ROCK MECHANICS – THE BASIC MINING SCIENCE: CHALLENGES IN UNDERGROUND MASS MINING

E T Brown

Elders and betters, mentors and teachers

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- James Foots
- Charles Fairhurst
- Evert Hoek
- John Jaeger
- Manuel Rocha
- Doug Stewart
- Hugh Trollope

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First ISRM Congress, Lisbon, 1966

Orebodies at the Neves Corvo Mine, Portugal

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Underground ore loading at the Neves Corvo Mine, Portugal

Outline
- Overview of modern mass mining
- Introduction to block and panel caving (BPC)
- Industry trends in BPC, including the next generation of “super caves”
- Rock mechanics challenges
- Implications for the discipline of rock mechanics

Underground mass mining involves
- Mining by block and panel caving, sublevel caving, and open and sublevel stoping, and their variants; and
- Production rates of at least 30,000 tonnes of ore per day, or about 10 million tonnes per year.
Evolution of daily production rates at selected large underground mines

Some planned “super caves”

- Andina Sur Sur underground project, Chile
- Chuquicamata transition project, Chile
- El Teniente New Mine Level, Chile
- Grasberg, Indonesia
- Oyu Tolgoi, Mongolia
- Resolution, USA

Known operating and planned block and panel caving mines

Open pit and block cave, Palabora Mine, South Africa, April 2004
Reasons for a transition from open pit to underground mining by block and panel caving

- Unfavourable economics of further open pit cut-backs
- Inability to ensure the continuing stability and safety of high open pit slopes
- Adverse environmental impact of further open pit development
- Cost and productivity advantages of BPC over other underground mass mining methods

Outline

“Projections based on current reserves show that in about 15 years’ time, Rio Tinto could be producing more copper from underground than from open pits”

John O’Reilly
Rio Tinto, 2004

Classification of underground mining methods

(after Brady & Brown 2004)

Schematic showing the essential features of block caving
Historical development of block and panel caving (continued)

- **Late 1960s**: LHD vehicles developed for underground mining
- **1970**: LHDs used with block caving at El Salvador mine, Chile
- **1981**: Mechanised panel caving introduced in the primary ore at El Teniente mine, Chile
- **1990s**: Planning of the new generation of block caves with larger block heights in stronger orebodies (e.g. Northparkes, Palabora)
- **2005 on**: Planning the next generation of “super caves”

Conditions under which BPC may be used

- Requires an orebody of large horizontal and vertical extent with well disseminated mineralisation
- May be used in thick flat-lying deposits, steeply dipping veins of sufficient width and diamondiferous pipes
- The lateral extent of the orebody must be large enough to allow caving to be initiated
- This width will depend on the strength of the orebody – traditionally weak, but now may be strong
- The height of the ore column should allow adequate production lives of individual drawpoints and an acceptable rate of return on development and production costs
- Because production costs are low, BPC may be used for lower grade orebodies than other underground mass mining methods
**Trends in block and panel cave mining**

- Application to stronger, less easily cavable and more coarsely fragmenting orebodies
- Application to deeper orebodies (including "blind" deposits) under higher stresses
- Application to lower grade orebodies than those mined by other underground methods
- Larger block heights
- Increased automation towards the "underground rock factory" concept and miner-less mining

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**Some engineering challenges in the next generation of super caves**

- Their massive scale and the associated project management challenges
- Very long lead times
- High capital costs
- Large amounts of pre-production development required with long design lives
- High in situ rock temperatures at depth and the associated ventilation and refrigeration requirements

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**Trends in block and panel cave mining (continued)**

- New ore handling philosophies and underground layouts
- Transitioning from large open pits to underground mining by BPC methods
- Greater risks and an increased emphasis on "getting it right" in early decision making
- Changing demands on, and skill sets of, managers, engineers and operators

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**Some engineering challenges in the next generation of super caves (continued)**

- The desirability of no entry mining and the automation of excavation and production
- The development of new and improved methods of working and production
- Water and environmental management
- Underground communications and control systems
Key block cave design activities

- Geotechnical Characterisation
- Caveability Assessment
- Fragmentation Assessment
- Caving Performance Assessment Including Undercutting
- Draw Strategy
- Draw Tools
- Initial and/or Trial Excavation
- Monitoring
- Implementation of Final Design
- Monitoring During Construction and Mine Operations

Key rock mechanics challenges

- Caving mechanics and cavability assessment
- Fragmentation assessment
- Caving performance, including caving initiation by undercutting and continued propagation
- Extraction level stability under the range of stress conditions applying throughout the life of the cave
- Assessing the risk and ameliorating the effects of major operational hazards
- Surface subsidence prediction

Vertical section through a rock mass that is well-suited to gravity caving

Conceptual model of stress caving (Duplancic & Brady 1999)
Progress of caving, Northparkes E26 Lift 1
(van As & Jeffrey 2000)

Schematic section showing the path of the Northparkes E26 Lift 1 air blast
(Ross & van As 2005)

Evolution of fracturing in a SRM sample
(Mas Ivars et al 2007)

Advanced microseismic analysis in caving prediction
(ASC & Itasca 2007)
Summary of preferential structures observed in SRM samples and microseismic clusters, Northparkes E26 Lift 2, Australia

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Fragmentation at Salvador Mine, Chile

- Coarse fragmentation at Salvador Mine, Chile
- Good fragmentation at Salvador Mine, Chile

FracMan model of a 50 m x 50 m x 70 m block, and identification of blocks connected to the undercut

(Reyes-Montes et al. 2007)

Professor Hugh Trollope AO FTSE

(Rogers et al. 2007)
Mechanisms of secondary fragmentation

- Extension of pre-existing discontinuities
- Opening of filled or healed discontinuities
- Opening of bedding or schistosity planes
- Crushing of blocks under superimposed weight
- Failure of blocks in compression arising from arching
- Failure of blocks in induced tension arising from point or line loading
- Bending failure of elongated blocks
- Abrasion of block corners and edges

Key rock mechanics challenges

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Remnant pillars on the undercut level with pre-undercutting

Cave initiation by undercutting: advanced undercutting

Extraction level excavation design and stability issues

- High extraction ratios and stresses
- Varying stress paths and stress levels throughout their service lives
- Several possible rock mass responses and failure modes
- Stringent service requirements and long service lives
- Drawpoint and drawpoint brow stability
- Demanding service requirements of floors

Extraction level at the end of construction using an advanced undercut, DOZ mine, Freeport Indonesia (Moss 2005)
Subsidence resulting from block and panel caving, Salvador Mine, Chile
(Flores & Karzulovic 2002)

Crater perimeter
Caved rock

Comparison of continuous and discontinuous subsidence
(Kvapil et al 1989)

Continuous subsidence
Discontinuous subsidence
Original surface
Crater with caved rock
Steps

Exploitation of thin layer
Extracted block

Block and panel caving subsidence terminology
(Flores & Karzulovic 2004b)

Influence zone & (continuous deformations)
Stable zone
Crater perimeter (maximum extension of discontinuous deformations)
Pre-existing open pit slopes

Underground cave mining
Cave material
Undercut level
Orebody

ψ, Angle of break
δ, Influence zone

North-south vertical section, Palabora open pit and block cave, South Africa
(Moss 2005)

Slope ravelling & bench failure
Factors influencing the angle of break

- The dip of the orebody
- The plan shape of the orebody
- The depth of mining and the associated in situ stress field
- The strengths of the caving rock mass and of the rocks and soils closer to the surface
- The slope of the ground surface

Factors influencing the angle of break (continued)

- Major geological features such as faults and dykes intersecting the orebody and/or cap rock
- Prior surface mining
- The accumulation of caved or failed rock, or the placement of fill, in a pre-existing or a newly formed crater
- Nearby underground excavations

Indicative surface projection of the Resolution orebody

(Hehnke 2005)
Surface features, Apache Leap, near Superior, Arizona
(Photographs: M Scoble)

Resolution interpretive geology, East-West section
(Hehnke 2005)

Subsidence resulting from block caving operations, San Manuel Mine, USA
(Flores & Karzulovic 2002)

San Manuel subsidence reconstruction, July 1959
(Brummer 2006)
San Manuel subsidence reconstruction, 1967
(Brummer 2006)

San Manuel subsidence reconstruction, 1973
(Brummer 2006)

3D subsidence reconstruction, 1955-73,
San Manuel Mine, Arizona
(Brummer 2006)

Brown’s First Law of Caving Geomechanics

There are no easy answers

Corollary

There are no recipes or cook books
The ISRM for honouring me with this award;
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Glück Auf!