2012 SEG
Distinguished Lecture
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- Sponsor Scientific Investigations
- Disseminate Results
- Support the Profession Globally
Society of Economic Geologists (SEG)

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- Members in 100 Countries
- 71% of Members are from outside the USA

Member Affiliation:

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- 20% Students
Society of Economic Geologists (SEG)

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  - Special Publications & Reviews

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  - Research Grants, Fellowships, Field Trips
  - Student Mentoring Program
  - Student Chapter Program
  
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Society of Economic Geologists (SEG)

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- Distinguished Lecturer
- International Exchange Lecturer
- Thayer Lindsley Lecturer
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- Honorary Lecturers
Crucial Challenges to Discovery and Mining

Tomorrow’s Deeper Ore Bodies
Lecture Objectives

• Focus on mass mining
• Identify some challenges
• Link discovery & mining
• Show “deep” is difficult/ but possible
Content

• ‘Deep Earth’ and mass mining
• Discovery & mining – challenges
• Some Cadia discovery examples
• Posit some reflections
Cadia Discoveries*

*porphyry Au/Cu mineralisation

• Cadia Hill – cropped out – open pit
• Cadia Quarry – cropped out
• Ridgeway – 500 m deep – sublevel cave
• Cadia East – >200 m deep
• Cadia Far East – 800 m deep – Super-cave
• Total mineral resource of > 44 M oz Au & 7.5 M t Cu
‘Deep Earth’ for mass mining

• Crucial to future mining/discovery

• Constrained economically

• Present u/g range: 300 – 2,000 m?

• Future u/g depth limit – 3,000 m?

• Present o/p range: 0 – 1500m?
Discovery Implications

• Deposit geometry/area crucial

• Surface-area will influence:

• Very deep open pits (Ultra-deep)

• Very large cave mines (Super-caves)
Surface Area Effects

- Surface area affects the waste to ore (W:O) ratio in an open pit – Ultra-deep pits require a large surface area.
- Block cave mines generally have smaller surface dimension – Super-caves require a large surface area to maximise panel caving.
Discovery Challenges

- Geology-related
- Mining-related
- Corporate – self-inflicted
Geology-related

- Subtle/zero near-surface evidence
- Obscuring & poor 4D geology
- Ore deposit ‘models’
- Rock temperatures
Mining-related

• Mass mining trend

• ‘Deep Earth’ depth constraints

• Ultra-deep open pits & Super-caves

• Future ore grade – in 10 or 20 years
Some Mining Effects

- Capital Intensity
- Political Risk – adds to cost
- Ore Grade & Operating Cost
- Increasing need for by-product credit
- Use of NPV to determine mine size
Possible ‘Wild Card’

• ‘State Capitalism’

• Increasing world influence

• “The world’s ten biggest oil-and-gas firms, measured by reserves, are all state-owned” – The Economist, January 2012
Capital Intensity vs Cu Price for New Cu Mines, 2001 - 2010

(Source: Metals Economics Group's Cu Reserves Replacement Strategies, June 2011) NOTE: by-product credit not included in capital intensity calculation
Capital Intensity vs Cu Mine Head Grade, 2001 - 2010

Weighted Average Head Grade
% Cu

Capital Intensity
US$/t of copper production/yr
(3 year rolling av.)

(Source: Metals Economics Group’s Cu Reserves Replacement Strategies, June 2011)

NOTE: by-product credit not included in capital intensity calculation
Capital Intensity vs Production Capacity for New Cu Mines, 2001 - 2010

(Source: Metals Economics Group’s Cu Reserves Replacement Strategies, June 2011) NOTE: by-product credit not included in capital intensity calculation
Production Challenges

• Top ten Cu mines in 2010 produced:
  • Open pit: 245 – 1,000 kt Cu/yr
  • Underground: 80 – 425 kt Cu/yr
• Set against increasing Cu demand
Copper Demand

- 1900 – 0.5 M t
- 1930 – 1.9 M t
- 1960 – 3.2 M t
- 1990 – 8.1 M t
- 2009 – 16.0 M t
- 2030 – ≥30 M t or >
- 4 % growth/year
2010 Top Ten Cu Mines

- Open pit total – 4.5 M t Cu
- Underground total – 2.2 M t Cu
- Combined total – 6.7 M t Cu
- 2009 demand – 16.0 M t Cu
Equipment Size – an Issue

- Only incremental increases
- 300 t trucks, after 30 – 40 years
- 55 cu m Shovels
- SAG Mills 40 – 42 ft/float cells?
Discovery to Production

• Lengthening time

• Impacts future target grade

• > 5 M oz Gold deposit now > 10 years

• > 5 Mt Copper deposit is > 20 years
Some Copper Examples

• All still in feasibility study stage
• El Pachon, Argentina – >48 years
• Frieda River, PNG – >42 years
• Galeno, Peru – >20 years
• Tampakan, Philippines – >19 years
• Resolution, USA – >16 years
Corporate Challenge

• Growth – discovery vs M & A

• Leadership vs management

• Growth = management = bureaucracy

• Discovery has to be led
Typical Corporate Trend

Growth: Junior  Major miner
Corporate Challenge Cont.

- Bewilderment with discovery process
- Discovery risk – not understood
- Desire to ‘manage’ discovery
- Need for discovery ‘business model’
Discovery ‘Business Model’

• Not running a factory
• Forget conventional theory
• Antithesis of the ‘need to measure’
• Encourage creativity – no rules
Past Discoveries

• ‘Easy’ to make?

• Surface/near-surface – prospecting

• ‘Good’ geology often important

• Some were ‘Deep Earth’
A Prior Discovery Model

• “Where best to look – shadow of the headframe” – Sig. Muessig, Getty

• Why – “the closer to ore, the lower the risk” – Sig. Muessig, Getty
An Example: Cadia Hill

• ‘Old-fashioned’ & ‘easy’?
• Surface prospecting
• Influenced by people, time, gold price and geological thinking
“Lateral” Comparison

• Ok Tedi porphyry Au/Cu deposit

• Skarn & Ok Tedi porphyry – yes

• Skarn & Cadia porphyry – why not?

• Supporting evidence – where?
"Lateral" Thought

Mineralised Waste

Ore & Ok Tedi

3D dartboard

Altered waste & skarn
Western Cadia Hill – prior to discovery
Cadia Hill: Section 14,020E

- NC47
- NC40
- NC44

Legend:
- 0.30 - 0.49
- 0.50 - 0.99
- 1.00 - 1.49
- >1.50 g/t Au

Measurements:
- 158m, 0.89 g/t Au
- 243m, 1.21 g/t Au
- 256m, 1.15 g/t Au

Scale: 200 m
Cadia Hill: Section 14,020E – Gold Intersections

- 132m @ 1.10 g/t Au
- 74m @ 0.56 g/t Au
- 800m RL 48m @ 0.42 g/t Au
- 69m @ 0.73 g/t Au
- 46m @ 0.62 g/t Au
- 69m @ 0.70 g/t Au
- 59m @ 0.65 g/t Au
- 26m @ 0.65 g/t Au
- 119m @ 1.40 g/t Au
- 159m @ 1.26 g/t Au
- 110m @ 0.42 g/t Au
- 89m @ 0.95 g/t Au
- 31m @ 0.76 g/t Au
- 73m @ 1.34 g/t Au
- 46.6m @ 0.50 g/t Au
- 99m @ 0.43 g/t Au

Scale: 200m
‘Deep Earth’ Discoveries

• More difficult & less ‘obvious’
• Much greater depth
• Possibly lower grade
• Need to be much larger
Transitional ‘Deep Earth’

- 200 – 500 m to top of ore
- Not presently open pit?
- Geometry/grade determine mining
- Mass underground mining is likely
Ridgeway Deposit

- Completely blind
- 500 m deep
- 20-80 m post-mineral cover
- Weak mineralisation halo
Cadia East

Longsection 21,750mN

Geology

Pre-Discovery of Cadia Far East
IP Traversing

- Trialled over Cadia Hill/East
- 200 m dipole-dipole array
- Deep low-order chargeability responses
- Possibly good for 200 m cover
CADIA - RIDGEWAY
LINE 11,000E
DIPOLE - DIPOLE PSEUDO SECTION

APPARENT CHARGEABILITY
(mSECS)

Ridgeway

CONTOUR INTERVAL : 2mSECS
8m @ 0.42g/t Au
0.51% Cu

CADIA - RIDGEWAY
Discovery Drill Sequence
CADIA - RIDGEWAY
Discovery Drill Sequence

8m @ 0.42g/t Au 0.51% Cu
118m @ 0.10% Cu
Fault

8m @ 0.42g/t Au 0.51% Cu

118m @ 0.10% Cu

102m @ 0.13g/t Au 0.40% Cu

CADIA - RIDGEWAY
Discovery Drill Sequence
Early Subsidence
Mass Mining Trend

• Much larger scale & depth

• Ultra-deep pits – 1500 m deep

• Super-caves – 2000 m deep

• Increasing automation
A Current Large Open Pit

- Two pits – sulfide & leach Cu ores
- 250 k tpd sulfide & 200 k tpd leach
- 750 k tpd waste; <2:1 W:O
- 1.2 M tpd total = 438 M t per year
- 1.0 M t Cu produced
Hypothetical Ultra-deep Pit

- Pit: 11 km x 5.5 km.
- Depth: 1500 m
- Ore milled: 0.8 – 1.5 M tpd.
- Waste removed: > 3.0 M tpd.
Potential Size Increase

• Ore treated: by up to $x_3$
• Waste removed: more than $x_4$
• Total moved: 1.8 billion tonnes per year
Evolution of Cave mining

(Courtesy of Chitombo, 2011)

- **1898**
  - First Block Cave
  - Pewabic Mine (Iron Ore)

- **1970s & 1980s**
  - Grizzly and slusher systems
  - Weak rocks and shallow depths

- **2010 - 2020**
  - Contemporary caves
  - Strong rocks at moderate depths

- **Beyond Super-caves**
  - Massive footprints
  - Lower grades
  - Deep deposits
  - Panel caving

- **In-situ metal recovery??**
Cost Comparison

Sublevel Stoping (SLS) vs. Sublevel Caving (SLC)

- Mining cost reduction
  - ~50%

Block Caving (BC) vs. Panel Caving (PC)

- Lower Capital Costs
  - After Flores 2011
Some Current Caving Styles

Northparkes Australia

El Teniente Chile  (courtesy Chitombo, 2011)  Grasberg Indonesia

El Teniente Chile  (courtesy Chitombo, 2011)  Grasberg Indonesia
Possible Super-caves

(Courtesy Chitombo, 2011)
Likely Scale Comparison

(Courtesy Chitombo, 2011)

• Contemporary cave
  – Footprint = 200 m X 200 m
  – Block height < 500 m
  – Tonnage: 10,000 – 40,000 tpd
  – Undercut level = < 1000 m deep

• Super-cave
  – 2000 m x 2000 m
  – >500 – 800 m
  – 70,000 – 100,000 tpd (single panel)
  – >1500 – 2000 m deep
‘Deep Earth’ Environment

- >500 m – >1000 m to top of ore
- Obscuring post-mineral rocks
- Science-based risk-taking essential
- Robust deposit-halo models needed
- Geophysics for ‘sulfur’ anomaly
Cadia Far East Deposit

- 800 m to ore body top
- 100 – 200 m of post-mineral rock
- ‘asking good questions’ and ‘testing these’ - *Tedder, 2001*
- Technical key was Au:Cu vector
Cadia East
Longsection 21,750mN
Geology
Pre-Discovery of Cadia Far East
Cadia East
Longsection 21,750mN
Mineralisation Zones
Pre-Discovery of Cadia Far East
Cadia Far East Beckons

- > 1000 m Au/Cu mineralisation to SE
- August 1996, hole NC494 from 1164 m
- 112 m @ 2.1 g/t Au & 0.56 % Cu
- within 229 m @ 1.3 g/t Au & 0.49 % Cu
In the CADIA EAST map, the areas show:

- Increasing %Cu/<Au:Cu
- Reducing %Cu >/Au:Cu
- ? Increasing Au

The color legend indicates:
- >3000 ppm Cu
- 1200 - 3000
- 500 - 1200
- 100 - 500

CADIA Long Section 21,700mN Block Model Resources Copper
Cadia East Mine Configuration

(courtesy Newcrest Mining Limited)
Thermal gradient

- Rarely considered
- Potentially significant issue
- Resolution and Far Southeast
- Engineering solutions/research required
Crucial Challenges

• 4D geology/better ore body models
• Geometry/size/grade of target
• Mine capital intensity & grade
• Corporate diversions – culture effect
Some Reflections 1

- Discovery is a business
- Science-based risk-taking is essential
- Risk needs to be reduced quickly
- Success is more likely if low-risk
Some Reflections 2

• Emulate past successes – lessons
• New ore body models required
• ‘Deep Earth’ isn’t scary
• Just harder
Finally

• Large deposits are easier to find
• Discovery is random/unscripted
• Correct exploration decisions are not always MBA material
Final Finally

• Forget conventional wisdom

• Think then act

• “IQ gets you there ... 

• ...but NQ finds it” – Muessig, Getty
My Thanks To

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• Metals Economics Group of Canada
• BHP Billiton
Thank You
Top-ten Open Pit Cu Mines, 2010

- Escondida, Chile – 1,011,00 t Cu
- Grasberg, Indonesia – 603,284 t Cu
- Chuquicamata, Chile – 528,377 t Cu
- Collahuasi, Chile – 504,043 t Cu
- Los Pelambres, Chile – 384,600 t Cu
- Radomiro Tomic, Chile – 375,344 t Cu
- Cerro Verde, Peru – 303,455 t Cu
- Antamina, Peru – 301,455 t Cu
- Bingham Canyon, USA – 249,800 t Cu
- Batu Hijau, Indonesia – 245,850

(Source: MEG 2011)