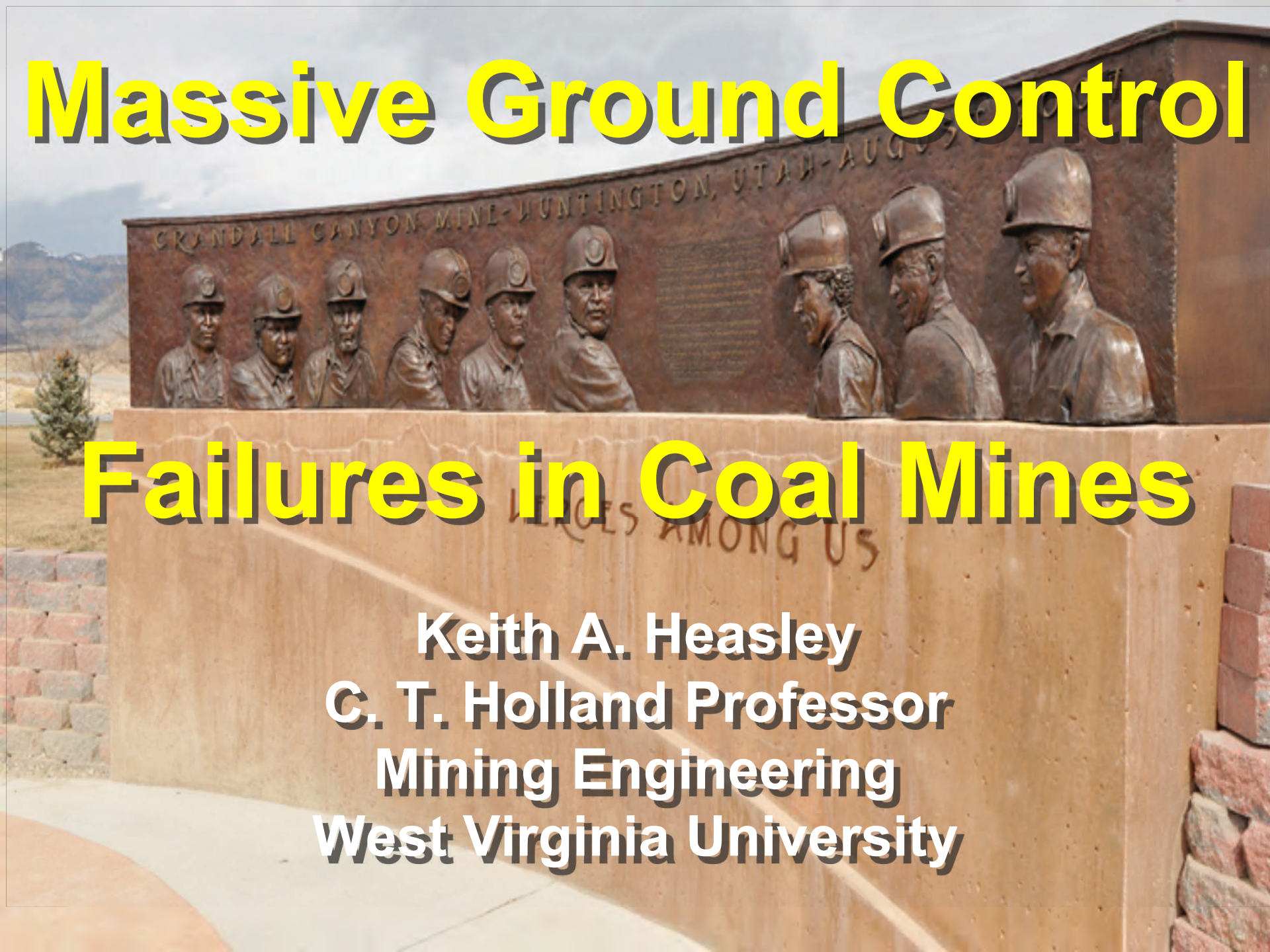


Massive Ground Control Failures in Coal Mines

Keith A. Heasley
C. T. Holland Professor
Mining Engineering
West Virginia University

Objectives

- Highlight a number of historic massive ground failures
  - aka: Massive Pillar Collapses (MPC), CPF, pillar runs, dominoe-type failures
- Explain Present Understanding of Mechanics
- Describe how to Prevent MPC

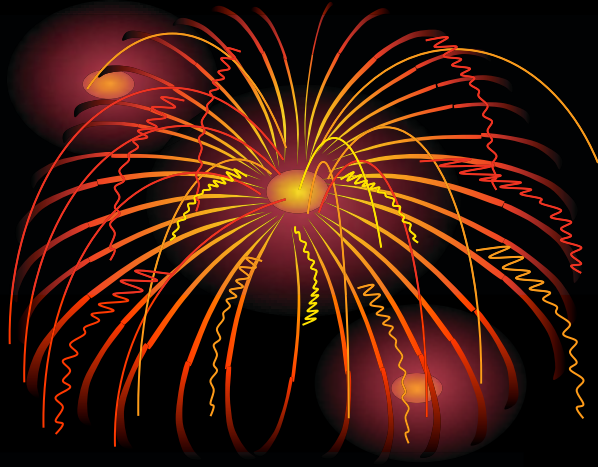
Massive Failures

- Coalbrook North Colliery, 1960 - SA
- Solvay Trona Mine, 1995 - WY
- Crandall Canyon Mine, 2007 – UT
- Others…

Coalbrook North

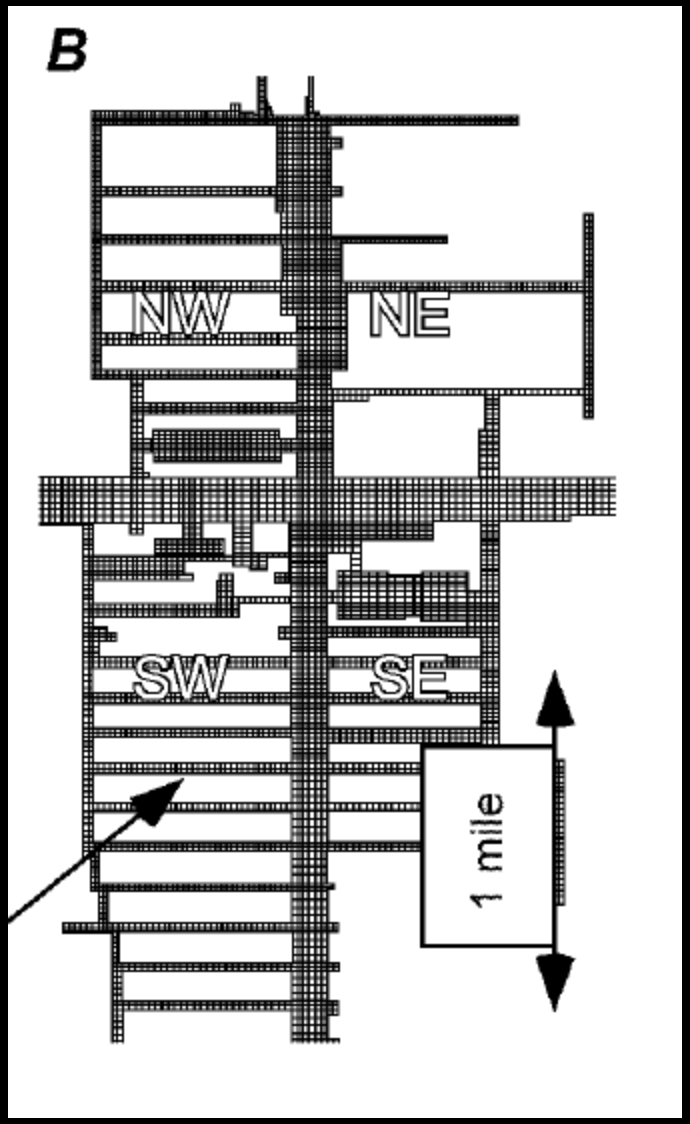
- South African Coal Mine, 1960
- 40 X 40 X 14 ft Pillars
- 470 ft Deep, 750 Acres
- 437 Fatalities

Solvay

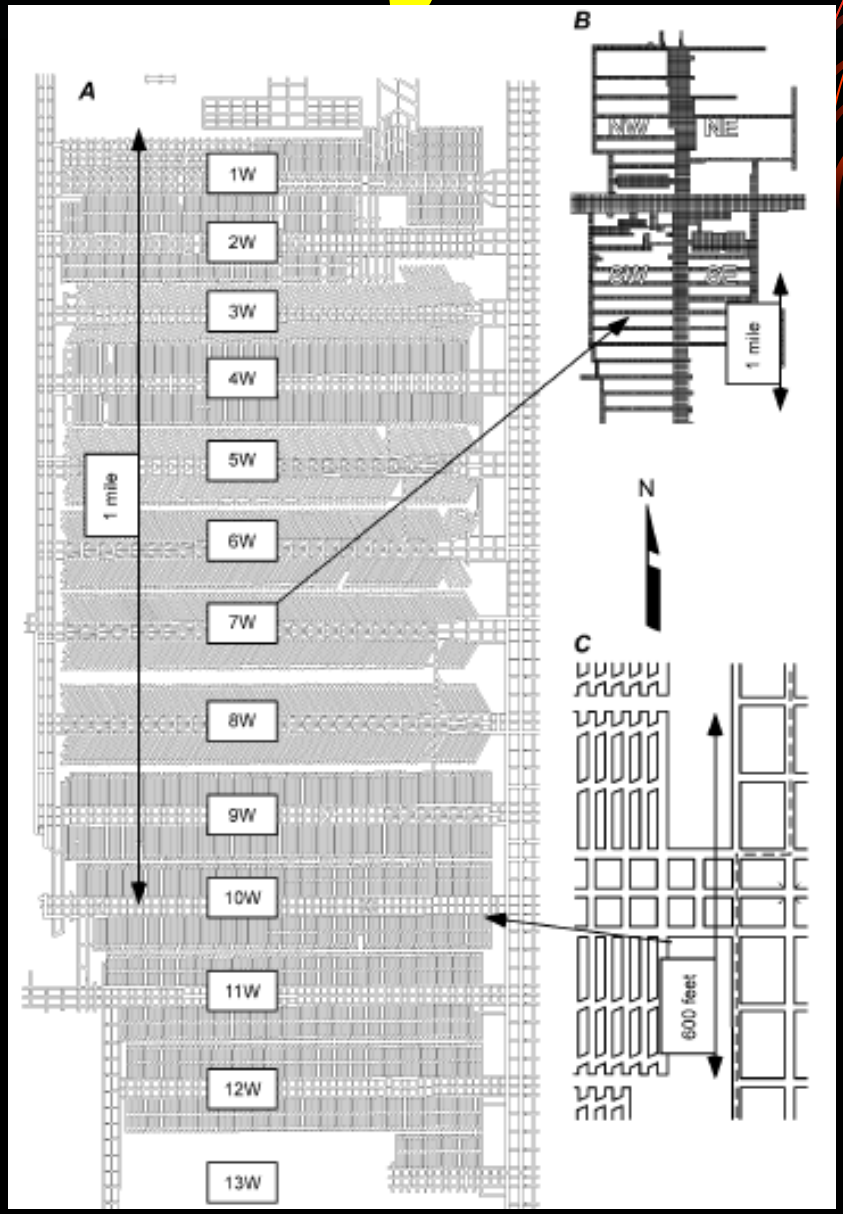


- Wyoming Trona Mine, 1995
- 13 X 95 X 19 ft Fenders
- 1600 ft Deep, 400 Acres
- 5.3 Richter Event
- 30 M ft^3 of Methane Released
- 1 Fatality

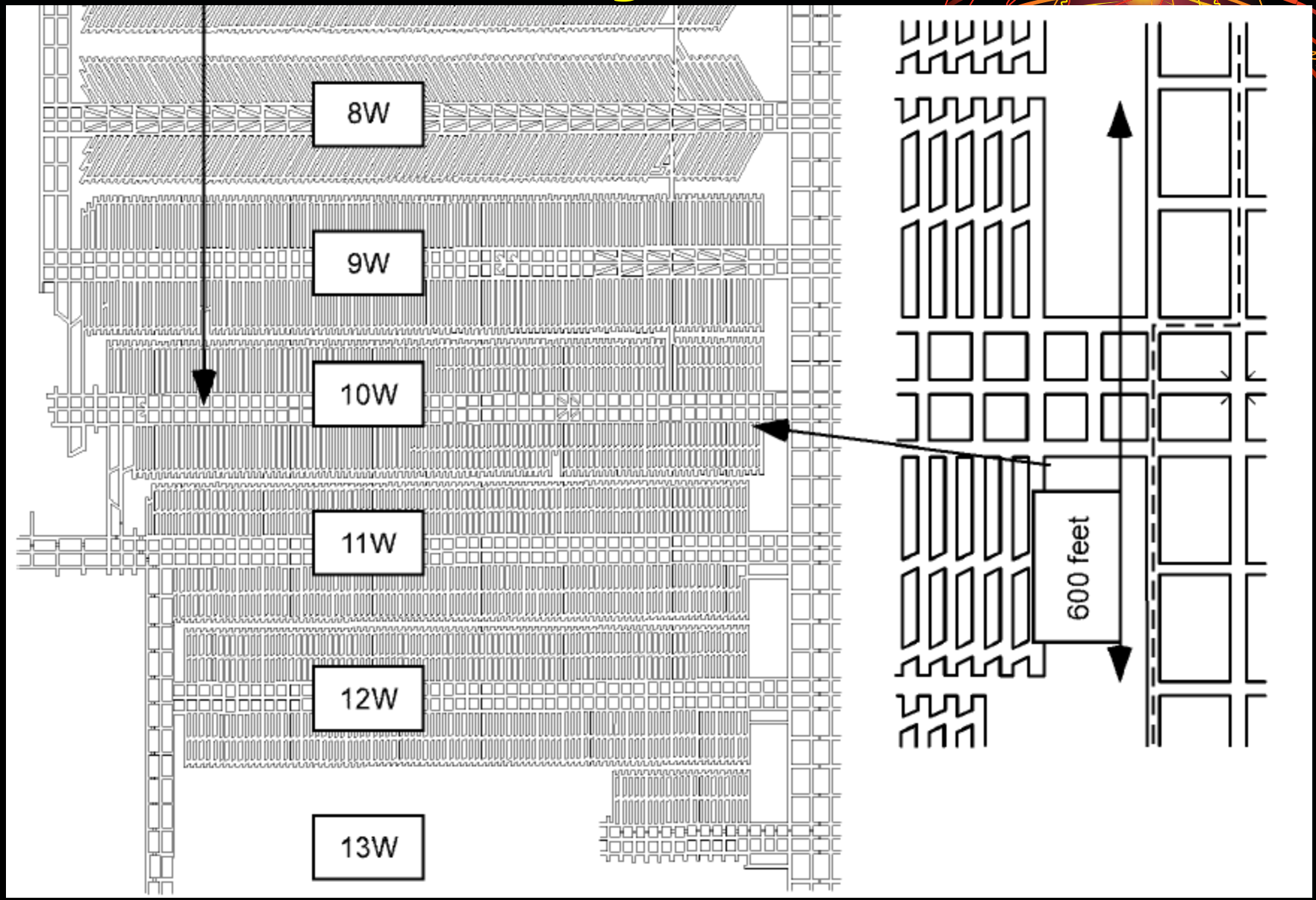
Solvay Mine



Solvay Mine


A
1W
2W
3W
4W
5W
6W
7W
8W
9W
10W
11W
12W
13W
1 mile
B
NW
NE
SW
SE
1 mile
N
C
600 feet

Solvay Mine

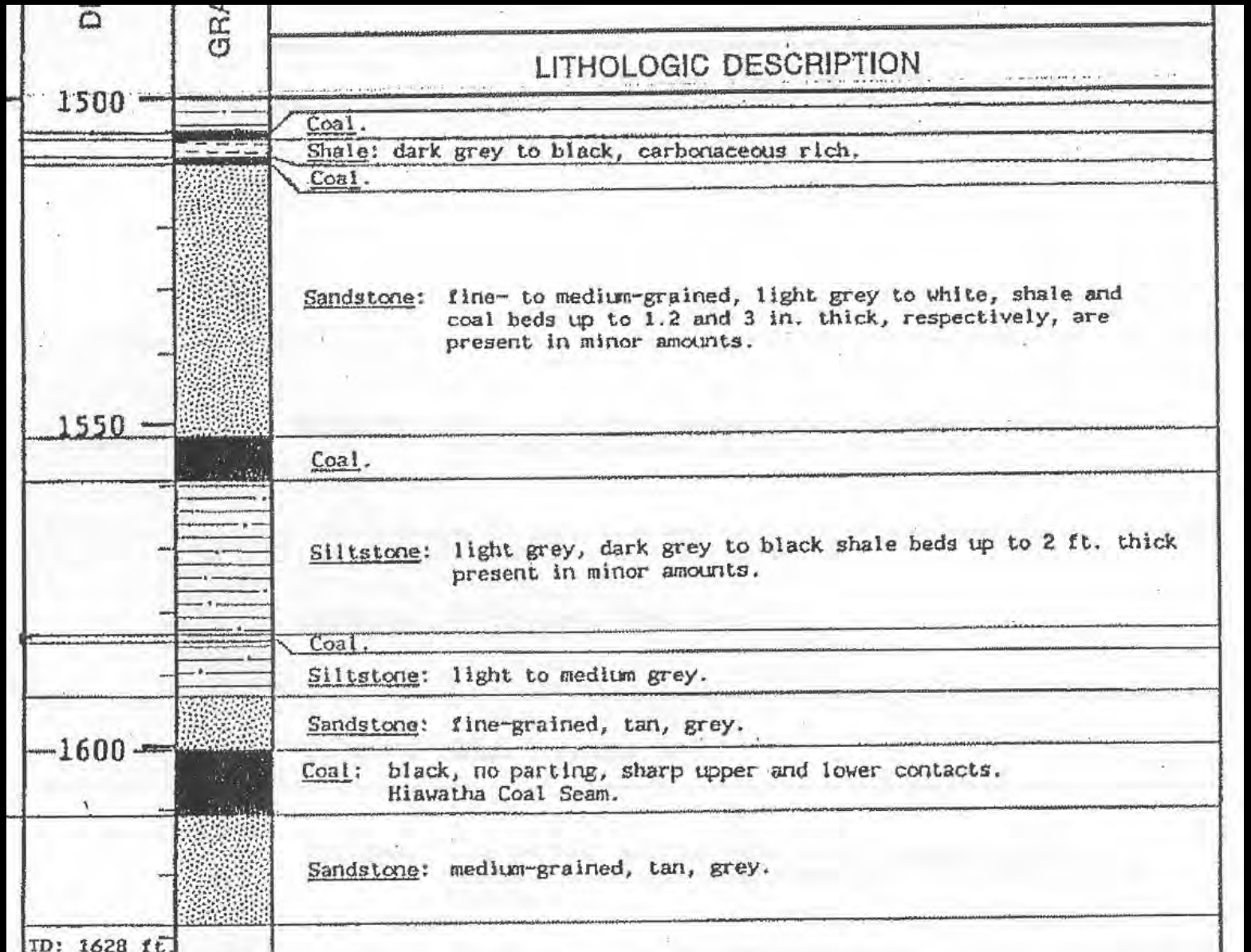


Crandall Canyon

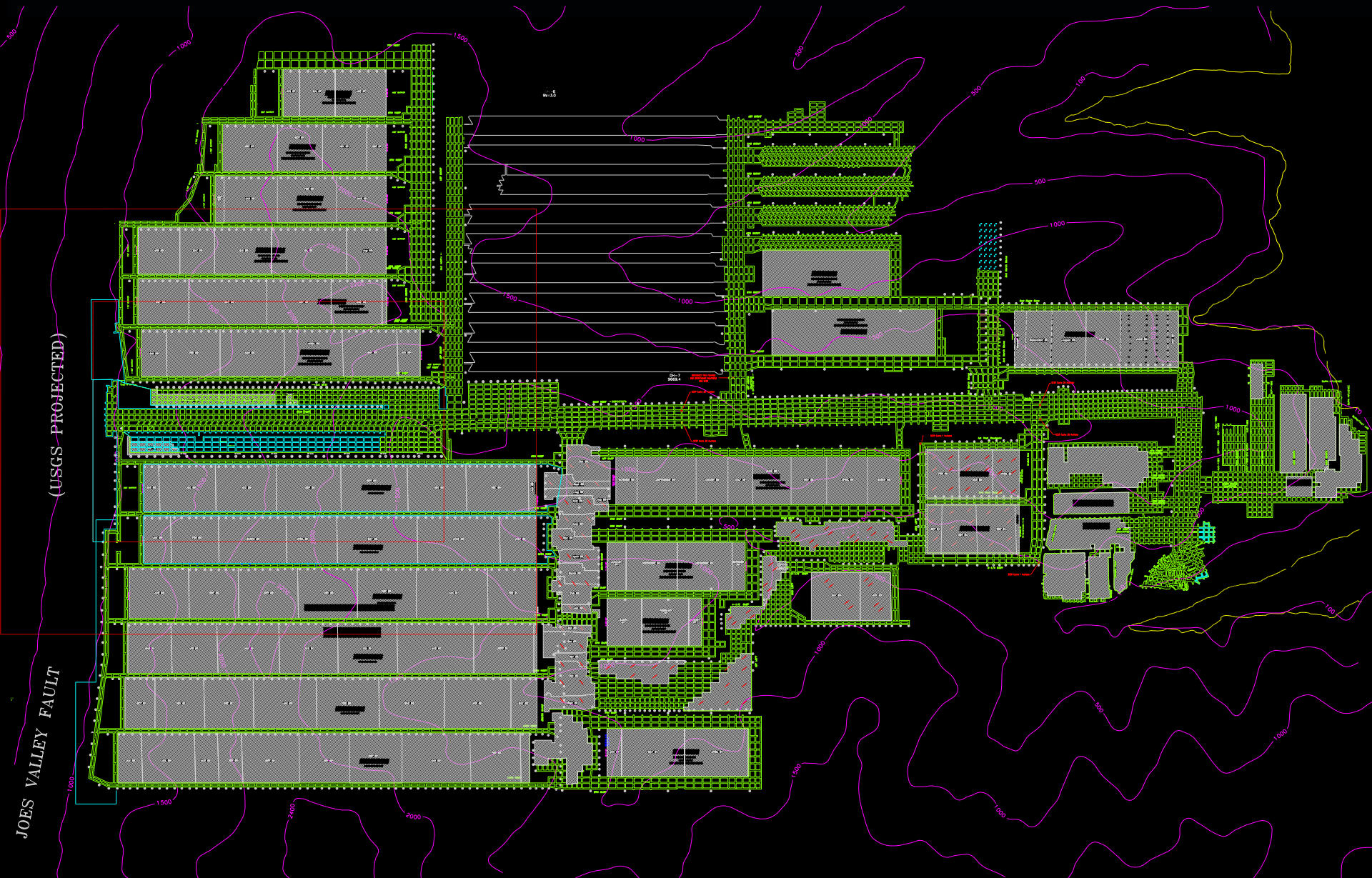
- Utah Coal Mine, 2007
- 60-77 X 72-105 X 8 ft Pillars
- 2200 ft Deep
- 3.9 Richter Event
- 6 + 3 Fatalities


Crandall Canyon Mine
August 6, 2007
Massive Pillar Failure
9 Fatalities

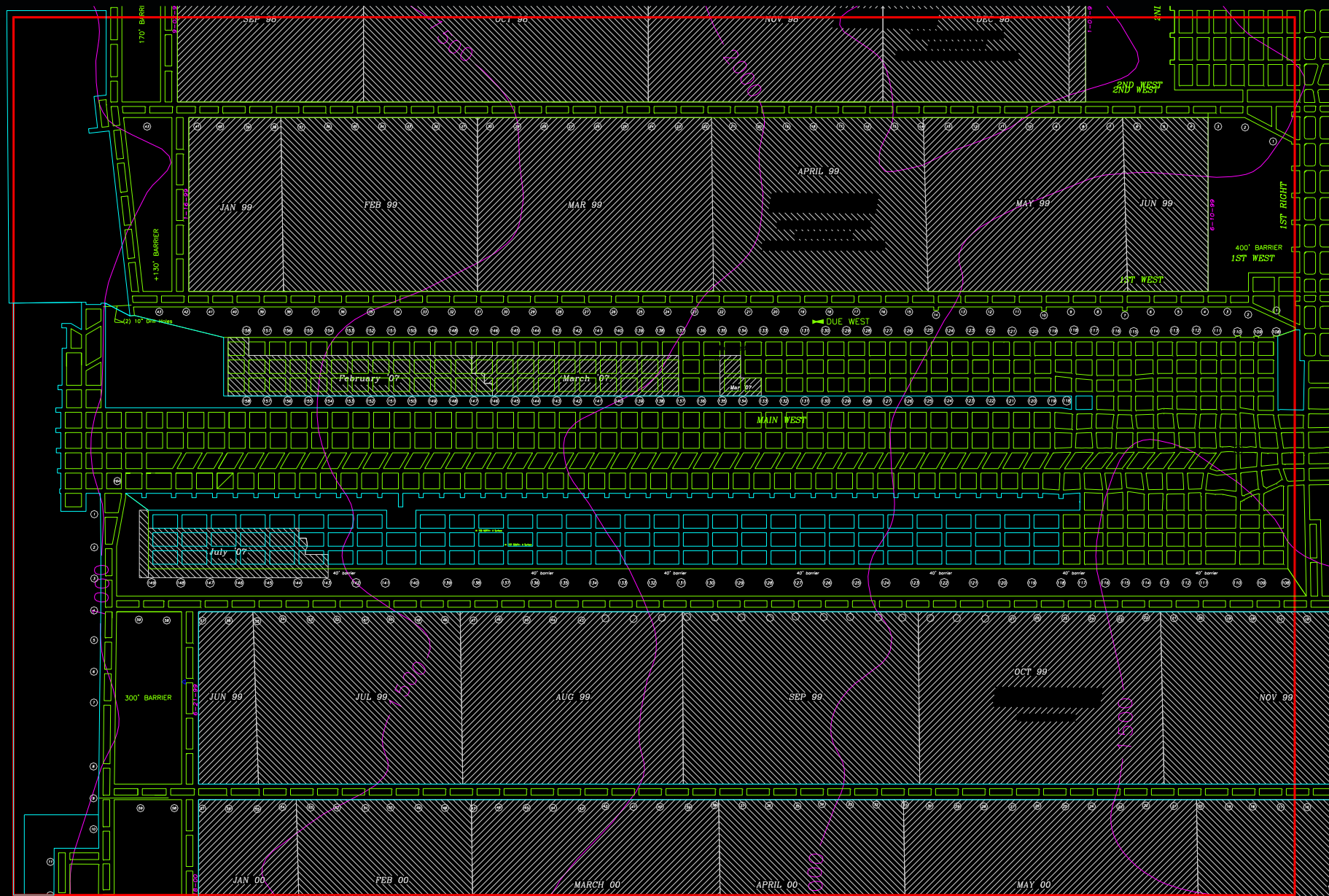
Geology


LITHOLOGIC DESCRIPTION
1500
Coal.
Shale: dark grey to black, carbonaceous rich.
Coal.
Sandstone: fine- to medium-grained, light grey to white, shale and coal beds up to 1.2 and 3 in. thick, respectively, are present in minor amounts.
1550
Coal.
Siltstone: light grey, dark grey to black shale beds up to 2 ft. thick present in minor amounts.
Coal.
Siltstone: light to medium grey.
Sandstone: fine-grained, tan, grey.
1600
Coal: black, no parting, sharp upper and lower contacts. Hiawatha Coal Seam.
Sandstone: medium-grained, tan, grey.

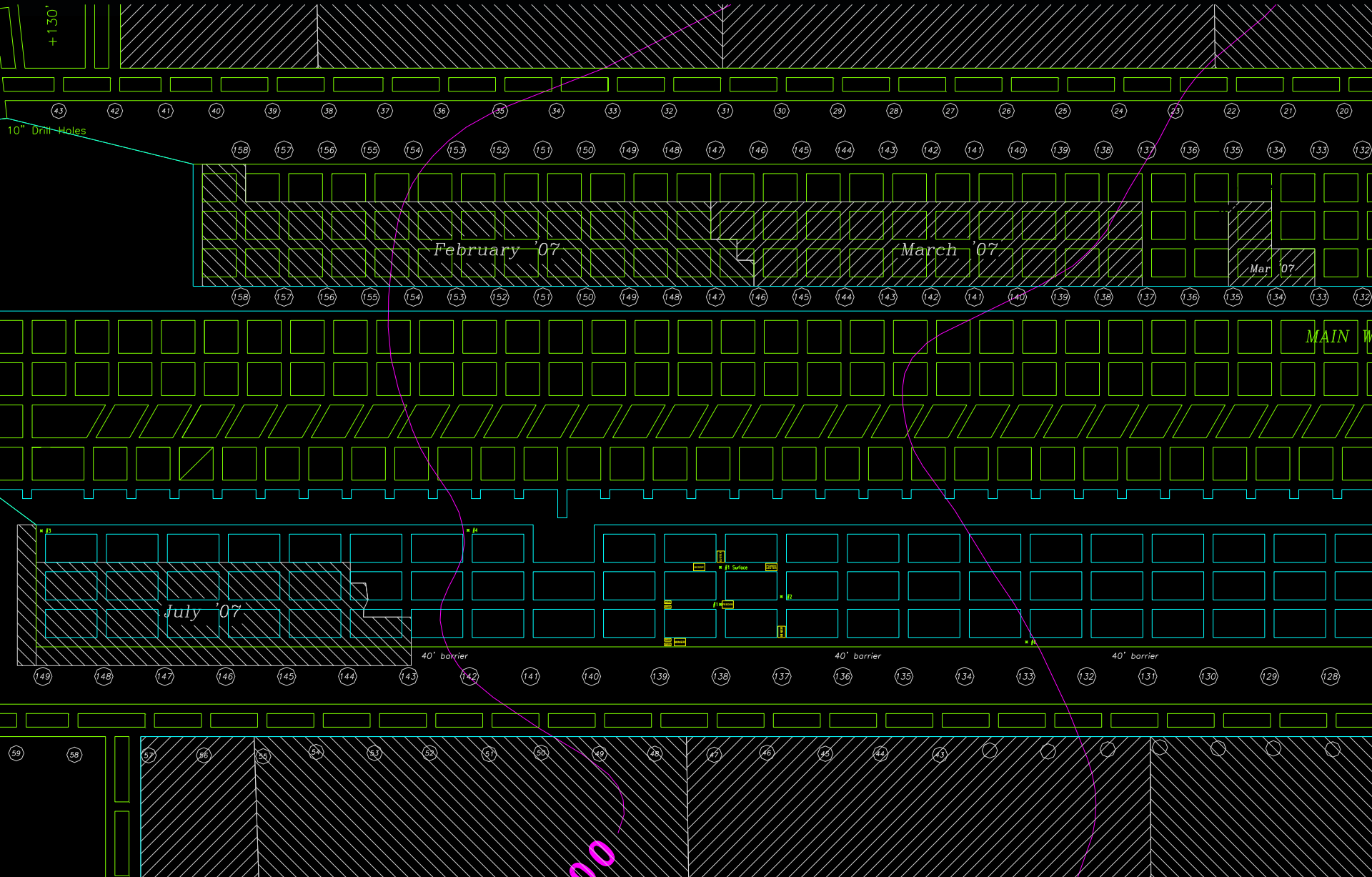
Mine Map



Mine Map


SEP 98
OCT 98
NOV 98
DEC 98
2ND WEST
2ND WEST
JAN 99
FEB 99
MAR 99
APRIL 99
MAY 99
JUN 99
1ST RIGHT
400' BARRIER
1ST WEST
1ST WEST
DUE WEST
February 07
March 07
MAIN WEST
July 07
JUN 99
JUL 99
AUG 99
SEP 99
OCT 99
NOV 99
300' BARRIER
JAN 00
FEB 00
MARCH 00
APRIL 00
MAY 00

Mine Map


+130'
10" Drill Holes
February '07
March '07
Mar '07
MAIN
July '07
40' barrier
40' barrier
40' barrier

Pillar Sizes

- Main West Pillars– 70’ X 72’ (rib-to-rib), 8’ high
- North Barrier Pillars – 60’ X 72’ (rib-to-rib), 8’ high
- South Barrier Pillars – 60’ X 109’ (rib-to-rib)
- Original Barriers – 450’
- Final Barriers – 130’, 80’

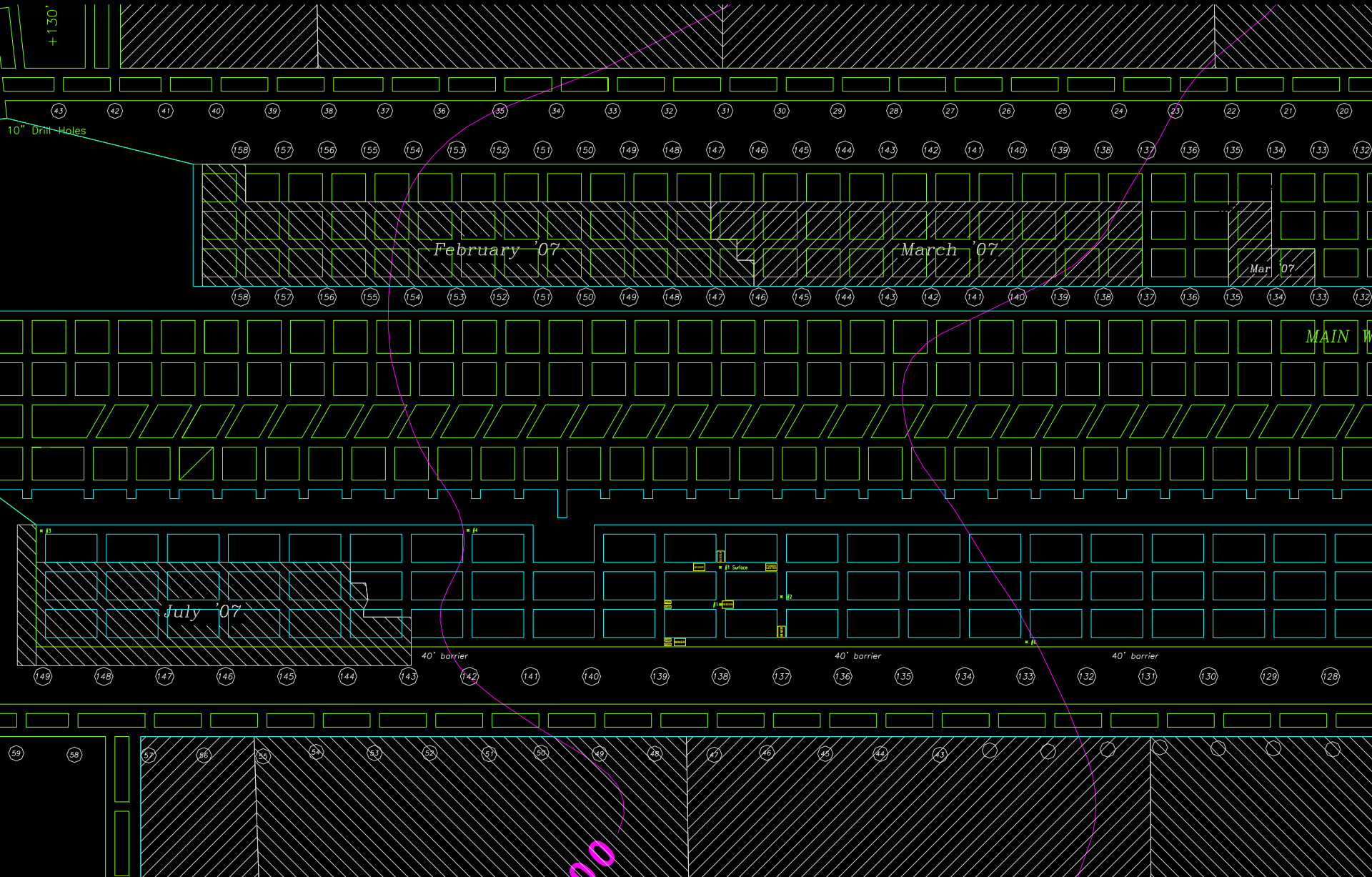
TimeLine

- Monday, 8/6/07, 02:48 – 3.9 Richter, 4.6 min.
  - Next 24 hours, 10 – seismic events, 0.8-2.1
- Tuesday, 8/7/07, Starting mining XC 119
- Thursday, 8/9/07, Small bump covered miner, XC 121 (see photos)
- Saturday, 8/11/07, 21:06, Big bump, XC 124

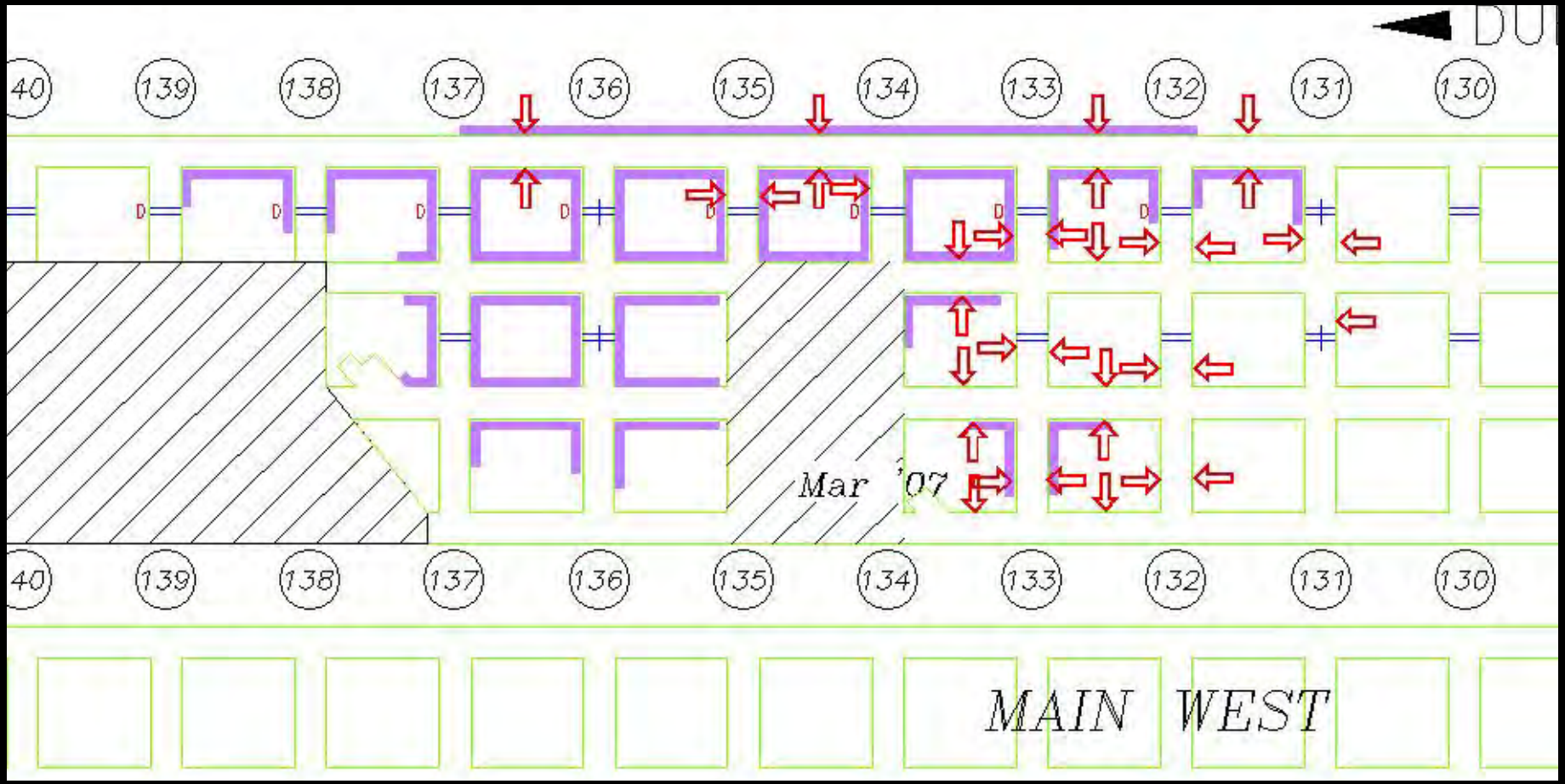
TimeLine

- Wednesday, 8/15/07, 02:26, Bump (1.2), inby XC 125, Broke cutter shafts, blew out Kennedys.
- Wednesday, Bumps outby at XC 116-118
- Thursday, 8/16/07, 10:05, Bump (1.5) covered miner, XC 126
- Thursday, 8/16/07, 18:42, Bump (1.6), 3 fatals, 6 injuries

Mine Map


+130'
10" Drill Holes
February '07
March '07
Mar '07
MAIN
July '07
40' barrier
40' barrier
40' barrier

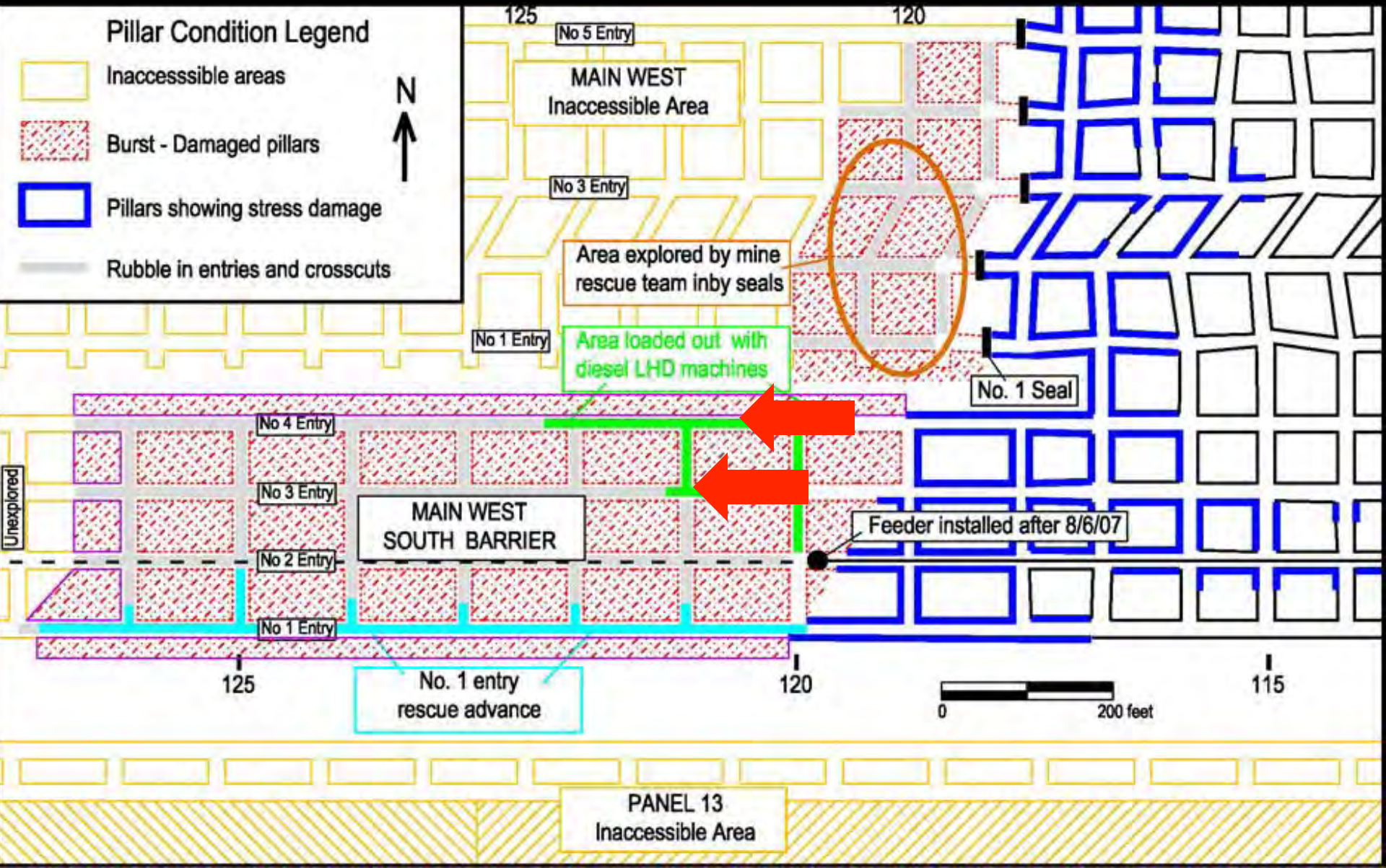
North Barrier Bump



North Barrier Bump

North Barrier Bump

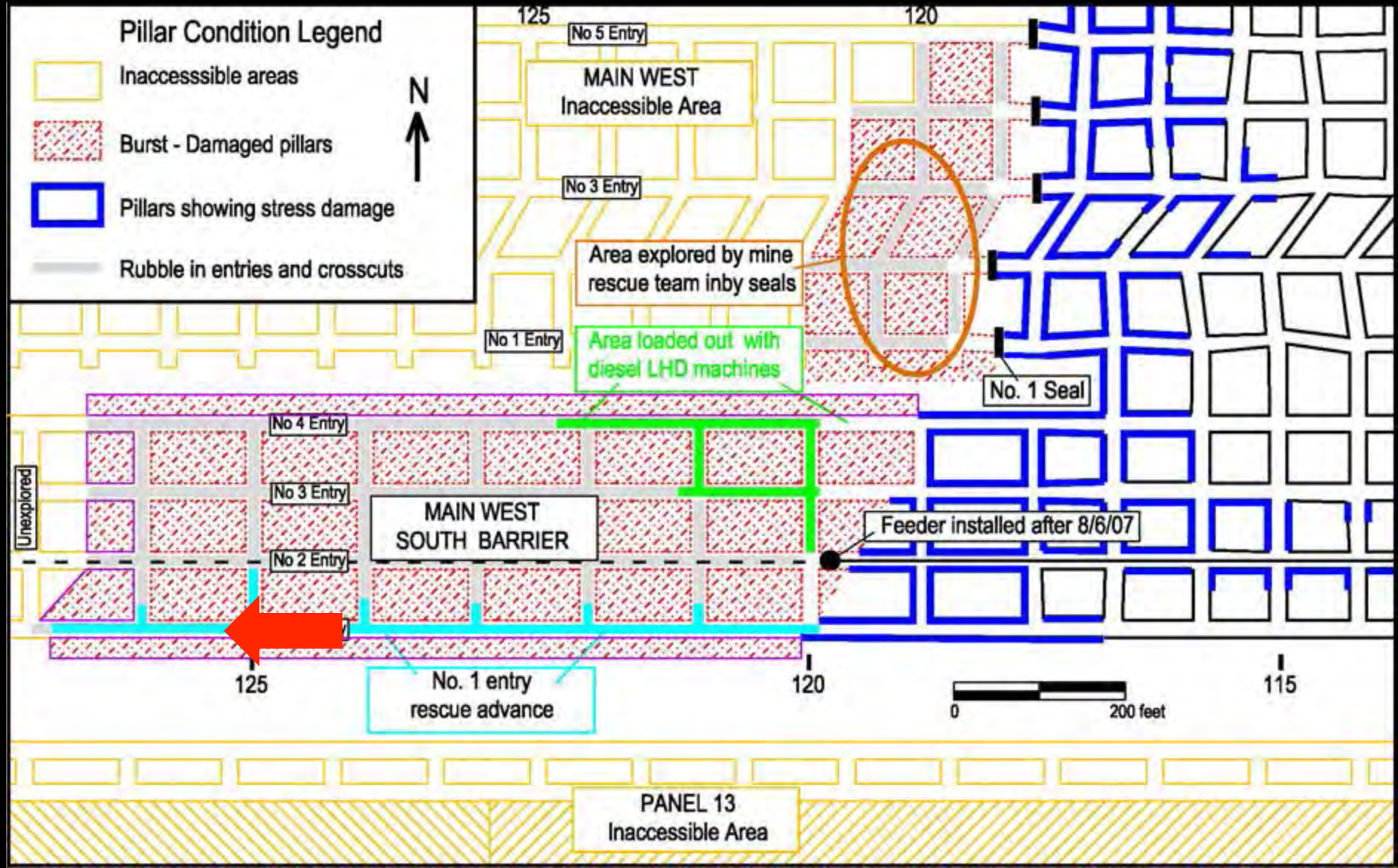
August 6th Collapse



South Barrier 4entry Looking inby CC120 in #3 entry, 8/9/07 – Bump Damage

South Barrier 4entry Looking inby CC119 ½ in #4 entry, 8/9/07 –Bump Damage

South Barrier Observations



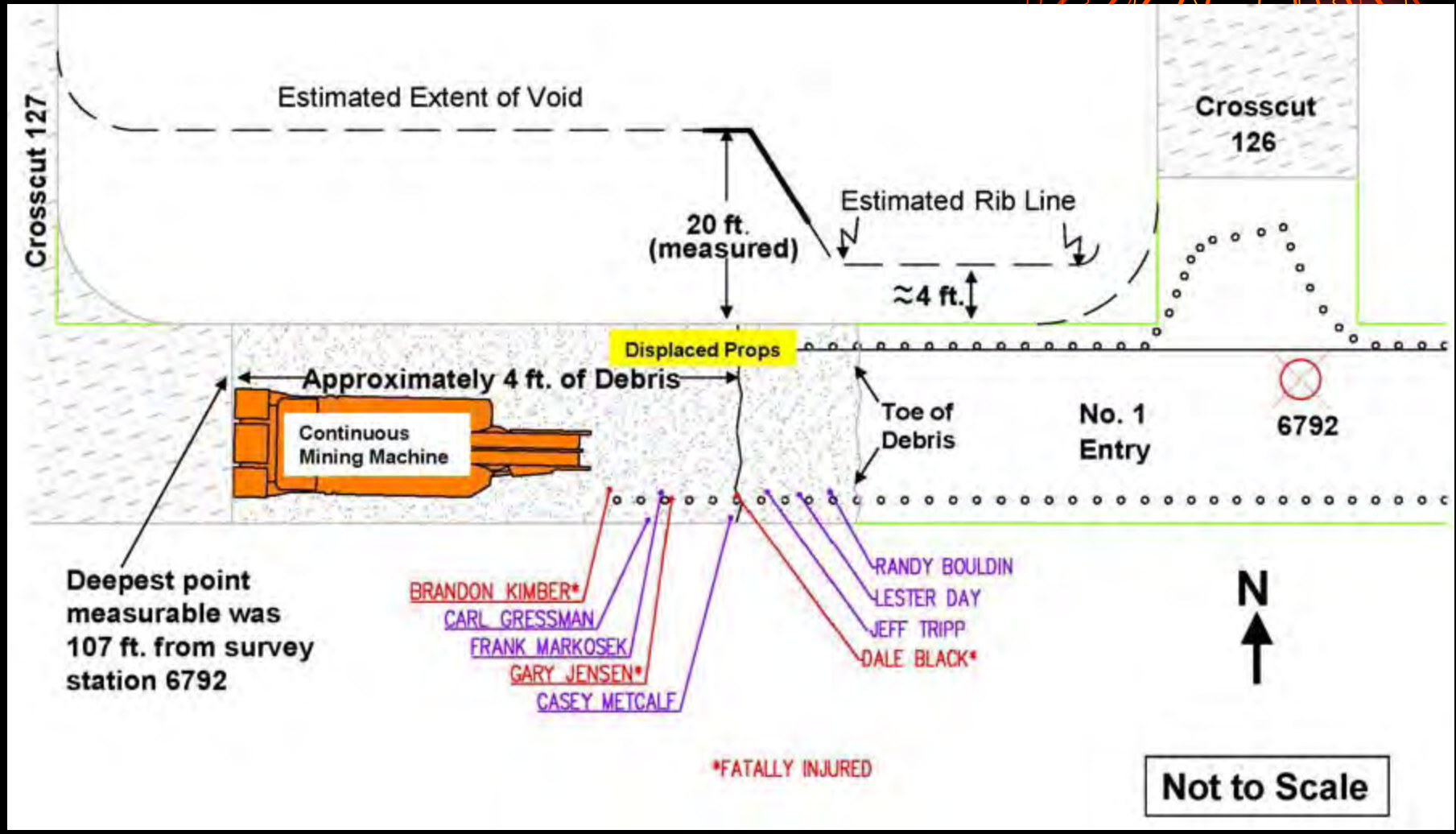
Installation of Rock Props near #1 and 121CC, 8/9/07

Installed Rock Props #1 entry, 8/9/07

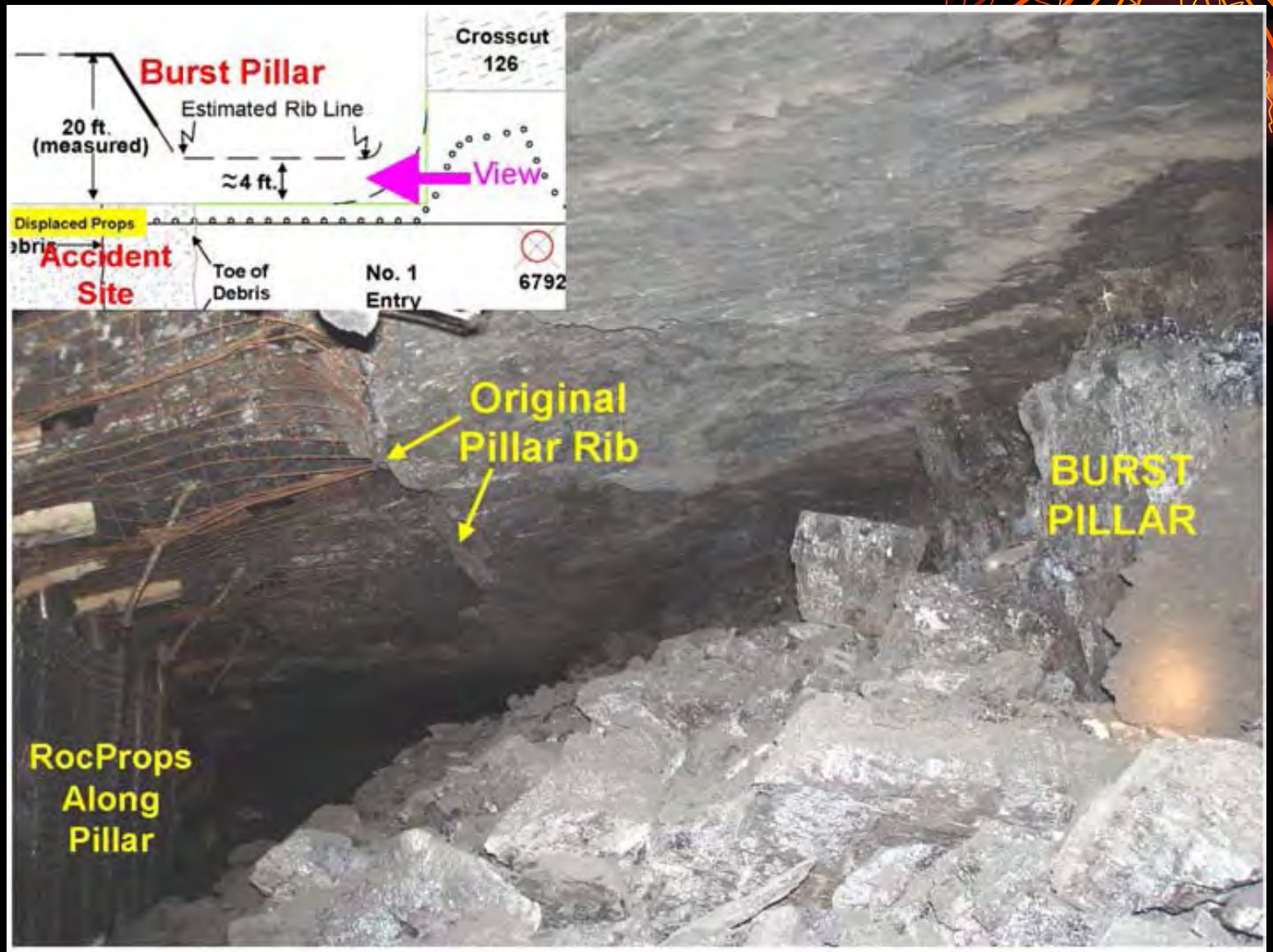
Lexan shield for CM operator, 8/9/07

South Barrier Observations

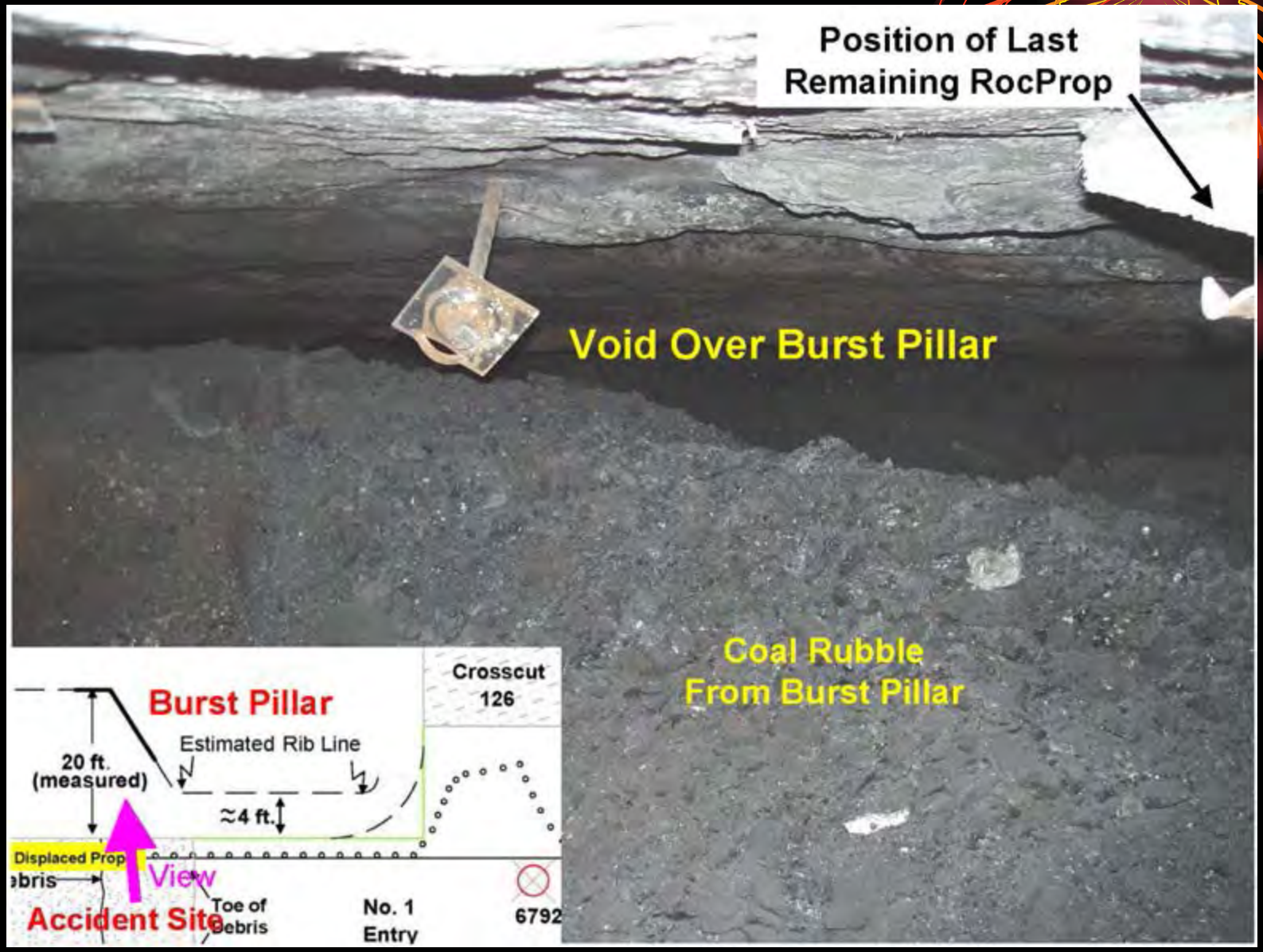
August 17th Bump



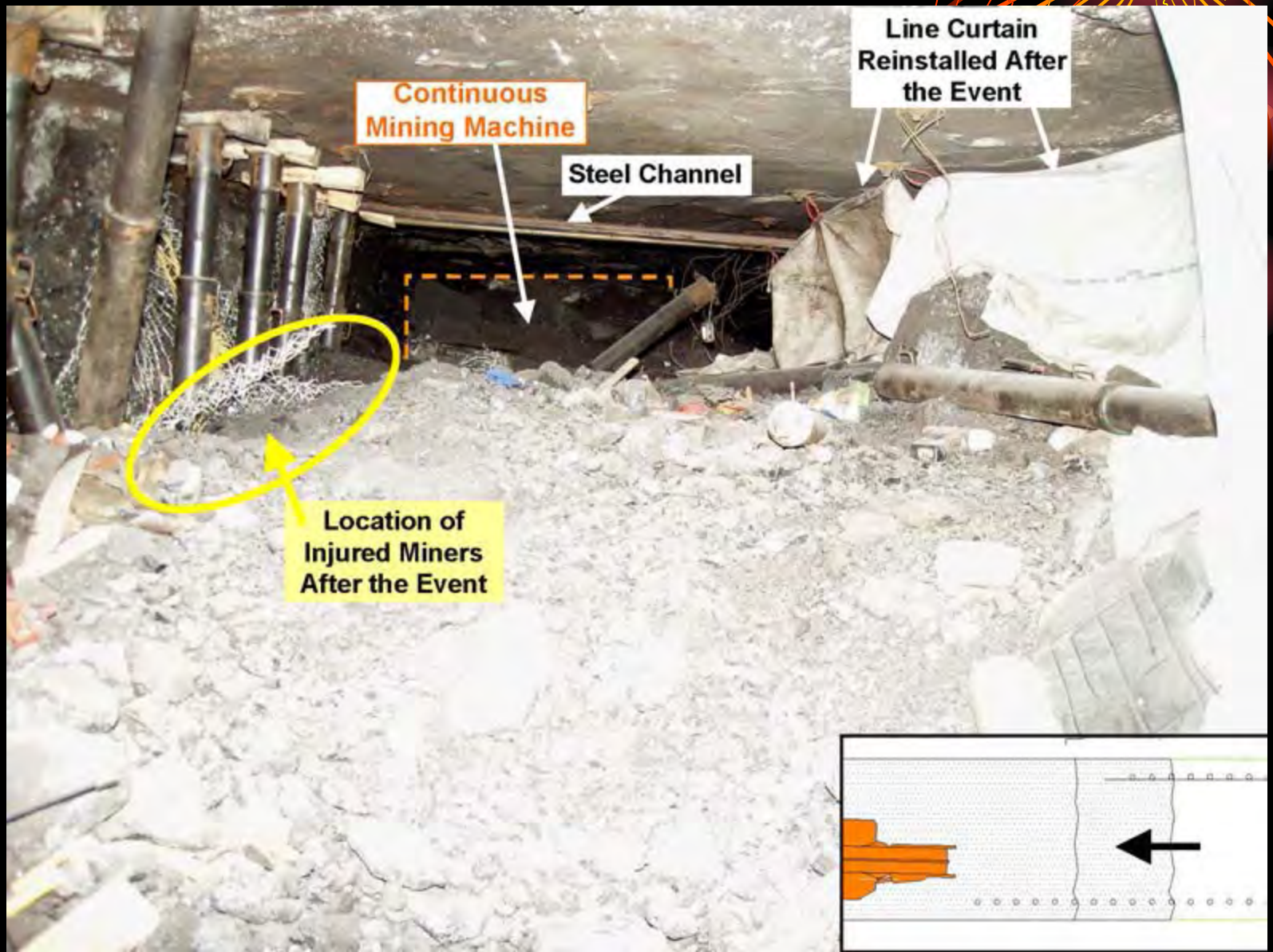
August 17th Bump



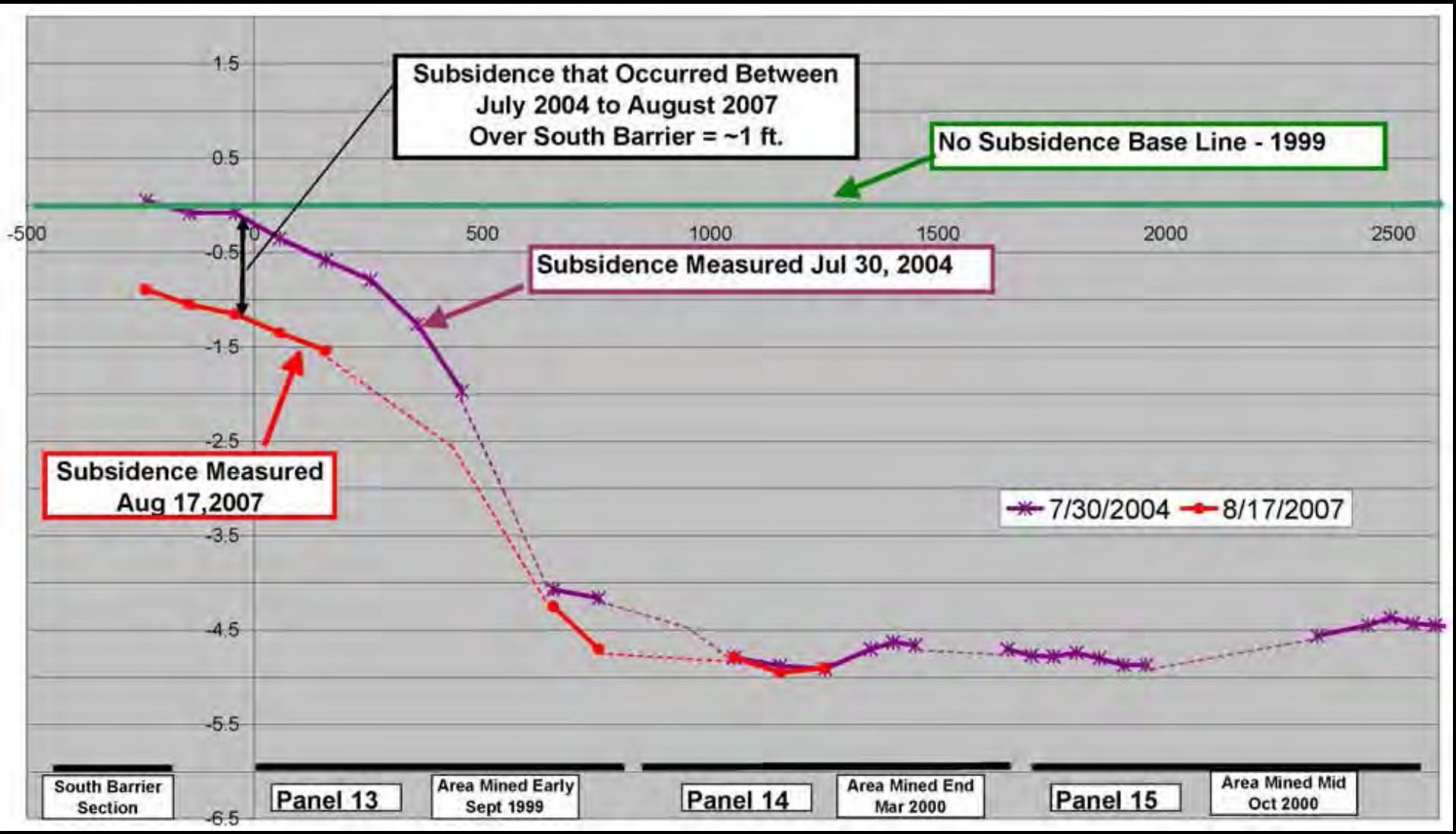
August 17th Bump



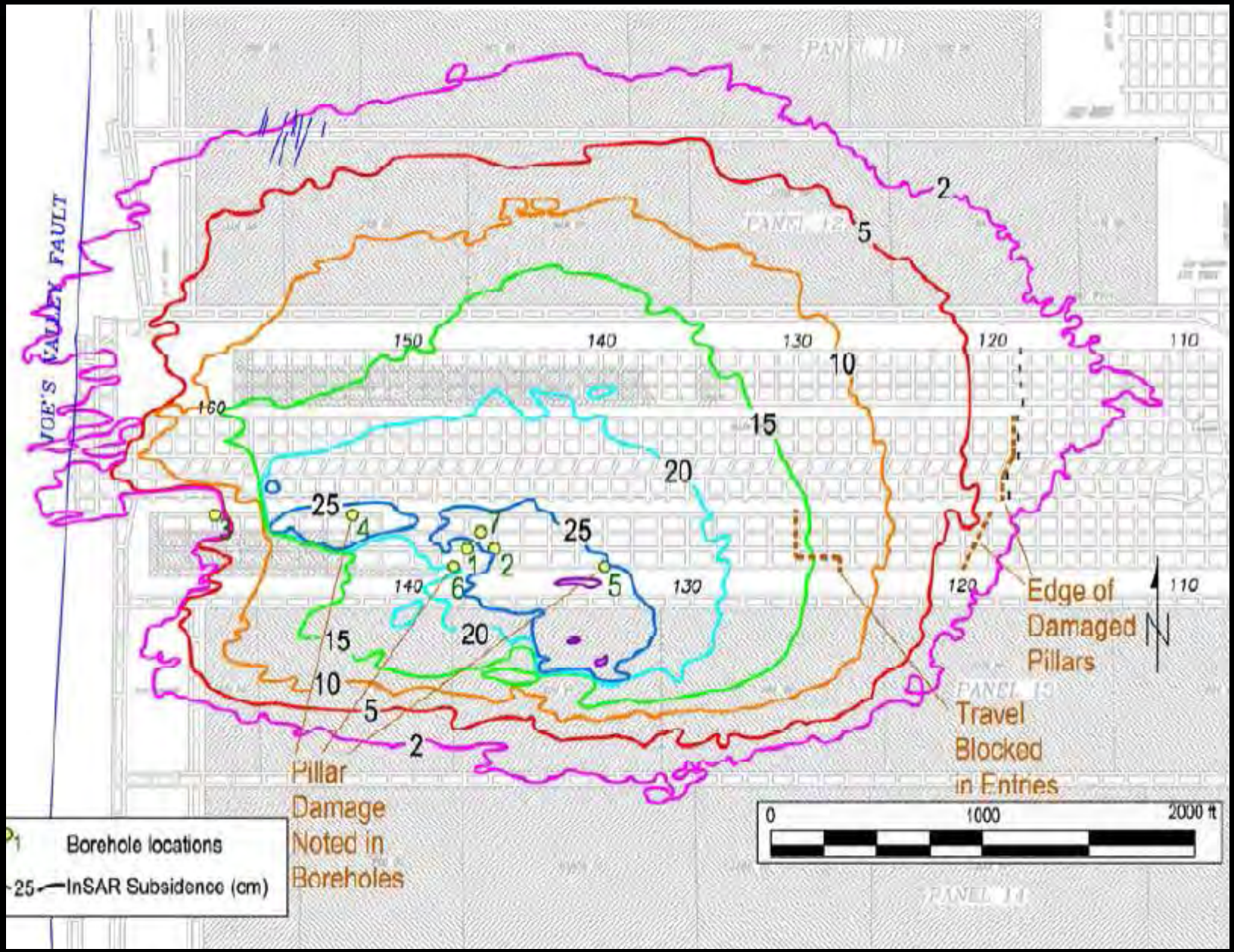
August 17th Bump



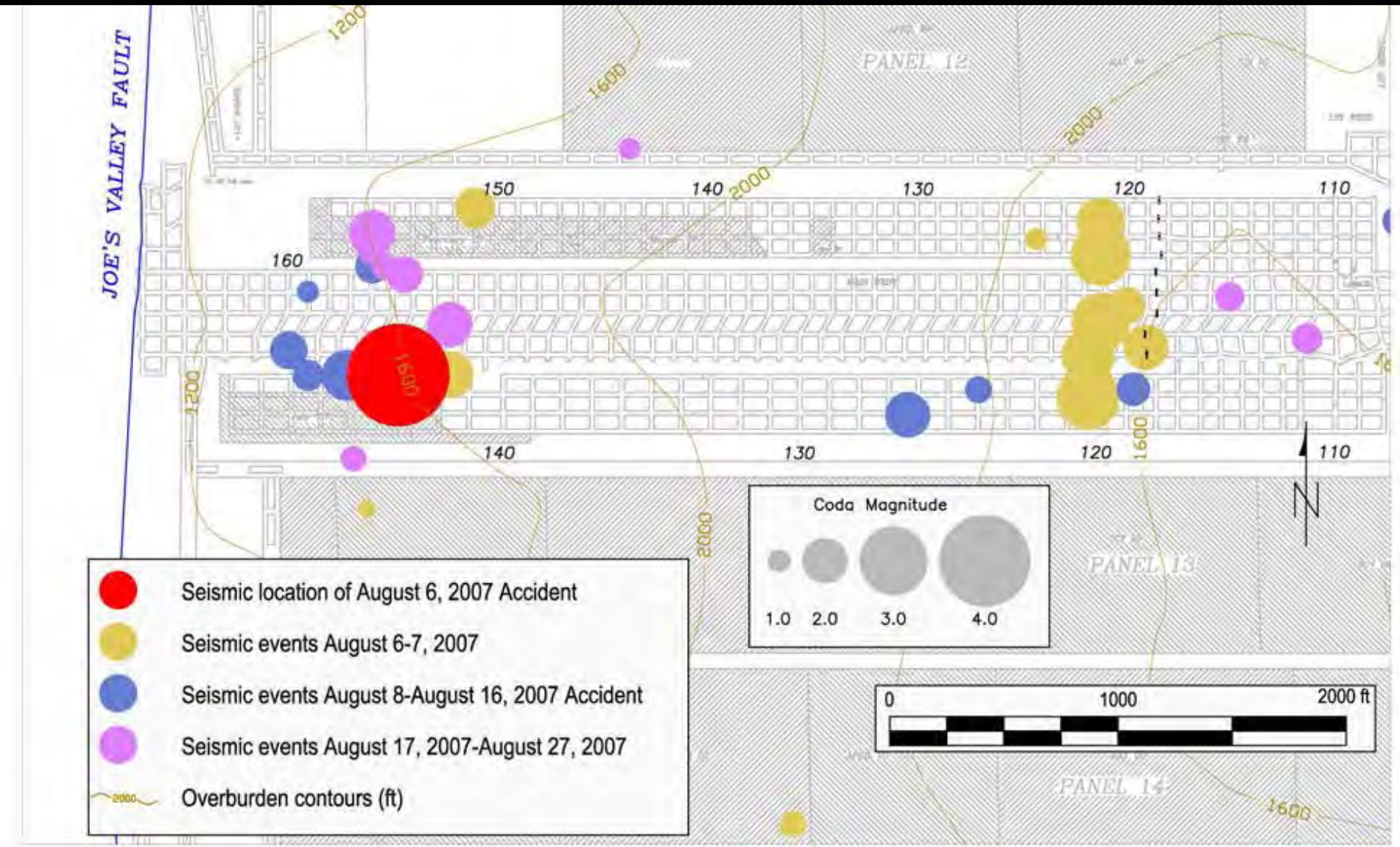
Surface Subsidence



Surface Subsidence



Seismic Events



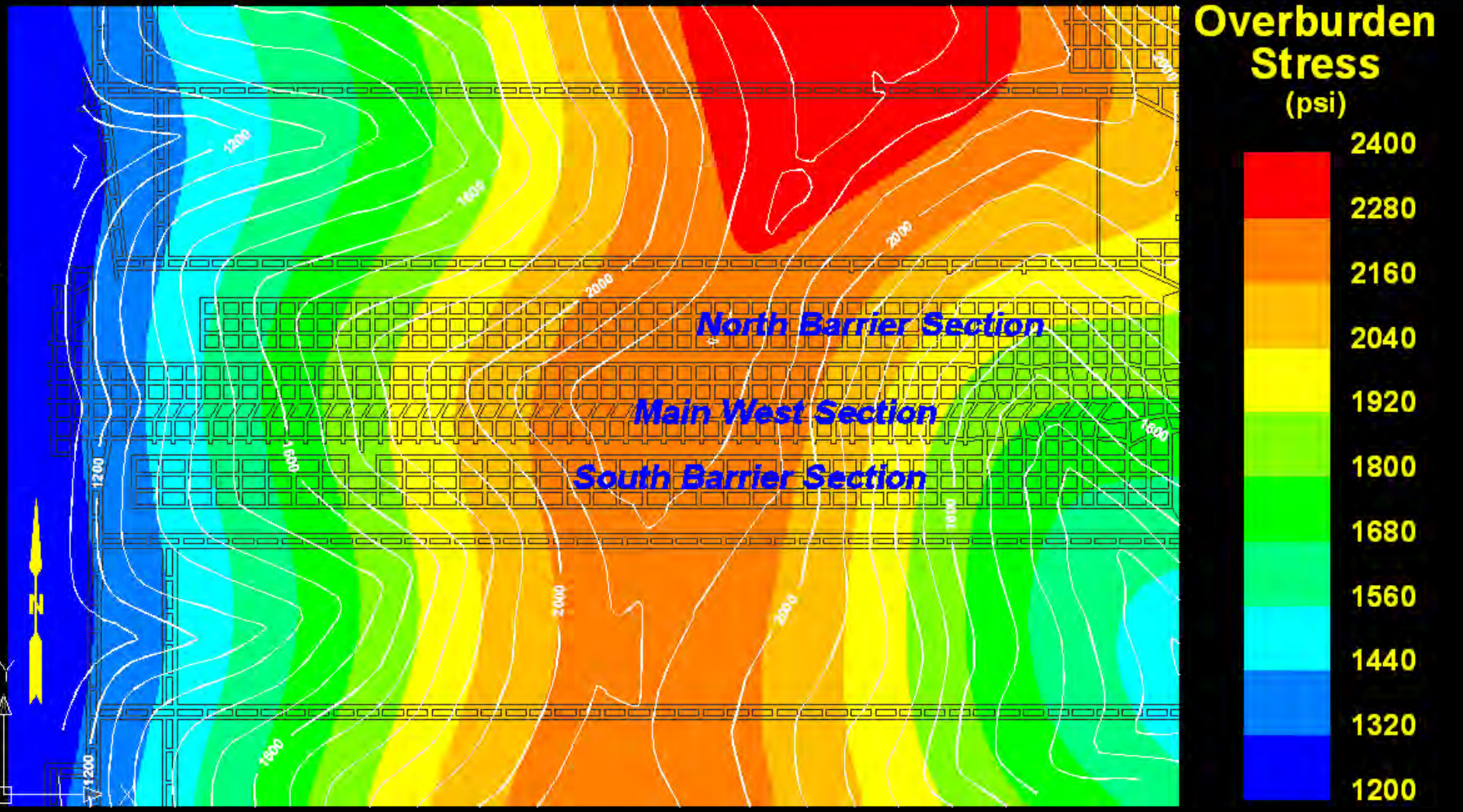
My Objective

- Utilize LaModel to Back-Analyze the August 6th 2007 collapse at the Crandall Canyon Mine
- Better understand the geometric and geo-mechanical factors which contributed to the collapse
- Help determine improvements in mine design to eliminate similar events in the future

Back Analysis Procedure

- Develop base mine grid
- Calibrate properties against March bump
- Model South Barrier

Overburden Stress



North Barrier Bump

A. Retreat Line at XC 141

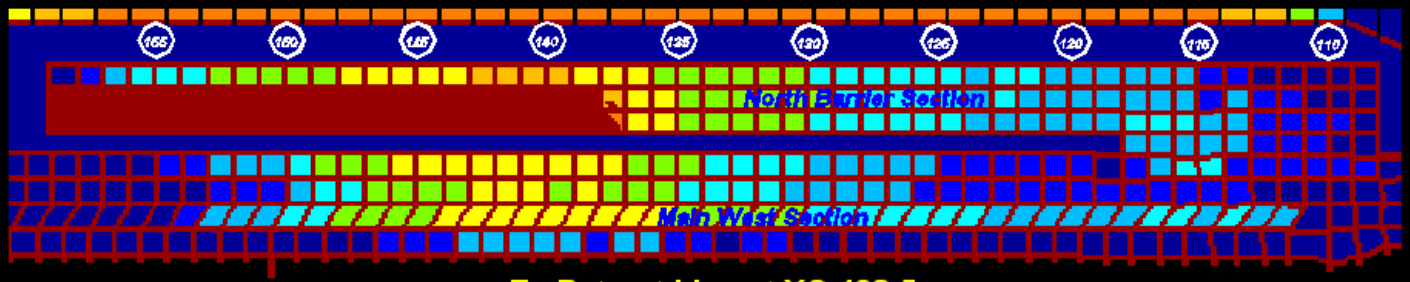
B. Retreat Line at XC 140

C. Retreat Line at XC 139

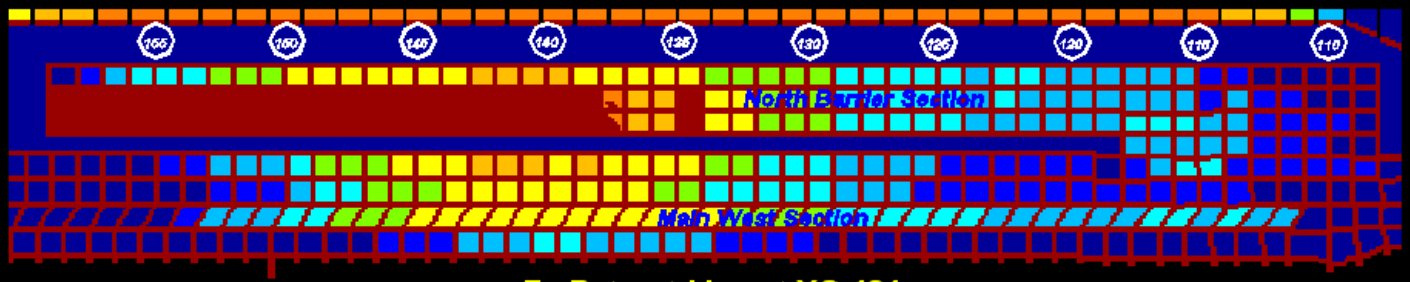
Pillar Safety Factor

North Barrier Bump

D. Retreat Line at XC 138



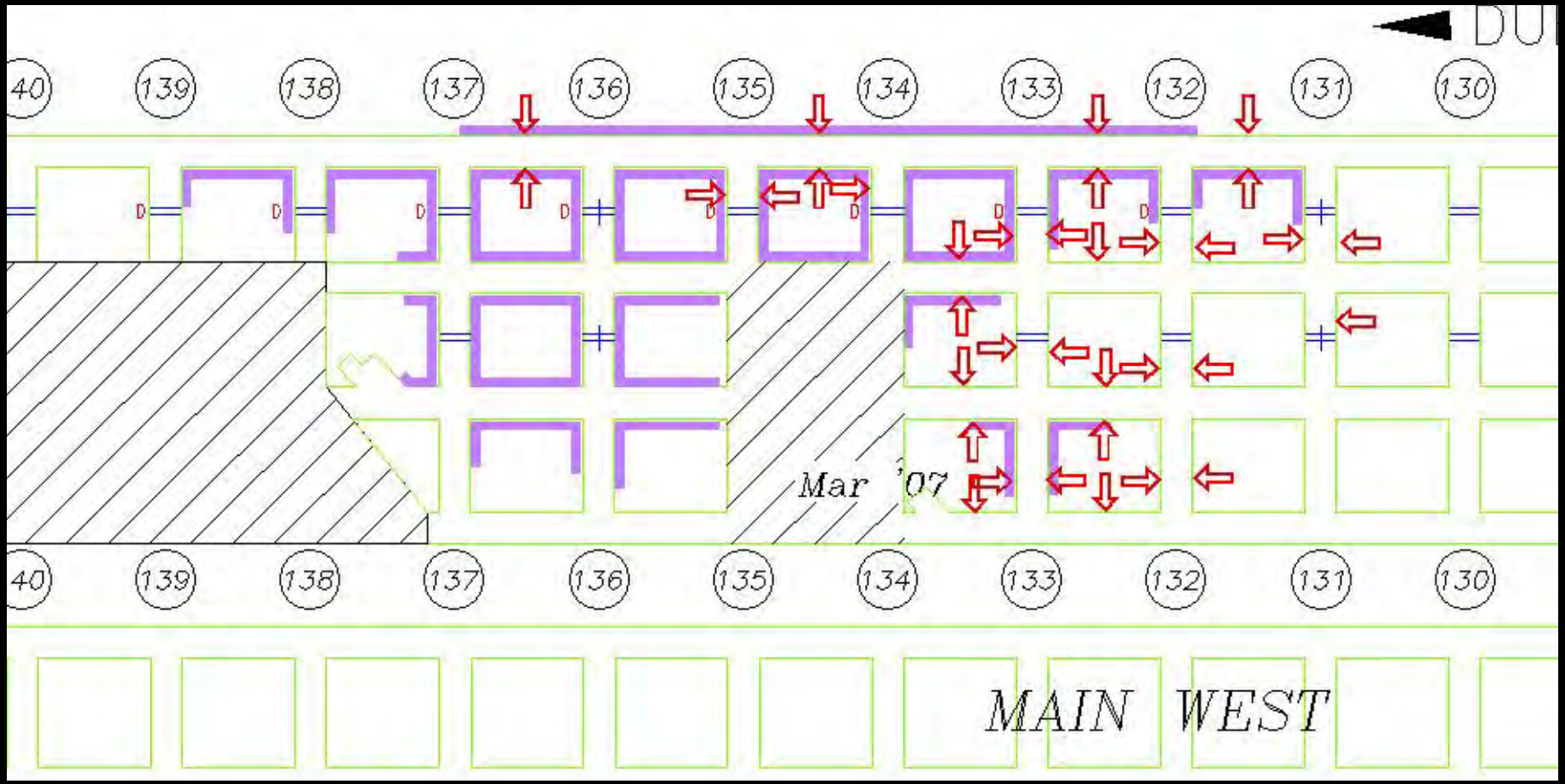
E. Retreat Line at XC 138.5



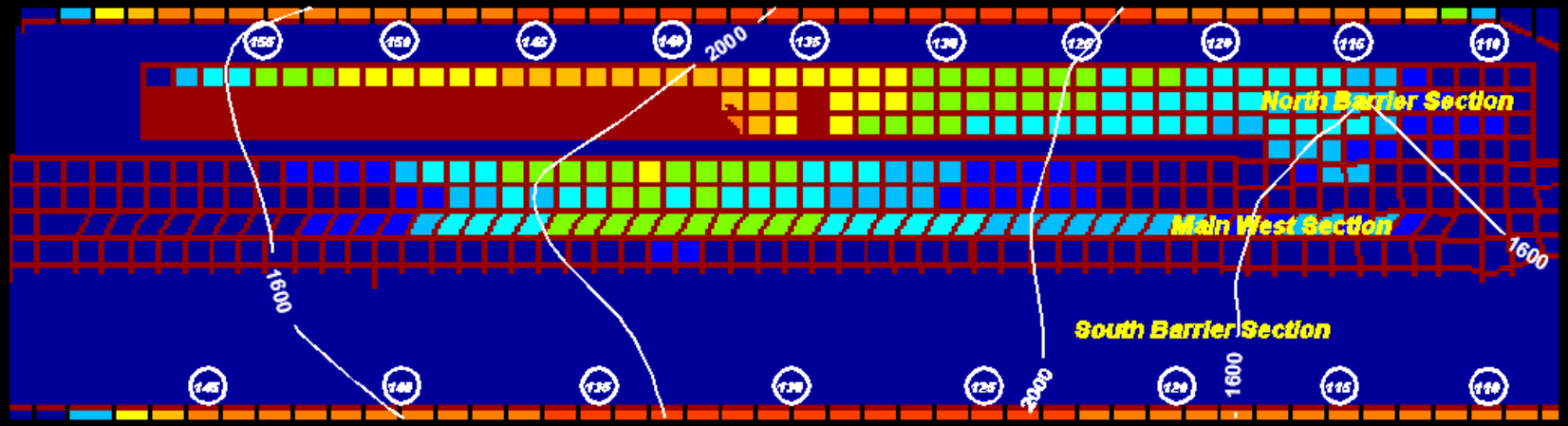
F. Retreat Line at XC 134

Pillar Safety Factor

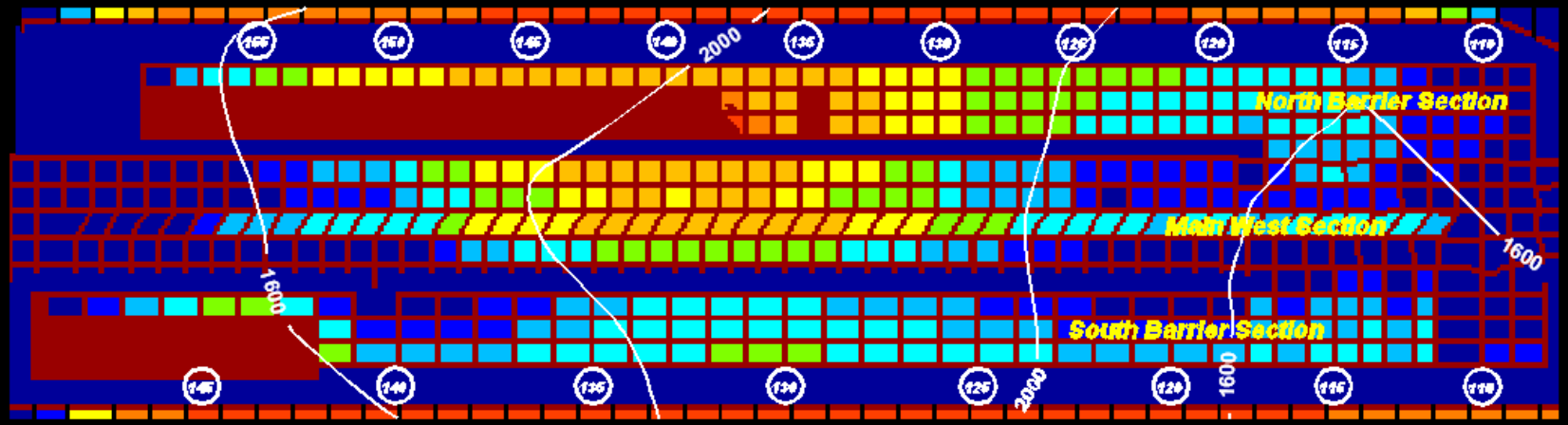
North Barrier Bump



Final North Barrier



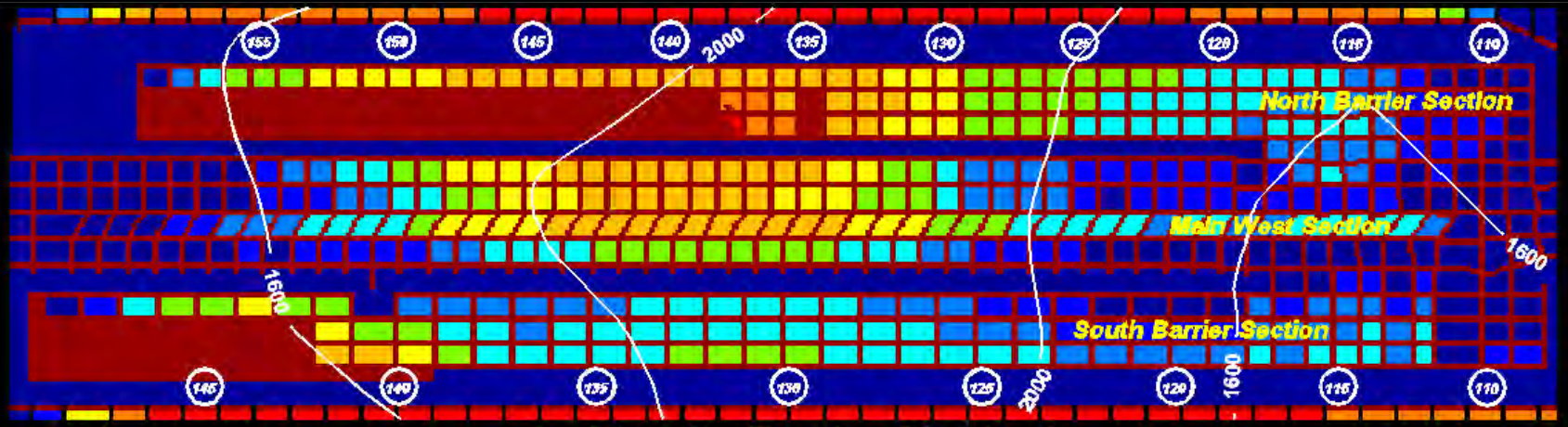
A. Step 3 - North Barrier Bump



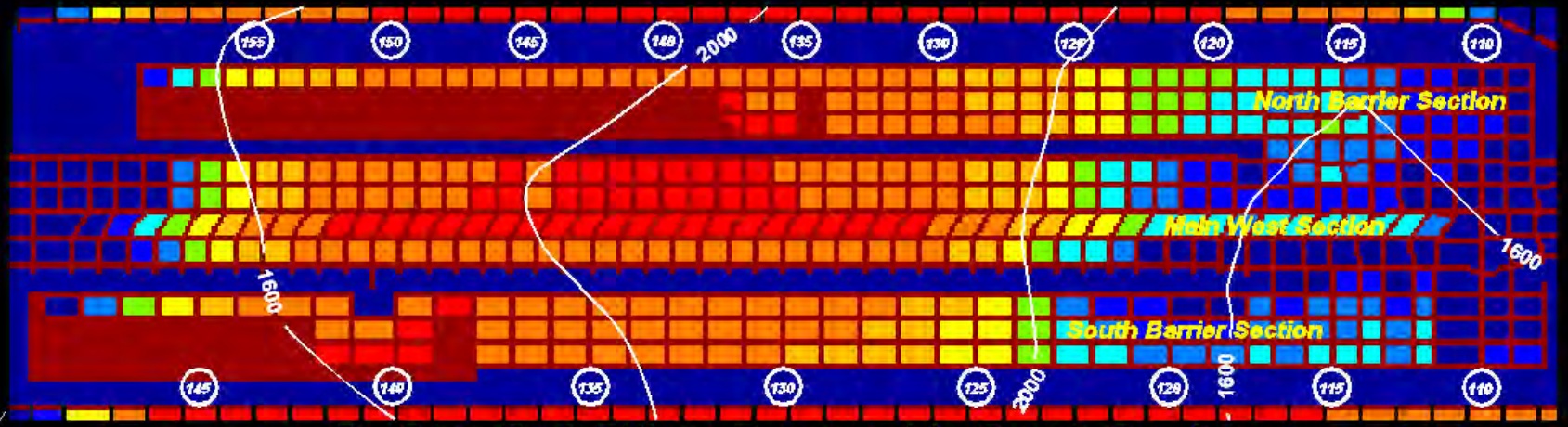
B. Step 5 - South Barrier Retreated

Pillar Safety Factor

Final Model

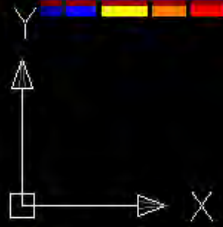


A. Step 6 - Barrier Slabbed



B. Step 7 - 2 Pillars Removed in South Barrier

Pillar Safety Factor



Pillar Sizes

- Main West Pillars– 70’ X 72’ (rib-to-rib), 8’ high
- North Barrier Pillars – 60’ X 72’ (rib-to-rib), 8’ high
- South Barrier Pillars – 60’ X 109’ (rib-to-rib)
- Original Barriers – 450’
- Final Barriers – 130’, 80’

Crandall Canyon Conclusions

- Main West area primed for massive collapse
  - Similar sized pillars (± 15%)
  - High Overburden (SF < 1.5-2.0)

- Longwall and active abutment stresses
- Mining from shallow to deep cover
- Modeling does not specify trigger
- Subsidence, Seismicity and Modeling agree well on the location and extend of the collapse

Massive Pillar Collapses NIOSH Research

- 12 Case Histories in U.S. Coal Mines

- References:
  - Mark et al., 1997
  - Zipf and Mark, 1996
  - Chase et al., 1994

Massive Pillar Collapses

Mine	State	Depth (ft)	Pillar Sizes (ft)	ARMPS SF	W/H Ratio	Collapse Area (acres)	Collapse Size (ft)	Damage
A	WV	275	10 X 40	0.75	1.05	5.7	500 X 500	26 Stoppings, 1 Injury
B1	WV	240	10 X 40	0.84	1.00			32 Stoppings, Fan Wall
			10 X 60	0.96	1.00			
B2	WV	245	10 X 40	0.82	1.00	4.1	350 X 500	40 Stoppings
B3	WV	280	30 X 30	1.46	3.00	6.8	600 X 600	70 Stoppings
			20 X 40	1.30	2.00			
C1	WV	195	10 X 40	1.00	1.00	5.2	450 X 500	103 Stoppings
C2	WV	325	30 X 30	1.15	3.00	4.8	350 X 600	Minimal
D	WV	225	20 X 20	1.15	1.82	4.3	350 X 540	37 Stoppings
			30 X 30	1.42	2.73			
E1	WV	300	10 X 40	0.79	1.42	18.2	800 X 950	Major Damage
E2	WV	300	10 X 40	0.71	1.11	16.6	720 X 900	Major Damage
F	OH	250	7 X 39	0.66	2.12	4.9	300 X 700	Minimal
G	UT	550	40 X 40	0.95	2.29	19.4	480 X 1620	Major Damage, 1 Injury
R	CO	400	12 X 80	0.57	1.71	6.8	600 X 500	Minor Damage

Mine A

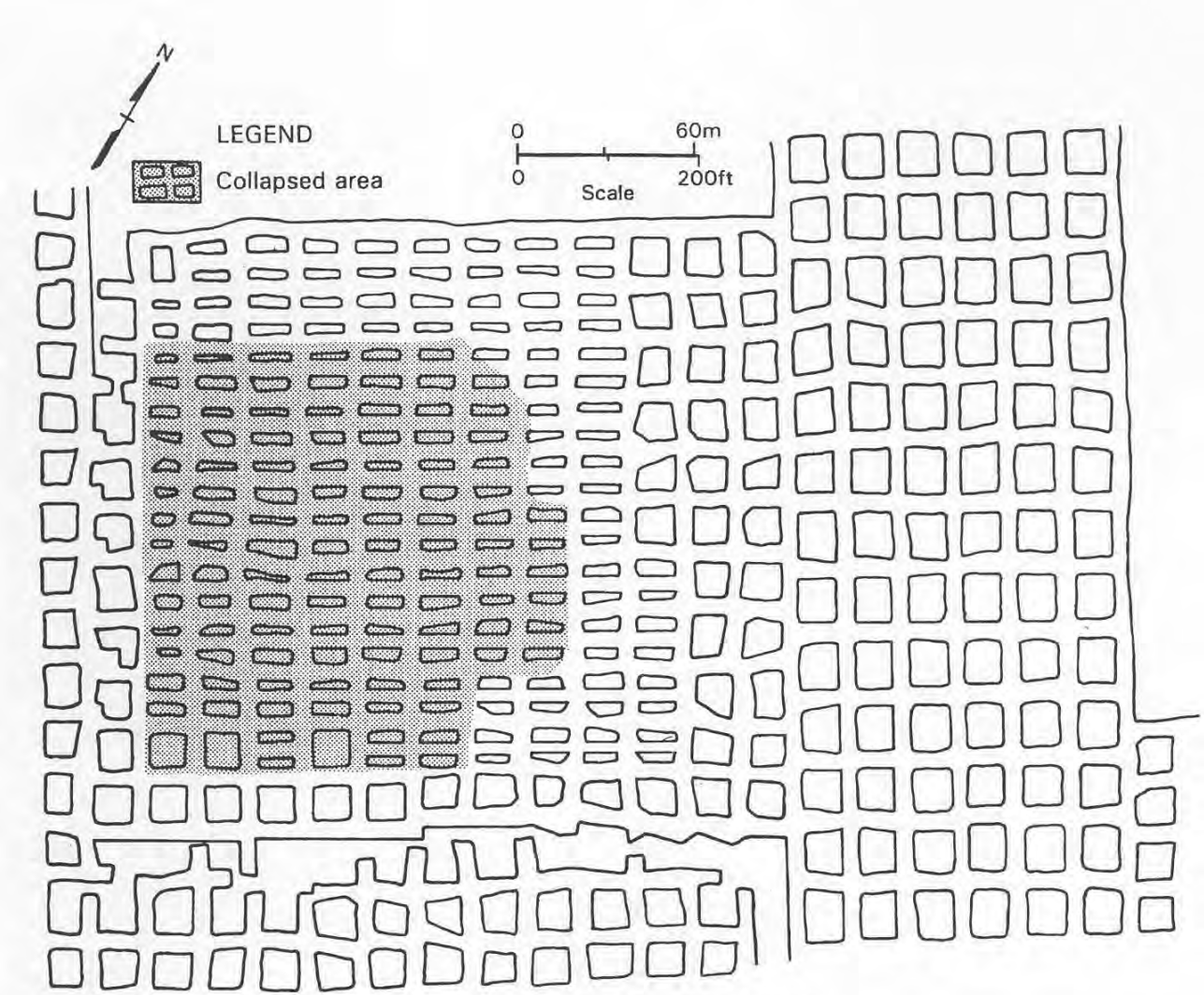
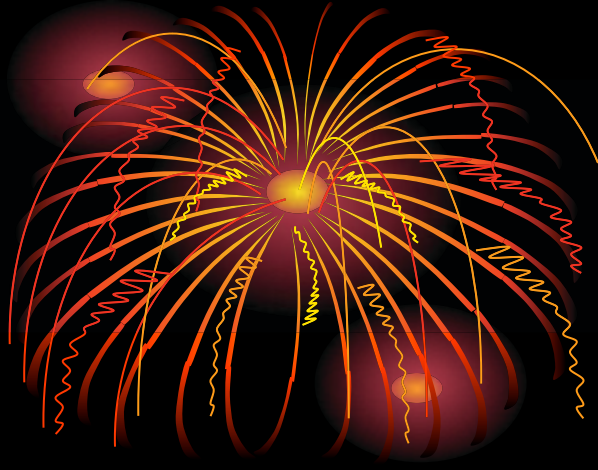


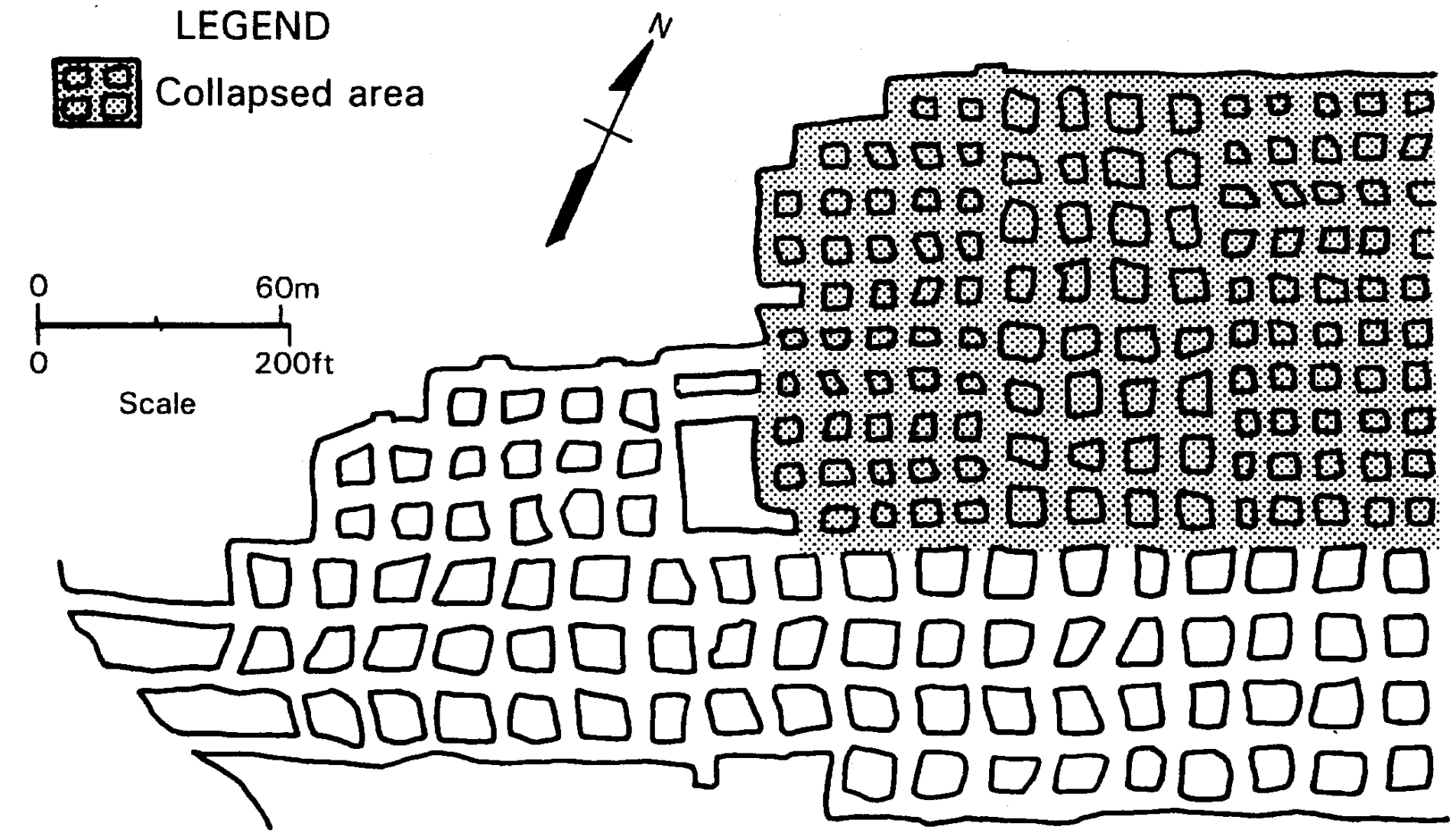
Figure 1.—Failed split-pillar workings in Mine A.

Mine A

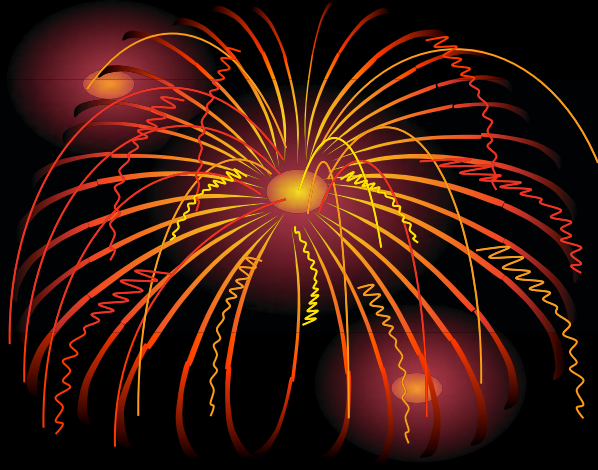


- Mine A – Mingo County, WV (1991)
  - Coalburg Seam – 9.5 ft Thick
  - 10 X 40 ft Fenders, 275 ft Deep
  - ARMPS SF = 0.75, CMRR = 74
  - 450 X 500 ft Area
  - 107 Fenders, 26 Stoppings
  - No Fatalities

Mine D



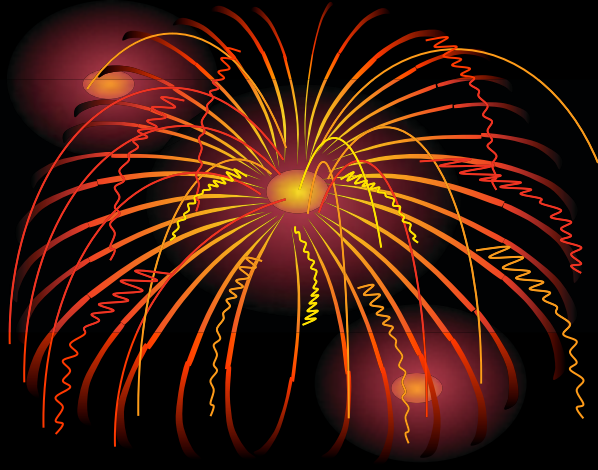
Mine D



- Mine D – Mingo County, WV (1992)
  - Dorothy Seam – 11.0 ft Thick
  - 20 X 20 ft Pillars, SF = 1.15
  - 30 X 30 ft Pillars, SF = 1.45
  - 225 ft Deep, CMRR = 81
  - 106 Fenders, 37 Stoppings
  - No Fatalities, (Blocks Blown 500 ft)

Mine G

Mine G



- Mine D – Utah, (1992)
  - O’ Connor Seam – Developed 8.0 ft, Retreated 18.0 ft Thick
  - 40 X 40 ft Pillars, SF = 5.0 -> 2.2
  - 550 ft Deep
  - No Fatalities, (Miners Blown 100 ft)

Database Summary

- ARMPS SF < 1.5
  - ARMPS SF < 1.2 in 81% of Cases
- Slender Pillars - W/H < 3.0
- Strong Roof
- Minimum Area – 4 Acres
- Minimum Collapse Width – 350 ft

MPC Scenario

- Undersized Pillars help the stiff competent roof bridge a wide span,
- A Pressure Arch is created with the overburden load bridging the pillars
- Pillars are shielded from the full Overburden Load.
- Pressure Arch breaks down

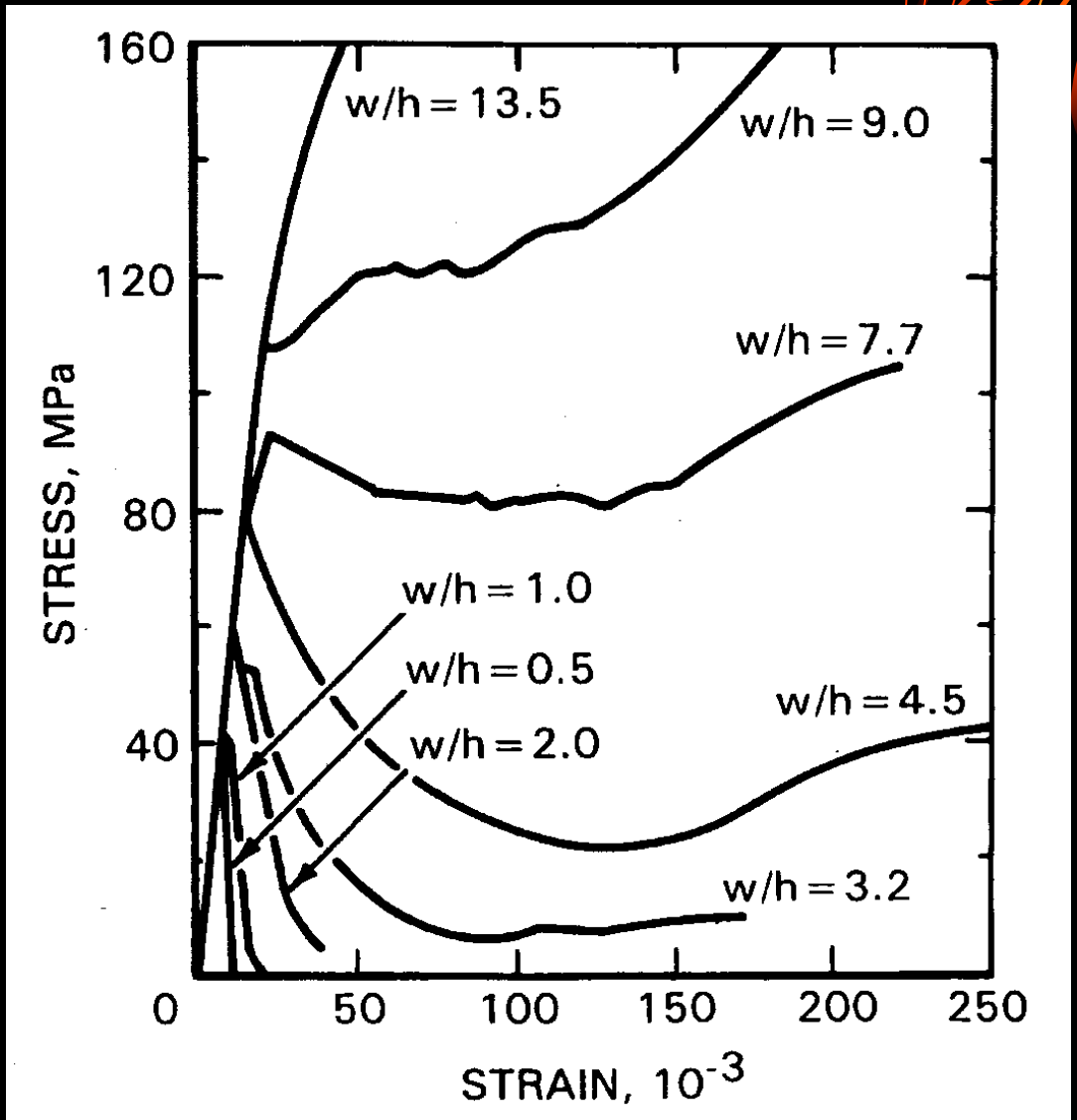
Collapse Triggers

- Extraction Width becomes too large to bridge the span
- Mining approaches a Fault or Discontinuity
- Roof Weakens over time
- Pillars Weaken over time

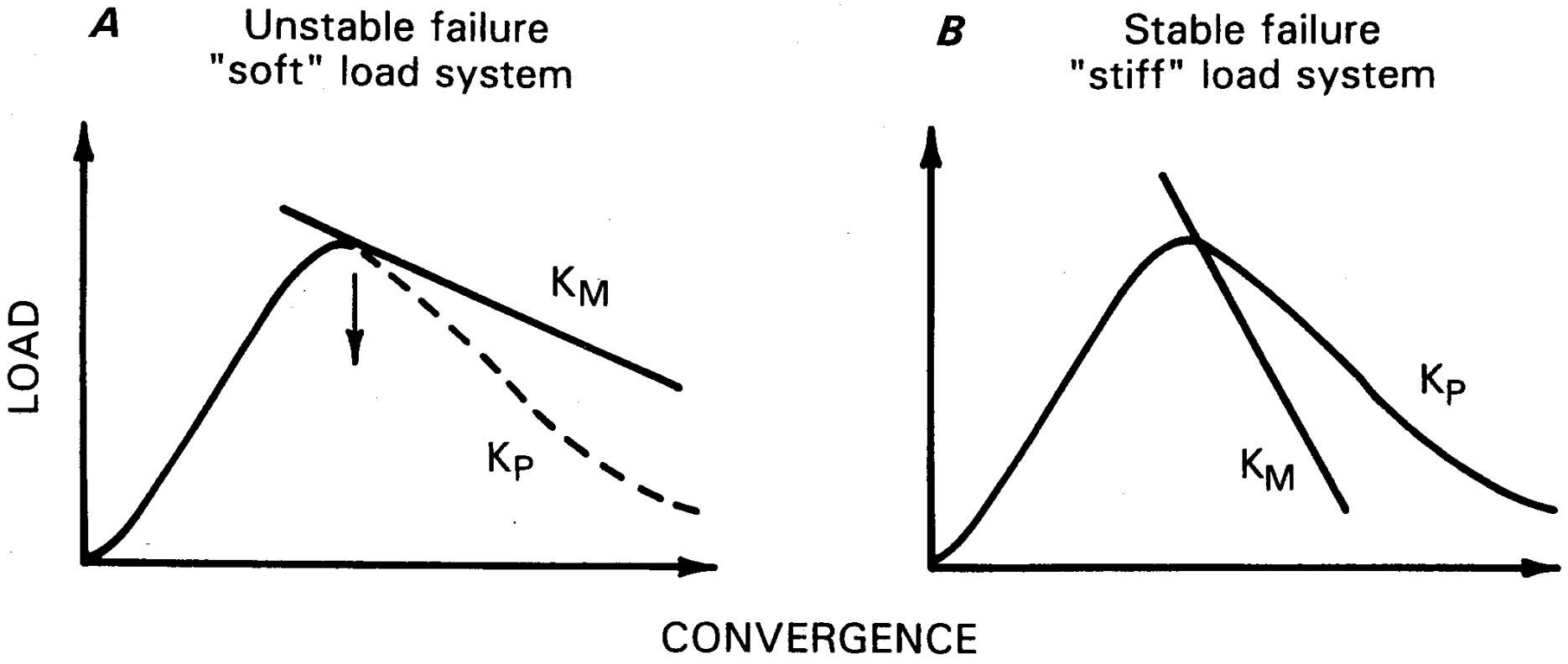
Collapse Runs

- Slender pillars shed load
- Slender pillars have steep post-failure modulus
- Local Mine Stiffness criteria is violated

Stress-Strain Behavior



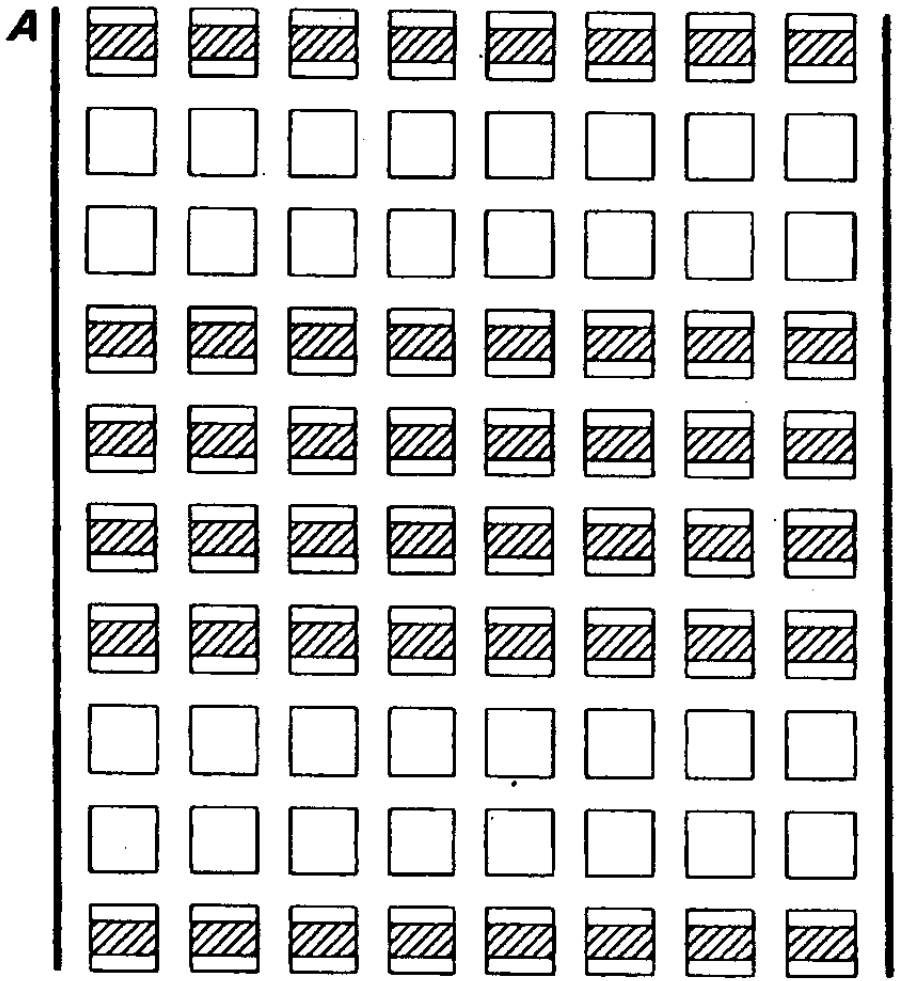
Local Mine Stiffness



Controlling MPC

- PREVENTION:
  - ARMPS SF > 2.0
  - W/H > 4.0 ???
- CONTAINMENT:
- Keep Maximum Area < 3.2 Acres
- Keep Maximum Width < 300 ft
- Keep Sufficient Barriers

Containment



Additional Thoughts

- NIOSH study never determined PROBABILITY of failure

- NIOSH study all less than 550 ft Deep
- Crandall Canyon Mine
  - 1500 – 2000 ft Deep
  - W/H > 6.0

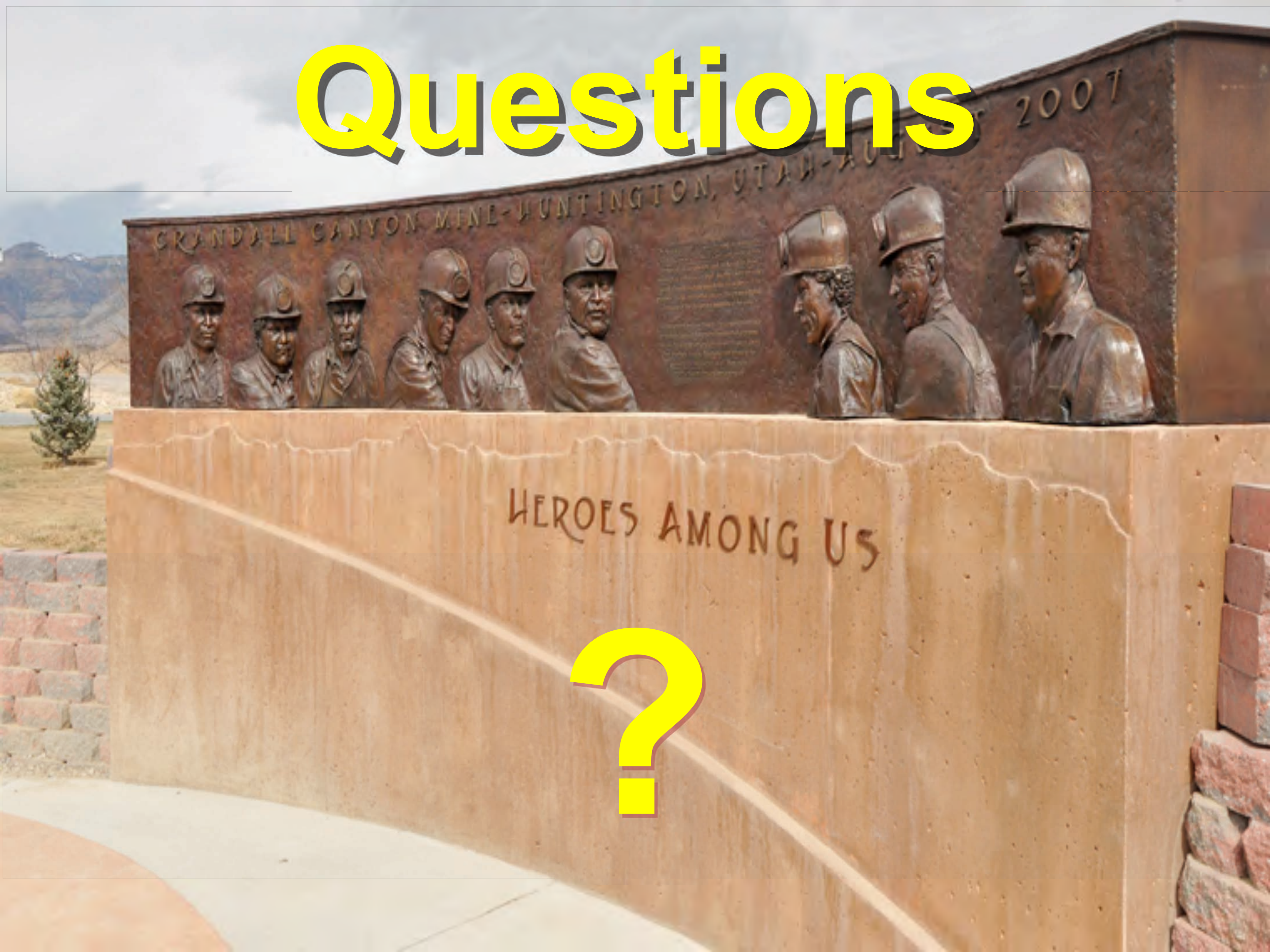
Summary

- Presented some historic Massive Pillar Collapses
  - Coalbrook, Solvay, Crandall Canyon
- Explained the Mechanics of MPC
  - Low SF, Low W/H, Large Area
- Described the Prevention of MPC
  - Prevention, Containment

Closing

- The potential for Massive Pillar Collapses is one area of mine design that is often overlooked.
- But it needs to be considered in every roof control plan if Massive Pillar Collapses are to be prevented in the future.
- I hope this presentation has been informative and brought the problem of MPC to your attention.

Questions



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