Two-Entry Yield Pillar Gateroad Systems in Western U.S. Longwall Mines

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Consulting Engineers

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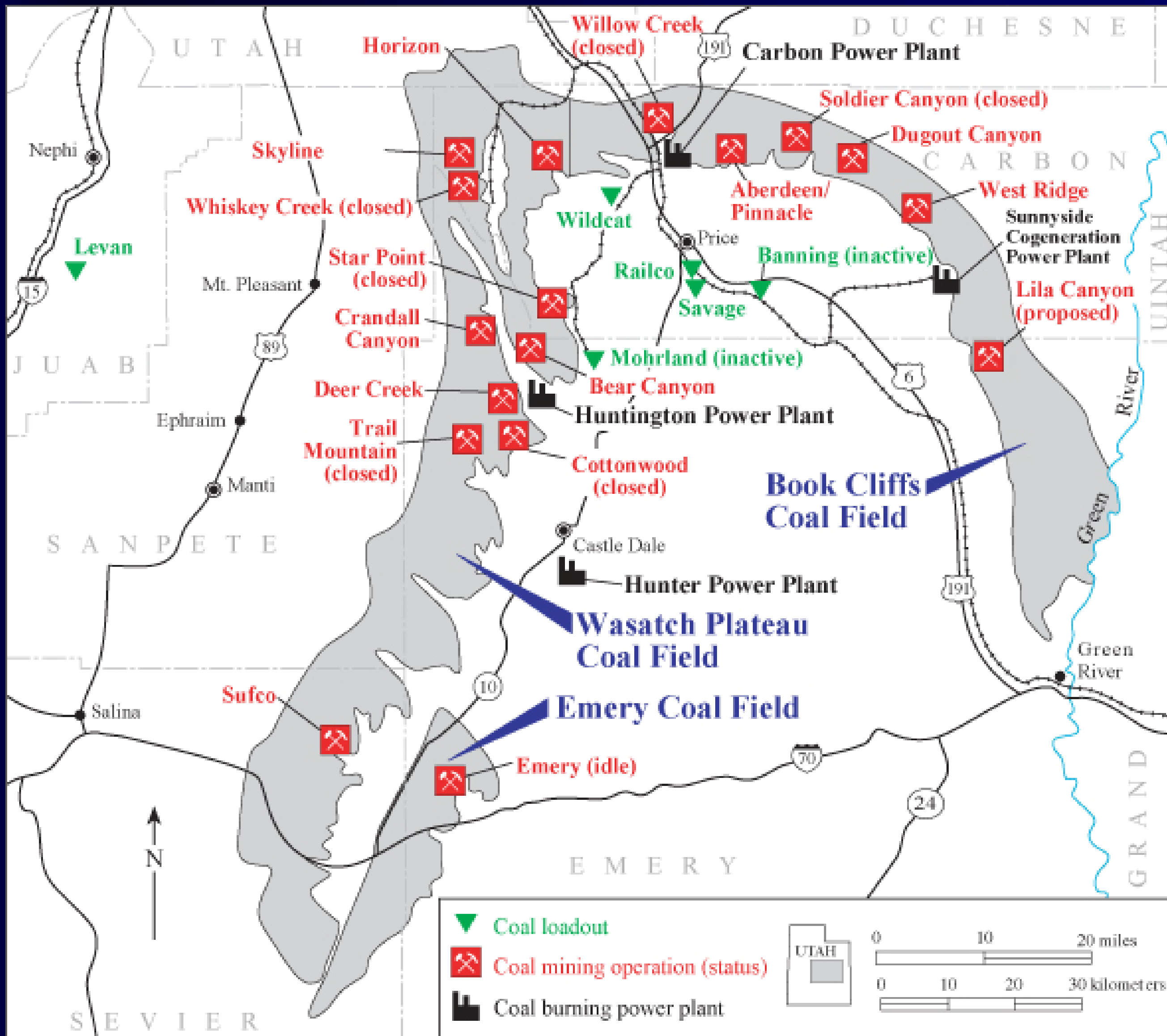
Agapito Associates, Inc.

- Mining and geological engineering firm
- Founded 1978
- Offices in Grand Junction, Denver, and Chicago
- Specialize in geomechanics and mine design
- Western U.S. longwall coal clients (past and present):

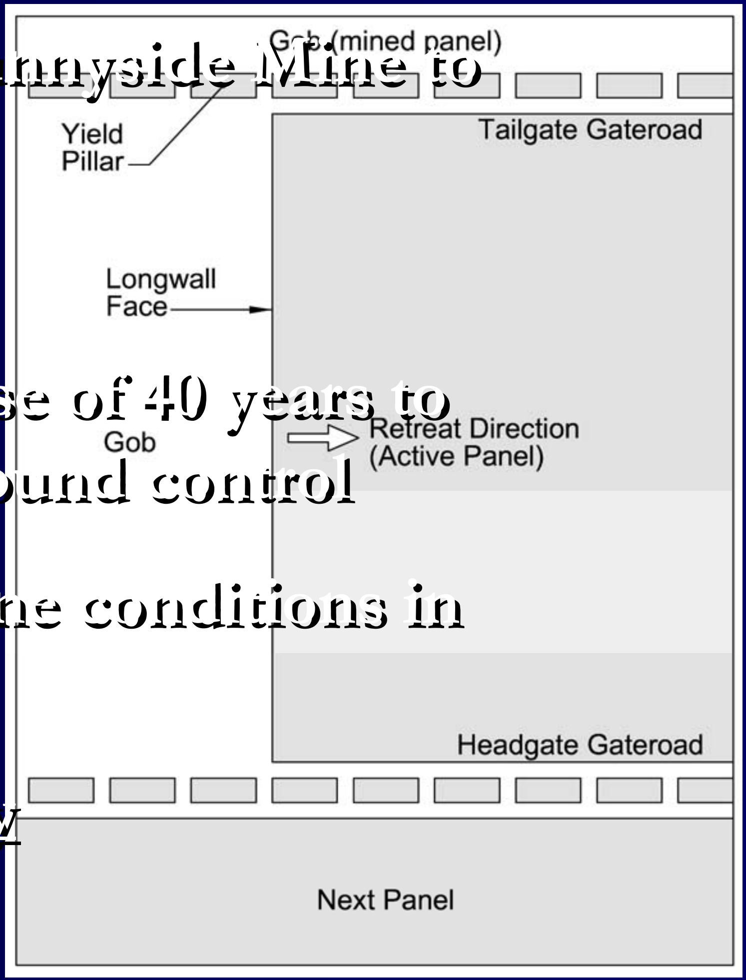
Andalex/Tower	Skyline	West Ridge
Bowie No. 2	Soldier Creek	West Elk
Crandall Canyon	Star Point	Trail Mountain
Dugout Canyon	Sunnyside	SUFCO
Deer Creek	Willow Creek	Shoshone
	San Juan	

Utah Coal Fields



Introductory Points

- Two-entry yield pillar system unique to Western U.S. longwall coal mining
- System evolved over time—Sunnyside Mine to present
- Analyzed extensively
- Proved superior over the course of 40 years to other gateroad systems for ground control
- A system tailored to burst prone conditions in the West
- A system used out of necessity



What is different about Western U.S. ground conditions?

Western U.S. Coal Mining Conditions

- Very deep cover—currently reaching 3,000 ft
- Highly variable topography
- Frequent multiseam mining
- High stress environment
- Bump prone geology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Book Cliffs

Book Cliffs

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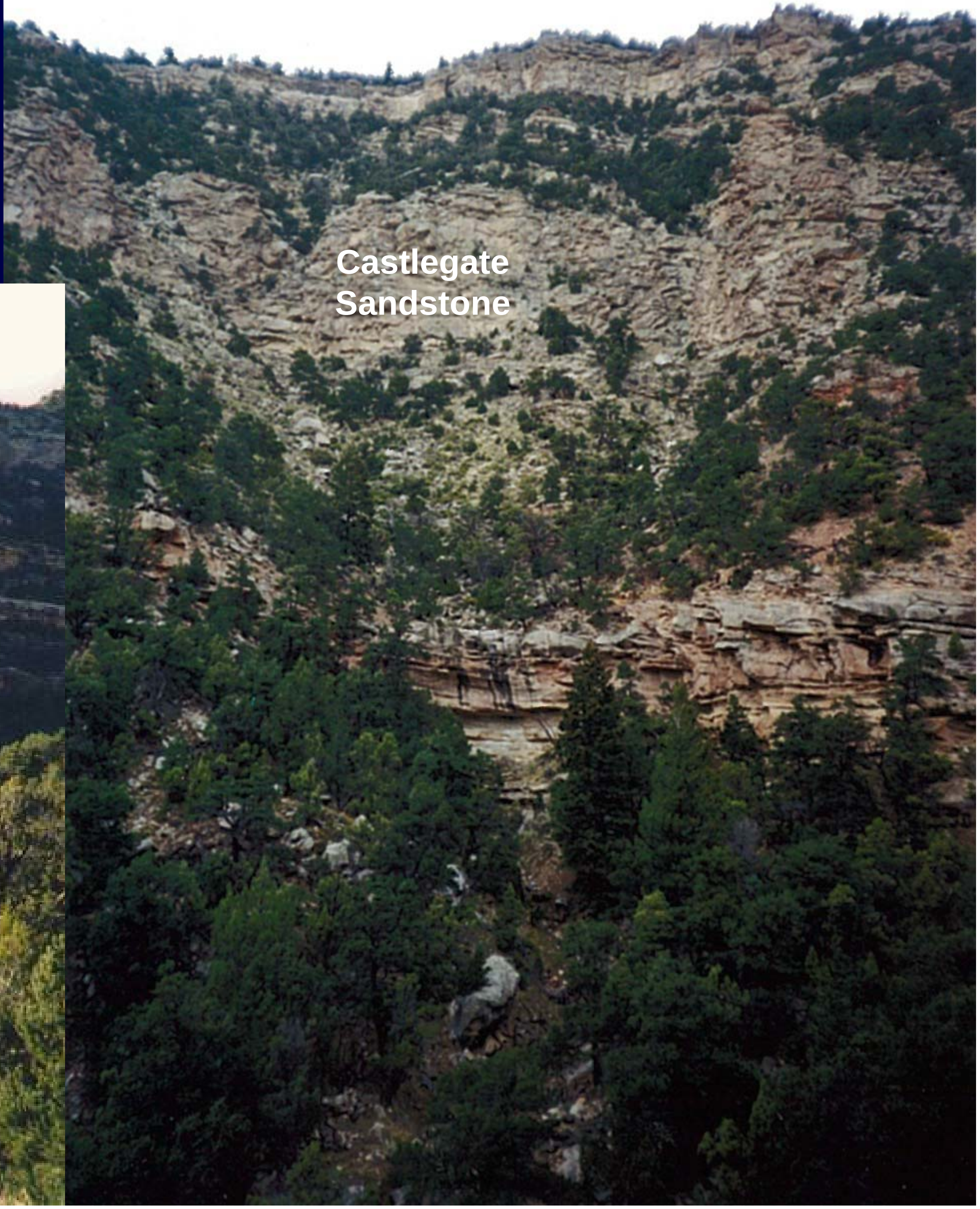
Western U.S. Bump Prone Geology

1. Thick and competent overburden strata—causes bridging leading to high abutment stresses

Massive Cliff Forming Overburden



Western U.S. Bump Prone Geology

1. Thick and competent overburden strata—causes bridging leading to high abutment stresses
2. Uncleated or weakly cleated, strong coal—leads to storage of strain energy and sometimes violent releases
3. Highly competent roof and floor strata that confine coal and resist breakage—creates a "bounce sandwich"
4. Sand channels—cause stress concentrations
5. Massive overburden—resists caving and increases loads on pillars and longwall face

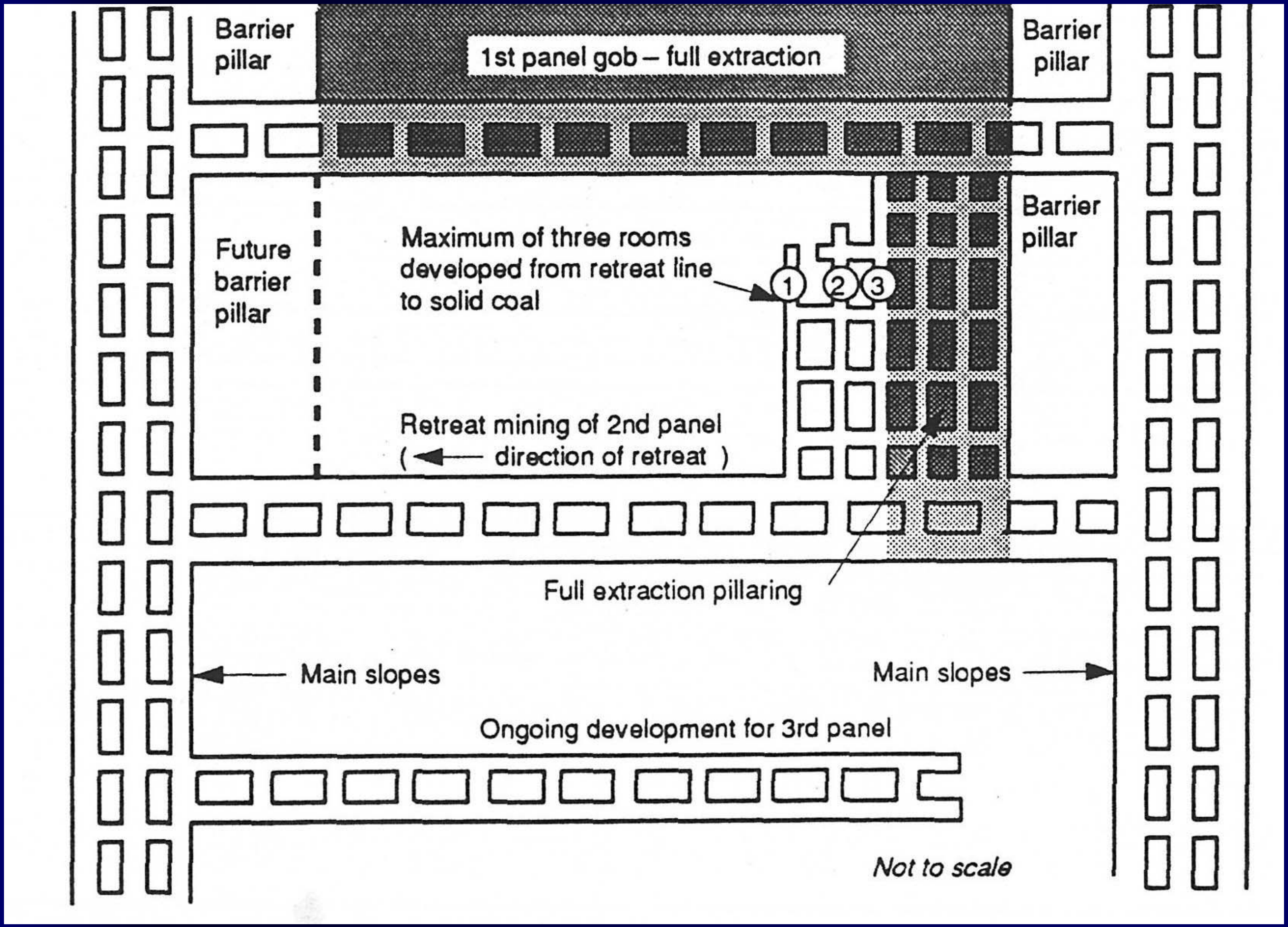
Comparison - Typical Conditions

Western U.S.	Eastern U.S.
Cover: deep (typ. 1,500-3,000 ft)	Cover: shallow (typ. 500-1,800 ft)
Topography: rugged	Topography: limited relief
Coal: strong (3,000+ psi)	Coal: variable strength
Roof: strong and stiff	Roof: weak and soft
Floor: strong and stiff	Floor: weak and soft
Overburden: massive strata	Overburden: highly laminated
Burst Proneness: high	Burst Proneness: low

Evolution of the Two-entry System and Yield Pillars in the Western U.S.

Origin in Western U.S.

- Two-entry mining system was the predominant method of room-and-pillar mining at Sunnyside Mine since 1897
- Most used historical room-and-pillar method in West
- Established prior to the 1969 Coal Mine Health and Safety Act
- Sunnyside experienced severe bumps and bump-related roof falls at depths greater than about 800 ft
- Solution was to limit the width of the pillar/entry system
- The two-entry system significantly reduced bumping on room-and-pillar development

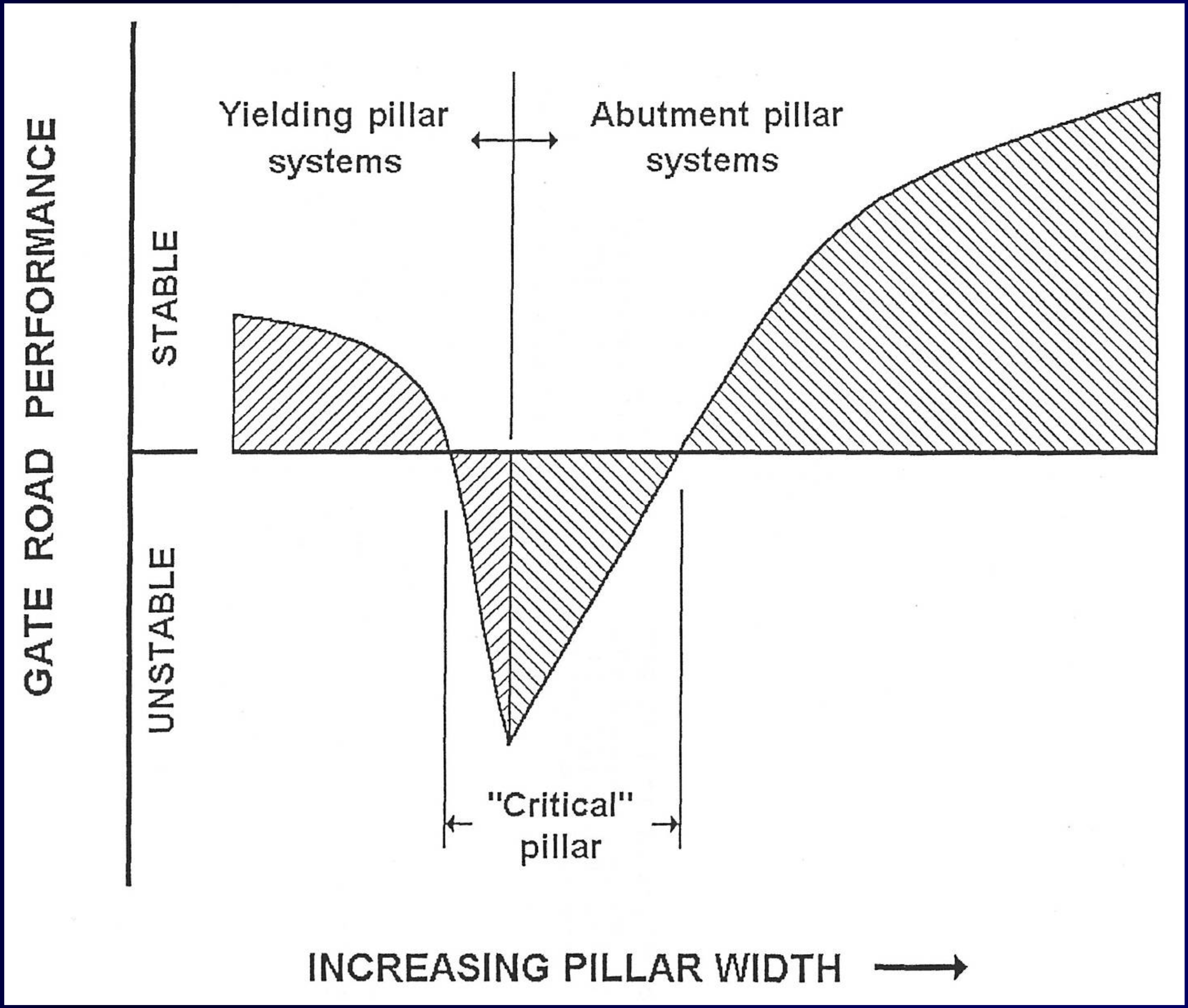


Sunnyside Room-and-pillar Panel Mining System

Origin in Western U.S.

- Bumps continued to occur on room-and-pillar retreat
- Narrow "yielding" pillars were tested to control bumping in the room-and-pillar panels
- 25- to 35-ft-wide pillars virtually eliminated bumping
- 50-ft-wide pillars were tried to improve roof stability, but proved dangerously bump prone

Critical Pillar Concept



Origin in Western U.S.

- Yield pillars ultimately proved successful eliminating bumps, but resulted in lower pillar recovery on retreat because of roof falls
- A higher recovery system was sought…

Origin in Western U.S.

- Longwall mining was introduced to Sunnyside in 1961 by John Peperakis and others based on the German method
- Longwall improved safety, resource recovery, and productivity
- Gateroad development proved analogous to room-and-pillar development…bumping was a problem >800 ft deep with large pillars
- The two-entry system previously used for room-and-pillar development proved to be the solution for controlling bumps during longwall development

Origin in Western U.S.

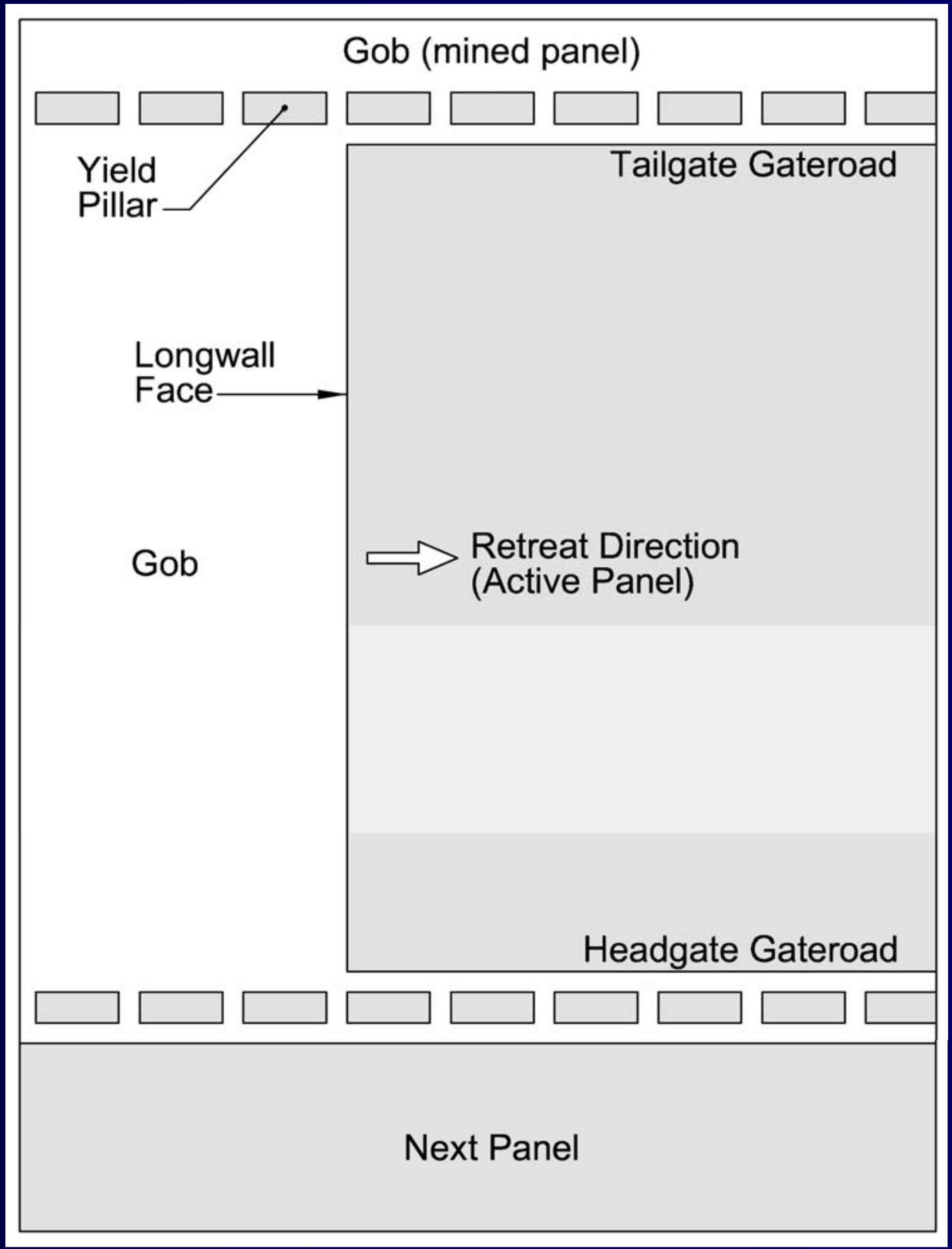
- Sunnyside conducted numerous trials to find the right gateroad pillar geometry—one that yielded nonviolently, yet provided adequate tailgate stability
- Three-entry yield pillar systems were tested—resulted in large roof deflections, floor heave, and unstable conditions in the headgate and tailgate gateroads
- Two-entry yield pillar systems provided significantly better pillar, roof, and floor conditions
- Single-entry systems provided the best overall ground conditions, but proved impractical for ventilation, access, and water control

Origin in Western U.S.

- Key conclusions from 32 years of longwall mining at Sunnyside with single and multiple seam mining and at depths approaching 3,000 ft:
  - ✓ Minimizing overall span of gateroad is key—two entries with narrow (yield) pillars optimal
  - ✓ Yield pillars are critical for controlling pillar bumps, roof damage, and floor heave
  - ✓ 25- to 35-ft wide yield pillars work best
  - ✓ Yield pillar gateroads with more than two entries result in significant increases in floor heave and roof falls

Evolution

- Since Sunnyside… the two-entry yield pillar system has become the *de facto* standard for deep longwall mining in the Western U.S.
- 30-ft-wide yield pillars typical

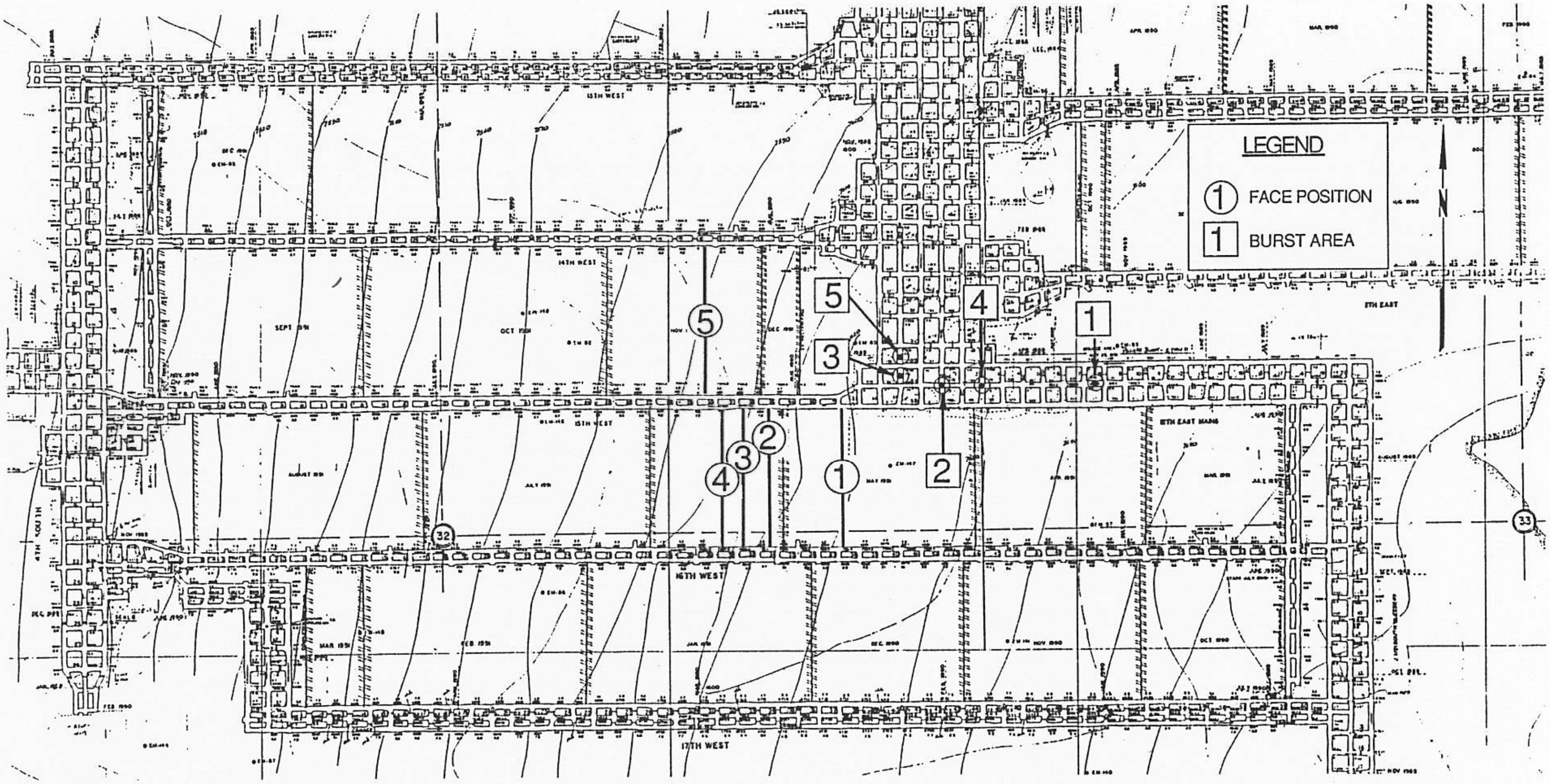


Engineering Research

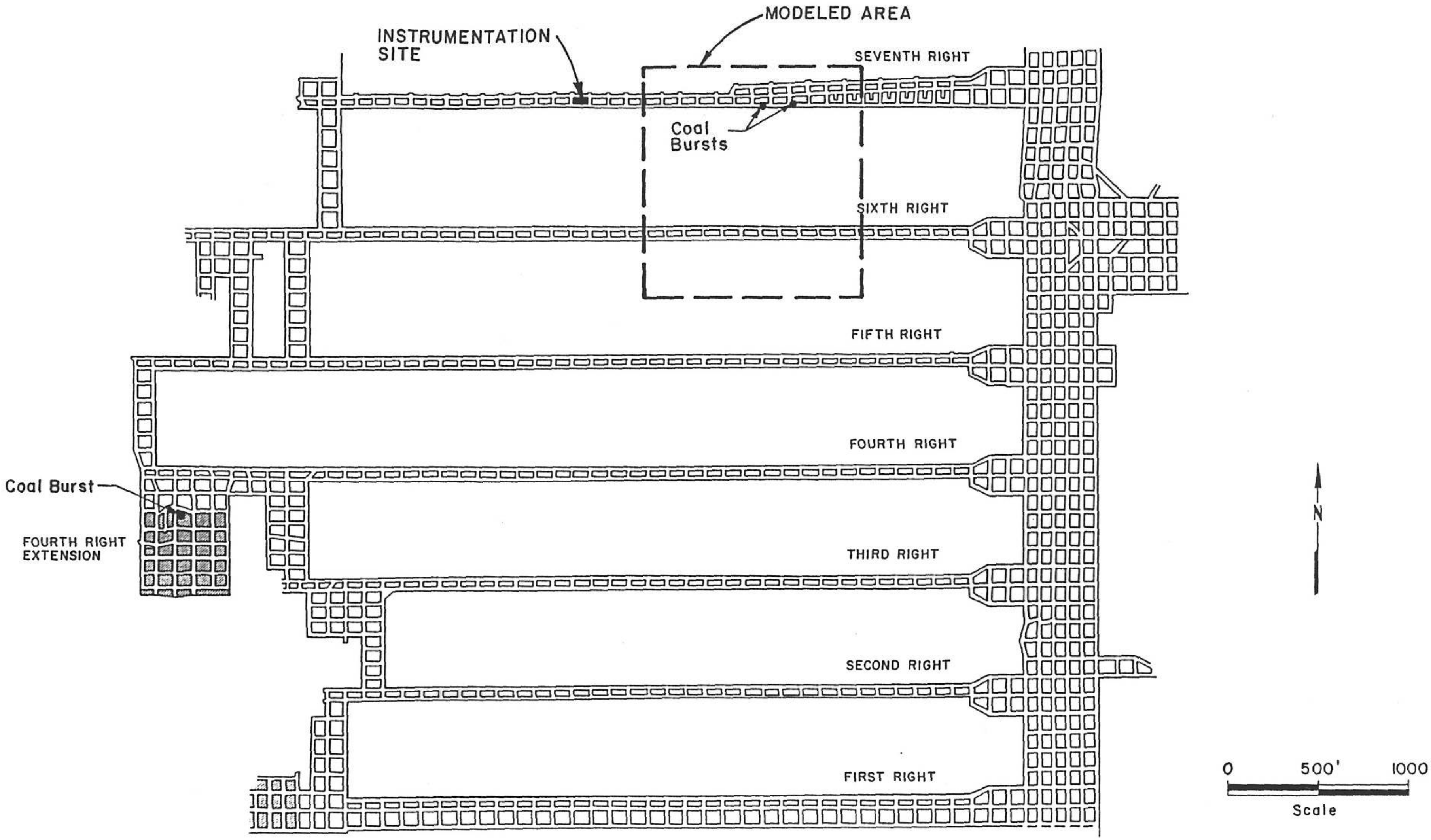
- Significant research has been conducted to evaluate the two-entry yield pillar system and alternative systems:
  - ✓ Decades of application and observation
  - ✓ Laboratory measurements of rock properties
  - ✓ Stress and convergence measurements
  - ✓ Numerical modeling
  - ✓ Many published papers

Example of Engineering Study—Cottonwood Mine

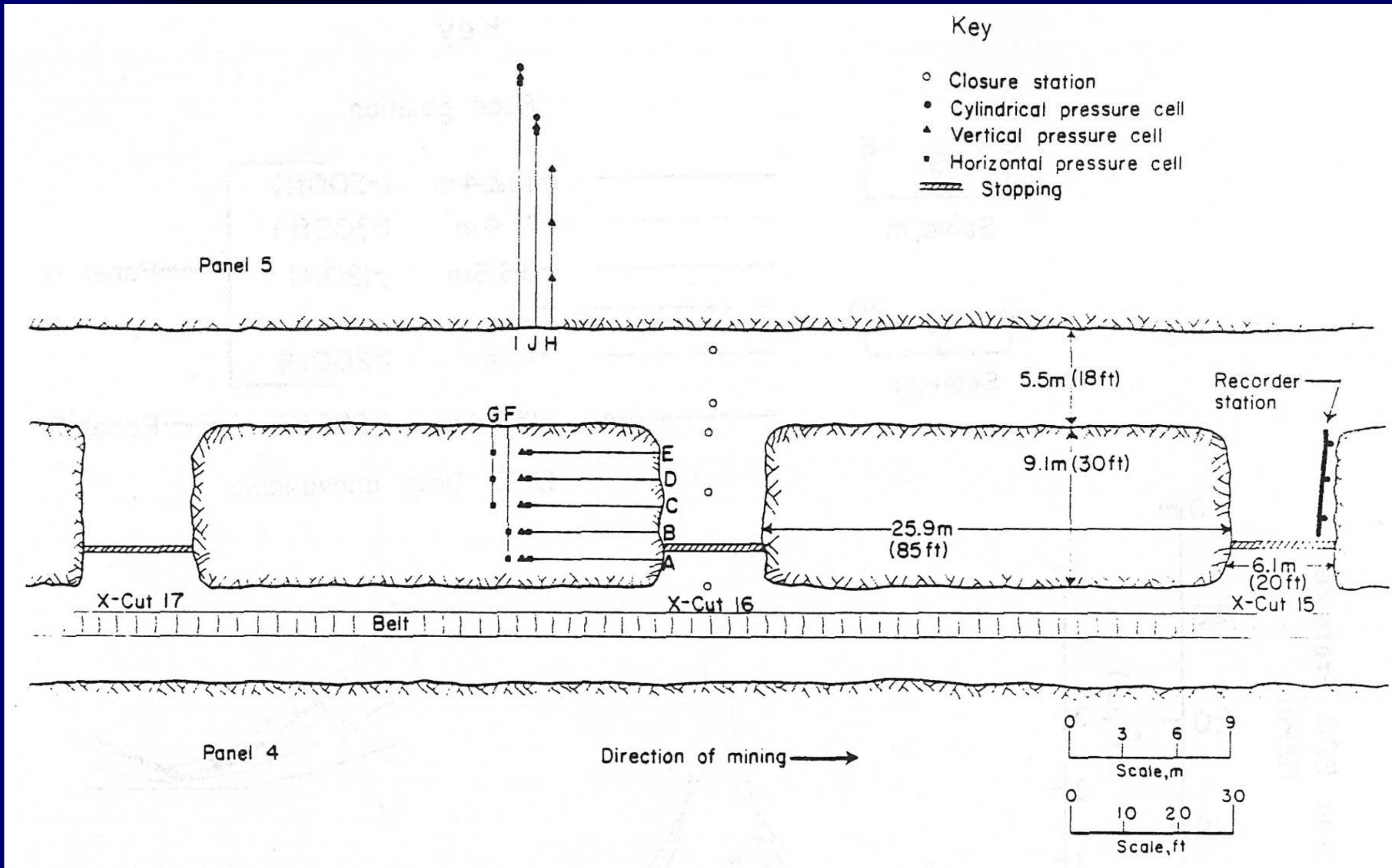
Example of Coal Burst Events in Cottonwood Mine



Example of Engineering Study—Deer Creek Mine

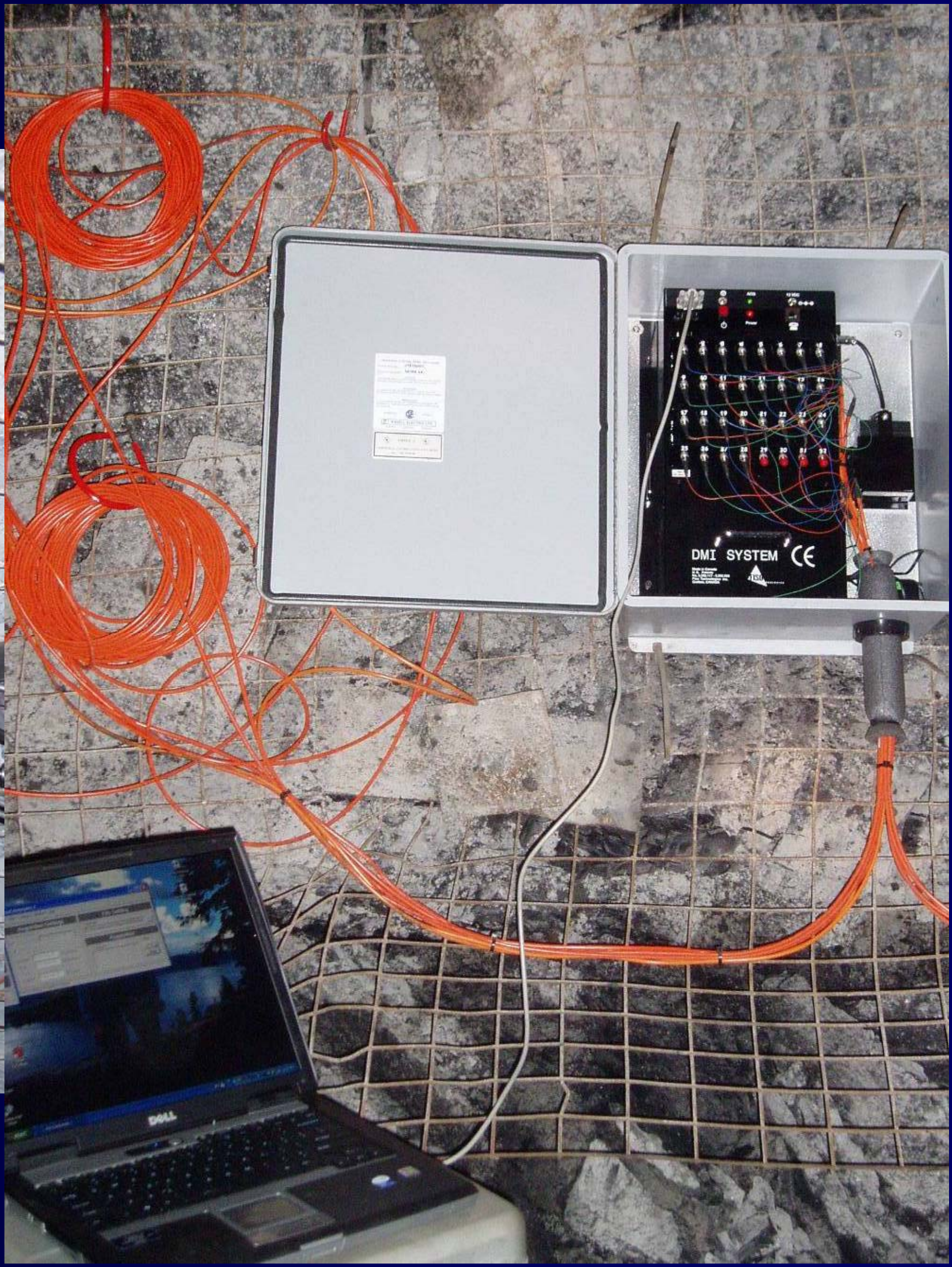


Example of Instrumentation—Borehole Pressure Cells and Convergence Stations, Deer Creek Mine

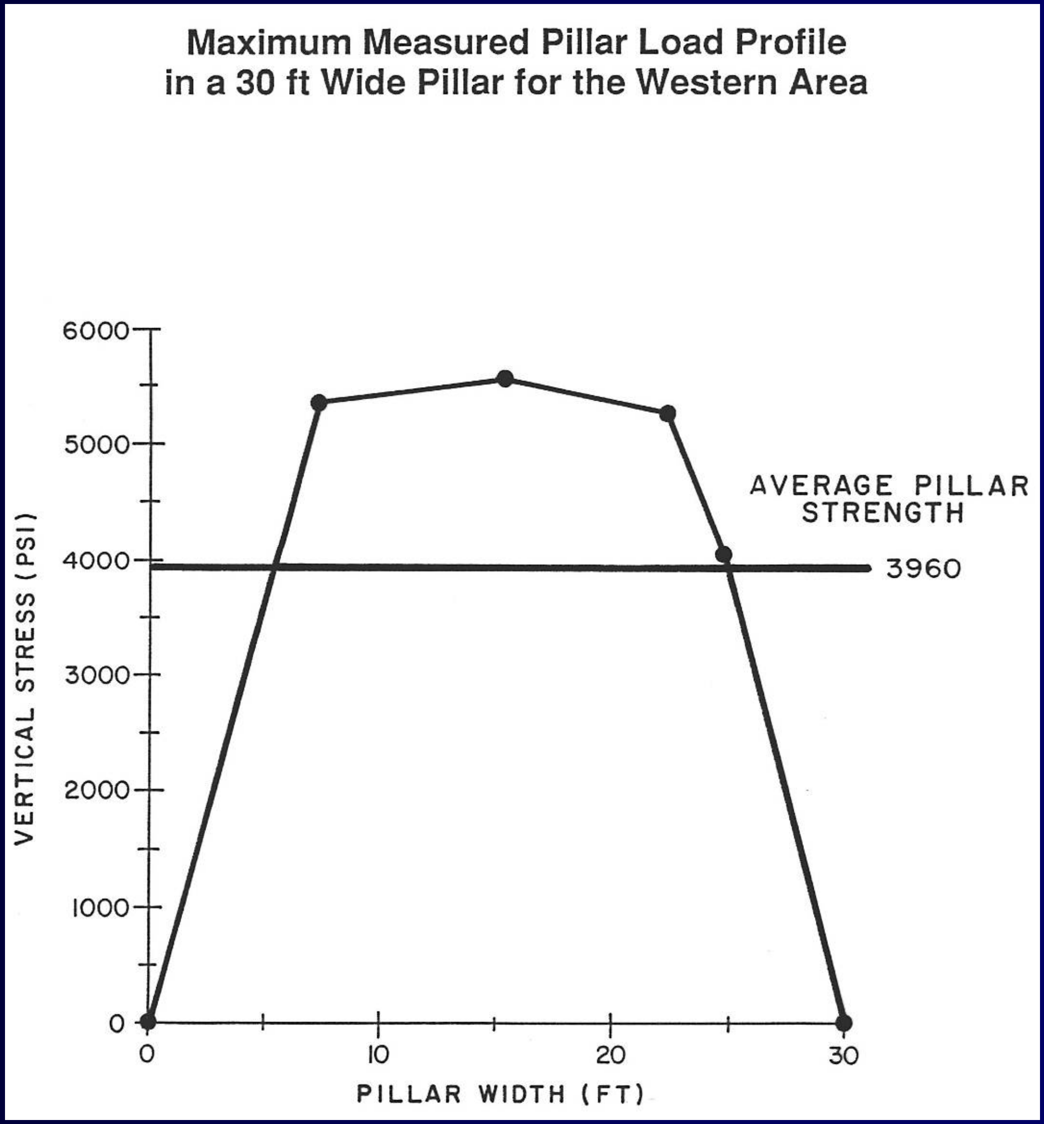


Installing Fiber Optic Roof Sag Meters to Measure Gateroad Pillar Performance—SUFCO Mine

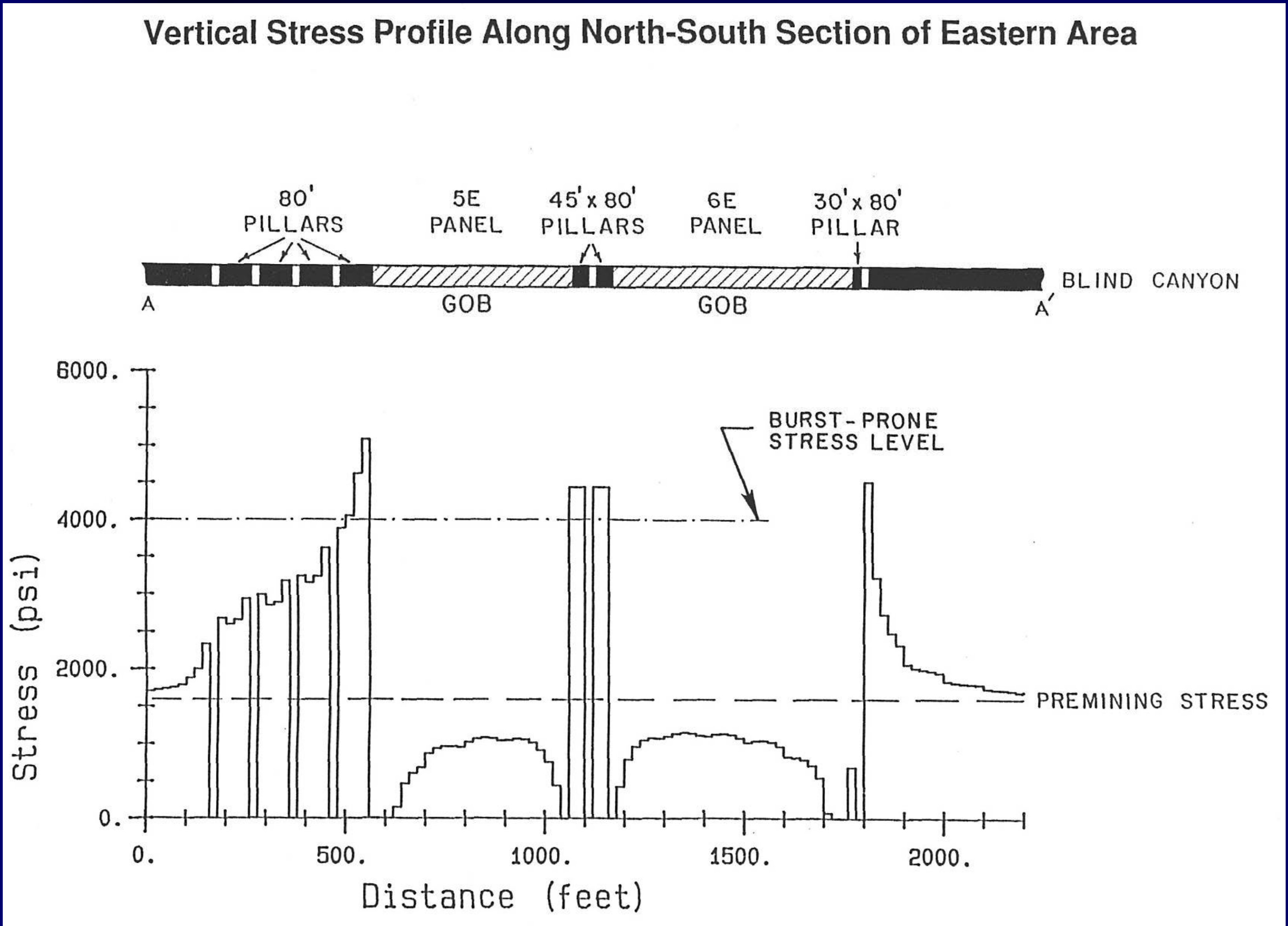
Installing Fiber Optic Borehole Pressure Cells—SUFCO Mine



Example of Measured Stress Profile through Yield Pillar—Deer Creek Mine



Example of Modeled Stress Profile—Deer Creek Mine

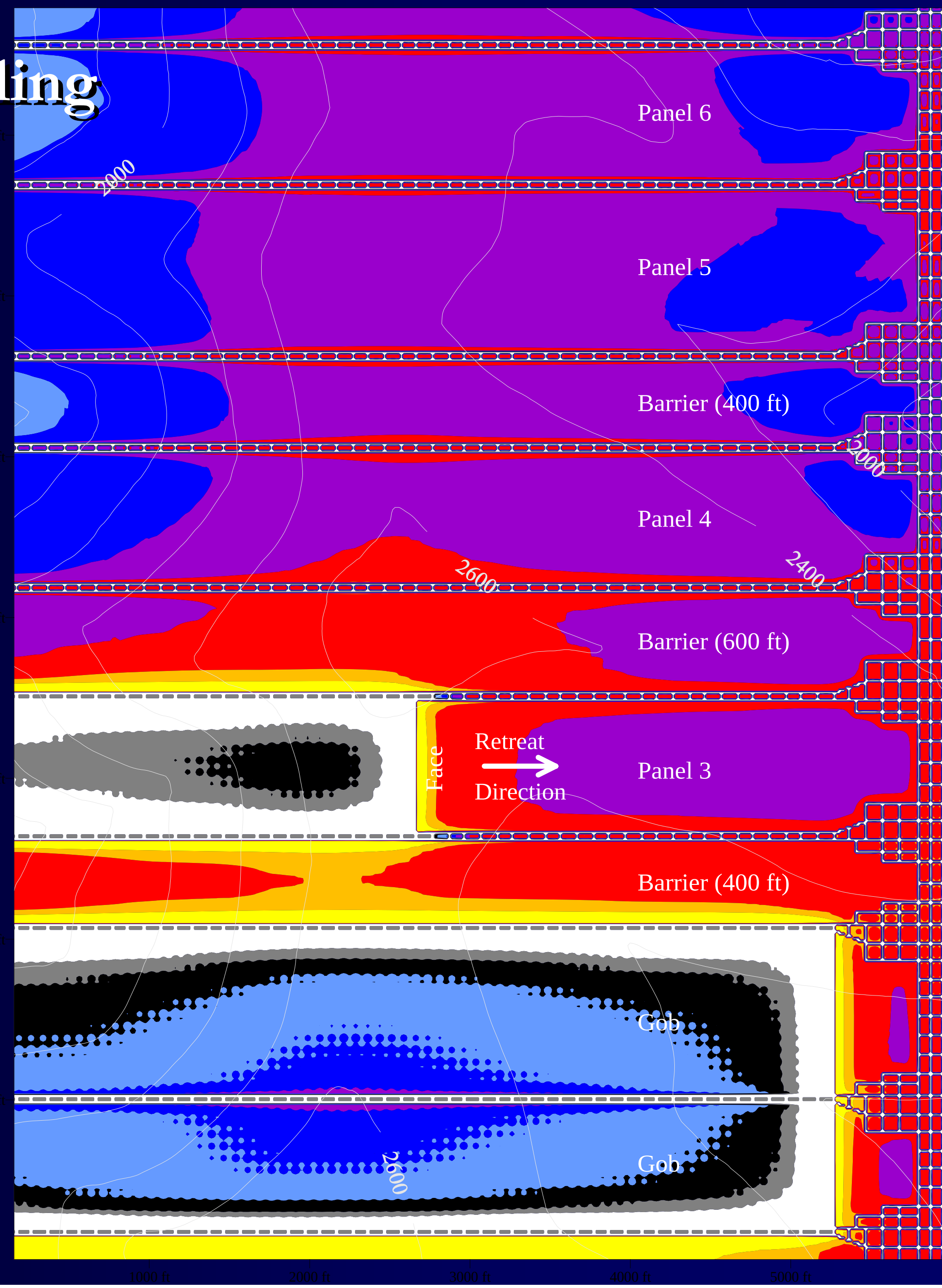


Example of Stress Modeling

Displacement Discontinuity Model

Vertical Stress

- 5000 psi
- 4000 psi
- 3000 psi
- 2500 psi
- 2000 psi
- 1500 psi
- 1000 psi
- 500 psi
- 0 psi



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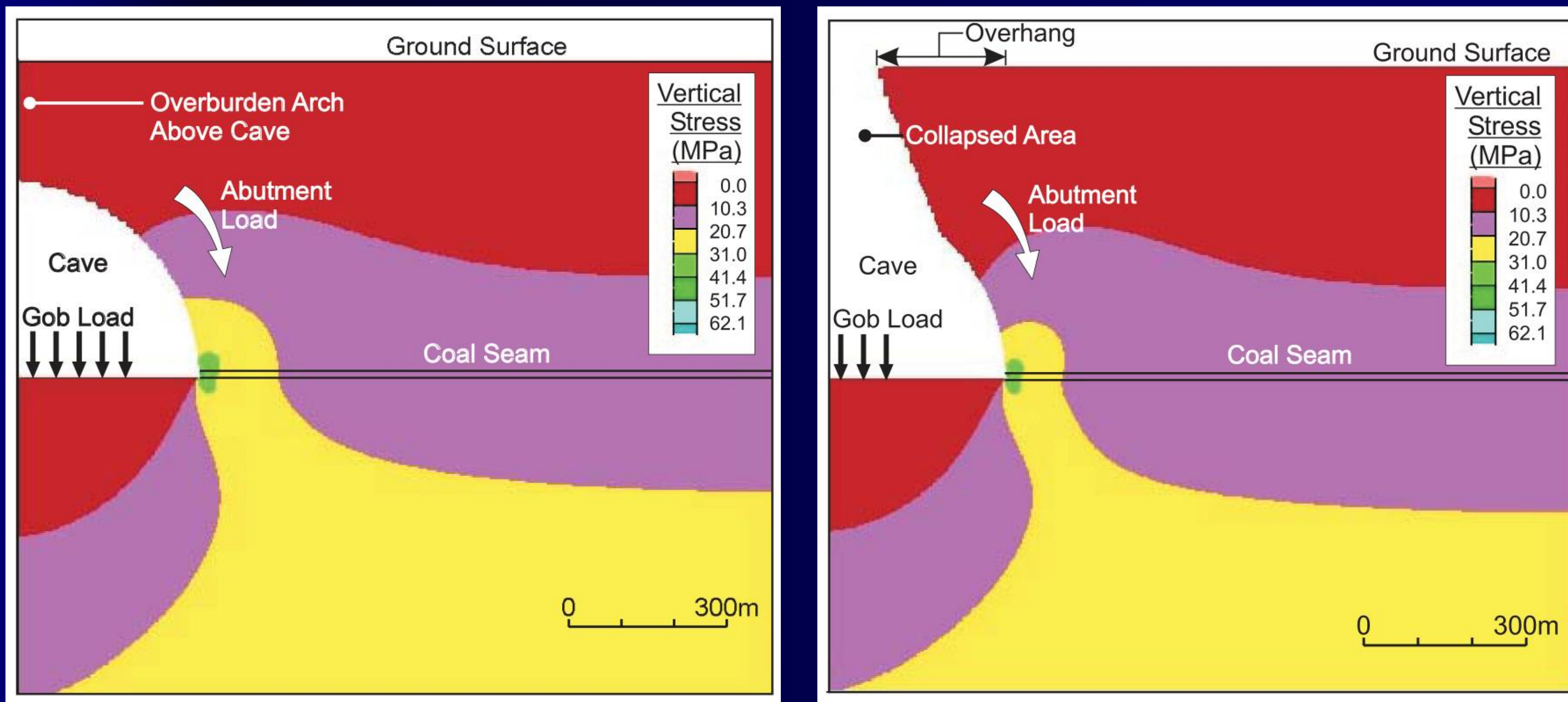
Example of Stress and Displacement Modeling

2D Finite Difference Model

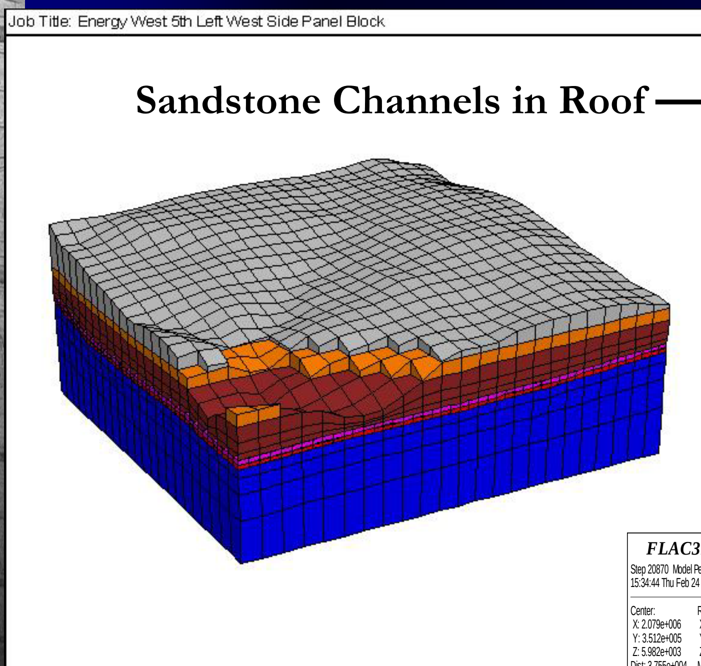
FLAC

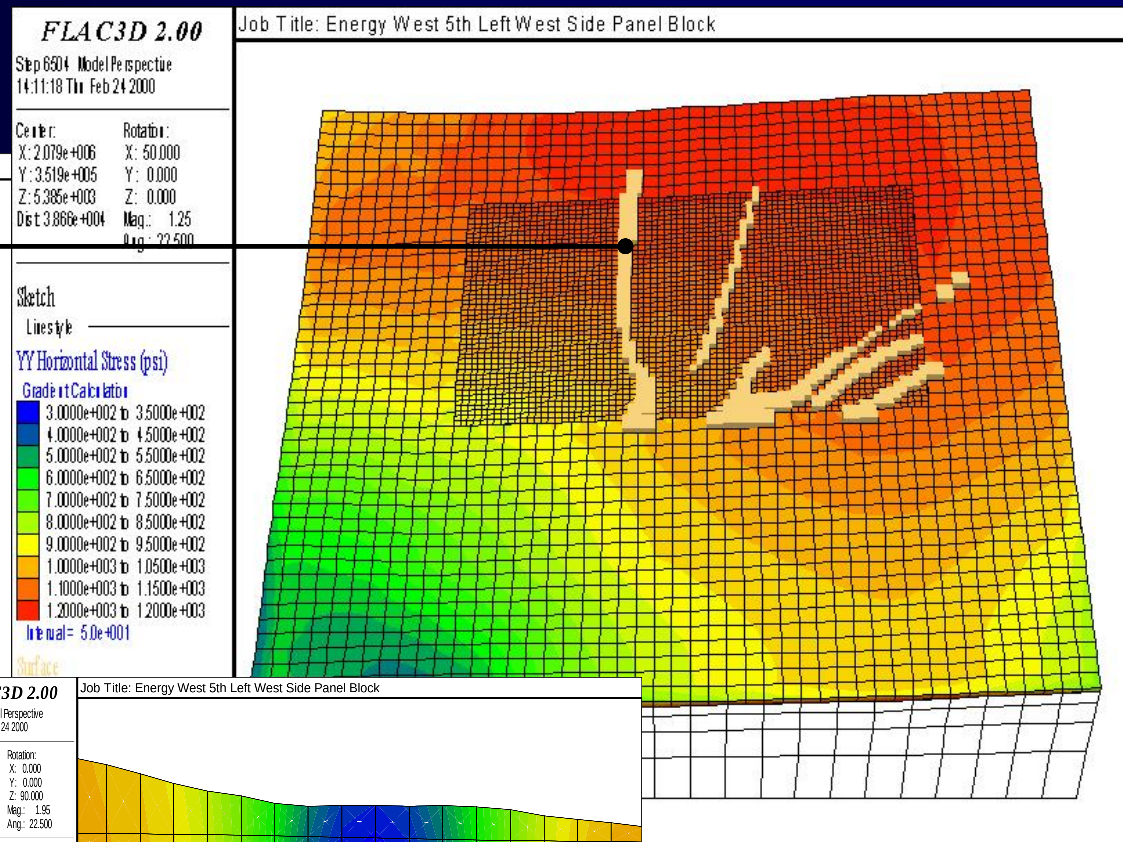


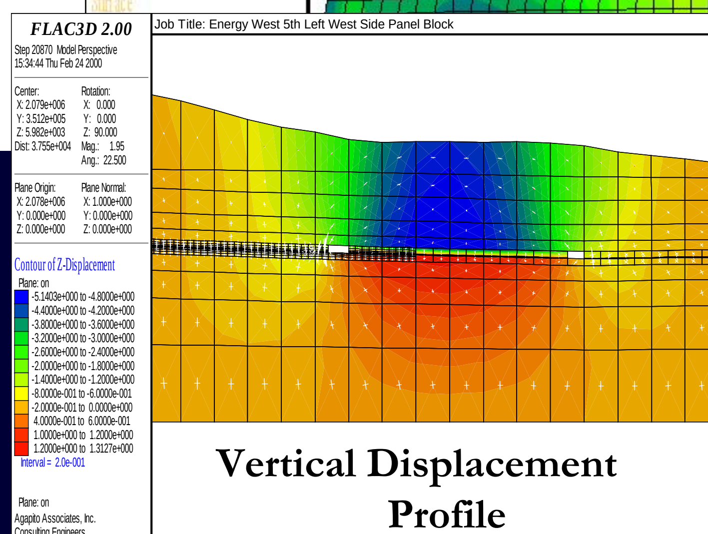
Simulation of Longwall Side-abutment Stress Arch

Example of Stress and Displacement Modeling

3D Finite Difference Model
FLAC3D







Simulation of Retreat Stresses and Subsidence

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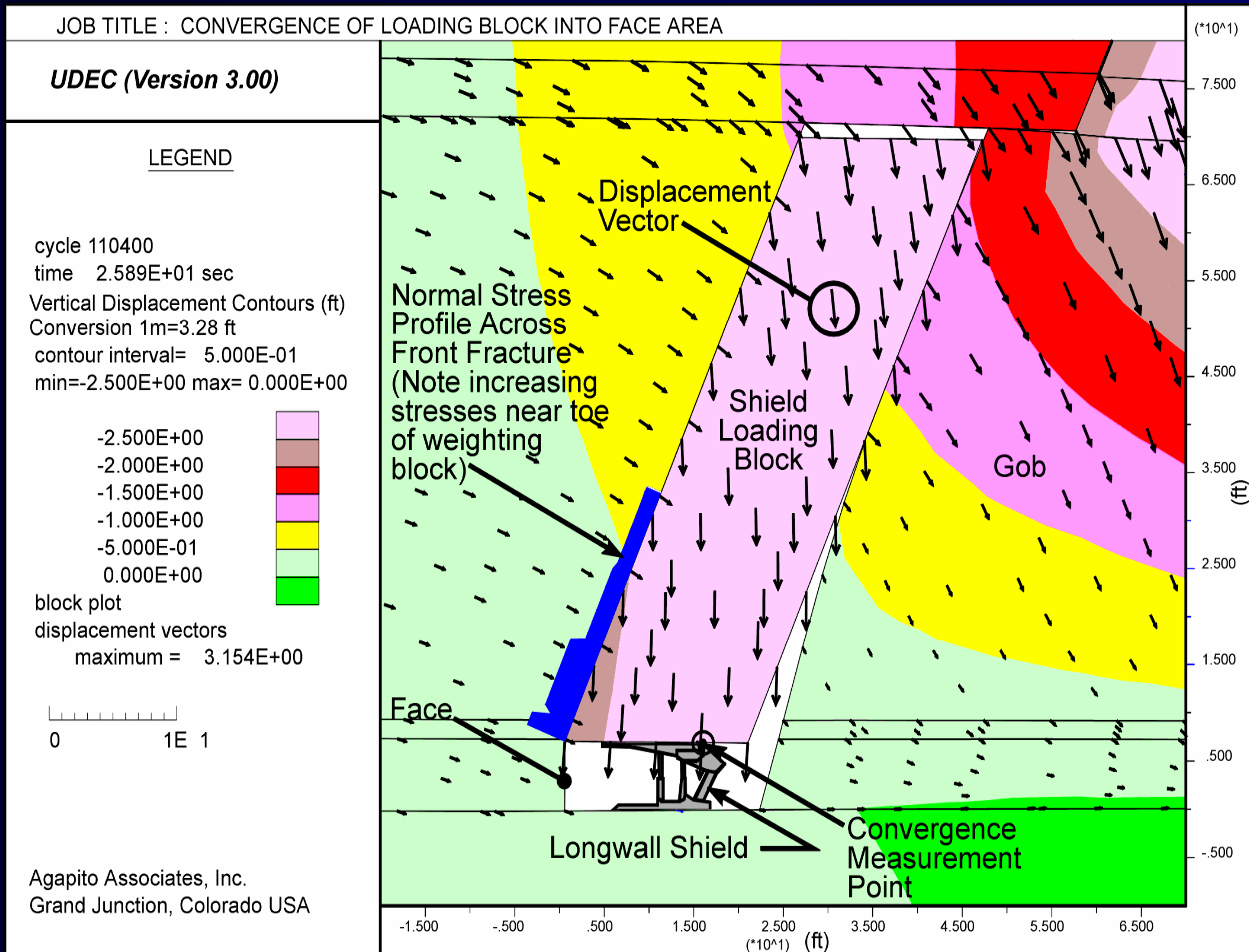
Example of Longwall Face Loading Modeling

2D Distinct Element Model

UDEC



Why yield pillars instead of rigid pillars?

Rigid Pillar

At risk for bumping under high stress conditions

Yield Pillar

Yielding prevents dangerous build-up of strain energy

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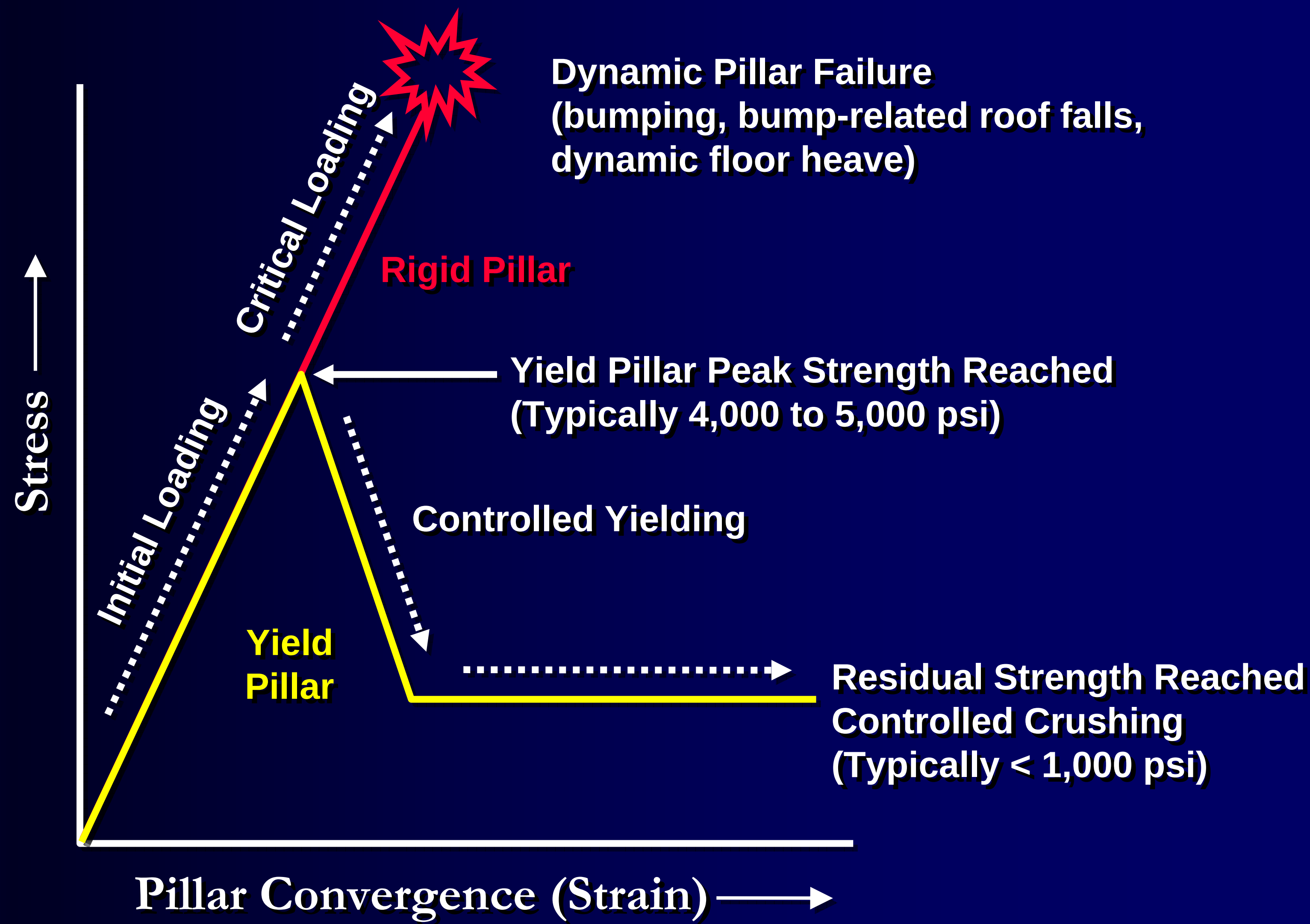
Gateroad Pillar Loading Simulated in Models

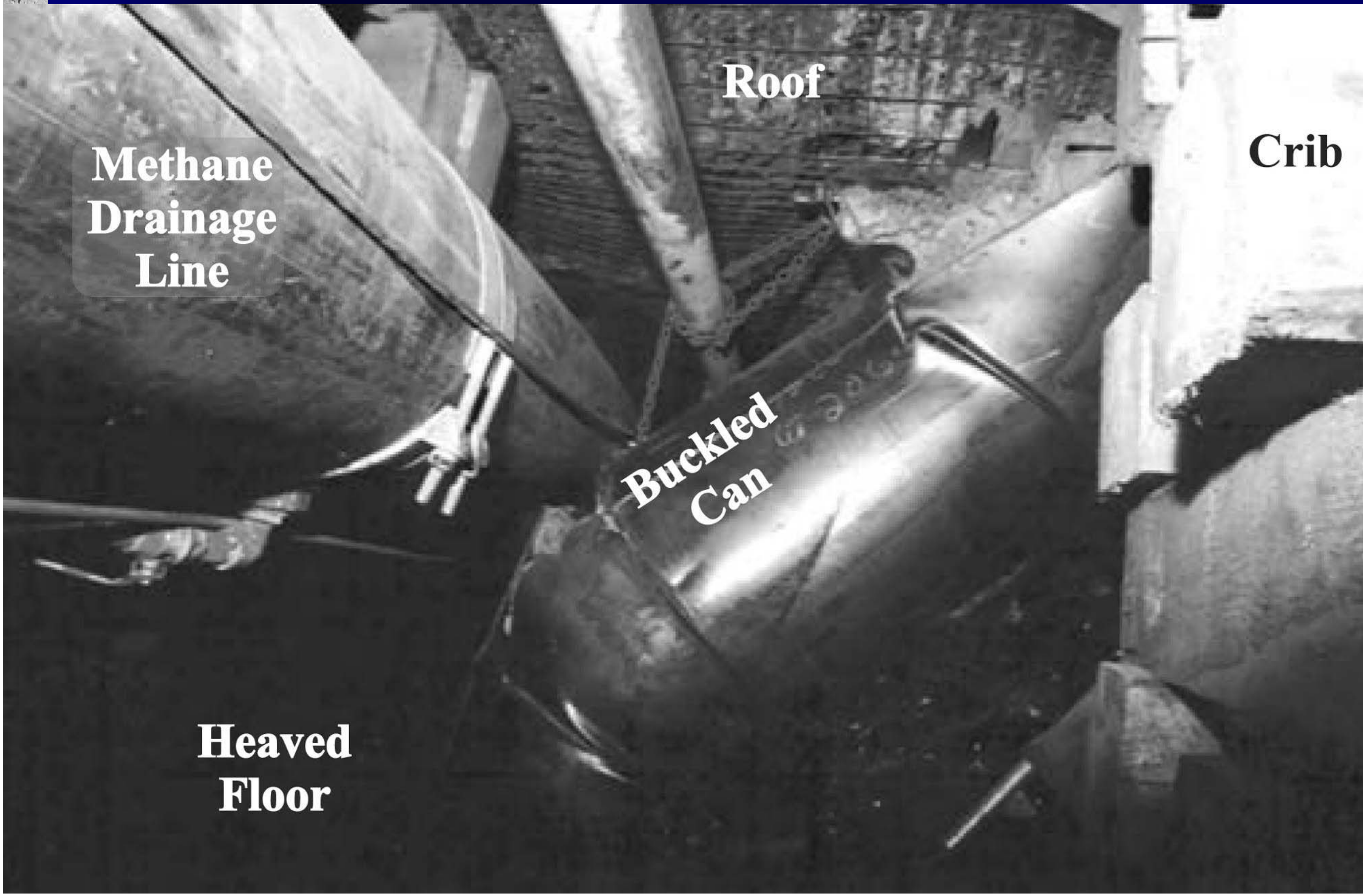



Bump in Overloaded Rigid Pillar


Bump at Base of Rigid Pillar

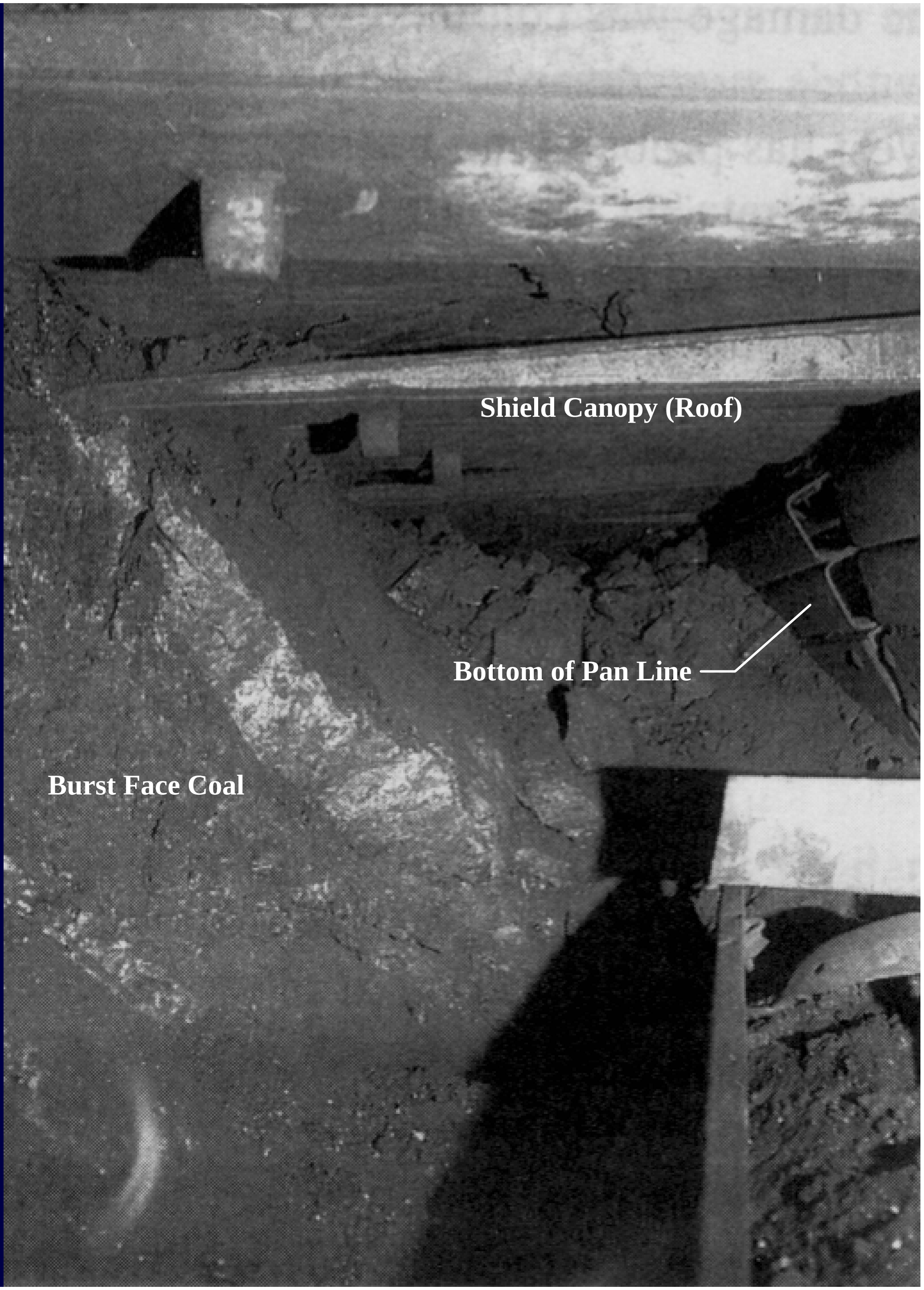
Dynamic Floor Heave with Rigid Pillars

Rigid Pillar Bump and Dynamic Floor Heave

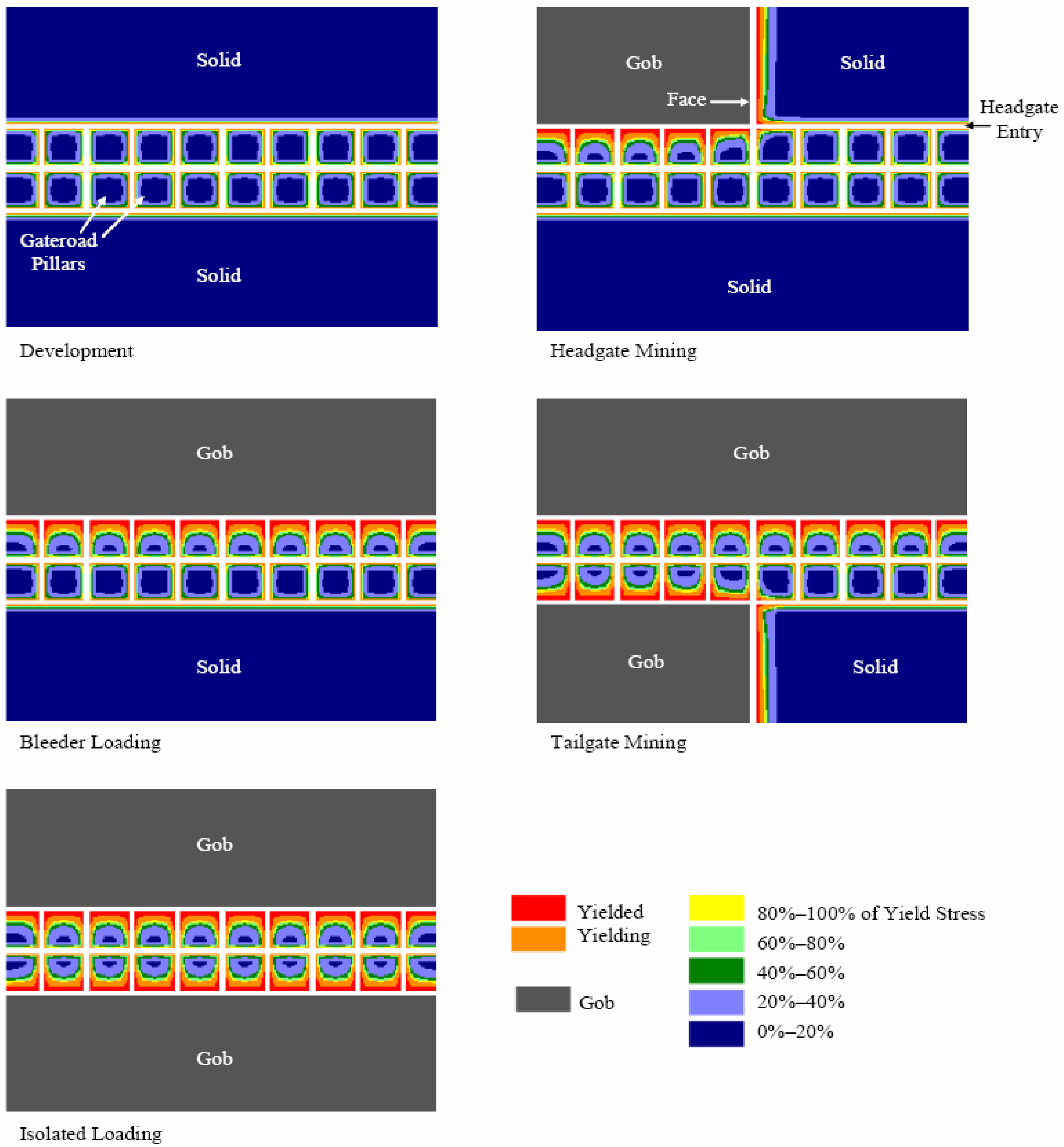


Longwall Face Burst

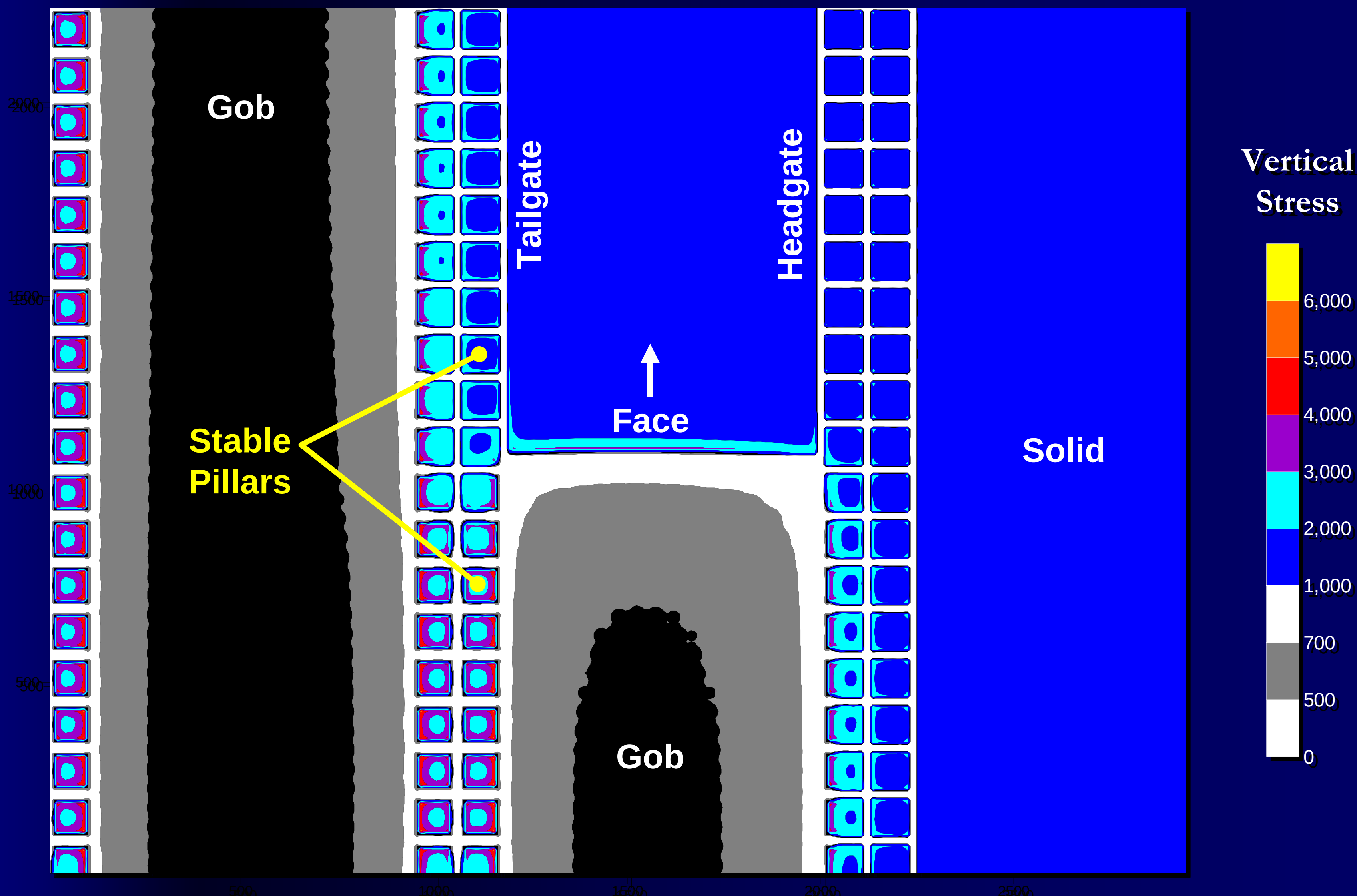
Can be triggered by gateroad pillar bursting



Simulated Stages of Gateroad Pillar Loading



Rigid Gateroad Pillars at Depth—3 Entry



1,000 ft Deep

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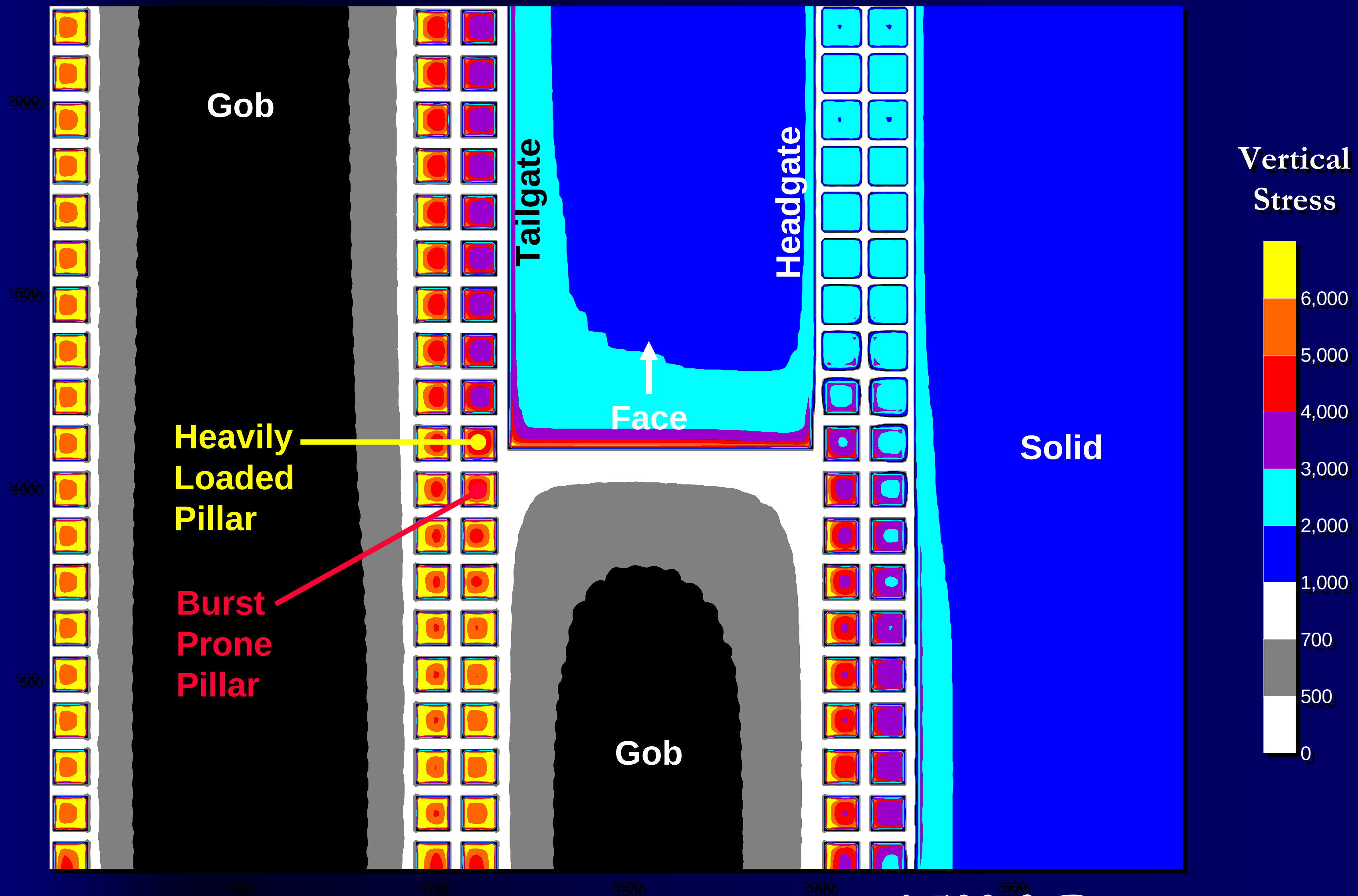
Rigid Gateroad Pillars at Depth—3 Entry



1,500 ft Deep

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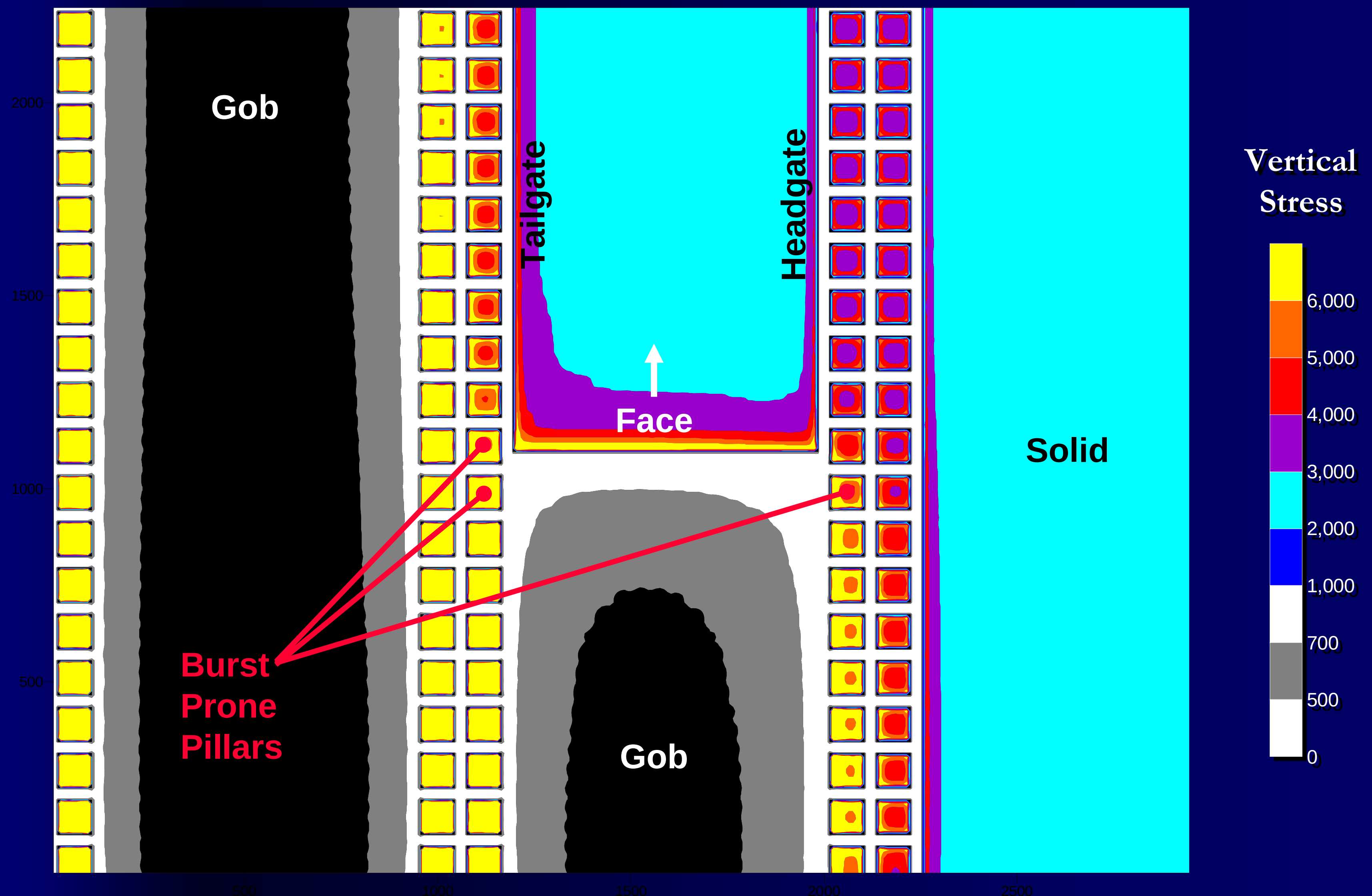
Rigid Gateroad Pillars at Depth—3 Entry



2,000+ ft Deep

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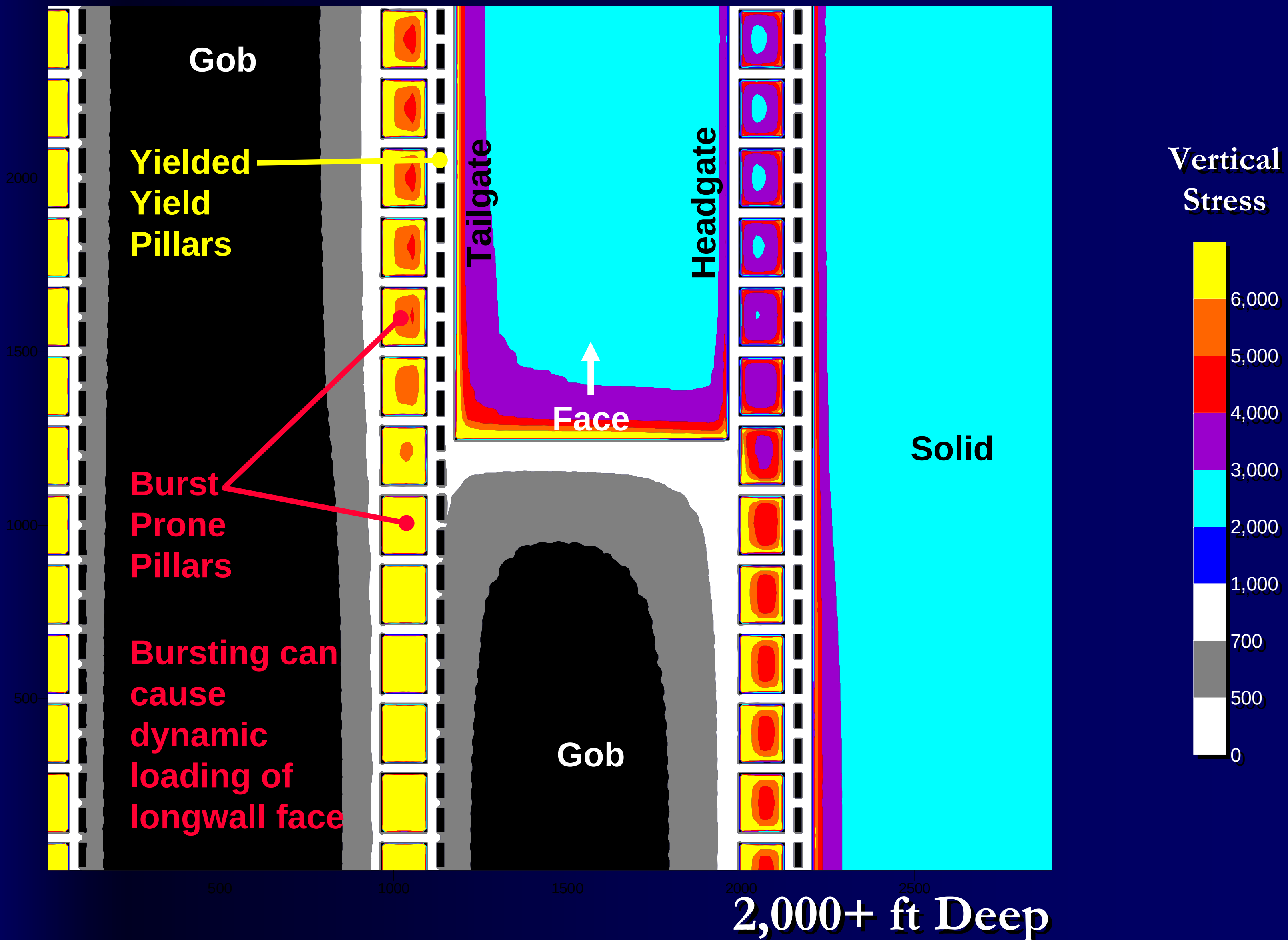
Yield-Abutment Gateroad System at Depth



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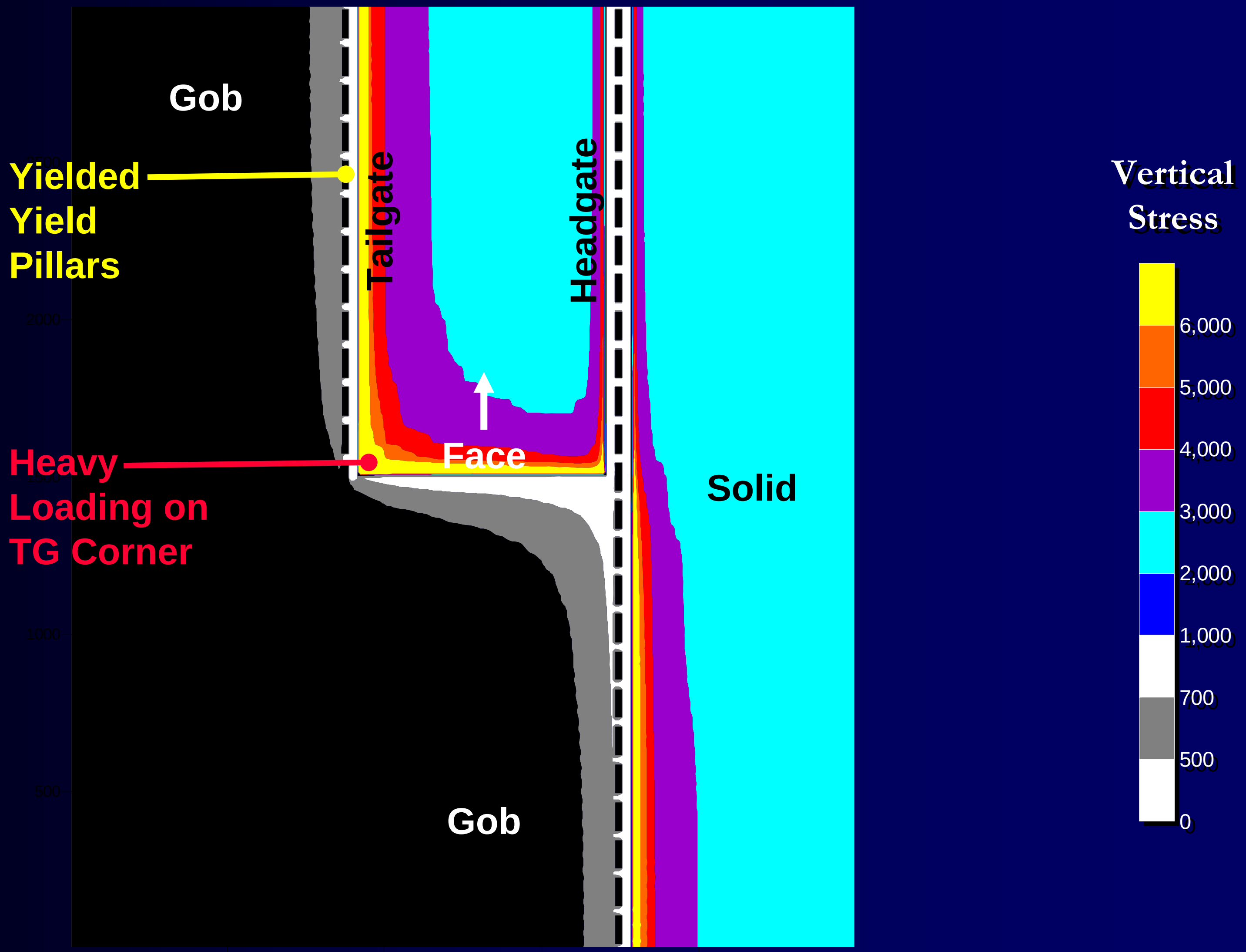
Two-Entry Yield Pillar Gateroad at Depth



2,000+ ft Deep

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Why a two-entry yield pillar system instead of three-entry yield pillar system ?

Two-Entry and Three-Entry Yield Pillar Gateroad Systems

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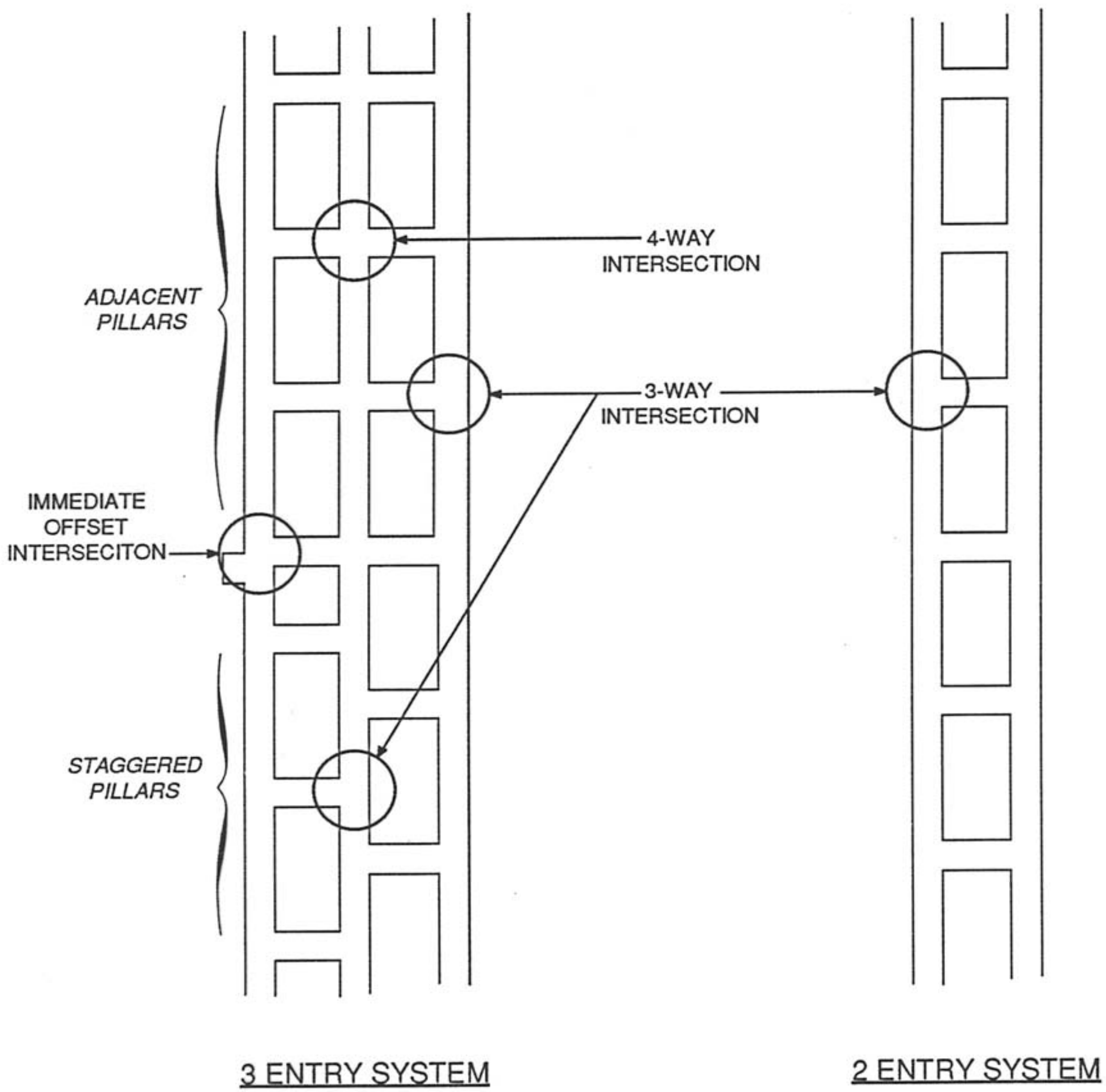
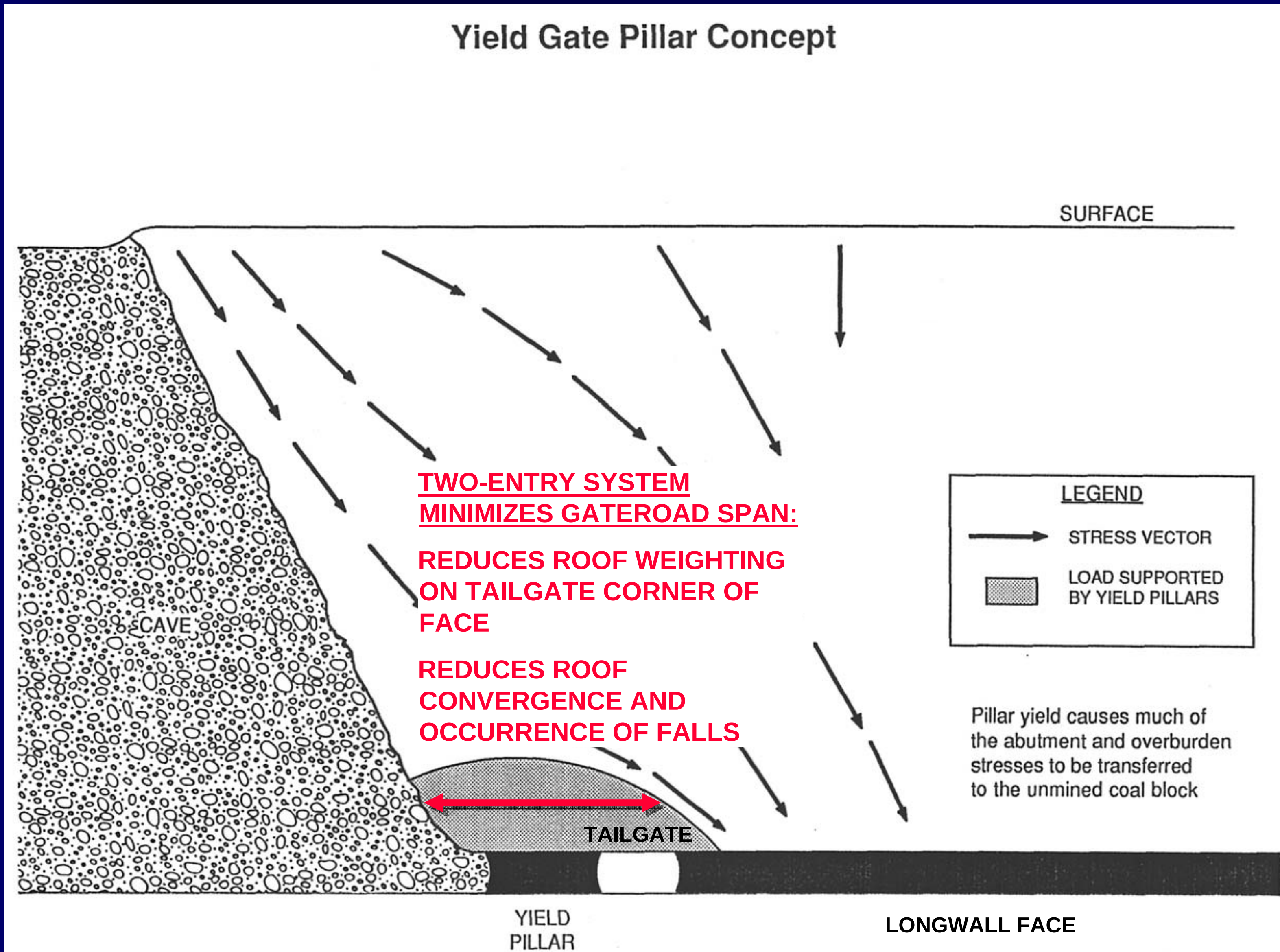
Three- and Four-Way Intersections



Two-Entry Yield Pillar Gateroad at Depth



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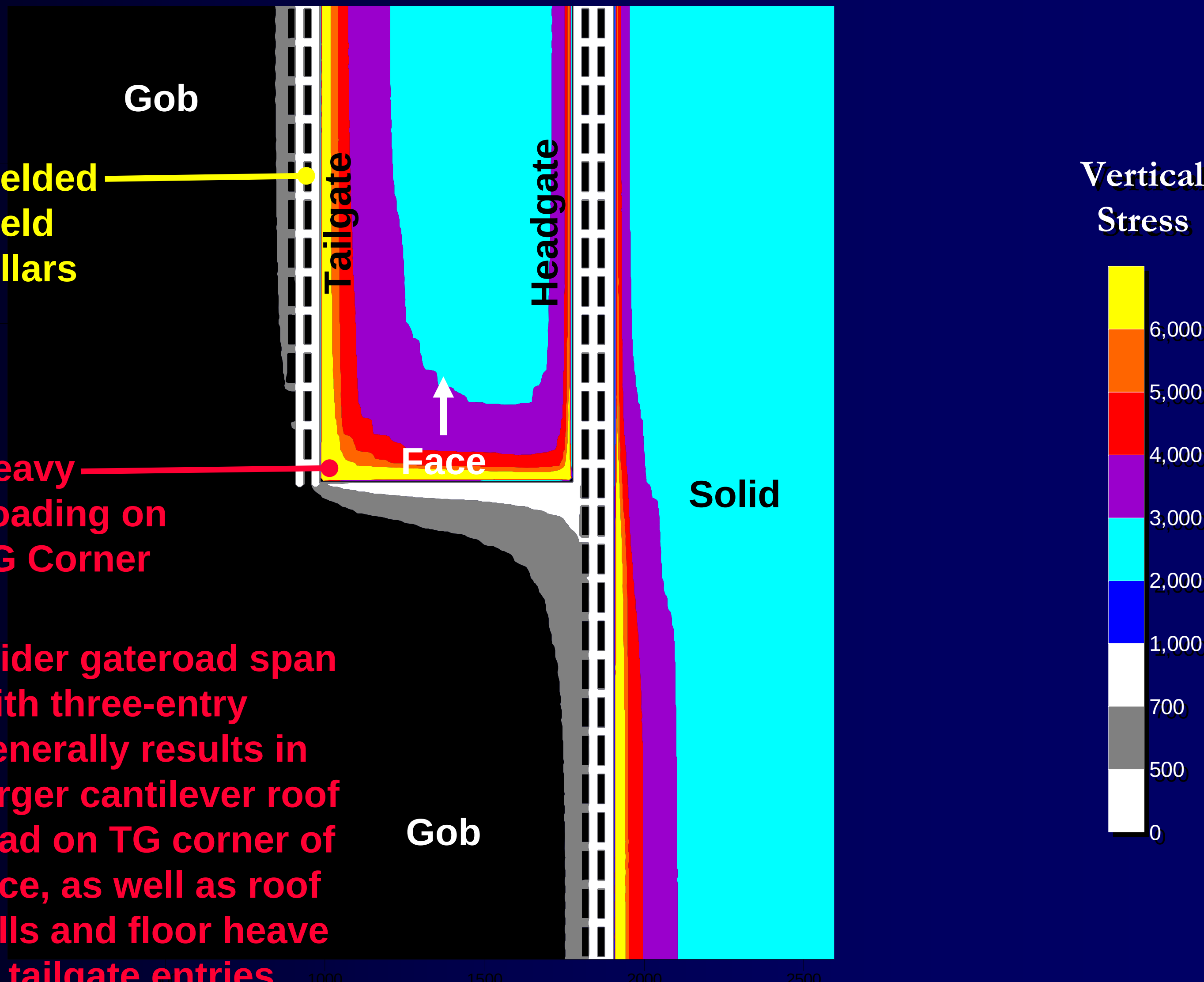
Three-Entry Yield Pillar Gateroad at Depth



Wider gateroad span with three-entry generally results in larger cantilever roof load on TG corner of face, as well as roof falls and floor heave in tailgate entries

2,000+ ft Deep

Two- versus Three-Entry Yield Pillar Systems

- Three-entry system proved problematic at most mines:

  Sunnyside

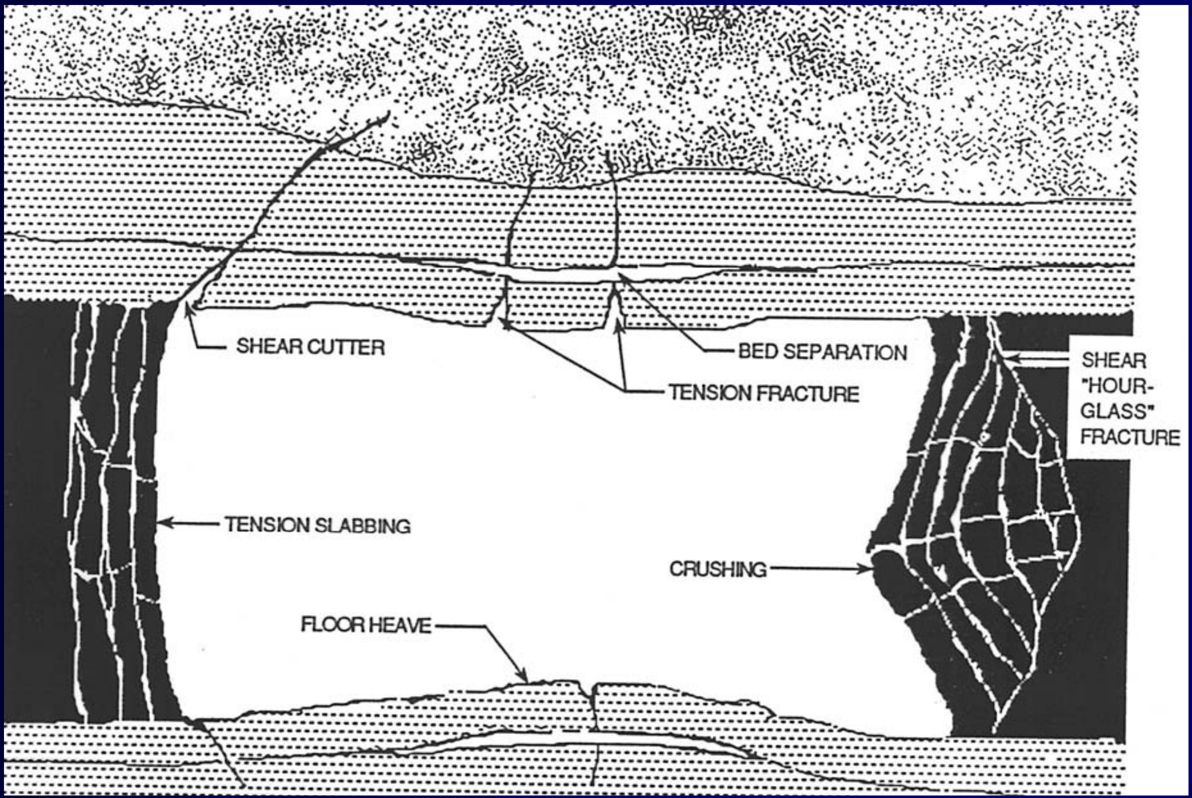
  Cottonwood

  Deer Creek

  Aberdeen

  Dugout

  Star Point



Conditions typically made worse with three entries

What does the future hold for Western U.S. longwall design?

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Alternative Longwall Designs

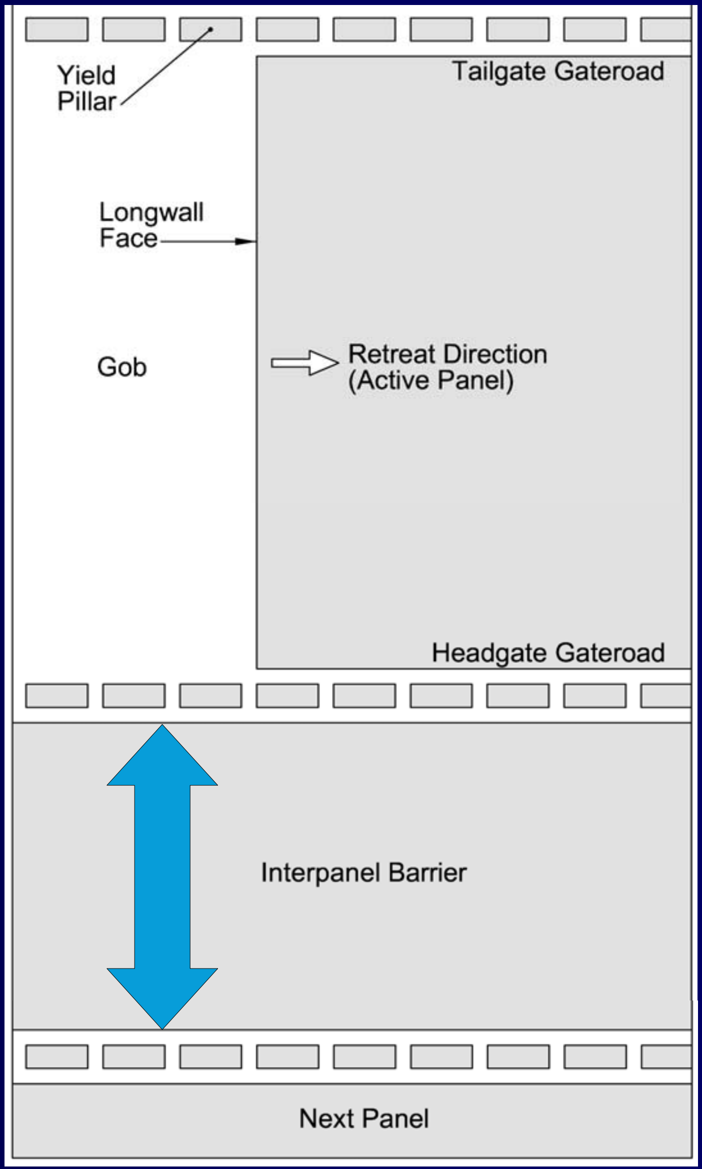
Panel-Barrier Gateroad System

- Uses an interpanel barrier between every panel
- Preserves first-panel conditions
- An attractive alternative when crosscuts become too long for adequate face ventilation or economic development
- Advantages:

  (1) Allows mining safely under extreme bump prone conditions

  (2) Flexibility to isolate individual panels with squeeze stoppings

  (3) Improved ventilation



Alternative Longwall Designs

Panel-Barrier Gateroad System

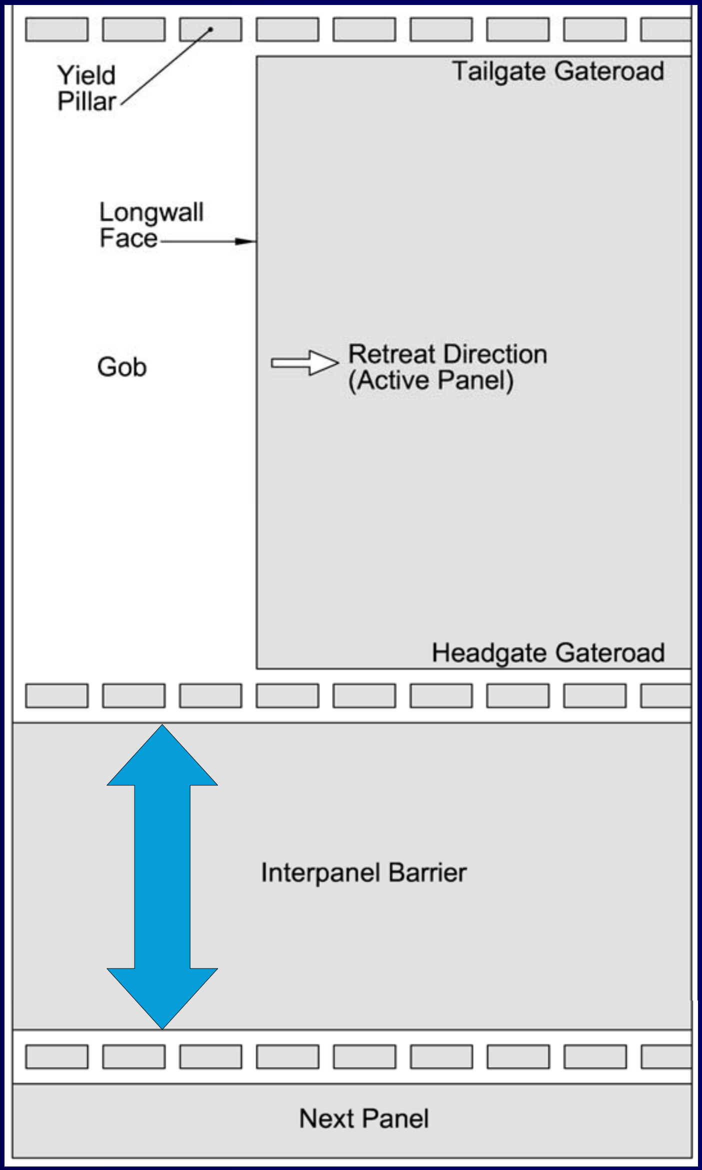
Disadvantages:

(1) Doubling of gateroad footages

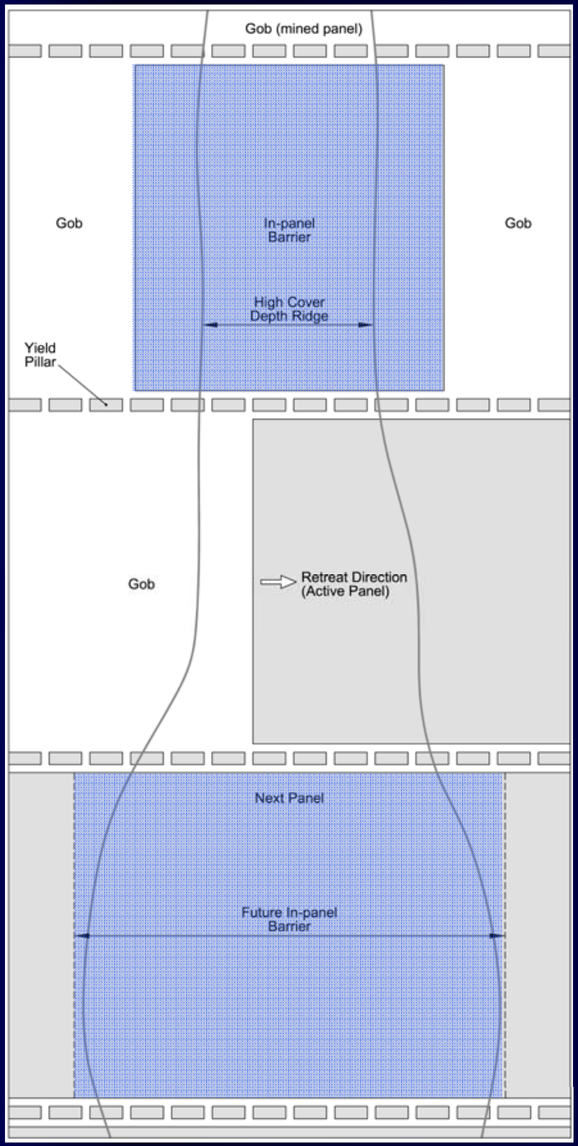
(2) Increase mains and bleeder development

(3) Sterilization of large amounts of longwall reserves

(4) Complicates multiseam mining



Alternative Longwall Designs

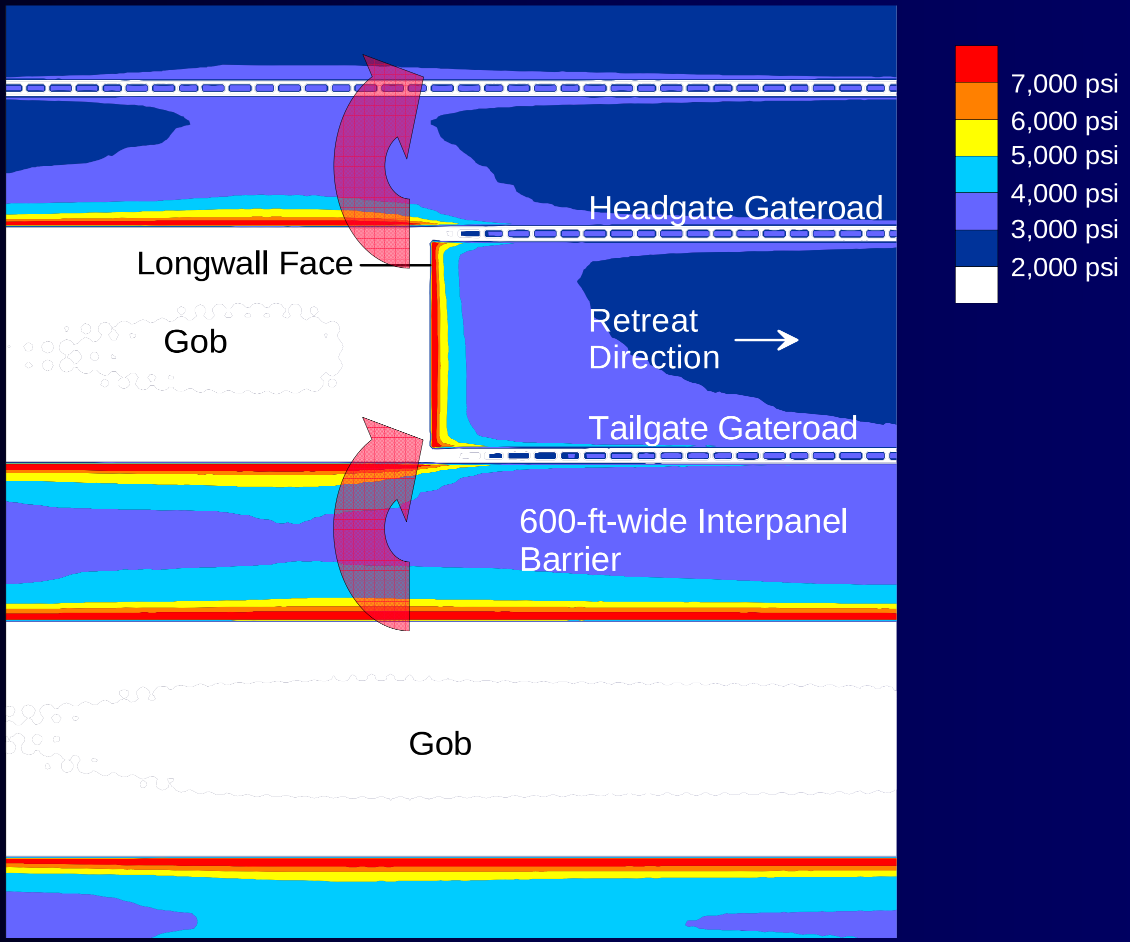


"Checkerboard" Panel Layout

- Mining every other panel under deep cover
- Limited applications…mainly to constrained layouts subject to variable cover

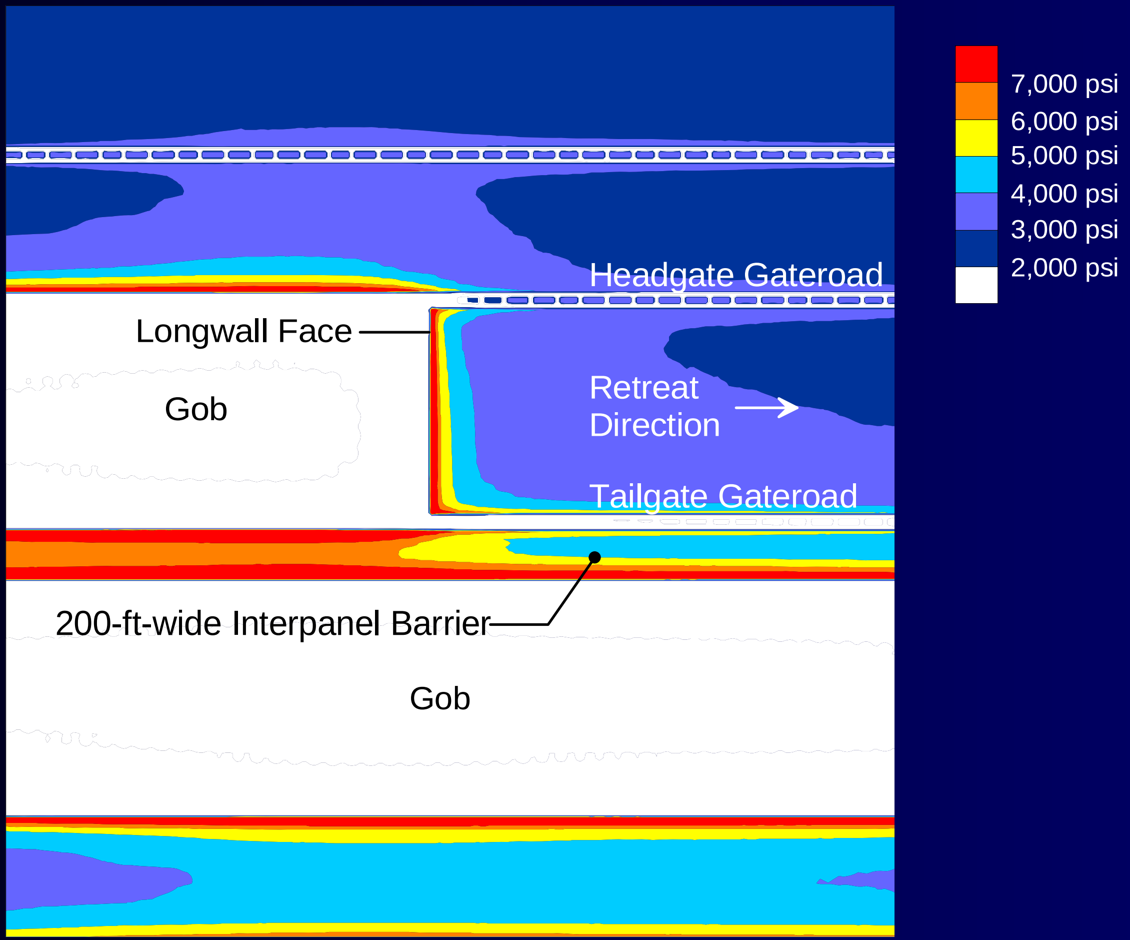
Alternative Longwall Designs

Interpanel Barrier Sizing



Alternative Longwall Designs

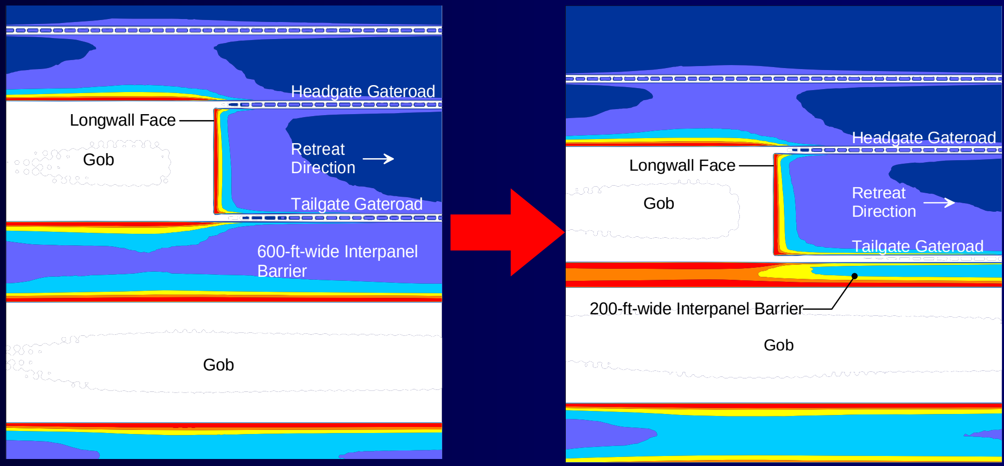
Interpanel Barrier Sizing



Alternative Longwall Designs

Interpanel Barrier Sizing

- ✓ Simulation shows that average tailgate corner vertical stress levels increase by approximately 1,000 psi by reducing a typical barrier from 600- to 200-ft-wide



- ✓ Results indicate that 400- to 600-ft-wide barriers can maintain tailgate stresses at historically safe Western U.S. levels when mining 2,500 to 3,000 ft deep

Is there an optimal gateroad solution for deep Western U.S. longwall mines…

Conclusions

- No gateroad system is optimal
- The two-entry yield pillar system is demonstrated by science and experience to be the best tradeoff for deep Western U.S. longwall mining
- It is a system used out of necessity to control the ground in a highly bump prone environment
- The two-entry yield pillar system has significantly reduced the risk of pillar bursting, bump-related roof falls, and floor heave and has made safe longwall mining possible at depths reaching more than 2,500 ft

Conclusions

- Three-entry yield pillar systems are not a good replacement for two-entry systems
- Three-entry yield pillar systems normally result in problematic roof and floor conditions
- Experience has shown that the added advantage of having a third entry in the tailgate is normally lost because of excessive roof and floor instability

Conclusions

- Rigid pillar systems risk pillar bumping in both the tailgate and headgate at depth
- Pillar bumping, even in the gob, can be hazardous in the gateroads and on the longwall face
- Bumping cannot necessarily be prevented by making a rigid pillar larger
- Developing very large rigid pillars is operationally difficult
- When rigid pillars become very large, interpanel barriers become an option

Conclusions

- Interconnecting crosscuts in large interpanel barriers are not practical and increase geotechnical and ventilation risks

The Future

- The two-entry yield pillar system eventually may not be able to protect the longwall face from severe abutment loads at future mining depths (>3,000 ft)
- Alternative systems will most likely be required
- The panel-barrier system is being used by three Utah mines

Non-Geotechnical Issues

- The two-entry yield pillar system was used at Cyprus Shoshone Mine (formerly Carbon County Coal Co.), Hanna, Wyoming, to manage spontaneous combustion events – a report justifying two entry longwall development was submitted to MSHA early 1988 (?)
- Sunnyside Mine successfully used squeeze stoppings in conjunction with two entry longwall gates to isolate individual longwall panel gobs to control methane and spontaneous combustion

Thank you.