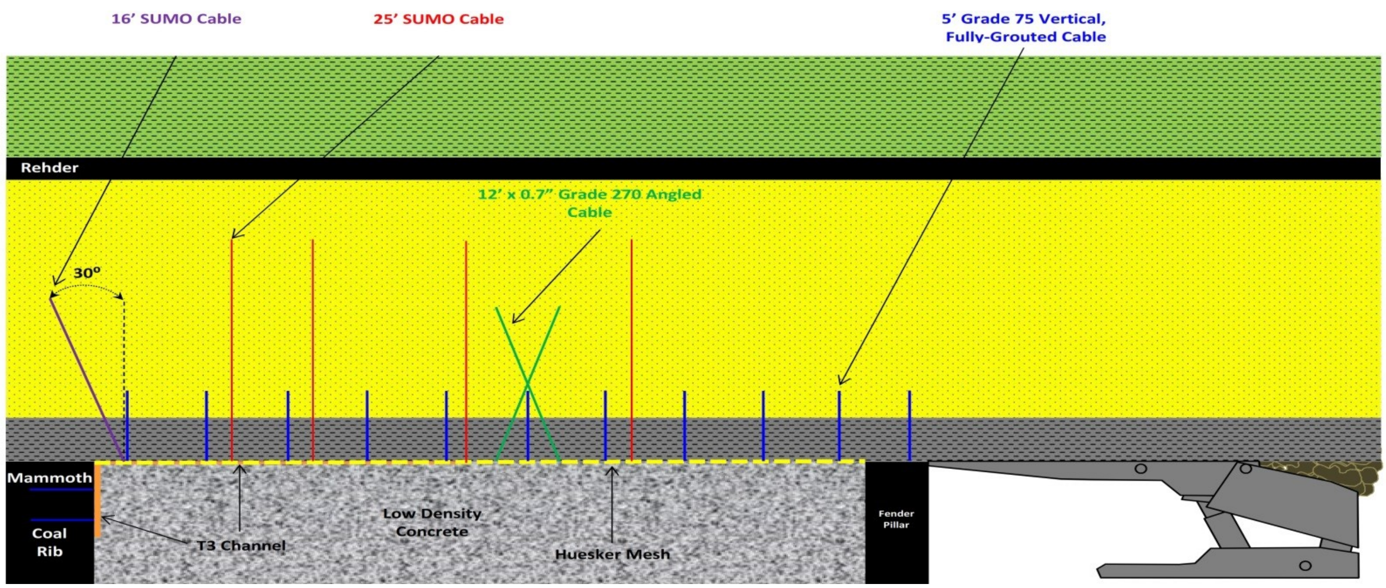
Looking at Phase 1 backfill from Phase 2 development

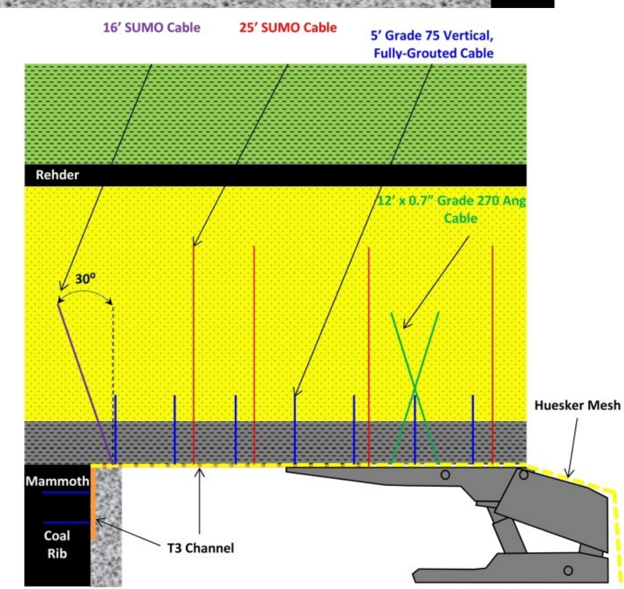
3 Right Recovery

- Completed mining the 3 Right panel in January 2014.
- 3 Right Recovery Room Conditions
  - Shallow cover (200’ Overburden).
  - Normal lithology (Sandstone Top).
  - Normal mining height of 11’ (9’ of coal & 2’ floor rock).
  - Interburden between the Mammoth and Rehder Seams greater than 20’.
- No indication of stress or roof rib sloughage.
- Pillar corners remained sharp.
- Abutment load transferred as planned.
- Shields yielded and leg pressures returned back to normal when the roof caved behind the shields
- Designed without the need to stop and install any supplemental roof support.

3 Right Recovery Room

Roof/Supplemental Support- Pre Fender & Final Position





3 Right Recovery
Mining Backfill

Mining the coal fender, no roof spalling. The face is standing straight. Mining within 13 feet of the backfill.

Mining the concrete backfill, no roof spalling. The face is standing straight.

3 Right Recovery
Roof Support

Exposed bolts, channel, and steel mesh

Huesker mesh (yellow) laid down behind the shields

3 Right Recovery

Final Pass

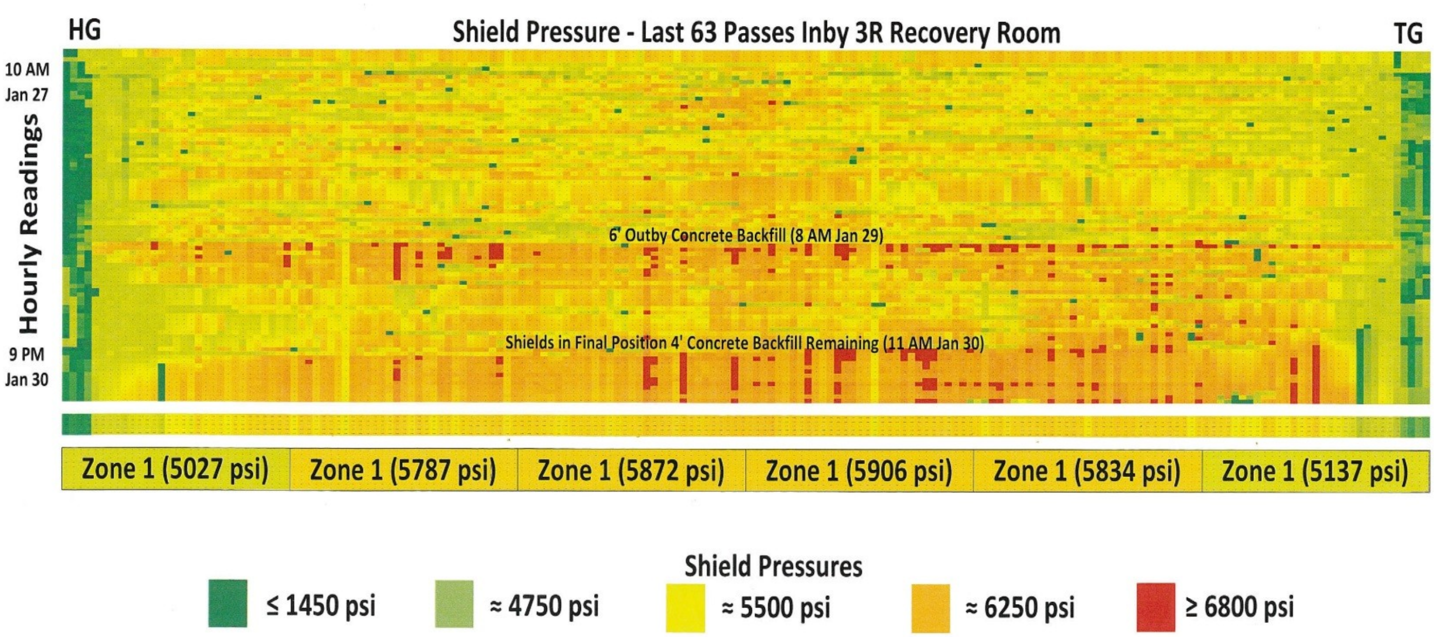
M

position.

Breakthrough to chute 2, no roof spalling. The face is standing straight.

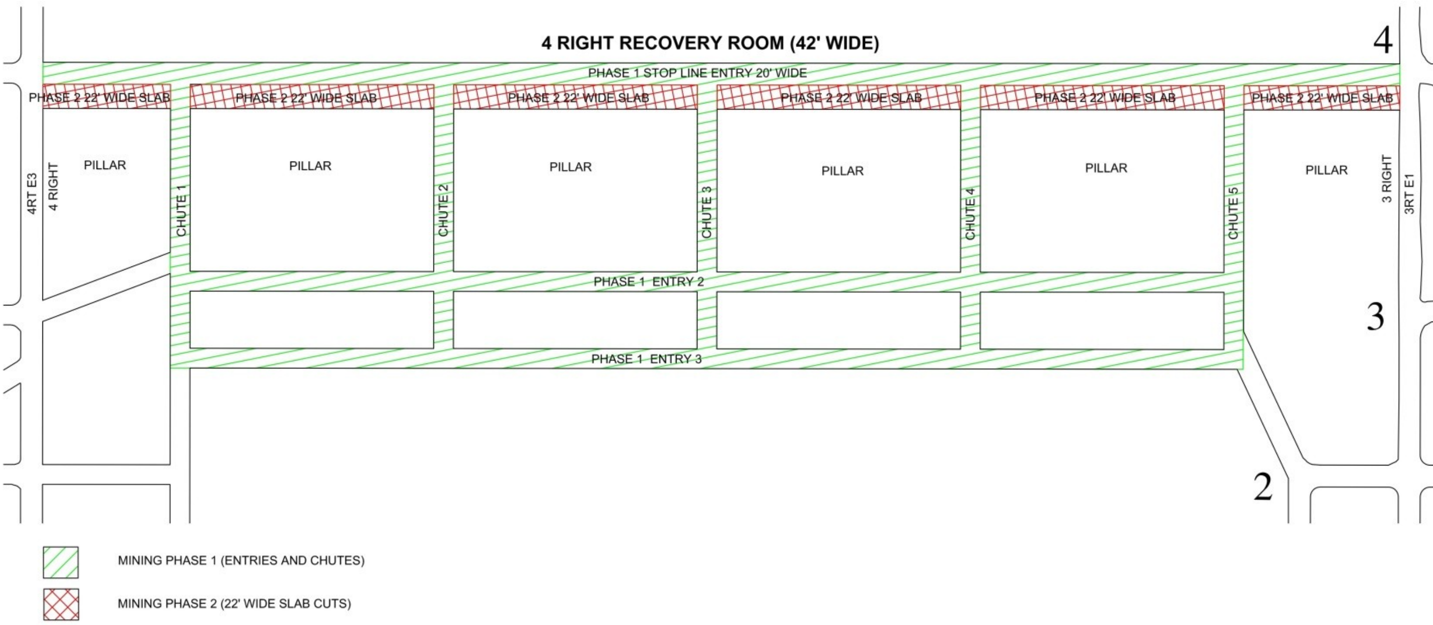
3 Right Post Evaluation

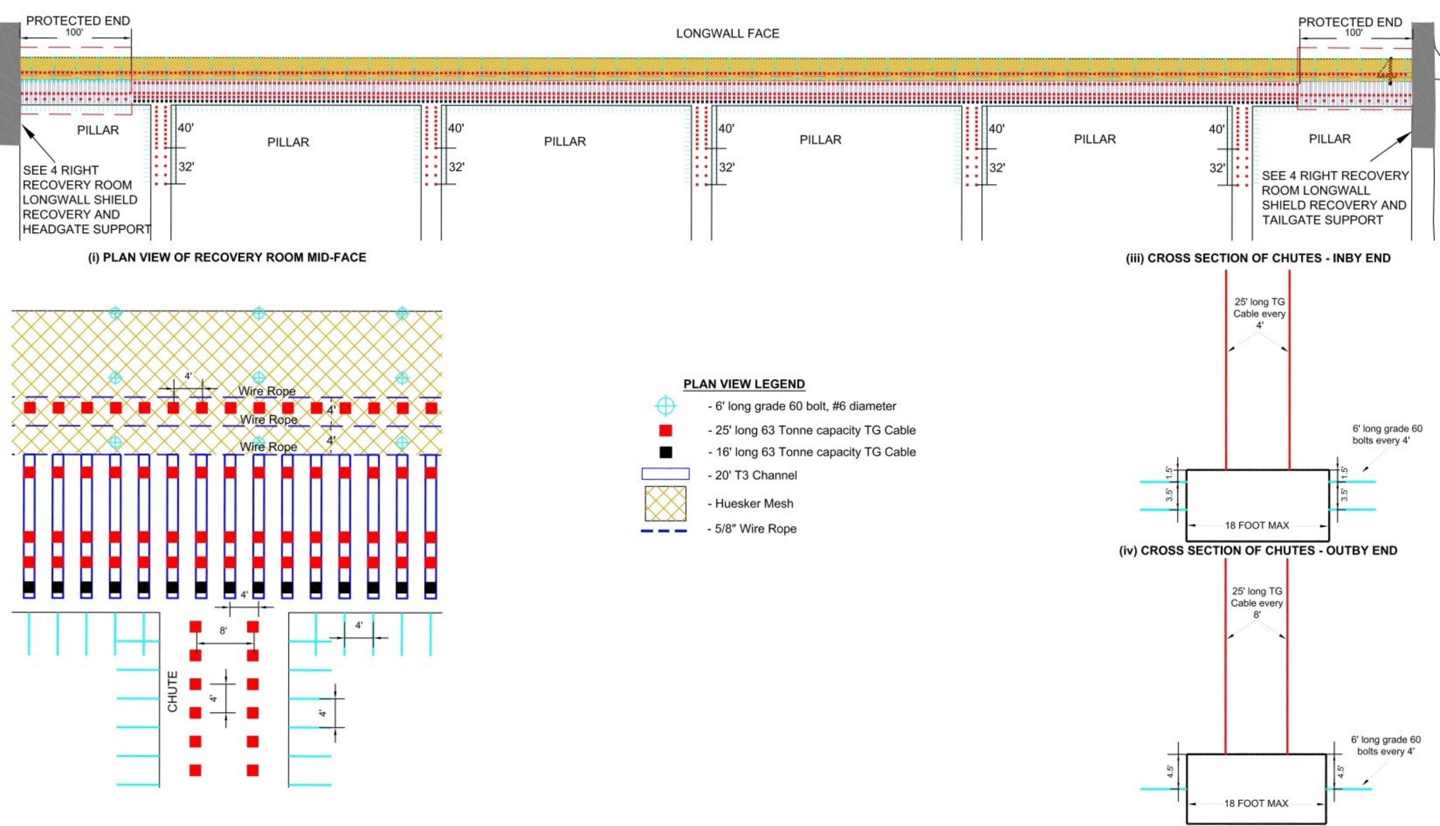
- Mining advanced into final position on schedule. Backfill (1-2 feet) was left to protect the outby pillar.
- The entire roof/rib support system sufficiently controlled the roof joints and established a competent beam structure to prevent roof/rib cutter and potential roof beam rotation.
- 3 Right Longwall equipment was moved from a pre-developed 42' wide recovery room in a record best 24 days equaling the move times for top Longwall operations in the country.
  - LW extraction took only 15 days
- Shield leg pressures showed 2 loading events.
  - 6 feet outby concrete backfill.
  - Shields in final position, 4 feet concrete backfill remaining.
- Shield pressures indicated that the shields in the middle and tailgate side of the face experienced higher leg pressures than the headgate side. A maximum 3.5" of convergence was measured.
- There were no roof falls, the final fender did not fail, no adverse shield convergence, and no accidents.



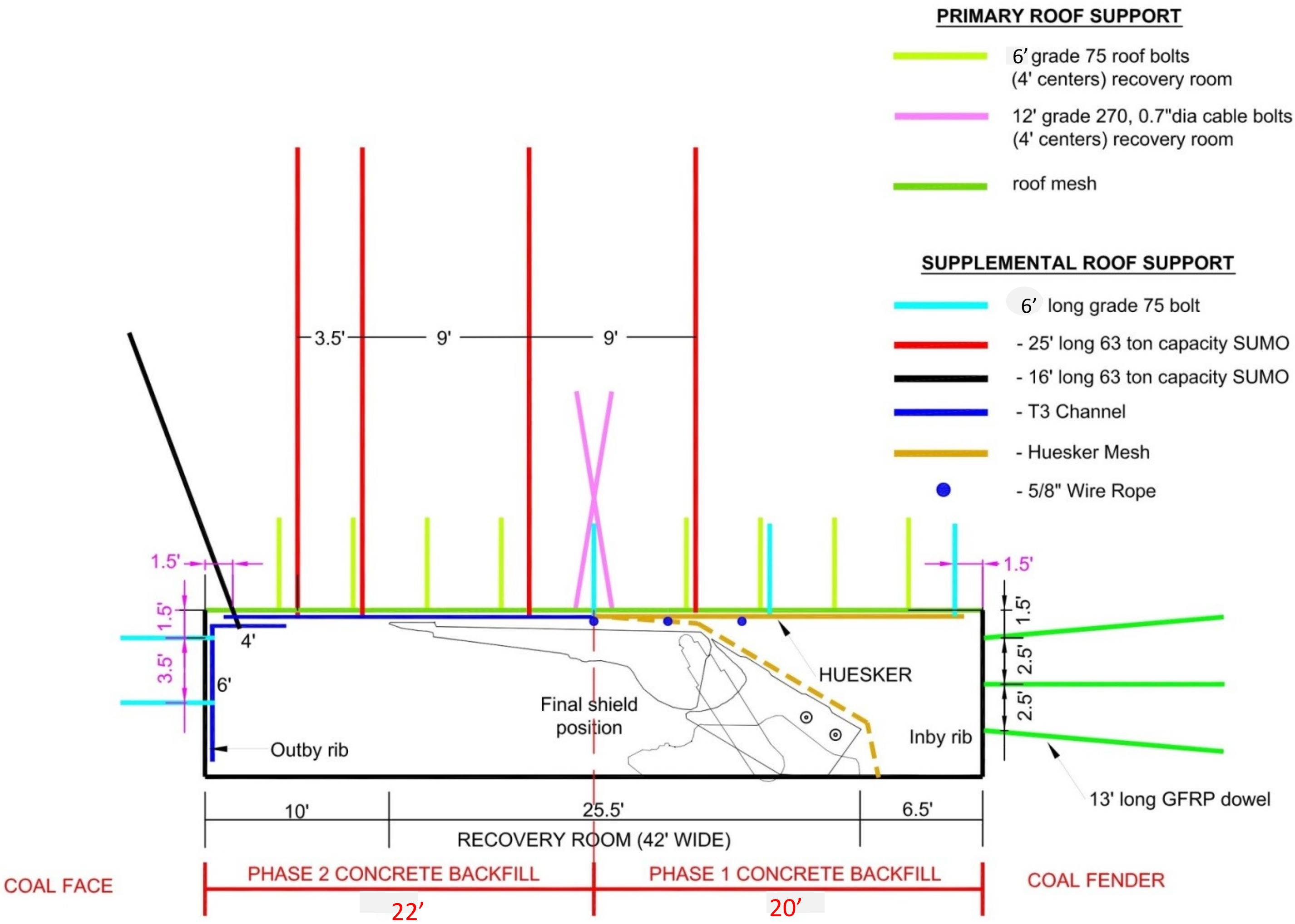
4 Right Recovery Plan

- 4 Right Changes
  - Lower backfill compressive strength (600 psi vs. 800 psi)
  - Extra chute (5 vs. 4)
  - Primary support (6’ bolts vs. 5’ bolts)
  - Phase width (20’ & 22’ vs. 21’ & 21’)



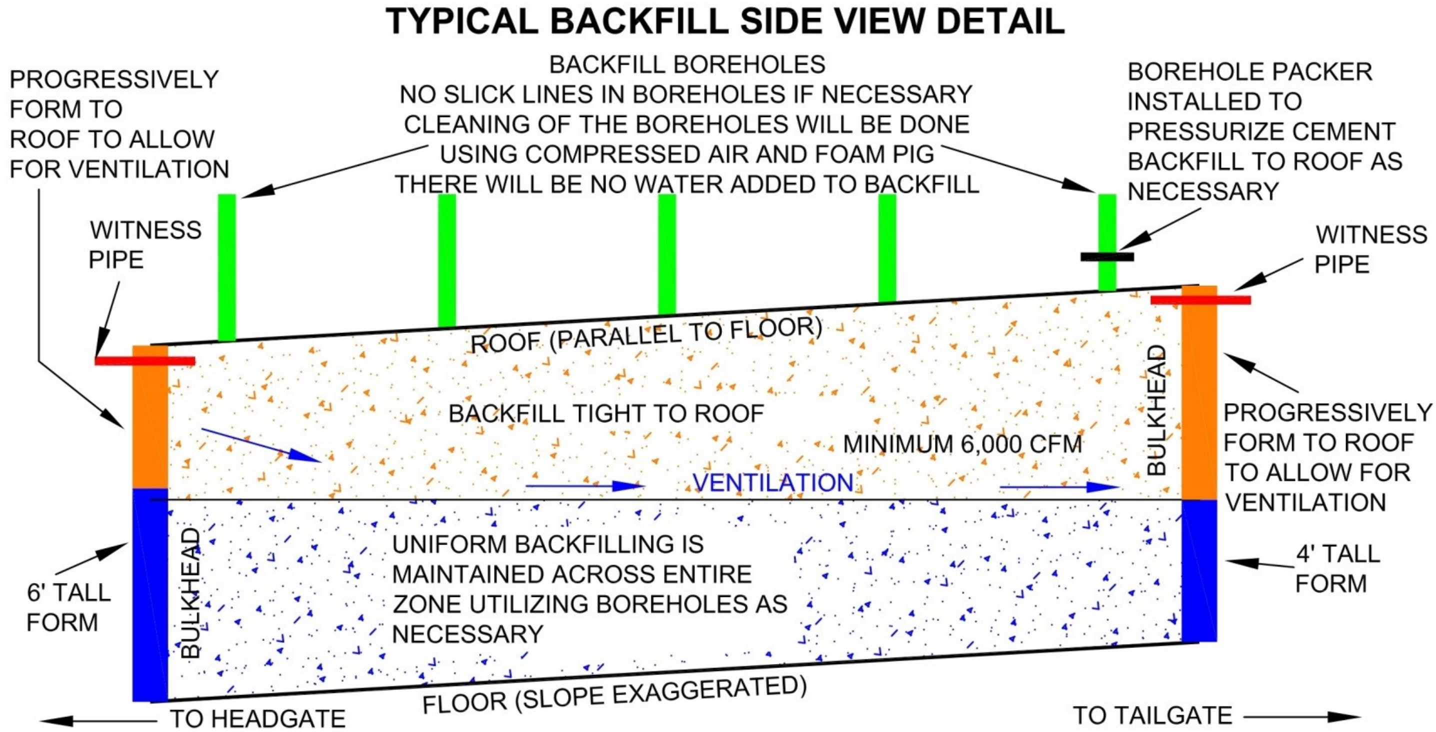


4 Right Recovery Plan



- 42ft wide recovery room developed in 2 stages.
  - Phase 1: 20 ft wide. Bolted with wire mesh and Huesker mesh. Then backfilled with low density concrete.
  - Phase 2: 22 ft wide. Bolted with wire mesh and backfilled.
- Primary & Supplemental Support
  - Primary: 6’ Grade, 75 J-Bar, non-tensioned, fully grouted bolts on 4’ centers with wire mesh.
  - Supplemental: 16’ and 25’, 62 ton capacity, fully grouted SUMO cable bolts with 20’ T-Channel.
  - Outby Rib: Two 5’ Grade, 75 J-Bar, non-tensioned, fully grouted bolts on 4’ centers with angled channel.
  - Transition Between Phase 1 & 2: Two 12’, grade 270, 0.7 inch cable bolts were cross installed.
  - Chutes: Two Rows of 25’ SUMO, 62 ton capacity, cable bolts with 30 ton cable truss system.

4 Right Recovery Plan



- **4 Right Recovery plan was MSHA approved August 2014.**
- **Low-Density Concrete Backfill**
  - Concrete was pumped from the surface to the recovery room through boreholes (approximately 120 foot spacing).
  - Backfill rates were maintained at 800 cubic yards or less, and no more than 2’ thick increments.
  - Brattice cloth used as barrier to protect roof support.
  - Backfill density was continuously monitored, and samples were taken every hour. Later tested for unconfined compressive strength greater than 800 psi.
  - Inspections to confirm full roof to floor cement contact were performed with borehole cameras, top of form witness pipes and vent pipes at high points.
    - Any voids found while developing phase 2 were filled with polyurethane or J-CRIB material.
  - Ventilation (6K CFM min) was provided across the top of the backfill until the final lift was poured.

Parameter	Overburden Depth m (ft)	CMRR	RDI, MPa·m	SSD, Mpa	Shield Capacity, Metric Ton
2 Right Recovery Room	67 (220)	59	0.99	0.34	1,025 (line shield) of 1,143 (gate shield)
3 Right Recovery Room	61 (200)	59	1.62	5.50	1,025 (line shield) of 1,143 (gate shield)
4 Right Recovery Room	61 (200)	59	1.58	4.14	1,025 (line shield) of 1,143 (gate shield)

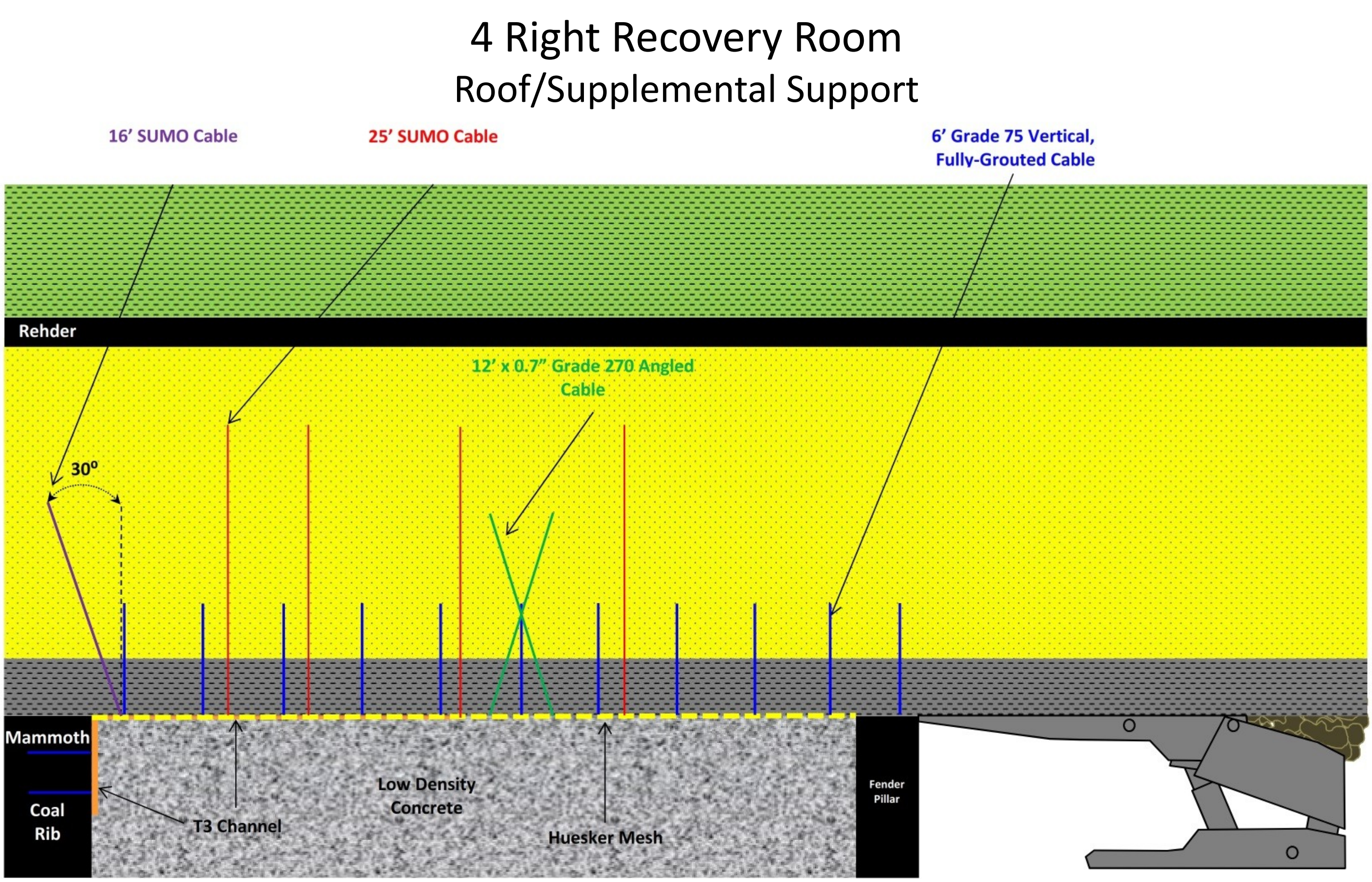
4 Right Recovery Plan

Backfilling 4 Right recovery room

Looking at Phase 1 backfill from Phase 2 development

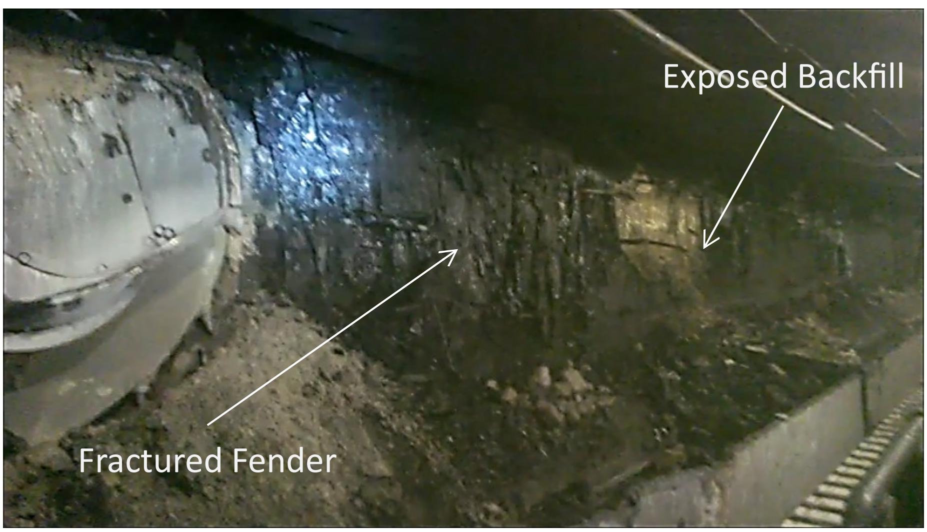
4 Right Recovery

- Completed mining the 4 Right panel in March 2015.
- 4 Right Recovery Room Conditions
  - Shallow cover (200' Overburden).
  - Normal lithology (Sandstone Top).
  - Normal mining height of 11' (9' of coal & 2' floor rock).
  - Interburden between the Mammoth and Rehder Seams greater than 20'.
- Designed without the need to stop and install any supplemental roof support.
- Pillar corners remained sharp.
- Abutment load transferred as planed.
- Shields yielded and leg pressures returned back to normal when the roof caved behind the shields
- After the shields were in final position convergence occurred between chute 1 and chute 2.



4 Right Recovery
Mining Backfill

Mining the coal fender approx. 5 feet of backfill. The fender is standing straight.



Mining the coal fender, first cut into backfill. Shield leg pressures showed loading.

Mining the concrete backfill, no roof spalling. The face is standing straight.

4 Right Recovery

Roof Support

Huesker mesh (yellow) laid down behind the shields.

Exposed bolts, channel, and steel mesh.

4 Right Recovery

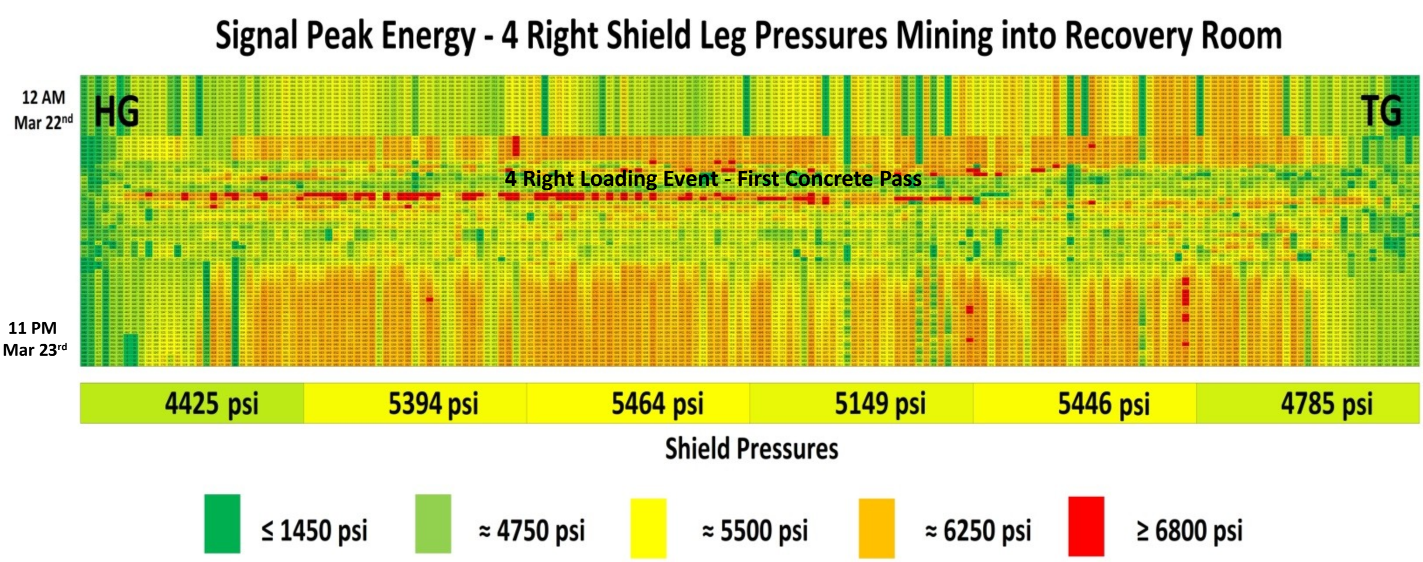
Chute Breakthrough

Shield in final position.

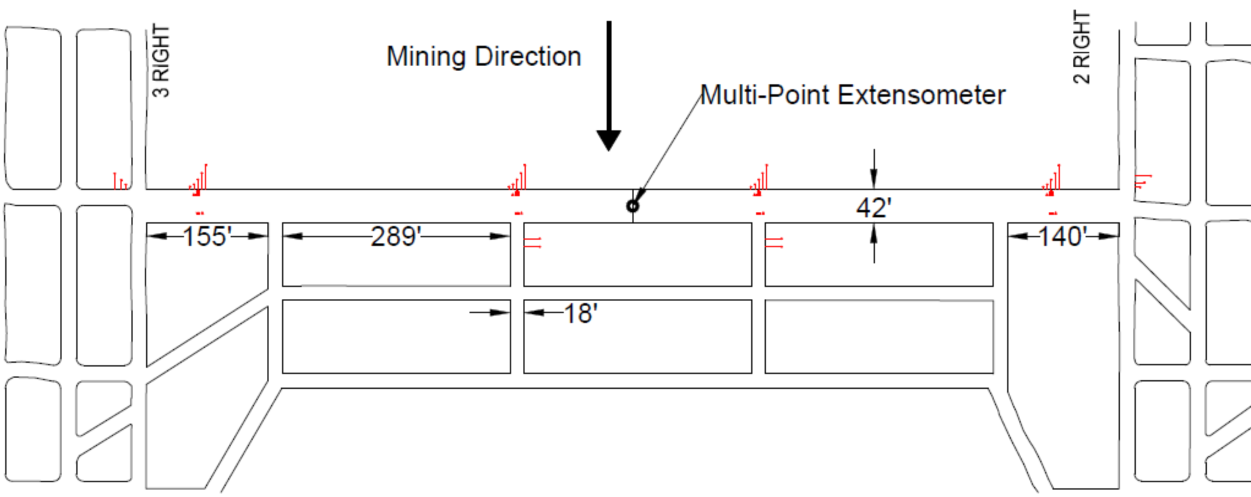
Breakthrough to chute 4, some spalling. The face is standing straight.

4 Right Post Evaluation

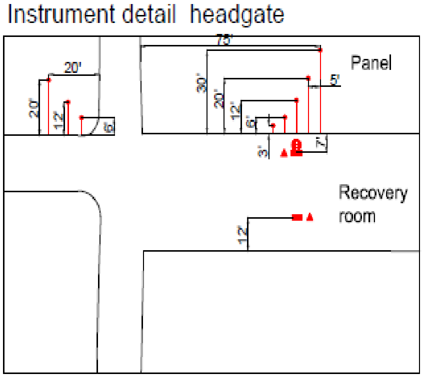
- Mining advanced into final position on schedule. Backfill (1-2 feet) was left to protect the outby pillar.
- The entire roof/rib support system sufficiently controlled the roof joints and established a competent beam structure to prevent roof/rib cutter and potential roof beam rotation.
- 4 Right longwall equipment was successfully moved from a pre-developed 42' recovery room. Manpower was reduced after the last shield was removed, slowing the move schedule. The move was completed in 40 days.
  - LW extraction took only 14 days
- Shield leg pressures showed loading when the first cut was made into the backfill.
- Chute pressure sensor data shows nearly all the pressure increases occurred during the first shearer pass into the backfill. The highest pressure observed was 130 psi in chute 4 ten feet from the coal fender.
- TG inby the face remained stable.
- Cracks and pillar corner sloughage observed in chutes 1, 2 and 3.
  - Loading occurred after the shields had set for five days. Inconsistency with a portion of the backfill.
- There were no roof falls, the final fender did not fail, no adverse shield convergence, and no accidents.



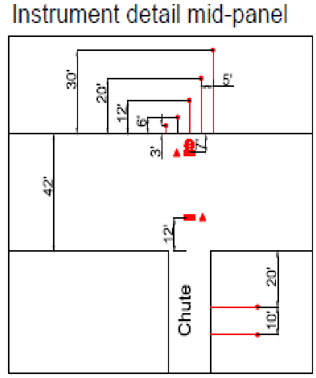
3 Right Instrumentation



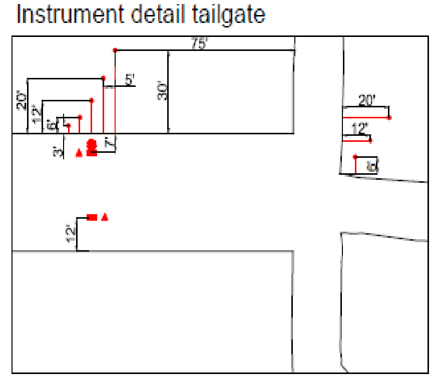
Instrument detail headgate



Instrument detail mid-panel

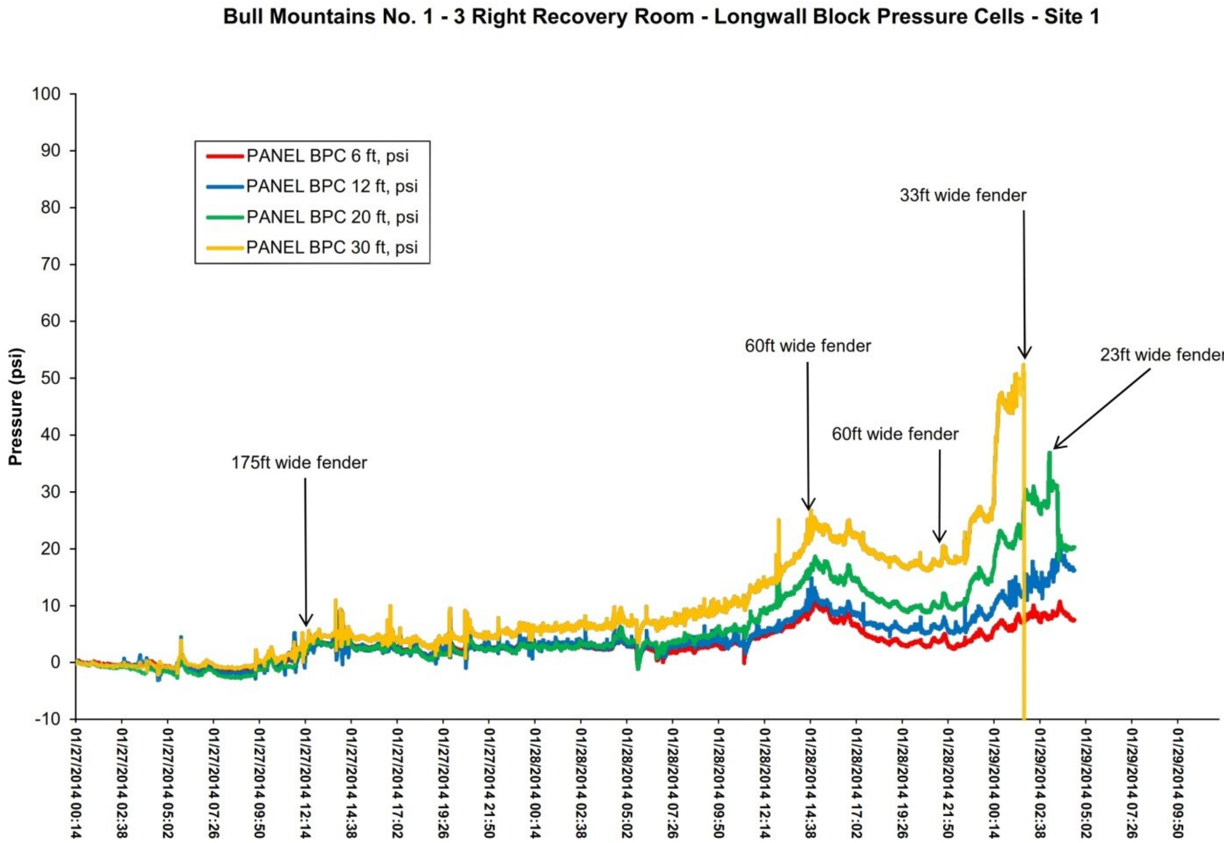


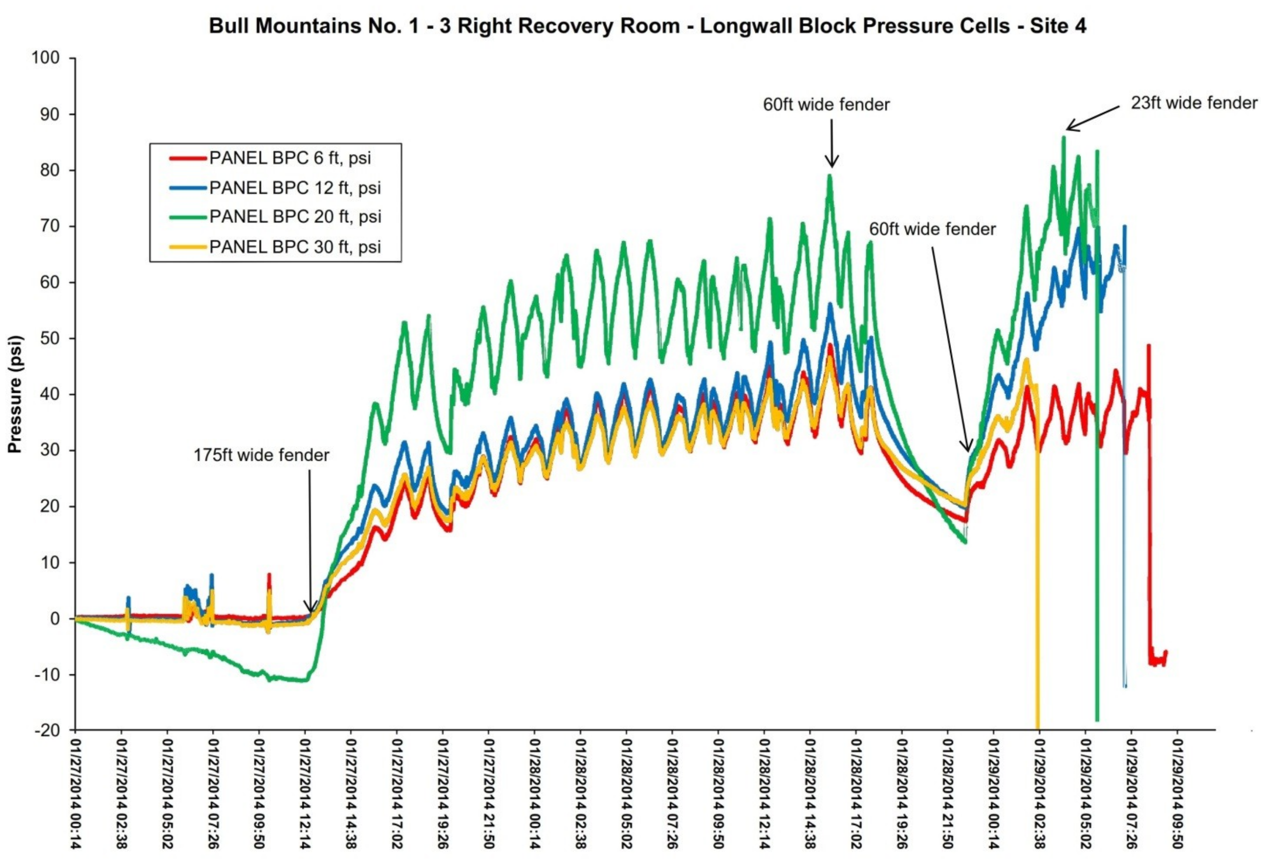
Instrument detail tailgate



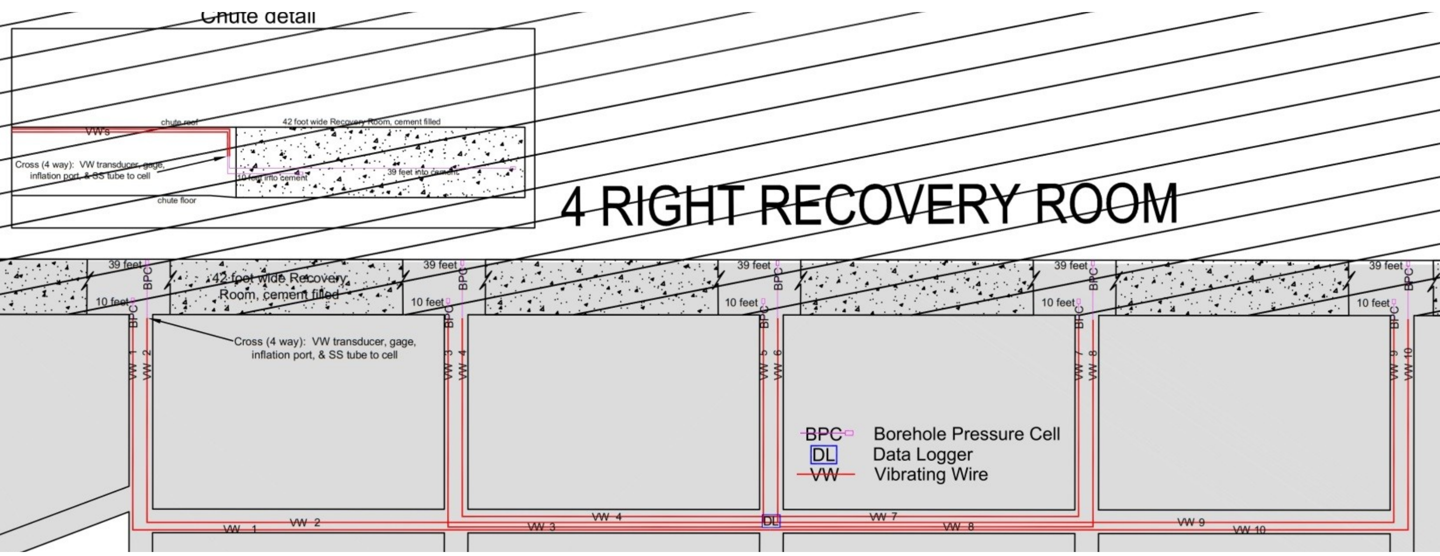
Key:
- Bore hole pressure cell in coal
- Bore hole pressure cell in fill material
- Extensometer in fill
- Thermistor in fill

3 Right Coal Fender
Borehole Pressures



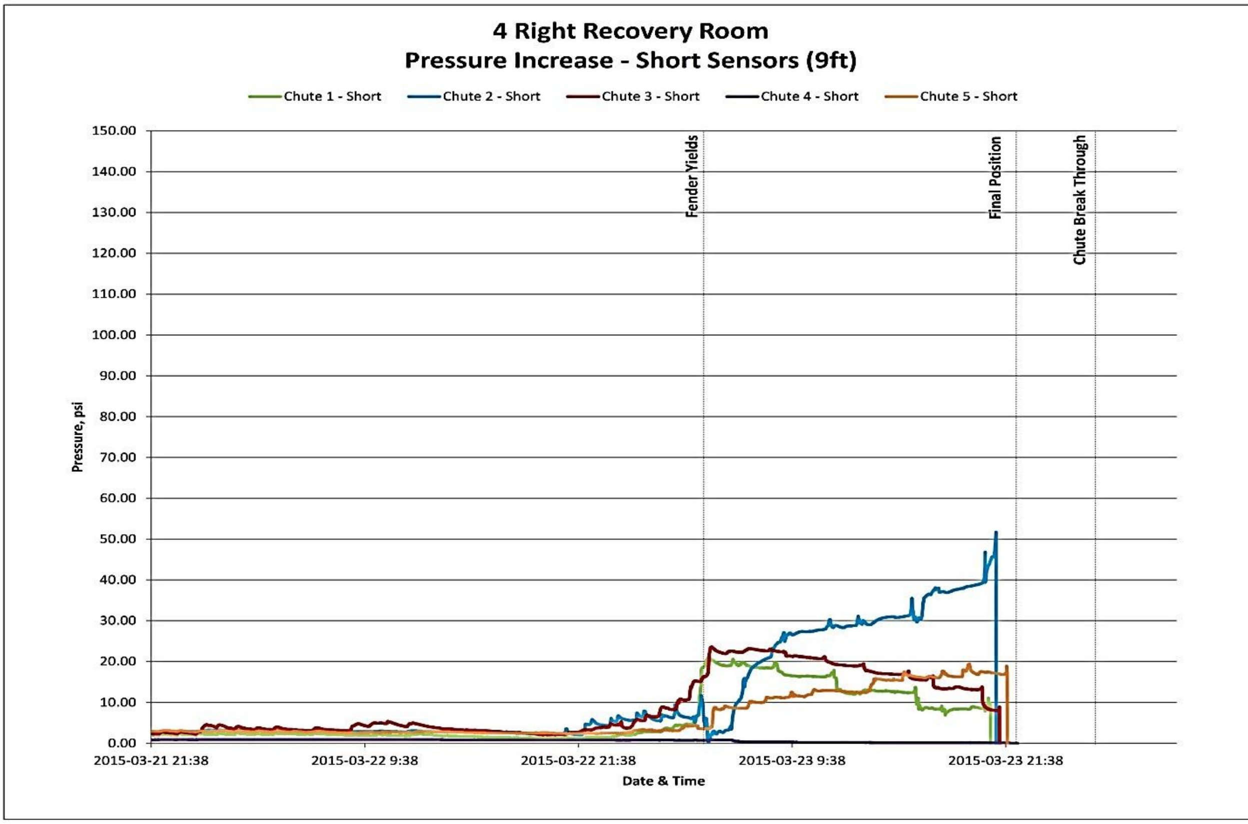


4 Right Instrumentation

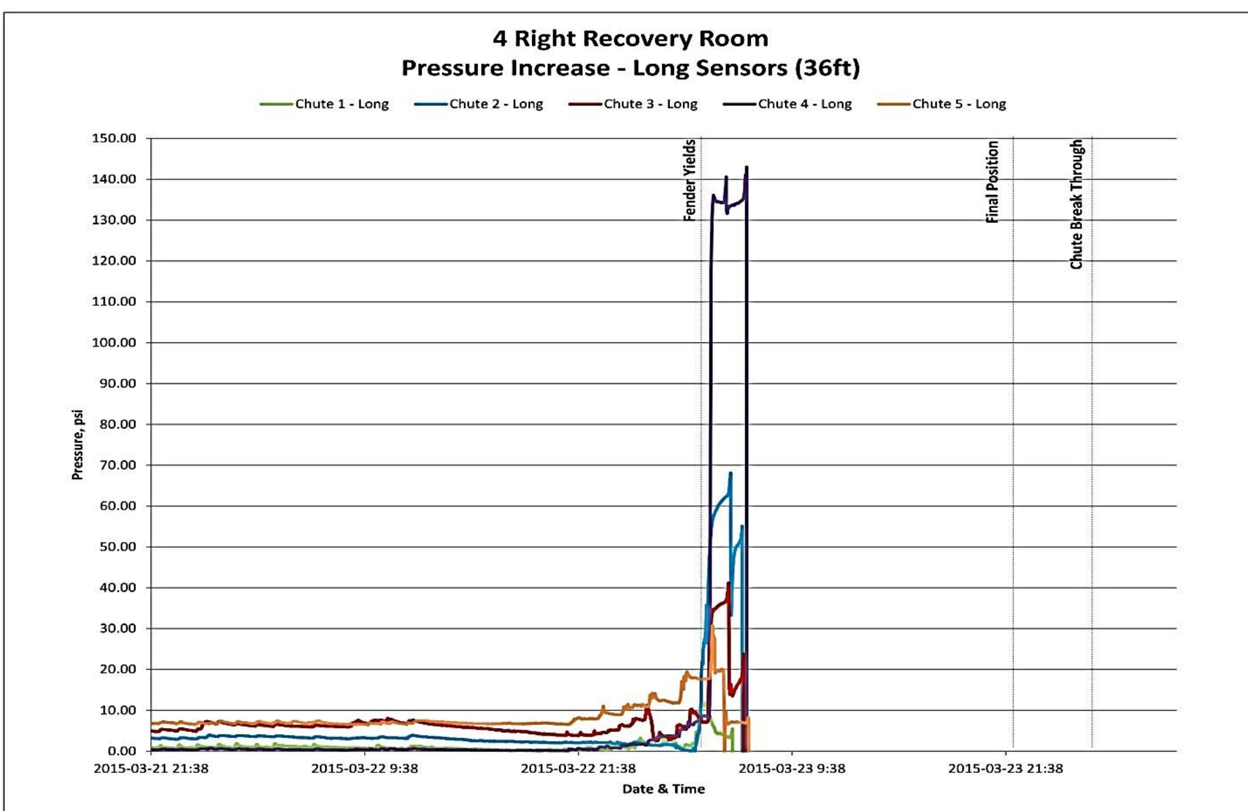


4 Right Backfill

Borehole Pressures



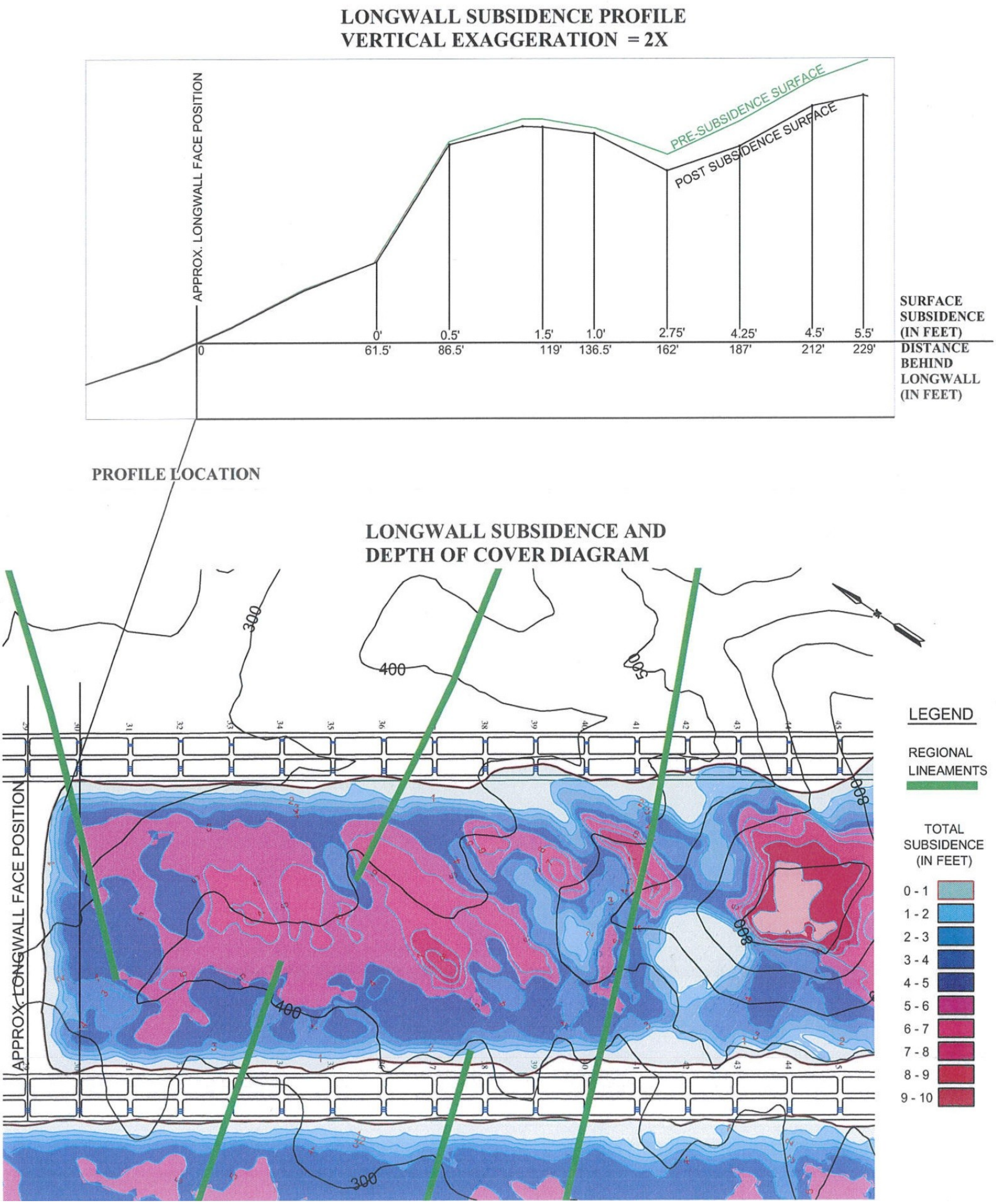
When the shields are at final position backfill thickness is 10’. At Chute breakthrough the backfill thickness is 1’-2’.



3 Right & 4 Right Recovery
Summary of Pressure Sensor Data

- Cuttable fiberglass dowels allowed the fender to maintain its support.
- Capacity and location of SUMO Cable minimized roof movement.
- Sensor and leg pressure measurements consistently show the maximum pressure occurs when the first pass of the backfill is mined.
- After the first pass of backfill is mined sensor and shield leg pressure measurements show little forward abutment pressure.

Subsidence


LONGWALL SUBSIDENCE PROFILE
VERTICAL EXAGGERATION = 2X
APPROX. LONGWALL FACE POSITION
PRE-SUBSIDENCE SURFACE
POST SUBSIDENCE SURFACE
0' 0.5' 1.5' 1.0' 2.75' 4.25' 4.5' 5.5'
0 61.5' 86.5' 119' 136.5' 162' 187' 212' 229'
SURFACE SUBSIDENCE (IN FEET)
DISTANCE BEHIND LONGWALL (IN FEET)
PROFILE LOCATION
LONGWALL SUBSIDENCE AND DEPTH OF COVER DIAGRAM
300
400
500
APPROX. LONGWALL FACE POSITION
LEGEND
REGIONAL LINEAMENTS
TOTAL SUBSIDENCE (IN FEET)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10