Longwall Caving in Potash Mining – Geomechanical Assessment of Damage and Barrier Integrity

Wolfgang Minkley, Christoph Lüdeling

Institut für Gebirgsmechanik, Leipzig

50th ARMA Symposium, Houston
29 June 2016
Sketch of Longwall Caving: Chances and Challenges

Overburden, potential aquifer

Hydraulic barrier

Potash seam

Rock salt
Sketch of Longwall Caving: Chances and Challenges

Overburden, potential aquifer

Hydraulic barrier

High recovery longwall extraction

Rock salt
Sketch of Longwall Caving: Chances and Challenges

Collapsing goaf

Subsidence, fractures and stress redistribution in protective strata
Sketch of Longwall Caving: Chances and Challenges

Collapsing goaf

Subsidence, fractures and stress redistribution in protective strata

Stress concentration at longwall face
Contents

1 Introduction

2 Rock Bursts: Longwall Caving vs. Room-and-Pillar

3 Integrity of the Hydraulic Barrier

4 Conclusions
Panels are extracted completely using mechanised mining at advancing longwall face, allowing roof to collapse behind face.

Only (barrier) pillars between panels and around access drifts remain.

High extraction ratio (above 70%–80%), comparatively simple mine layout.

Requires reasonably uniform seam geometry.

Large surface subsidence: Excavation collapse completely.

Longwall caving is common in coal mining, but rare in salt and potash compared to room-and-pillar:

- Historically in Alsace (France) and Navarra (Spain).
- Presently around Soligorsk (six mines in Belarus).
1 Introduction

2 Rock Bursts: Longwall Caving vs. Room-and-Pillar

3 Integrity of the Hydraulic Barrier

4 Conclusions
• Rock bursts mostly in carnallite: brittle failure
• After failure of one pillar (caused by blasting or creep rupture), chain reaction of pillar collapses destroys complete field
• Large seismic energy release $\sim$ Overburden weight $\times$ subsidence
  Local magnitudes up to $M_L = 5.6$
• Geomechanical basis: Softening of the rock weakens slender pillars
• For squat pillars, mechanism involves loss of adhesive resistance on bedding planes between pillar and hanging/footwall
  $\Rightarrow$ sudden loss of confining pressure and load-bearing capacity

[Minkley, Lüdeling 2015]
Rock Bursts in Room-and-Pillar Mines

- Rock bursts mostly in carnallite: brittle failure
- After failure of one pillar (caused by blasting or creep rupture), chain reaction of pillar collapses destroys complete field
- Large seismic energy release: $\text{Overburden weight} \times \text{subsidence}$
  Local magnitudes up to $M_L = 5.6$
- Geomechanical basis: Softening of the rock weakens slender pillars
- For squat pillars, mechanism involves loss of adhesive resistance on bedding planes
  $\implies$ sudden loss of confining pressure and load-bearing capacity

[Minkley, Lüdeling 2015]
Rock Bursts in Room-and-Pillar Mines

- Rock bursts mostly in carnallite: brittle failure
- After failure of one pillar (caused by blasting or creep rupture), chain reaction of pillar collapse destroys complete field
- Large seismic energy release: $\sim \text{Overburden weight} \times \text{subsidence}$
- Local magnitudes up to $M_L = 5.6$.
- Geomechanical basis: Softening of the rock weakens slender pillars
- For squat pillars, mechanism involves loss of adhesive resistance on bedding planes
  $\Rightarrow$ sudden loss of confining pressure and load-bearing capacity

[Minkley, Lüdeling 2015]
Rock Bursts in Room-and-Pillar Mines

- Rock bursts mostly in carnallite: brittle failure
- After failure of one pillar (caused by blasting or creep rupture), chain reaction of pillar collapses destroys complete field
- Large seismic energy release: \[ \text{Overburden weight} \times \text{subsidence} \]
  Local magnitudes up to \( M_L = 5.6 \)
- Geomechanical basis: Softening of the rock weakens slender pillars
- For squat pillars, mechanism involves loss of adhesive resistance on bedding planes
  \( \Rightarrow \) sudden loss of confining pressure and load-bearing capacity

[Minkley, Lüdeling 2015]
• Pillar failure is not main source of seismicity: Contour failure at the longwall face
• Energy release is limited – magnitudes $M_L \lesssim 3$
• Pillar failure is not main source of seismicity: Contour failure at the longwall face

• Energy release is limited – magnitudes $M_L \lesssim 3$

• Brittle rocks more dangerous (in particular carnallite – stress at face is almost uniaxial)

• If shear resistance at hanging and footwall is lost, seam can jump into the panel $\Rightarrow$ "translatory" rock burst

• Similar effect: contour failure at carnallite pillars known in carnallite mining under high-stress conditions
Rock Bursts in Longwall

- Pillar failure is not main source of seismicity: Contour failure at the longwall face
- Energy release is limited – magnitudes $M_L \lesssim 3$
- Brittle rocks more dangerous (in particular carnallite – stress at face is almost uniaxial)
- If shear resistance at hanging and footwall is lost, seam can jump into the panel
  \implies “translatory” rock burst
- similar effect: contour failure at carnallite pillars known in carnallite mining under high-stress conditions
Rock Bursts in Longwall

- Pillar failure is not the main source of seismicity: Contour failure at the longwall face
- Energy release is limited – magnitudes $M_L \lesssim 3$
- Brittle rocks more dangerous (in particular carnallite – stress at face is almost uniaxial)
- If shear resistance at hanging and footwall is lost, seam can jump into the panel $\Rightarrow$ “translatory” rock burst
- Similar effect known in carnallite mining under high-stress conditions

C. Lüdeling, IfG Leipzig

Longwall Caving in Potash Mining
Houston, 29/06/2016
Distinct-element code UDEC (Itasca)

1. Constitutive models for salt rocks and bedding planes (developed by IfG):
   - Nonlinear strength curves
   - Strain-dependent softening
   - Velocity-dependent shear behaviour on bedding planes

[Minkley, Mühlbauer 2007]
Distinct-element code UDEC (Itasca)

1. Constitutive models for salt rocks and bedding planes (developed by IfG):
   - Nonlinear strength curves
   - Strain-dependent softening
   - Velocity-dependent shear behaviour on bedding planes
   [Minkley, Mühlbauer 2007]

2. Discontinuous modelling: Split rock mass into Voronoi blocks
   [Minkley, Knauth 2014]
   - Fractures, shear displacement along boundaries
   - Fluid motion on grain boundaries – coupled hydromechanical simulation
Distinct-element code UDEC (Itasca)

1. Constitutive models for salt rocks and bedding planes (developed by IfG):
   - Nonlinear strength curves
   - Strain-dependent softening
   - Velocity-dependent shear behaviour on bedding planes

[Minkley, Mühlbauer 2007]

2. Discontinuous modelling: Split rock mass into Voronoi blocks
   - Fractures, shear displacement along boundaries
   - Fluid motion on grain boundaries – coupled hydromechanical simulation

[Minkley, Knauth 2014]

3. Dynamic (undamped) analysis for violent events
Results - Translatory Burst

carnallite seam
Results - Translatory Burst

C. Lüdeling, IfG Leipzig

Longwall Caving in Potash Mining

Houston, 29/06/2016
Results - Translatory Burst

carnallite seam
And now for...

1 Introduction

2 Rock Bursts: Longwall Caving vs. Room-and-Pillar

3 Integrity of the Hydraulic Barrier

4 Conclusions
Polycrystalline viscous solid:

- Impermeable grains fused at faces
- No connected pore space
- Fluids only move on boundaries
- Undisturbed rock salt impermeable (cf. gas outbursts)
Fluid Transport in Salt Rocks

Polycrystalline viscous solid:
- Impermeable grains fused at faces
- No connected pore space
- Fluids only move on boundaries
- Undisturbed rock salt impermeable (cf. gas outbursts)

Boundaries closed by normal pressure $\sigma_N$
Fluid pressure must open boundaries
$\Rightarrow$ *percolation threshold* $p \geq \sigma_{\text{min}}$
$\Rightarrow$ directed transport:
  - orthogonal to minor principal stress
$\Rightarrow$ dominant in far field
near field: damage – fractures and microcracks
Inflow Paths: Extension and Fractures

- no subsidence
- large subsidence

- barrier pillar or edge of panel
- mined-out longwall panel

water-bearing overburden
Inflow Paths: Extension and Fractures

- Water-bearing overburden
- No subsidence
- Large subsidence
- Extension
- Fracture zone
- Barrier pillar or edge of panel
- Mined-out longwall panel
Percolation: Coupled Hydromechanical Simulation

hydrostatic water pressure $p_{\text{hyd}} \text{ (MPa)}$

- 6.5
- 7.0
- 7.5
- 8.0
- 8.5
- 9.0
- 9.5
- 10.0
- 10.5

overburden

750 m: deepest groundwater level

hydraulic barrier: claystone, rock salt

fracture zone

excavated longwall panel: 1000 m

standing mining edge

longwall front

1100 m
And now for...

1 Introduction

2 Rock Bursts: Longwall Caving vs. Room-and-Pillar

3 Integrity of the Hydraulic Barrier

4 Conclusions
Longwall caving in potash poses two major geomechanical challenges:

- High, almost uniaxial stresses at the longwall face
  - Possibly fine for ductile rocks such as sylvinite
  - Rather problematic for brittle rocks, in particular carnallitite:
    - Translatory rock bursts at the longwall face – seam jumps into the panel (local magnitudes $M_L \sim 1 – 2$)
    - Shield supports don’t really help
  - More severe in greater depth

Hydraulic barrier is attacked from two sides:

- Caving creates a fractured zone going up from the seam
- Large subsidence creates extensional strains at the top of the barrier, lowering the minor principal stress below ground water pressure
  - If these permeable zones overlap, the mine will probably be flooded
- Less severe in greater depth

⇒ Careful analysis required!
Summary and Conclusions

Longwall caving in potash poses two major geomechanical challenges:

- High, almost uniaxial stresses at the longwall face
  - Possibly fine for ductile rocks such as sylvinites
  - Rather problematic for brittle rocks, in particular carnallitite:
    ⇔ Translatory rock bursts at the longwall face – seam jumps into the panel (local magnitudes $M_L \sim 1 – 2$)
    Shield supports don’t really help
  - More severe in greater depth

- Hydraulic barrier is attacked from two sides:
  - Caving creates a fractured zone going up from the seam
  - Large subsidence creates extensional strains at the top of the barrier, lowering the minor principal stress below ground water pressure
    ⇔ If these permeable zones overlap, the mine will probably be flooded
  - Less severe in greater depth

⇒ Careful analysis required!