Design & Operating Principles in Caving Methods

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B. Variations & Examples
C. Design Issues (safety + environmental + regional stewardship)
D. Operating Issues
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  - Economics
  - Bottom line
F. Delay-impact Example
G. Video
Caving method requirements

- Large orebodies
- Fragmentable rock mass
- Ground subsidence allowance
Caving Mining Methods

TOP SLICING

BC - System of draw)

With gravity draw and grizzly drifts

With LHD loading in draw drifts
Mining method production & cost

Average productivity, daily production and relative mining cost associated with various mining methods from mines using such methods as their major source of stope muck.

### SUMMARY - UNDERGROUND MINING METHODS

<table>
<thead>
<tr>
<th>Method</th>
<th>Tonnes / Manshift</th>
<th>Avg. Tonnes / Day Milled</th>
<th>Relative Mining Cost/Tonne</th>
<th>SELECTIVITY</th>
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<tbody>
<tr>
<td>Resuing</td>
<td>0.20 - 0.50</td>
<td>50 - 100 +</td>
<td>70+</td>
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<tr>
<td>Shrinkage</td>
<td>20 - 28</td>
<td>200 - 800</td>
<td>20 - 50</td>
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<tr>
<td>Cut and fill</td>
<td>12 - 48</td>
<td>500 - 1500</td>
<td>20 - 70</td>
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<td>Room and Pillar</td>
<td>15 - 150</td>
<td>1500 – 10 000</td>
<td>7 - 20</td>
<td></td>
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<tr>
<td>Open stoping</td>
<td>20 - 115</td>
<td>1500 – 25 000</td>
<td>7- 25</td>
<td></td>
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<tr>
<td><strong>Sub-Level Caving</strong></td>
<td><strong>65 - 180</strong></td>
<td><strong>1500 – 50 000</strong></td>
<td><strong>7 - 17</strong></td>
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<tr>
<td><strong>Block Caving</strong></td>
<td><strong>300 - 2000</strong></td>
<td><strong>10 000 – 100 000</strong></td>
<td><strong>1 – 2.5 ~ 9$/t average</strong></td>
<td></td>
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</tbody>
</table>

Source: BMO Capital markets 2011 Global Metals and Mining Conference
Contents

A. Principles

B. Variations & Examples SLC BC

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   o Design
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G. Video
Sublevel Caving - SLC

Schematic layout for sublevel caving (after Hamrin, 1982)

DEFINITION: A mining method which is applicable to low grade near-vertical metallic or nonmetallic deposits. Mining progresses downwards while the ore between sublevels is broken overhand with long hole uppers (fan-holes). The overlying waste rock (hangingwall or capping) caves into the void created as the ore is drawn off. Mining is conducted on sublevels from development drifts and crosscuts, connected to the main haulage level below by ramps, orepasses, and raises. Every tonne of ore is drilled and blasted which results in improved cavability and fragmentation compared to Block Caving. With care, recoveries in the order of 80% with dilution below 25% can be achieved.
The **basic principles** of SLC are:

- As ore is pulled from the blasted ring, it will be replaced with broken waste.
- This waste will be mixed with some of the ore as the chocked material is moving.
- Top down, flexible, low capital, selective for fragmentation.
- Continuous repetitive process, highly amenable to mechanization and automation for ‘rock factory’.
- Declining in popularity due to relatively high development cost & low recovery, replaced with BC or sublevel open stoping.

Page & Bull, 2001
SLC requirements:

- Massive, steeply dipping orebody
- Good cavability of ore/HW
- Solid enough ore to limit brow wear
- Competent FW for development

All design and operational efforts are directed towards extracting as much ore as clean as possible, delaying the appearance of dilution, and continuing the draw of the economic mixture of ore and waste for as long as possible.
Stobie Mine (SLC) - SUDBURY - CLOSED IN 2012
Sublevel interval = 30'
Fanholes up to 40' high
10' round
40'
16' x 12'
20'
30'
SLC at Stobie Mine 1968

Sectional View of Crosscut System
A sectional view of sublevel caving showing the location of the crosscuts and the drilling pattern of upholes used to blast the ore.
SLC at Stobie Mine

Lower Development - More tonnage/ring blast
Recovery = 80-90%  Dilution = 10-20%
Productivity>30t/manshift  Production = 12,000 t/day
Design parameters for SLC layouts

**Stope design**
- Drift dimensions
- Pillar width
- Sublevel interval
- Slot design
- **Ring pattern** (burden, spacing, inclination)
- **Brow condition**
- Support
- **Grade control**

**Zone design**
- Permanent openings (access-crusher-passes)
- **Crown**
- Development sequence
- **Mining sequence** (long-transverse)
- Haulage distance
- Production drilling sequence
- Draw - **mucking sequence**
- Dilution/recovery control Dilution blanket
- Fragmentation management (**oversize – fines**)
- Subsidence- displacements
Cavability as a function of rock mass conditions & hydraulic radius

Hydraulic Radius $HR$ (Area/perimeter)

Stability Diagram (Laubscher, 1994) : **STABILITY vs CAVABILITY**
Fragmentation Control

Blast Fragmentation Profile

- high density compacted waste
- coarser at the top and sides
- finer towards centre and bottom

GRADATION GRAPH

DISTINCT SHIFT IN FRAGMENTATION WITH DRILLING AND BLASTING CONCENTRATION ON THE OVERSIZED

Oversize

Blasting Effect

Fines
A good system of draw and grade control is key to the success of an operation and a number of changes will likely be needed before the ideal system is found during the mine life cycle.
Dilution

Conventional draw curves

As a guide for evaluating the extraction (assuming 110% of material [ore and waste] extraction), the following classification can be used:

1. Class I: Extraction is good as the ore is at least 80% and the waste is less than 30%.
2. Class II: Extraction is acceptable in certain cases as the ore is at least 75% and the waste is no more than about 35%.
3. Class III: Extraction is poor as the ore constitutes about 65% and the waste 45% or more.

(Kvapil, 1992)

Simplified chart of dilution development

If after a material extraction of 71%, the ratio is 60% ore and waste 11% (point A), one can expect that with 120% material extraction the ration will be about 77% ore and at least 43% waste (point B)
Dilution - Recovery in SLC: Grade & Tonnage Prediction

Draw model for calculation of extraction tonnage & grade

The model shows the proportion of ore (below the line) and dilution (above the line) as extraction increases along the x-axis.

(Bull & Page 2000)
Design considerations

Independent vs interactive draw

- Uneven Draw Down of Ore / Waste Interface
- Early Dilution Entry

- More Even Draw Down of Ore/Waste Interface
- Delayed Dilution Entry

Bull & Page, 2000
Design considerations

Recovery vs sublevel interval (Trotter & Goddard, 1981)

Effects of Draw Point Spacing

Interactive Draw

Independent Draw

decreasing effective width of draw

increasing drive spacing

Bull & Page, 2000
SLC at the Kiruna Mine, Sweden
Operating issues in SLC

- Long holes problems from drilling inaccuracies
- "Silo" type drilling pattern to drill and blast a shape similar to the ellipsoid of motion
- Less drilling through potentially damaged pillar zone
- Limits the zone of potentially poor breakage
- Shorter holes better drilling accuracy
- Flatter side holes to shorten height of blast

NB: If side holes are too flat they "over" choke and freeze.
Examples of operating problems in SLC

**Vertical Ring vs Inclined Ring**

**Vertical Ring**
- waste
  - drilled ore
  - draw cone
  - dilution

**Inclined Ring**
- waste
  - blasted ore
  - low mass density
  - high mass density
  - dilution
  - draw cone

**Inclined Ring**
- Better compatibility between shape and draw profile
- Delays introduction of waste from above
- Easier access to charge next ring

**"Frozen Rings"**

Potential Ore Loss Due to Blast "Freezing"
Examples of operating problems in SLC

"Ribs" of Ore Due to Incomplete Breakage at Toe End of Holes

Coarse Fragmentation in "Pillar" Area

RIBS

O R E

PILLAR

L O S S
Block Caving - BC
- Block/Panel/Mass Caving -

Has the potential to rival surface mining in production capacity and costs. Principle: “If a single enough area is undermined, any rock mass will eventually cave”.

With care, recoveries in the order of 120% with dilution held below 20% can be achieved.

Key question: “can it be caved, drawn, handled safely and delivered to the surface for processing-economically “? ← OPTIMIZATION
Block Caving - BC
- Block/Panel/Mass Caving -

Full use of gravity – unpredictability of caving & fragmentation

With LHD loading in draw drifts at the production level
The basic principles of BC are:

- Applicable to low grade subvertical massive ore deposits
- Ground subsidence allowance

- Both ore and waste are caved and drawn from below. Mining progresses downwards, while the ore is undercut. The waste will be mixed with some of the ore as the chocked material is moving

- The efficiency of the method is a function of the cavability and the fragmentation control of the material

- Continuous repetitive process, highly amenable to mechanization and automation for ‘rock factory’

- High initial capital cost. Time lag from development to production

- Risk for premature collapse, hang-ups, air blasts, oversize, mud-rushes.
Block Caving Principles

Progressive stages (a, b, c) of block caving, showing caving of ore and waste.

Elements of a caving method of mining (after Dravo Corporation, 1974).

- Develop
- Undercut
- Cave
- Draw
- Haul
- Crush
Variations of Caving Methods

Shape of caving area

Block caving

Mass caving

Panel caving
Variations of Caving Methods - A

- Shape of caving area
  - Block caving
  - Panel caving
  - Mass caving

- Orebody/mining regularity
  - Regular
  - Irregular

- Extend of active caving zone
  - Highly fractured
  - Moderately fractured
  - Weak
  - Strong

- Fracture intensity
  - Highly fractured
  - Moderately fractured

- Strength
  - Weak
  - Strong
Variations of Caving Methods - B

System of Draw

Gravity draw

Draw Drift Loading – LHD fleet

Slusher

OLD
Block Caving in a Kimberlite pipe

MELAPHYRE (STRONG VOLCANIC ROCK)

SOLID KIMBERLITE

CAVED GROUND

FALLEN DEBRIS

OPEN

SCRAPER DRIFT

GRANBY LEVEL
(15,000 tons/day)

KIMBERLITE PIPE

De Beers’ Mines in southern Africa

Laurentian University
School of Engineering
Premier diamond mine, SA
(Bartlett & Croll, 2001)

Levels
- Undercut (top)
- Extraction - production
- Haulage (bottom)

Production (extraction) level
Henderson Mine & Mill  Nevada, USA

Molybdenum

5M tonnes/yr

General cross section

Typical mining sequence for a caving panel
Mass Caving

Pit

More history is in the making at Creighton No. 3 shaft. Here is an artist's conception of the conversion to load-haul-dump equipment, showing the ramp from surface, typical tramways in which the big L-H-D machines operate as they draw caved ore through the bosholes, and the garage on 23 level where the trackless mining equipment is serviced.
Block Caving Cycle of Operations

- **Development** *(drill, blast, load, haul)*
  Levels, crosscuts, draw bells, cones, fingers, passes
- **Undercutting** *(fan drilling & blasting)*
- **Cave - Secondary blasting** *(<50% rule)*
- **Mucking** *(gravity flow & chute control)*
- **Hauling**
- **Crushing**
- **Hoisting or hauling**
Water inflow management (mud-rush danger!)

Water inflow in a block caving operation  (Butcher, 2000)
Block Caving Design parameters

- Production Requirements
- Cavability
- Primary Fragment
- Drift spacing
- Drawpoint interaction
- Draw zone spacing/pillar
- Drilling & blasting
- Hauling

- Crushing
- Layout
- Logistics
- Excavation stability
- Method of Draw
- Draw heights
- Sequence – rate of draw
- Ventilation

- Undercutting sequence
- Tonnage drawn
- Fragmentation size range
- Rockburst potential
- Induced stresses
- Support & rehabilitation drawpoint/drift/pass
- Ore extraction – dilution
- Ground subsidence
- Adjacent openings
- Water management

(Laubscher, 2001)
Block Caving Operating problems

- Operating complexity
- Air blasts
- Hang ups - premature collapses (U/C, draw point, ore pass)
- Oversize - secondary blasting requirements
- Caving & fragmentation prediction & control
- Recovery
- Dilution
- Water inflow
- Stresses/Displacmnts

- Rockbursts - seismicity
- Support-Rehabilitation
- Orepass, Drift, Drawpoint, Grizzly integrity
- Equipment performance
- Operating control
- Subsidence
- Mud/muck rushes
- Ventilation air loss
- LHD fleet management
El-Teniente Mine

Ore: 140,000 tonnes/day
Operating Challenges

- Access
- Depth – ground conditions
- Seismicity
- Heat Stress and ventilation
- Cost – capex, operating delays & logistics in BFS
Evolution of U/C design at El-Teniente Mine

High regional stresses, large displacements, rock bursts

→→ Develop as you go
Mining sequence at Henderson Mine

5M tonnes/yr

PRODUCTION LEVEL

UNDERCUT LEVEL & SEQUENCE

GLORY HALL
UNDERCUTTING METHODS

Separate level undercutting and extraction

Undercutting and trough development

Two-level undercutting
When will it cave?

Cavability as a function of rock mass conditions & hydraulic radius

Example

Parabora Mine, Calder et al, 2001

Stability Diagram (Laubscher, 1994)

MRMR, Mining Rock Mass Rating

Hydraulic Radius (Area/perimeter)

Parabora Mine, Calder et al, 2001

Stability Diagram (Laubscher, 1994)
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Criteria for decision making in project valuation & optimization

i. Recovery
ii. Dilution
iii. Grade
iv. Tonnage
v. Cost
vi. Time
vii. Resources utilization
viii. Delay impact
ix. Return on investment, $, %
x. Flexibility/robustness/risk
xi. Contingency
Consider the impact of risk on:

i. Recovery
ii. Dilution
iii. Grade
iv. Tonnage
v. Cost
vi. Time
vii. Resources utilization
viii. Delays
ix. Return on investment, $, %
xi. Flexibility/robustness/risk
xii. Contingency

Production Planning needs

• Geological model
• Geomechanics model
• Fragmentation model
• Reconciliation model
## Delays - Impact Example

### Cashflow analysis #1

<table>
<thead>
<tr>
<th>Year</th>
<th>Production Rate (t/yr)</th>
<th>Cashflow (current)</th>
<th>Cashflow (const.)</th>
<th>Cumulative Cashflow</th>
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**NPV =** $42,932.097

**IRR =** 30%

### Cashflow analysis #2

<table>
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<th>Year</th>
<th>Production Rate (t/yr)</th>
<th>Cashflow (current)</th>
<th>Cashflow (const.)</th>
<th>Cumulative Cashflow</th>
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<td>353,333,333</td>
<td>970,000,000</td>
</tr>
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**NPV =** $33,654.674

**IRR =** 26%
Block Caving Video

A visualization of the block caving method of underground mining


→ BC optimization of the KSM project
https://www.youtube.com/watch?v=oYc47CLOnGs

DEBOTTLENECKING & OPTIMIZATION:
http://www.stratusengr.com/Articles/DebottleOptions.pdf