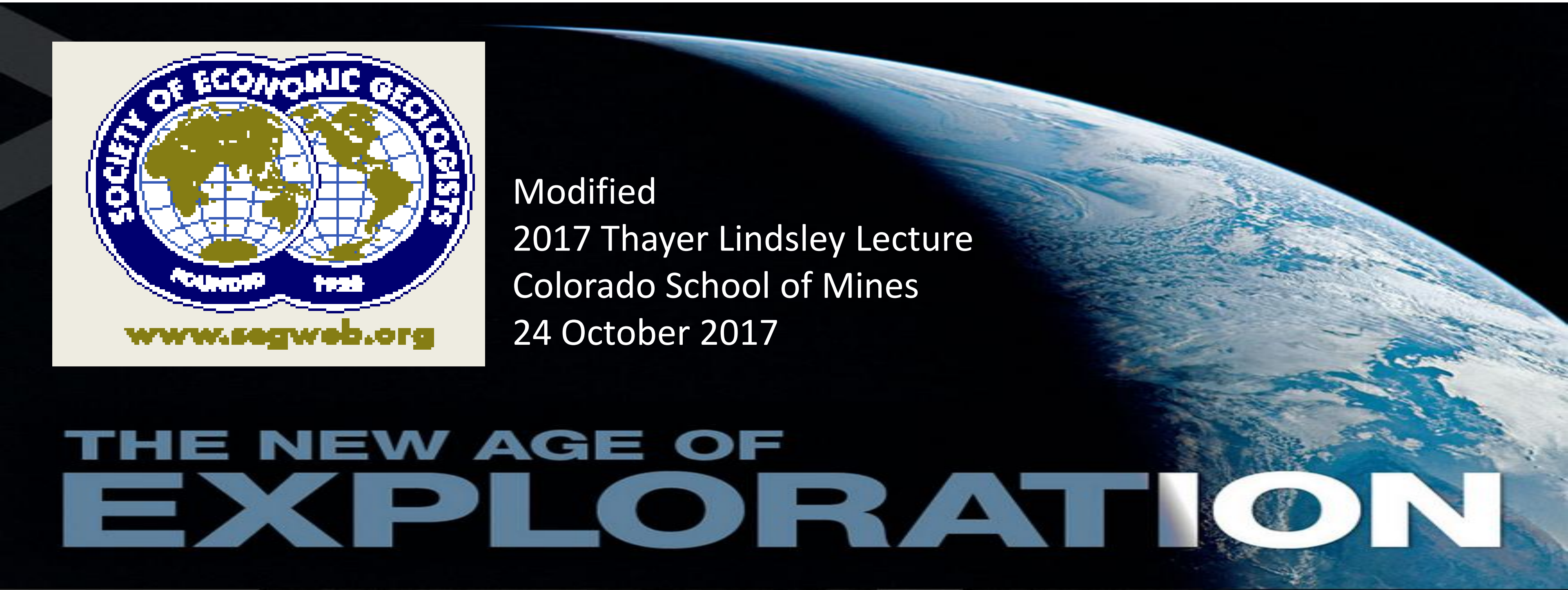
Future Exploration – *how we will need to explore*

Modified
2017 Thayer Lindsley Lecture
Colorado School of Mines
24 October 2017

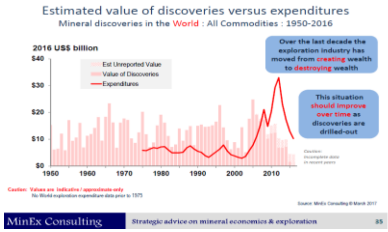


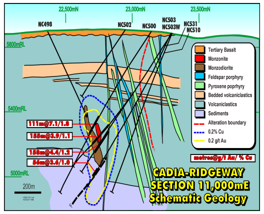
Content

- Some comments on exploration and what it entails

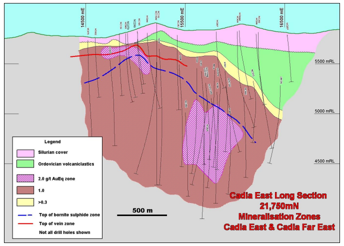
- *Why we get paid and how we presently explore*

- Exploration performance in recent years and what this means for how we should explore





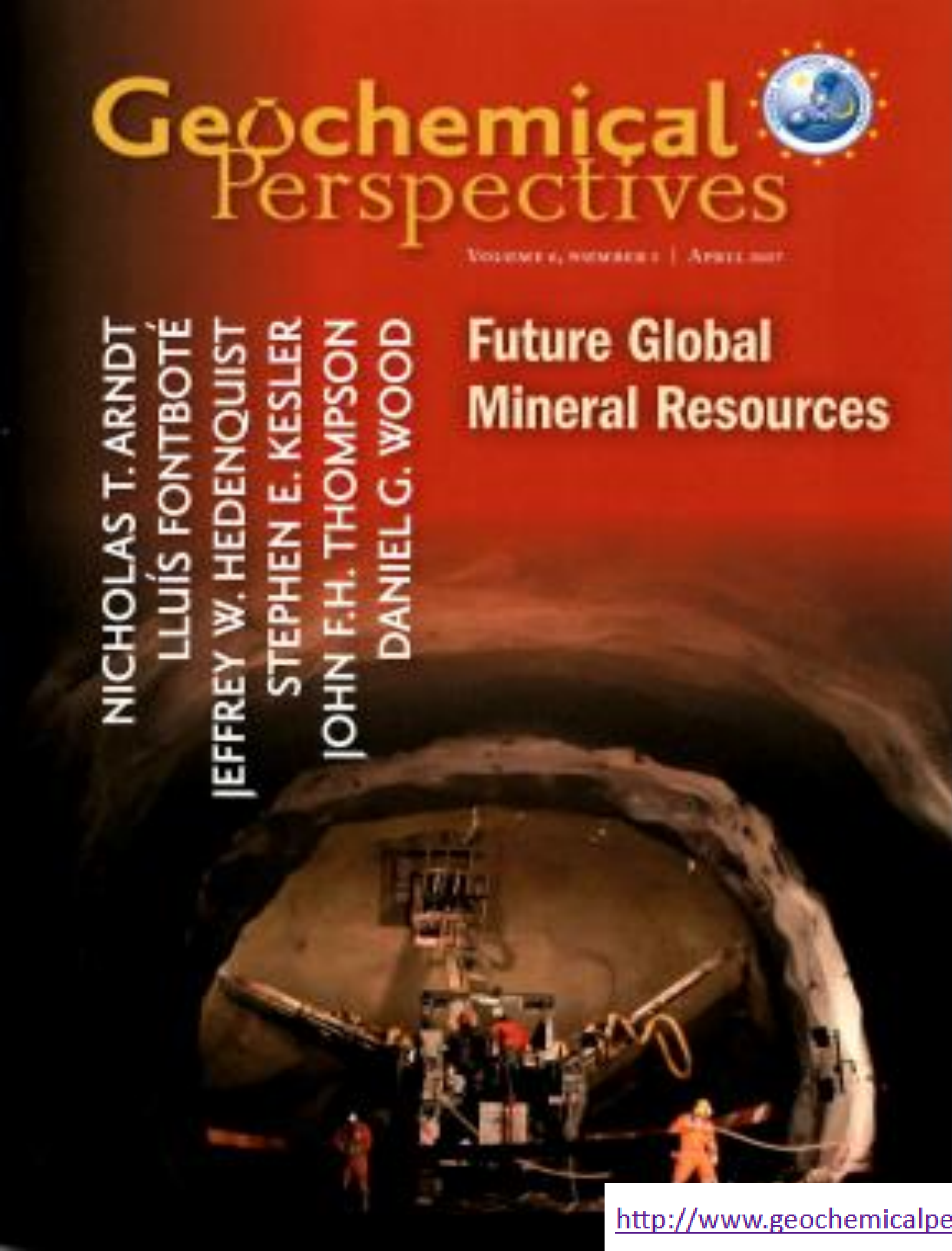
- *Some relevant porphyry Au-Cu discoveries, two of which produced mines*



- Some concluding remarks

An Important Observation

- Almost all of us who work in exploration were never trained in mineral exploration
- *We were trained mostly in one of the geosciences*
    - *geology*
    - *geochemistry*
    - *geophysics*
- Or in some other science – but usually in geology
- ***Mostly we have learned how to explore on the job, often at great cost to our employer and imperfectly***



A Useful Reference

(Free online from Geochemical Perspectives)

http://www.geochemicalperspectives.org/wp-content/uploads/2017/05/v6n11.pdf

What is Mineral Exploration?

It's the principal process for discovering ore deposits

There are two components

- *how to do it?*
  - *the "theory" side*
- *what tools to use?*
  - *the practical side*

This talk will focus on the "theory"

What is Exploration in Practice?

It's detective work

We seek clues to discover ore bodies

It's research by another name

How do we Explore?

We use inductive reasoning

As did Sherlock Holmes, the detective

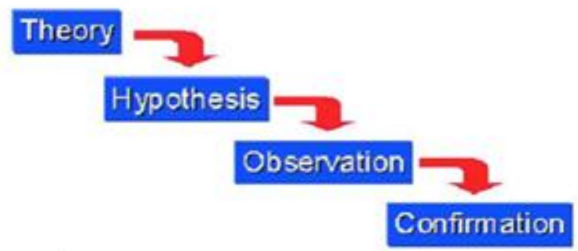
Success often comes from taking intuitive leaps based on meagre data

And finding lateral connections

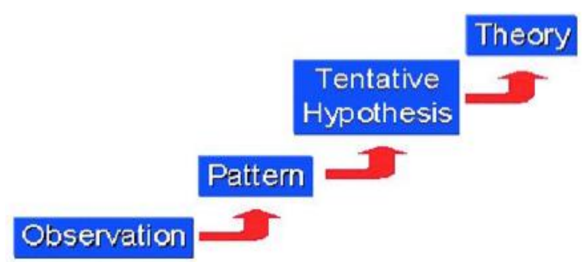
Deduction vs Induction?

Mathematics is a deductive science

Deduction



Exploration & Natural Sciences use induction



Induction

Induction in Exploration

A Qualitative Paradigm

Observation

↓

Pattern

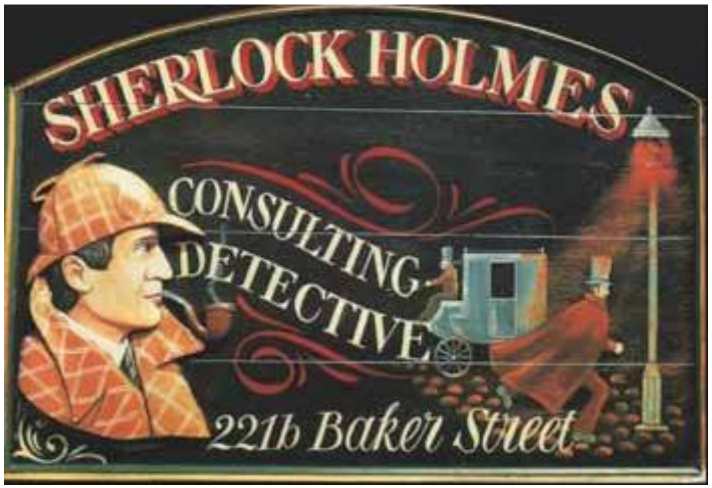
↓

Tentative Hypothesis

↓

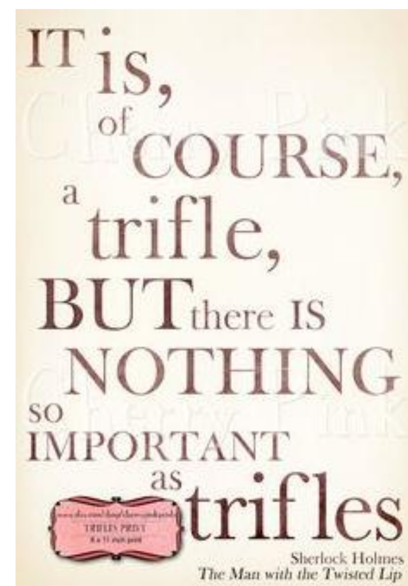
Discovery

Another Important Observation



Absence of Evidence
is not
Evidence of Absence

Particularly in exploration
where
Evidence is often difficult to recognise
and
What is important may not appear so



Why we get paid ?

- **We get paid for only one reason:**

- ***To create wealth***  = 

- By discovering ore  to mine 

- ***<u>Not</u>*** *mineralisation, which does not have immediate value – it may in the future when re-evaluated, probably by another company* 

Exploration Objective

- **To discover an ore deposit, cost-effectively and efficiently**
- ***To do this we have to:***

  - *know what is ore*

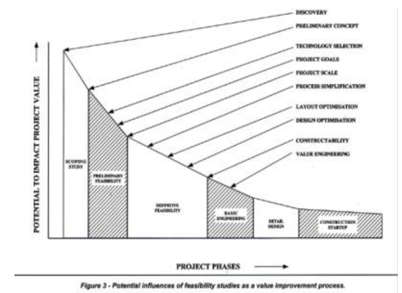
  - *determine how much it is sensible to spend in making a discovery*

  - *and, how much time we have in which to do this*

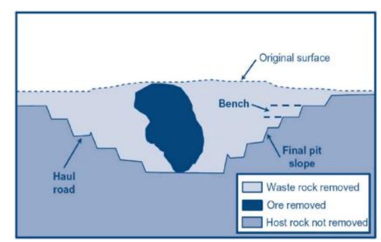
What is Ore?

- Ore is an economic term,
  it is not mineralisation

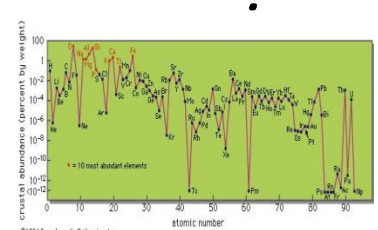
- *Mineralisation becomes ore by crossing mining, resource recovery, and economic hurdles*



- The grade at which mineralisation becomes ore and is mineable is the *cut-off* grade of a deposit

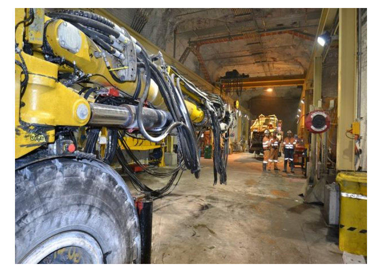


- *For Cu, Au & most metals this grade 100-1,000 times the crustal metal value*

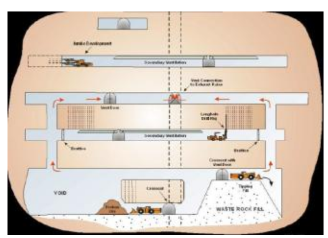


Mining Ore

- There are essentially two forms of mining: **open pit & underground**
- *Open pit mining is a matter of scale, how small or how large?*
- Underground mining is similarly one of scale and is of one of two types:

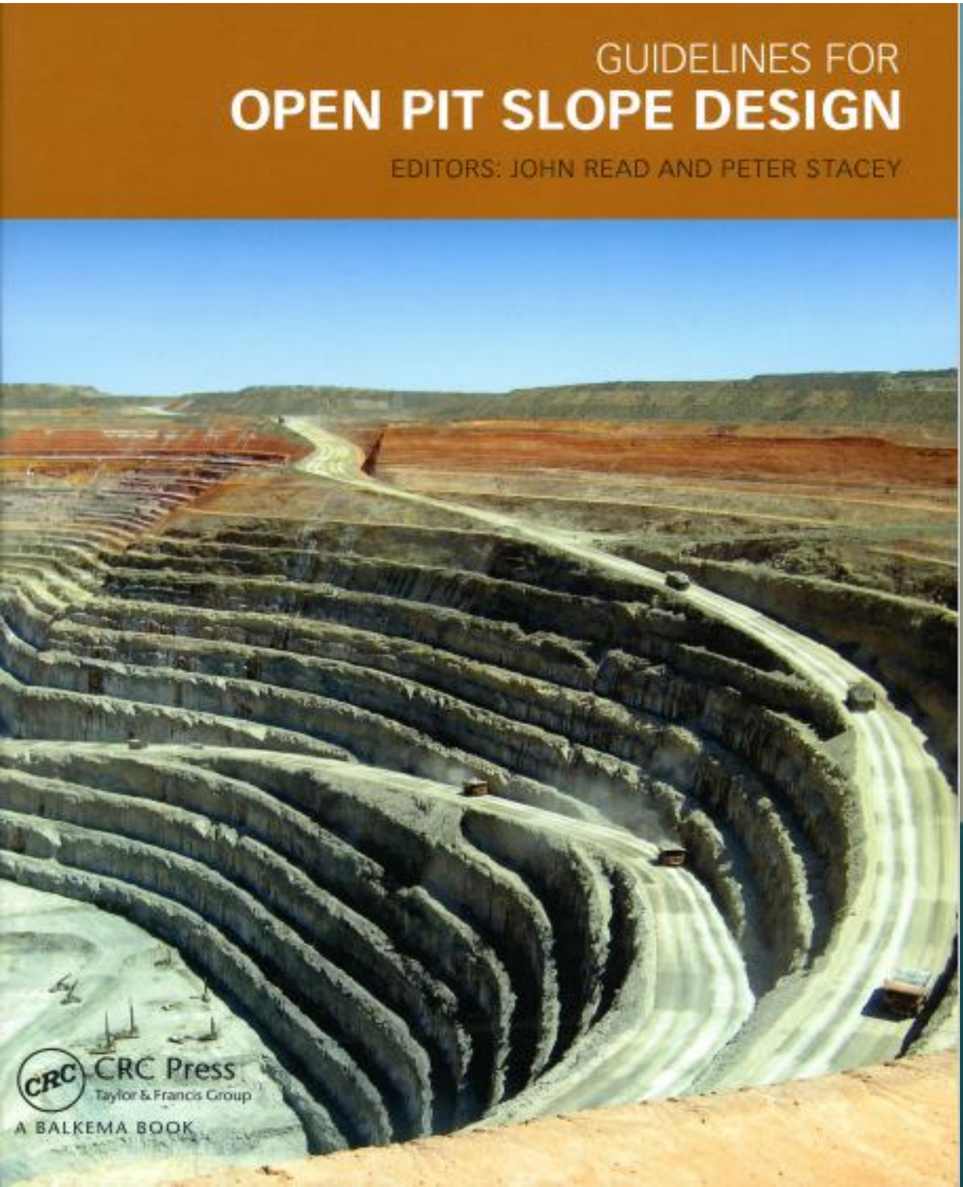


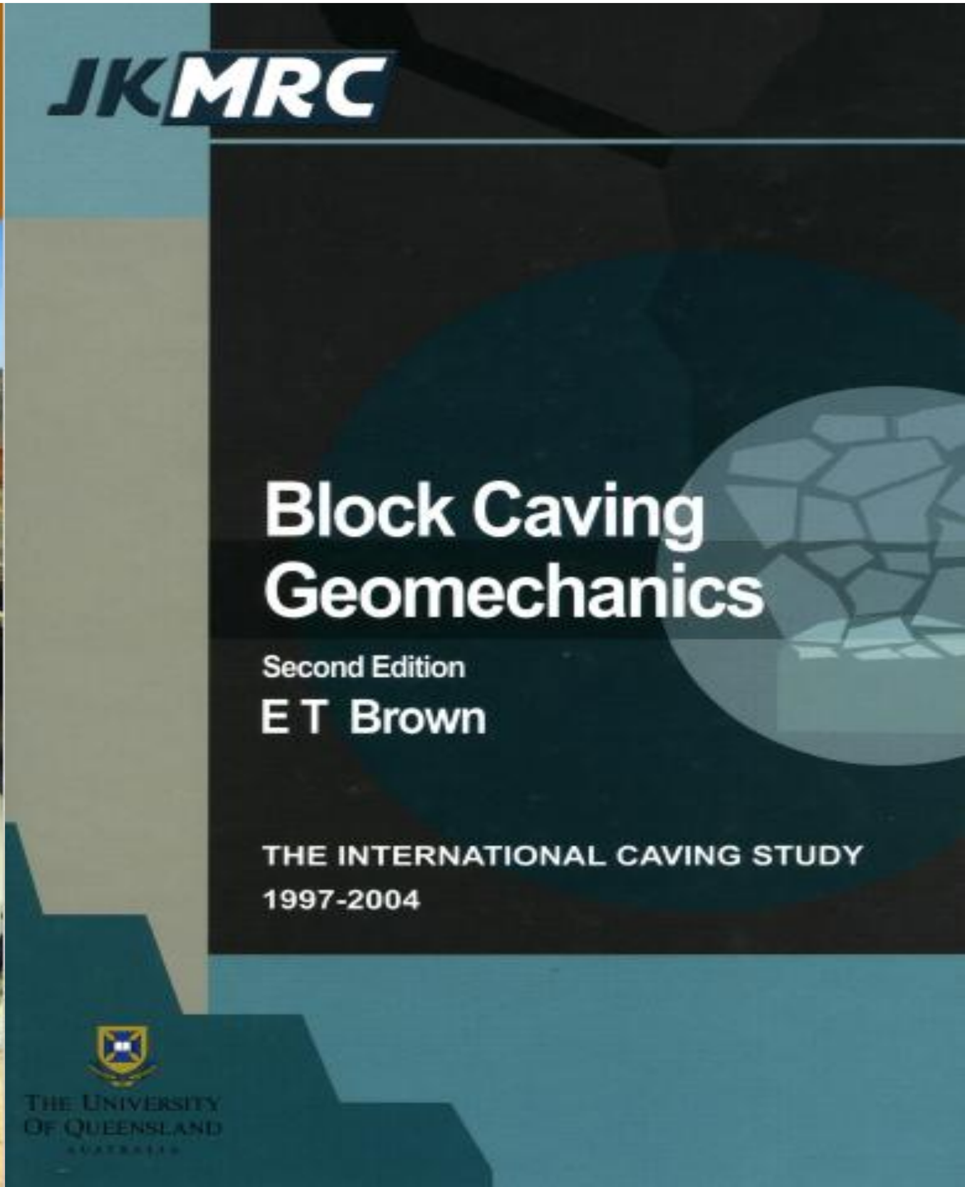
Narrow-body, mining many hundreds of tonnes per day



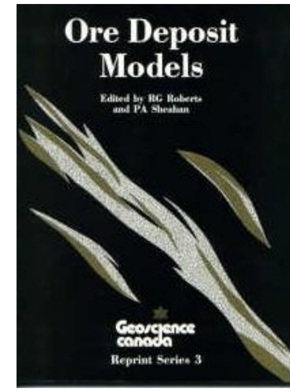
Mass mining, and mining many thousands of tonnes per day, up to 100,000 tpd

Two Mining Texts worth Consulting





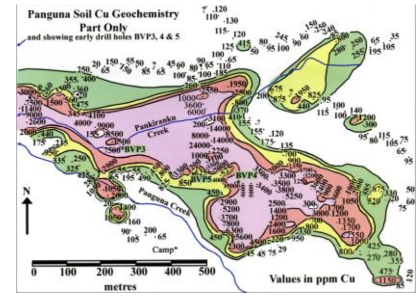
Discovering Ore



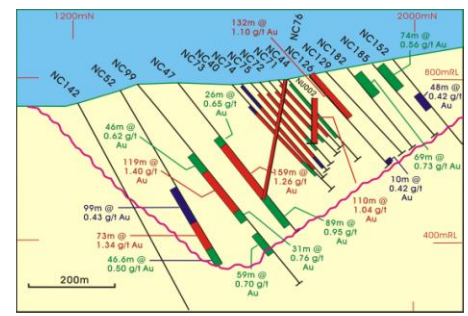
- **We use geosciences and ore deposit models to discover mineralization to convert into ore:**
  - ***no two deposits are exactly the same*** *and the models should be used only as a guide,* ***not prescriptively***
- ***Discovery is usually achieved by:***
  - *making mostly surface geological observations*
  - *collecting mostly surface geochemical data*
  - *combining these data with geophysical data, where acquired*
  - *to formulate a hypothesis to test*
- **Hypothesis-driven science is then used:**
  - to ask the right questions
  - using creativity in determining which questions to ask
  - e.g., might these observations?
  - discover this?

Ore Discovery Process

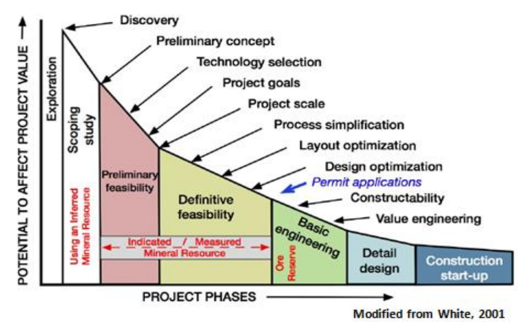
– **Detect an anomaly** related to a deposit containing a mineral resource, **and discover the deposit** by drilling a number of holes



– **Identify & quantify** the mineral resource by drilling and sampling many more holes



– **Convert the mineral resource to ore** by conducting mining studies

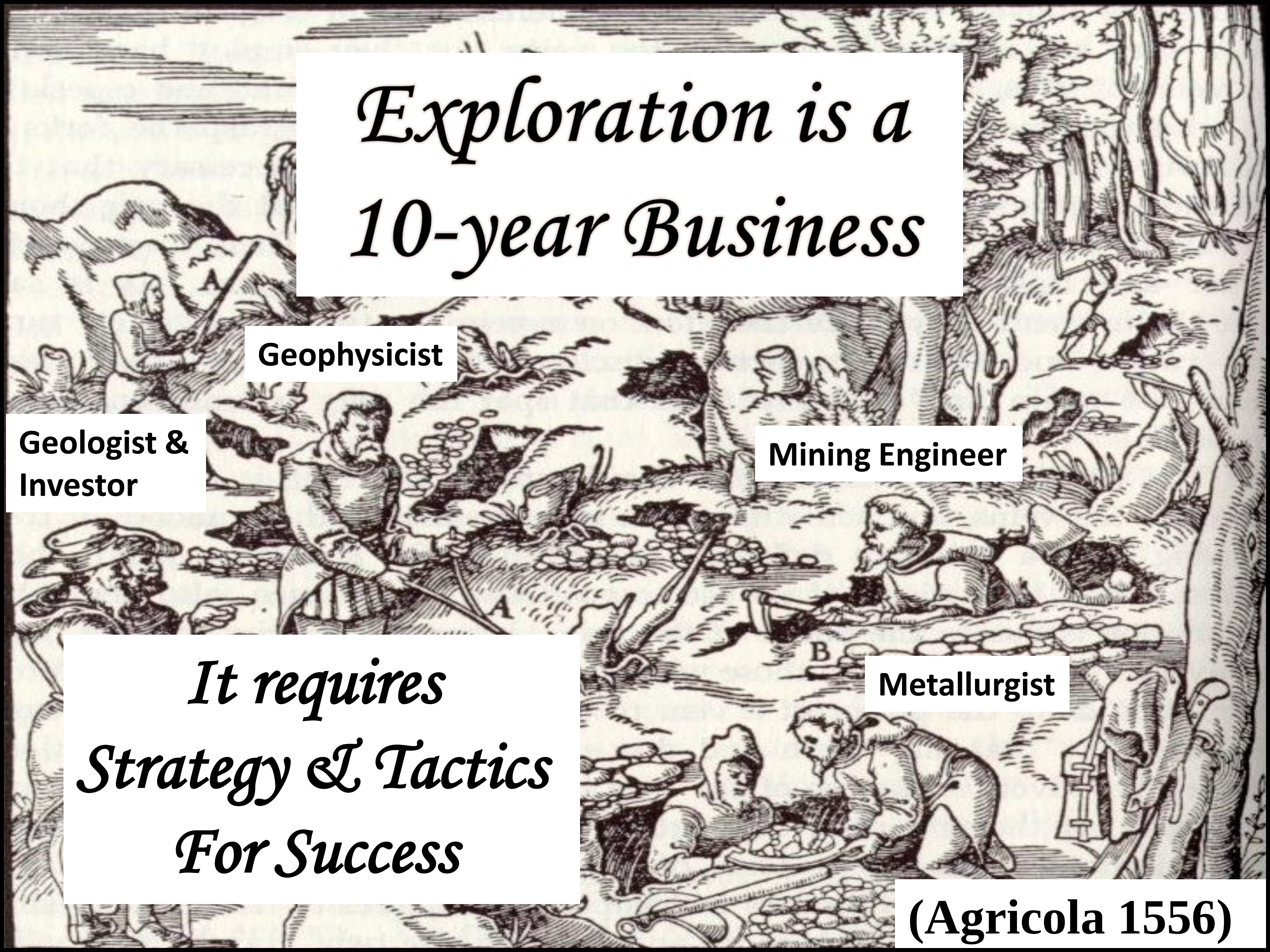


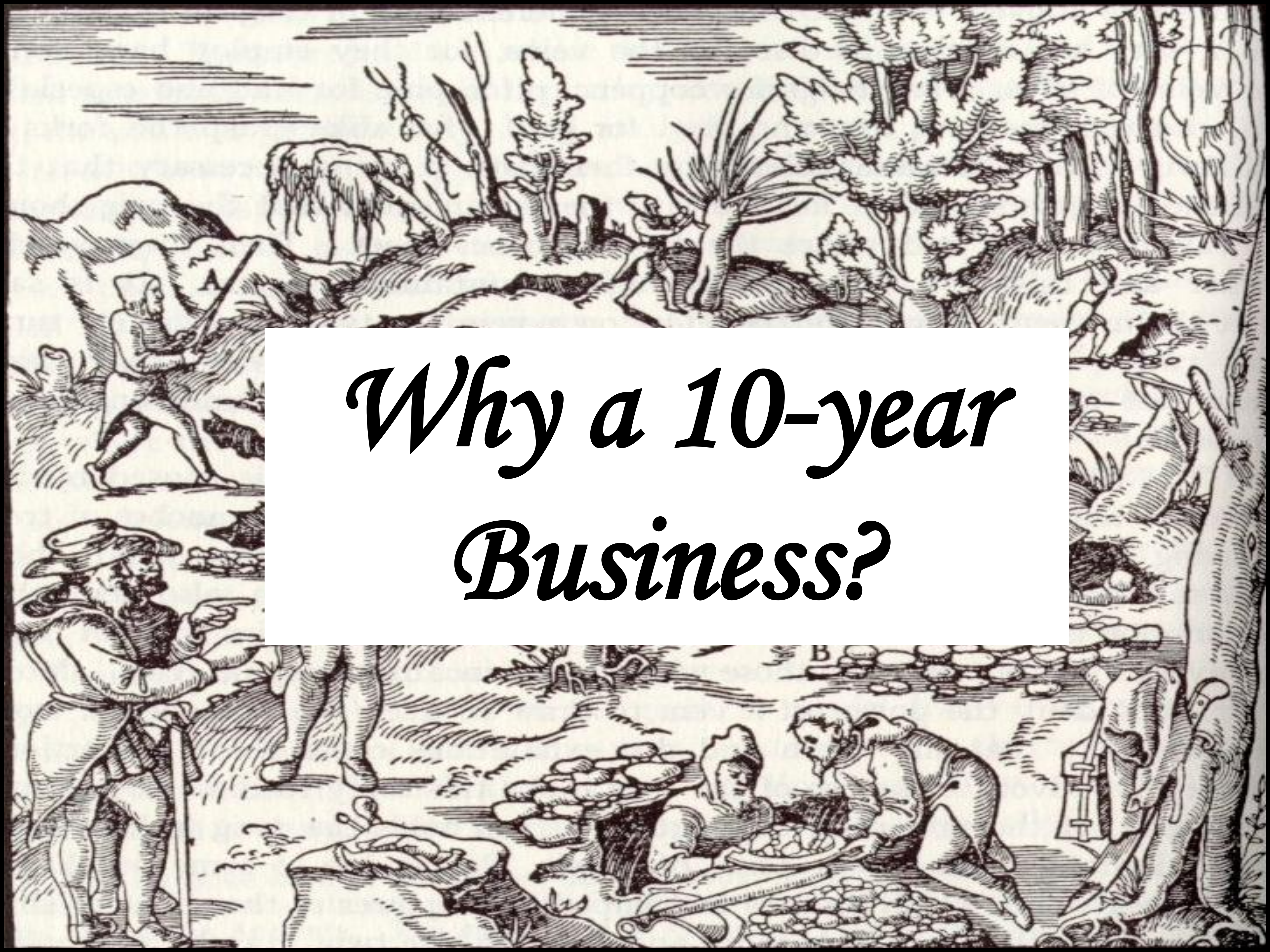
Conducting Exploration

- **There are really only two ways in which an ore deposit may be discovered**
- *Casino Approach* : *and rely completely on chance (luck) or good fortune*

- *Business Approach* : *and try to manufacture a discovery, but not as in producing, e.g., a car*

- *Casino Approach* : is gambling & requires an endless supply of money, which usually isn't available
- *Business Approach* : uses science, economics & money and has more chance of success than does the casino approach


Exploration is a 10-year Business
Geophysicist
Geologist & Investor
Mining Engineer
Metallurgist
It requires Strategy & Tactics For Success
(Agricola 1556)

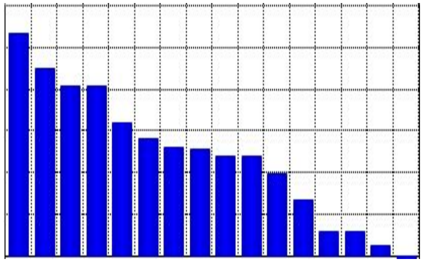


Why a 10-year Business?

10-year Reasons

- *Any shorter period is under-estimating the challenge and the difficulty*

- Success will have a different meaning depending on the size of the exploring company



- *Success will have a different dimension for a major company to what it will have for a junior explorer*

Exploration as a Business

- Exploration may succeed if there is a good business model

- *The principal challenge is managing risk*

- The major risk is exploring in the wrong place

- ***Area selection is the crucial decision***

Area Selection

- "It is very difficult to find a black cat in a dark room" **Old proverb**
- Even worse if it is Schrödinger's cat
- ***The difficulty in exploration is not only the state of the "cat", but whether or not it is there!***

Selecting the Right Area?

How to manage the risk & uncertainty?

The lowest risk approach is to explore where additional mineralisation may exist:

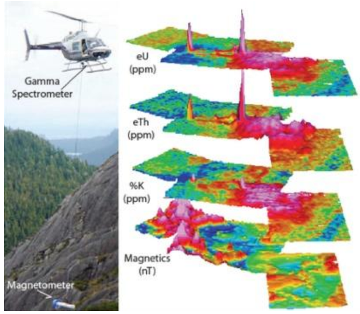
- close to an old mine
- in a known mining district, or
- where potential is indicated geologically

The highest risk is where there is no evidence of mineralisation

Uncertainty can only be resolved by drilling

How is Exploration Conducted?

- The earliest explorers were prospectors who relied on observation for their discoveries
- **After the 1950s, prospecting became more sophisticated – modern exploration was born**
- Observation is still crucially important, but it is commonly supplemented by geochemistry and geophysics
- ***Exploration usually follows a process***

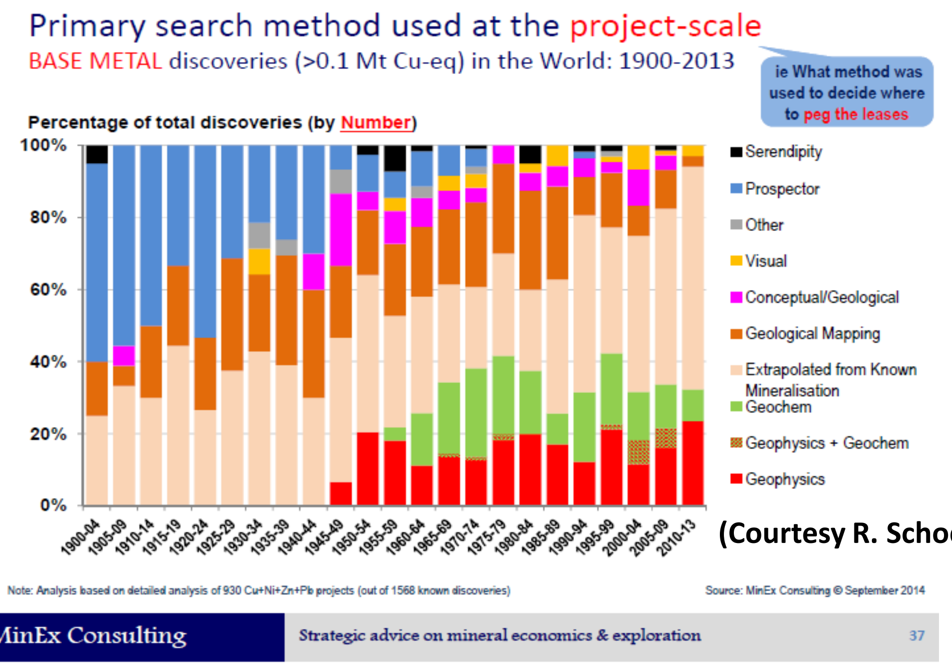


Elements of Exploration Process

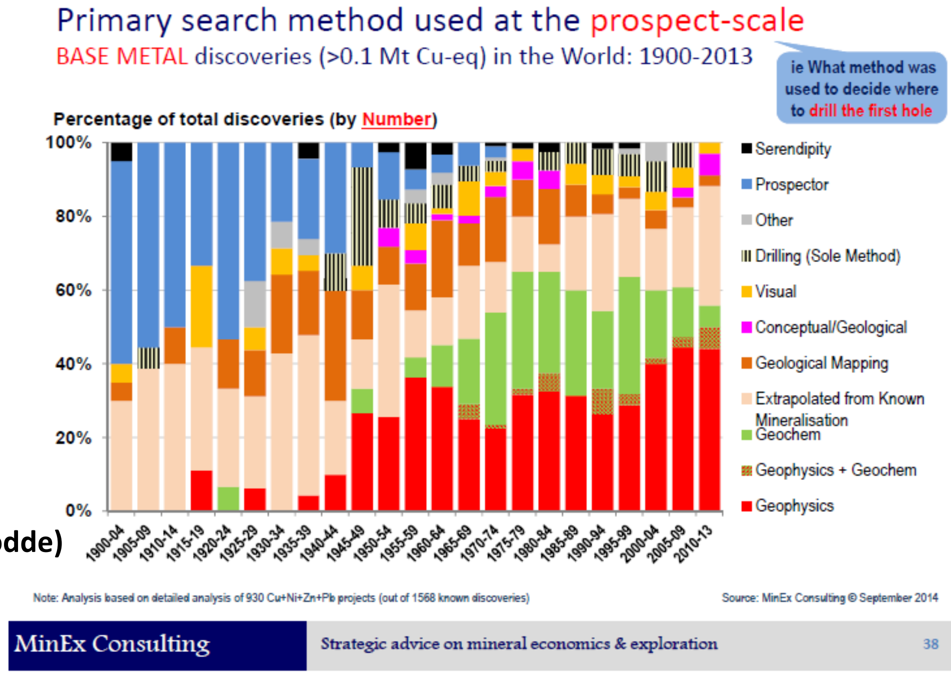
- **Exploration Objective**
- **Discovery Target**
- **Discovery Strategy for Success**
  - *Major versus junior company*
  - *Strategy & tactics*
  - *Chance of success*
  - *Risk*
  - *Mining method*
  - *Environmental & social*
- **Exploration Budget**
  - *Economic decisions in exploration*
  - *Discovery cost*
  - *Discovery challenges – why is discovery rarely achieved?*
- **Exploration Techniques**
  - *Principal Search Methods*
  - *Geology*
  - *Geochemistry*
  - *Geophysics*
- **Exploration Programme**
  - *Regional exploration*
  - *Prospect exploration*
  - *Discovery drilling*
  - *Deposit drilling*
- **Discovery Assessment**
  - *Resource delineation & definition*
  - *Resource estimation*
  - *Mining studies*

Only a few elements are addressed in this lecture

Use of Search Technology



(Courtesy R. Schodde)

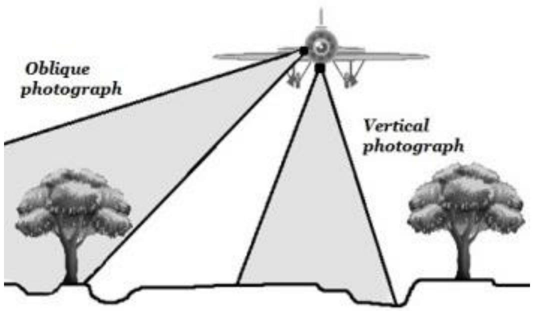


- Geochemistry or geophysics was used in 20 – 40 % of cases to **acquire an exploration project** after 1945
- The use of geochemistry has been tapering since 2000, to about 10 %
- The use of geophysics has stayed fairly constant since 1950, at about 20 %

- Geochemistry or geophysics was used 30 – 60 % of time to **select 1st drill site** after 1945
- The use of geochemistry has fallen significantly since 2000, to about 10 %
- Replaced by a gradual increase in use of geophysics, to about 40 %
- **DRILLING STILL REMAINS THE MAIN METHOD OF DISCOVERY, HOWEVER**

Mapping Technology

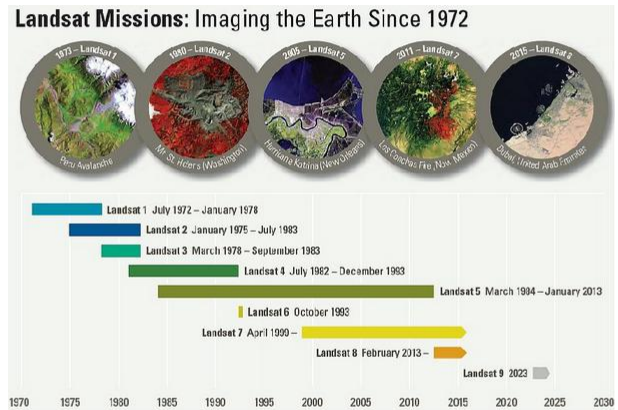
Aerial Photography



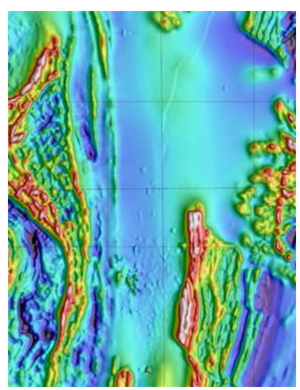
Black & white

Colour

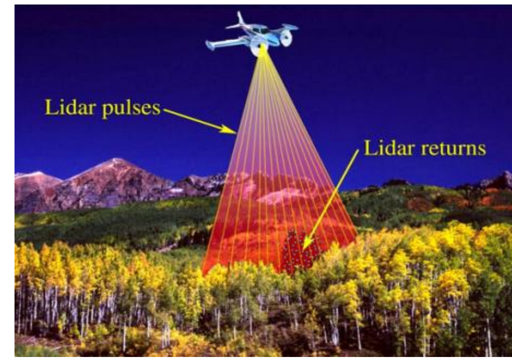
Satellite Imagery



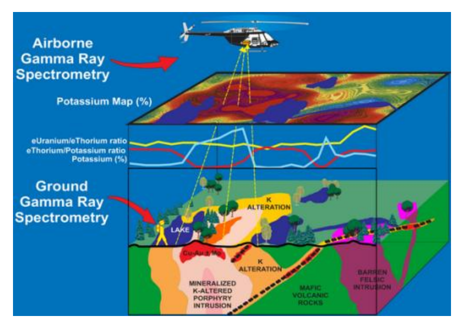
Aeromagnetics



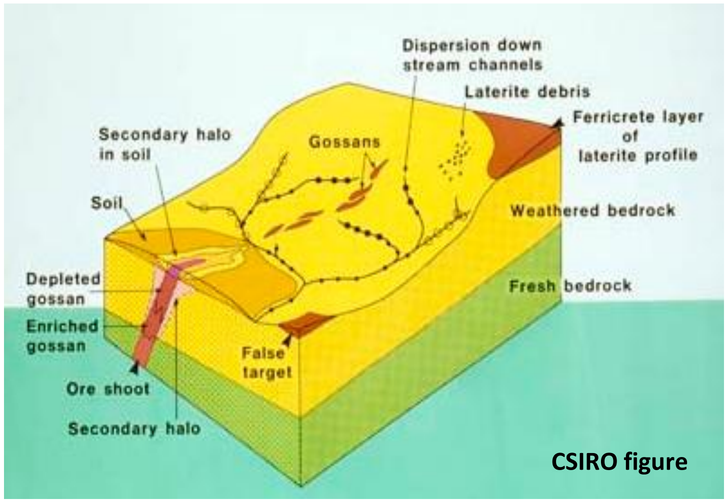
Surveying



Radiometrics

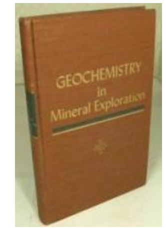


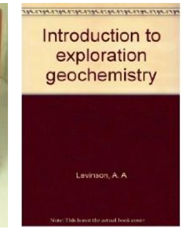
Geochemical Technology

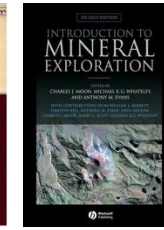


CSIRO figure

EXPLORATION GEOCHEMISTRY TEXTS







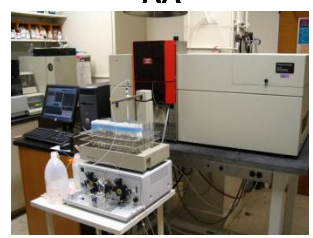
GEOCHEMICAL ENVIRONMENT MODELS

ANALYSIS

AA, ICP-MS, LA-ICP-MS, TIMS, SHRIMP, SIMS, GS, PIXE, BLEG, etc.

Laboratory

AA



SEM

Core shed

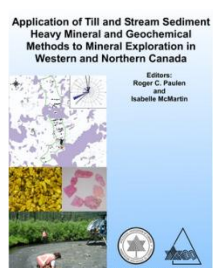
SWIR

SAMPLING

Stream sediment

Soil

Rock & Talus



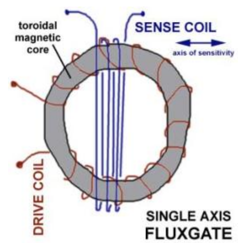
Field

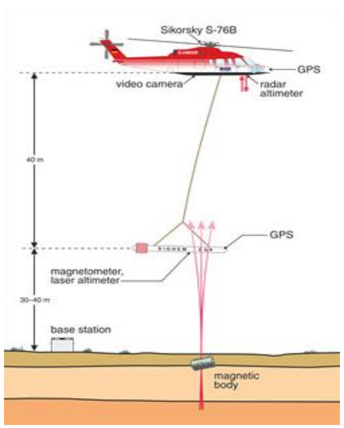
SWIR

XRF

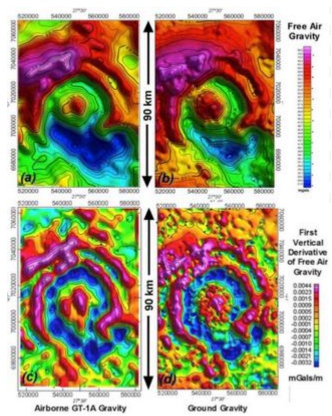
Geophysical Technology

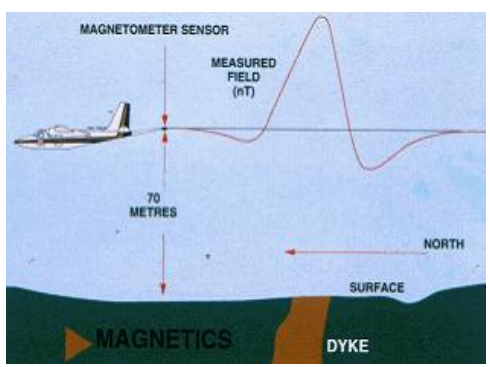
Magnetics



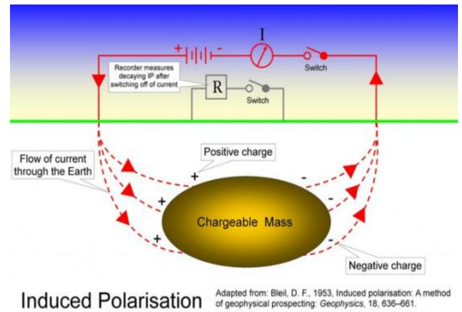


Gravity

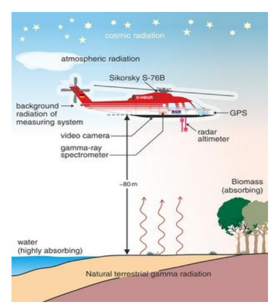




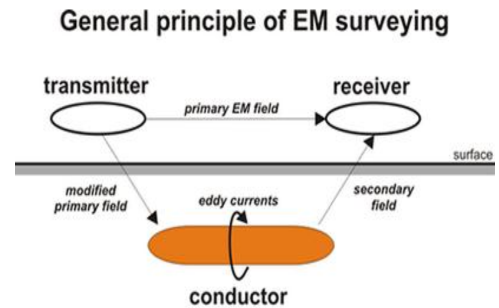
IP

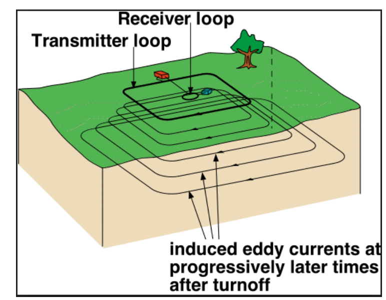


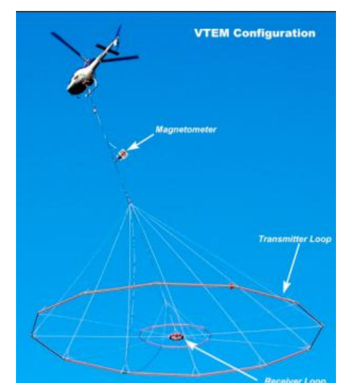
Radiometrics



EM

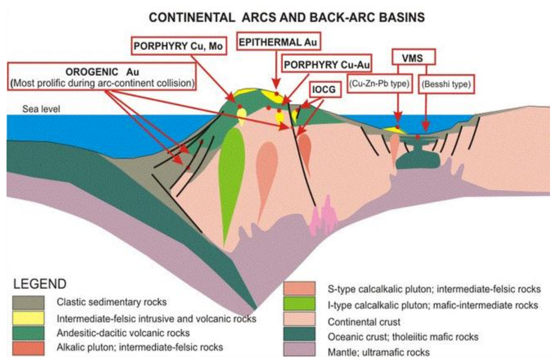


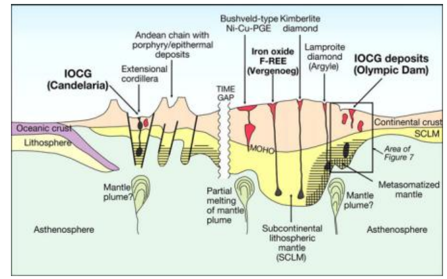


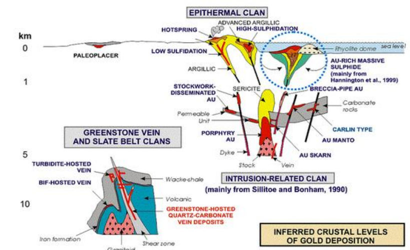


Ore Deposit Models

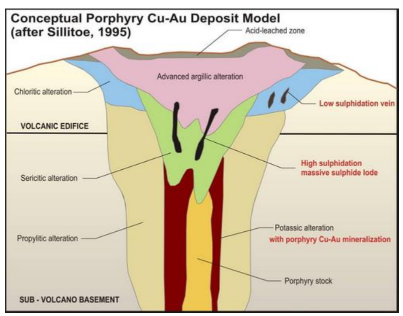
Tectonic Setting

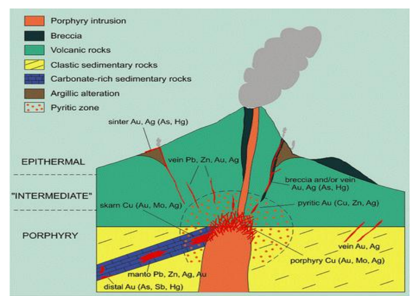


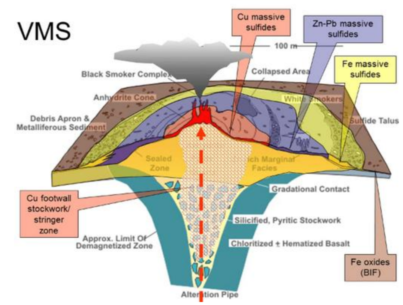


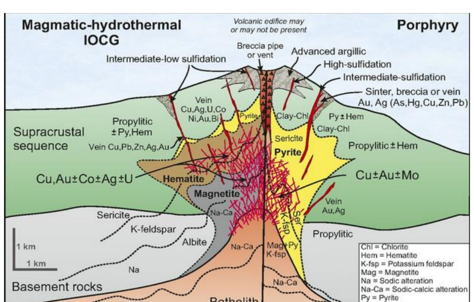


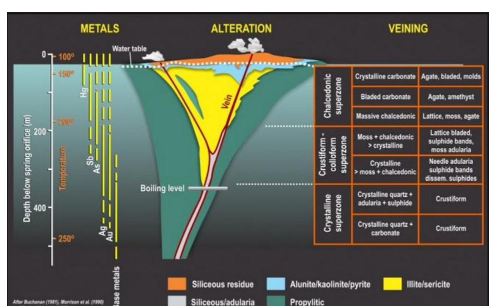
Deposit Type

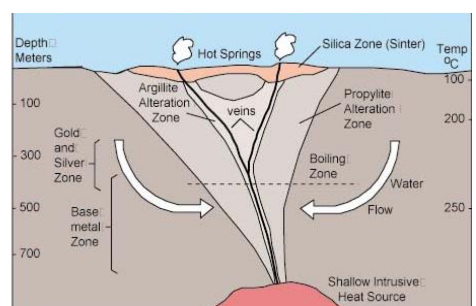


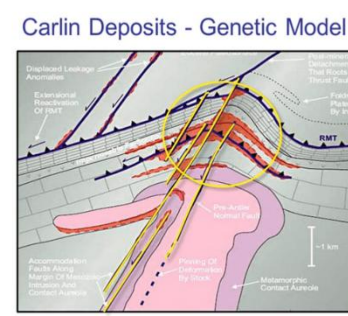






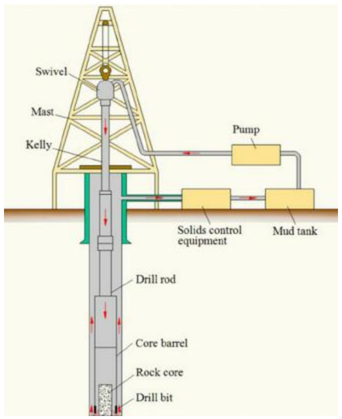






Drilling Technology

Diamond coring



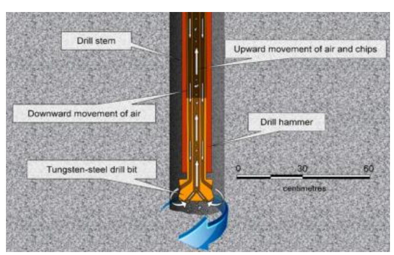
Improved Drill bits

Wireline

Multi-purpose

Rotary-percussion

Reverse-circulation



Improved Hammers

Geochemical Sampling

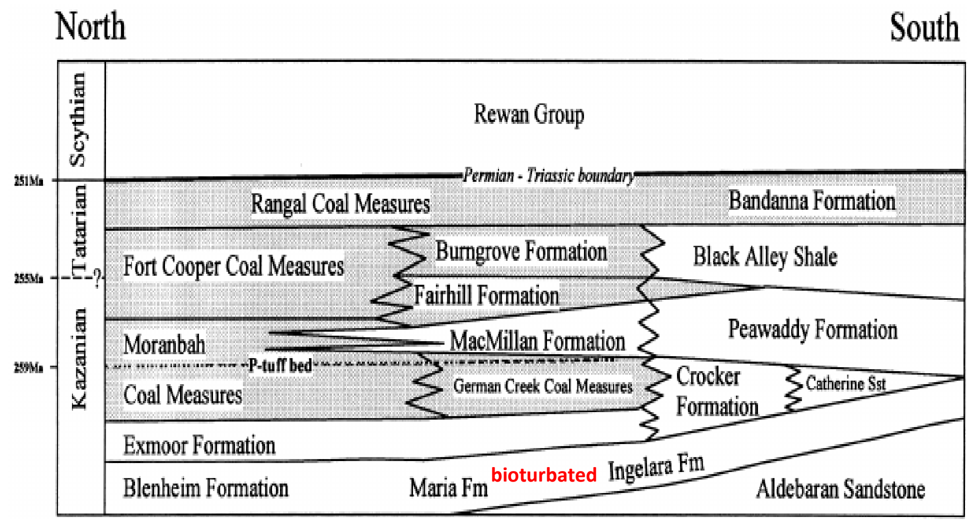
Aircore

Auger

Future use of Technology

- **It is common to hear geologists claim to be overwhelmed by data – BIG DATA**
- **On the assumption that all of these data are required for discovery**
- **And are now too much for the human brain to handle**
- **Seeking the solution in computing-related technology to "process" data and conduct prospectivity analysis**
- **I COULDN'T DISAGREE MORE!**
- **THE SOLUTION RESTS WITH BETTER EXPLORATION THINKING, USING RELEVANT DATA, AND ACTION**
- **We are kidding ourselves if we believe we need to use all of the data that is now available and could be "processed"**
- **A computer is not the solution to discovering ore, in my opinion**
- ***EINSTEIN DIDN'T USE A COMPUTER TO DISCOVER RELATIVITY!!***

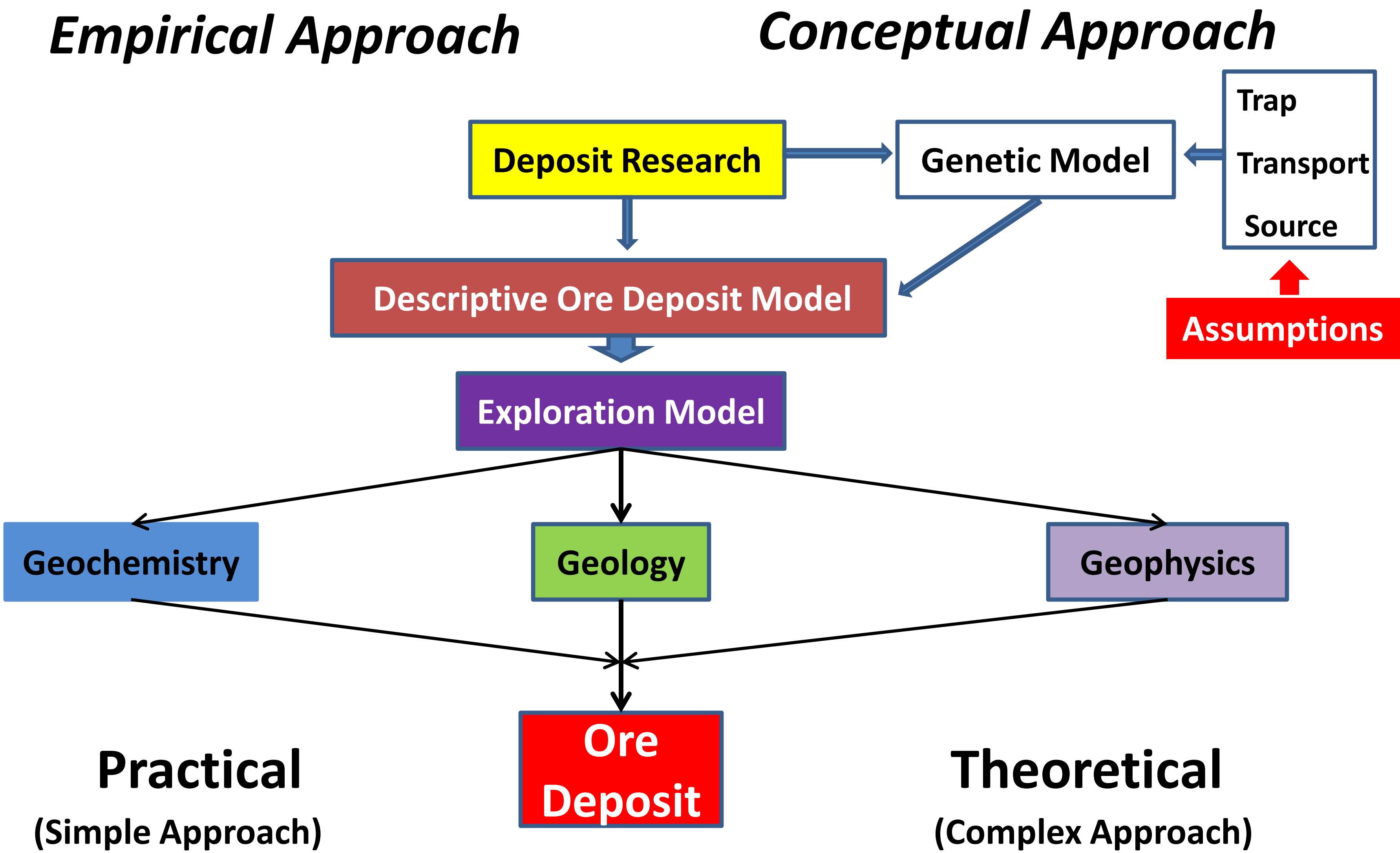
Thinking – Gregory Discovery



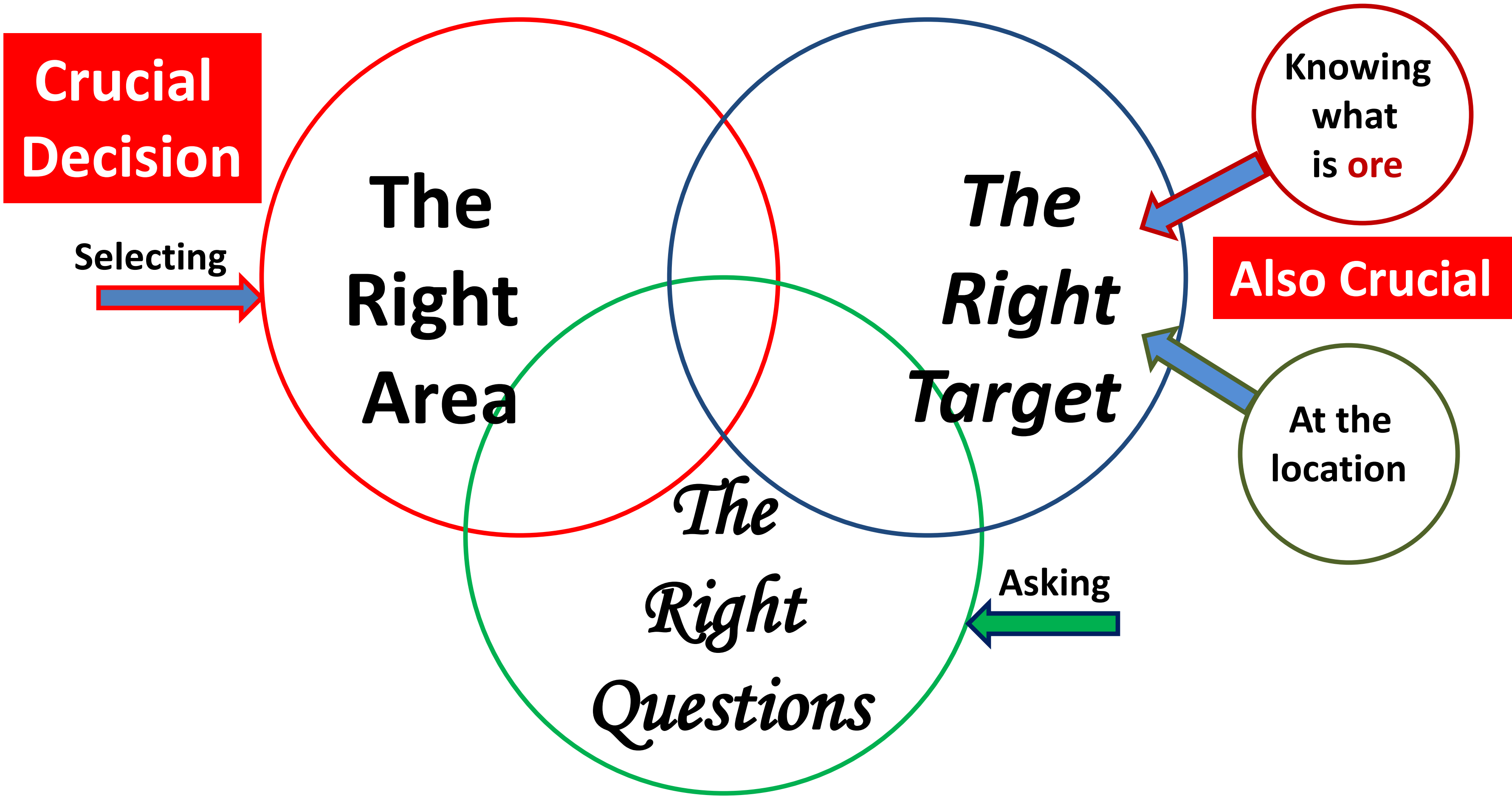
- In the late-1960s it was assumed that the western limit to the German Creek Coal Measures in the Bowen Basin of Queensland had a consistent SSE trend

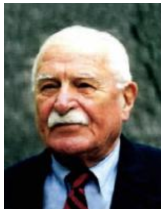
- The Gregory coal deposit was discovered for three reasons:
  - BHP geologist, Evan Pryor, spent his spare time logging cuttings from holes drilled across the western Bowen Basin on widely-spaced traverses, by Utah
  - he realised that drilling had not been extended far enough west in the Gregory area (the trend swung west)
  - because of the absence of bioturbation in an interpreted basal shale

Changing Approaches



Present Exploration Model





Sig Meussig's Canons

"IQ gets you there, but NQ finds it!"

- Exploration is not a science
- **Go with the facts, forget the theory**
- Try for the definitive test
- **The odds are best in the shadow of the headframe**
- Save the agonising for mineralised trends
- **Look for ore, not mineralisation**
- **To find an ore body, you have to drill holes**
- **There needs to be room for the ore**
- Improve it or drop it
- Do not chase spurious anomalies
- Do not be preoccupied with explaining anomalies
- **Do not be preoccupied with pathfinders**
- **Do not be preoccupied with stereotyped concepts**
- **Do not be technology driven**
- Acquire first, study later
- Disregard competitor's previous actions
- Go for the jugular
- It's the drill hole, stupid!

DREGS 1993

Discovery Performance

Acknowledgement

The Global Shift to Undercover Exploration

- How fast ? How effective ?

Richard Schodde
Managing Director, MinEx Consulting
Adjunct Professor, University of Western Australia

Society of Economic Geologists 2014 Conference
30th September 2014, Keystone, Colorado

MinEx Consulting | Strategic advice on mineral economics & exploration

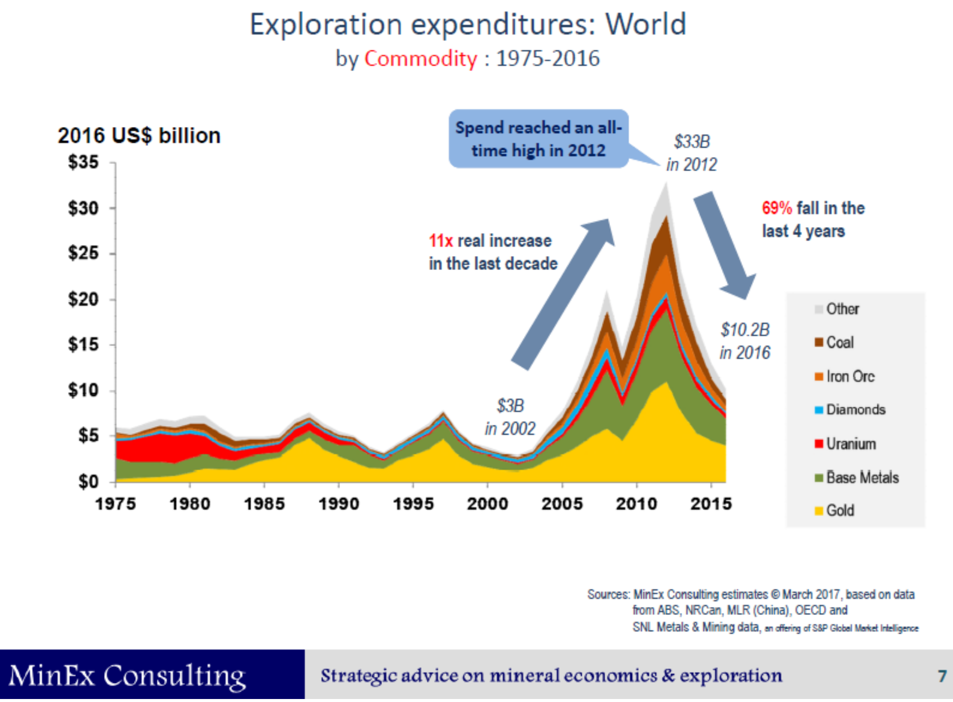
Recent Trends and Outlook for Global Exploration

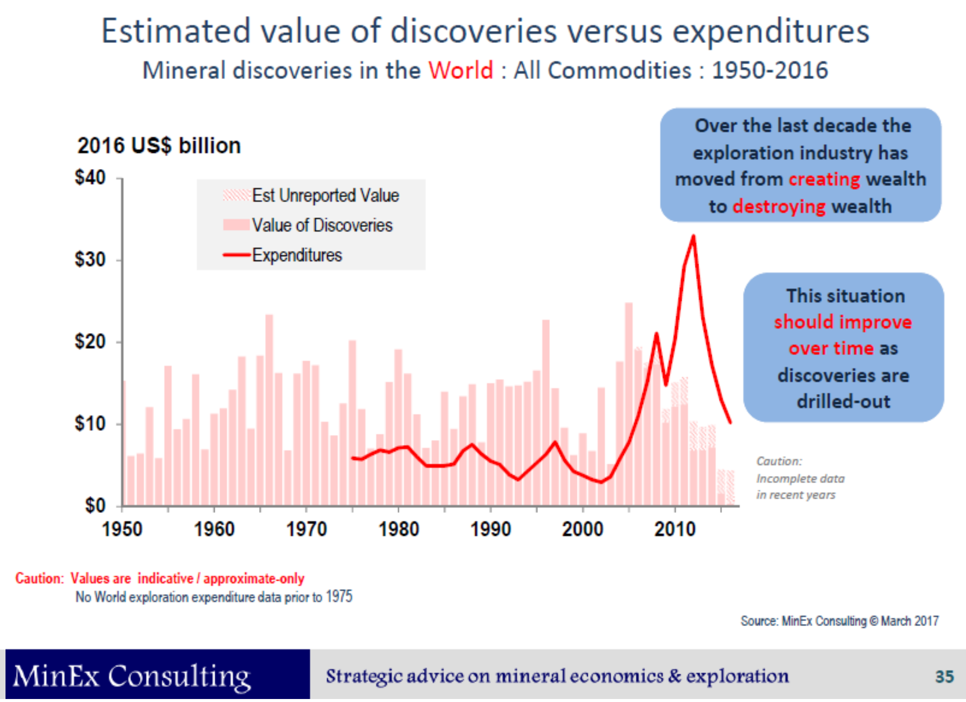
Richard Schodde
Managing Director, MinEx Consulting
Adjunct Professor, Centre of Exploration Targeting, University of Western Australia

PDAC 2017
6th March 2017, Toronto

MinEx Consulting | Strategic advice on mineral economics & exploration

Exploration Expenditure

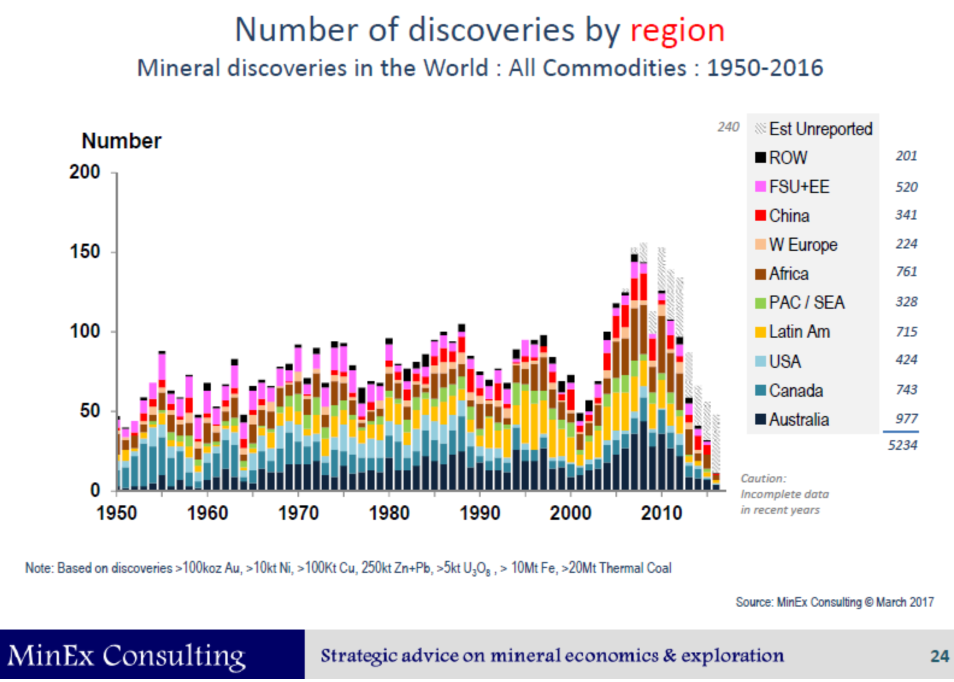


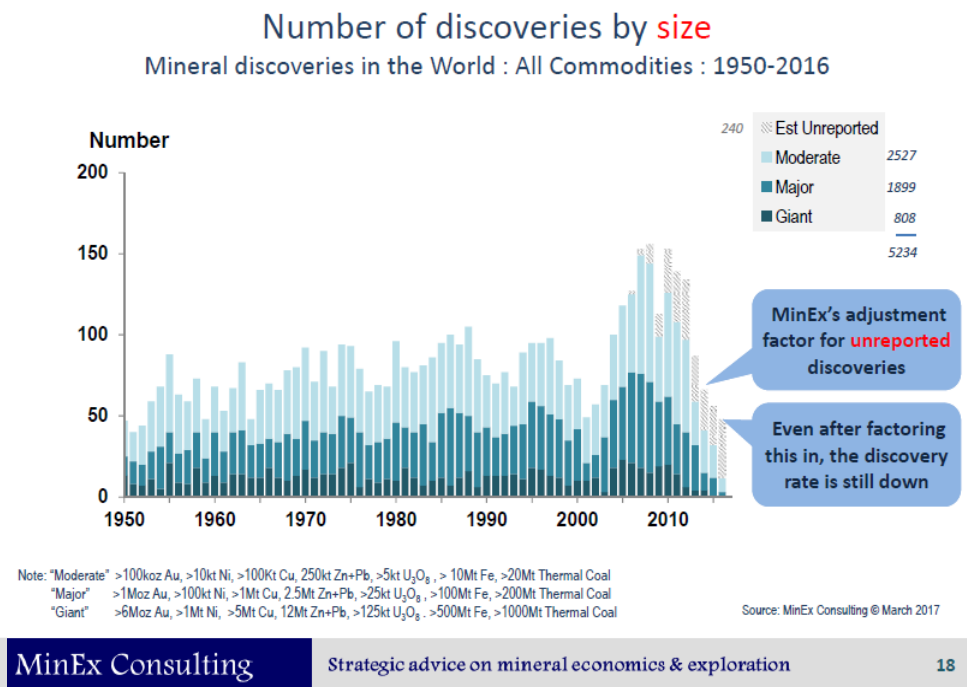


- **From 2005, annual expenditures on exploration far exceeded those prior to 2005**
- **Particularly for gold and base metals targets**
- **In hindsight, this seems irrational**

- **Up until 2008, wealth was created through exploration**
- **This doesn't seem to have been the case since then**
- **THIS WILL BE AFFECTING INVESTOR CONFIDENCE AND SUPPORT FOR EXPLORATION**

Discoveries



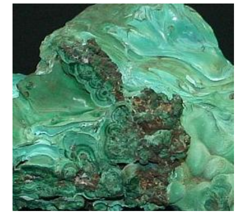


- **Since the late-2000s the number of discoveries per region seems to have fallen**
- **Which is strange given the different stages of maturity of the various regions**
- **It seems as though this fall off in discovery numbers is irrespective of deposit size**
- **OF GREAT CONCERN IS THE FALL IN NUMBER OF VERY LARGE DISCOVERIES, IF IT IS REAL**

No shortage of Discoveries

Uranium

Copper

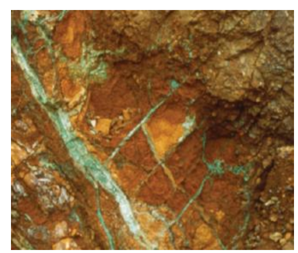


Bauxite

Lead-zinc

Iron ore

Nickel



Coal

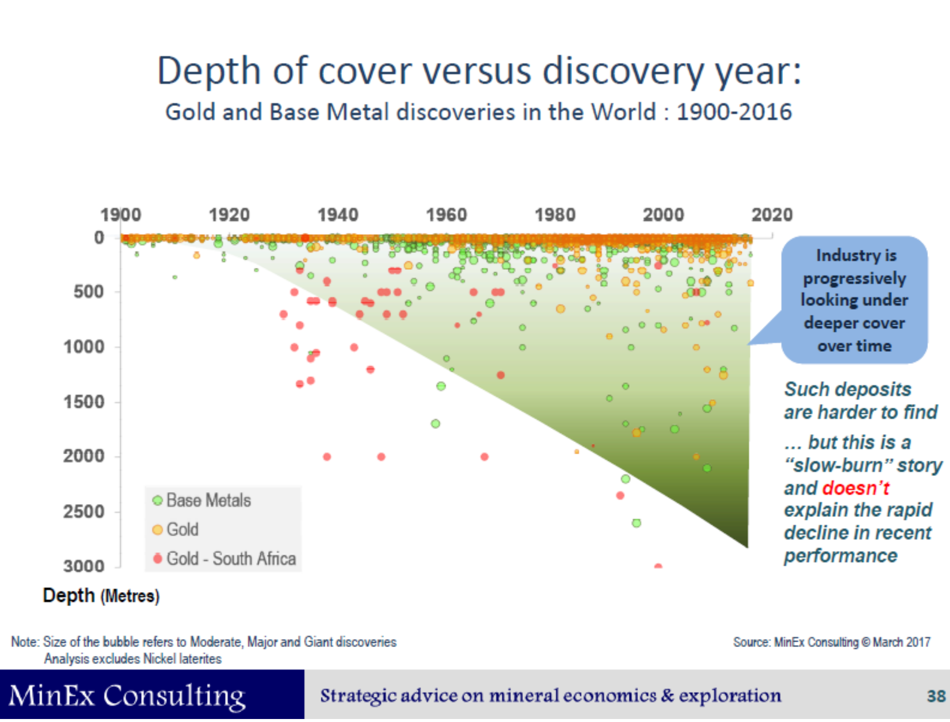
Diamond

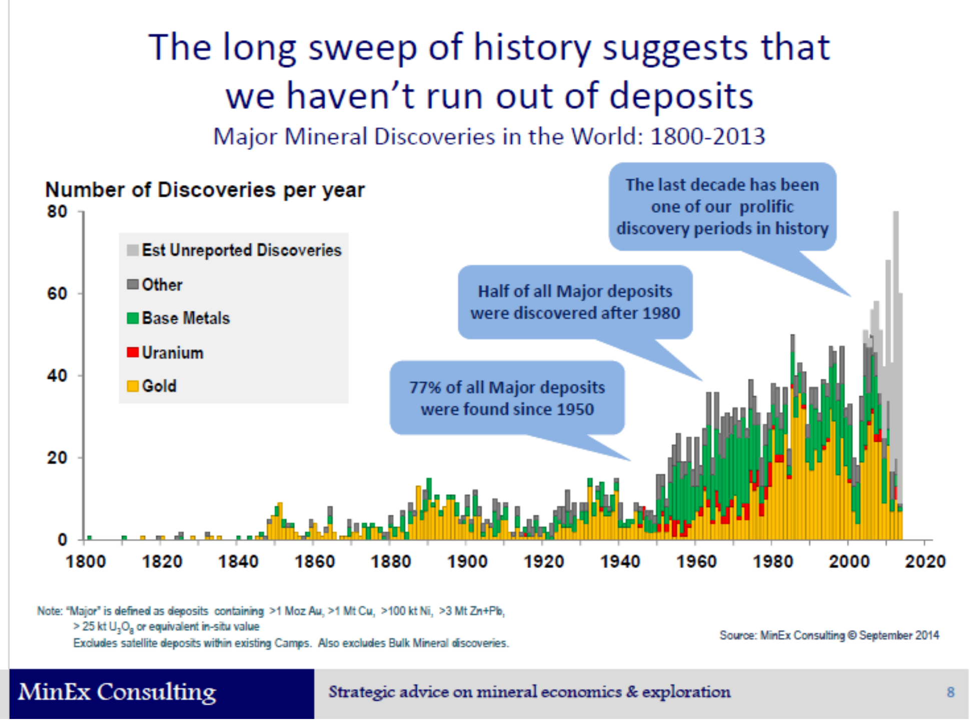
Gold

Deposit Types

- Porphyry – Cu ±Mo, Au, Ag
- VMS – Cu, Pb, Zn, Au, Ag
- Ultramafic – Ni, Cu-Ni
- Laterite – Al, Ni
- Sedex – Cu
- IOCG – Cu, Au, U
- Skarn Cu, Au
- Epithermal Au-Ag
- Orogenic Au
- Kimberlite diamond
- Others

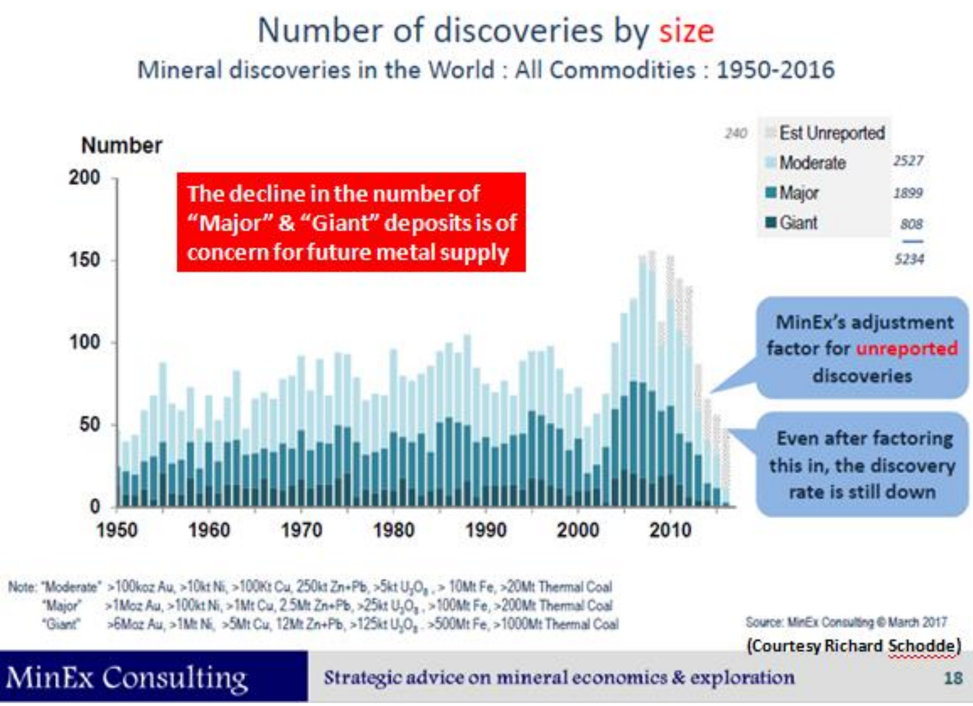
Future Implications

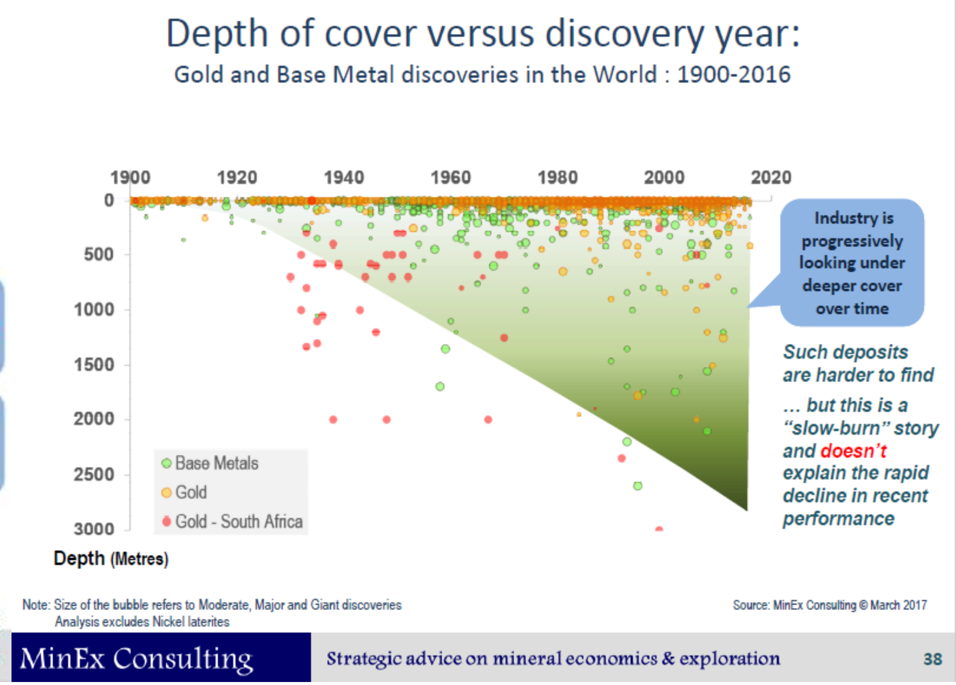




- **Most gold & base metals deposits occur at shallow depth (<200 m)**
- **They are/were mined mostly by open pit, which usually was the discovery objective**
- **Logically , there should be a large number of deposits to be discovered at >200 m depth, to 2,000 m, and the number should far exceed the post-1945 discovery total**
- **BUT THEY WILL BE MINED UNDERGROUND**

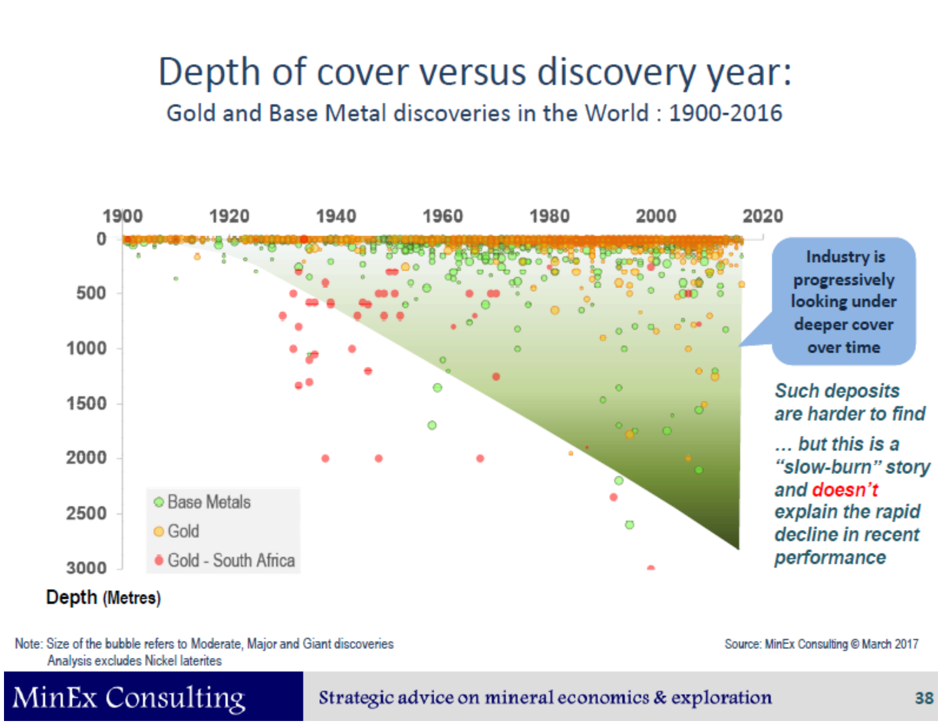
Future Focus?

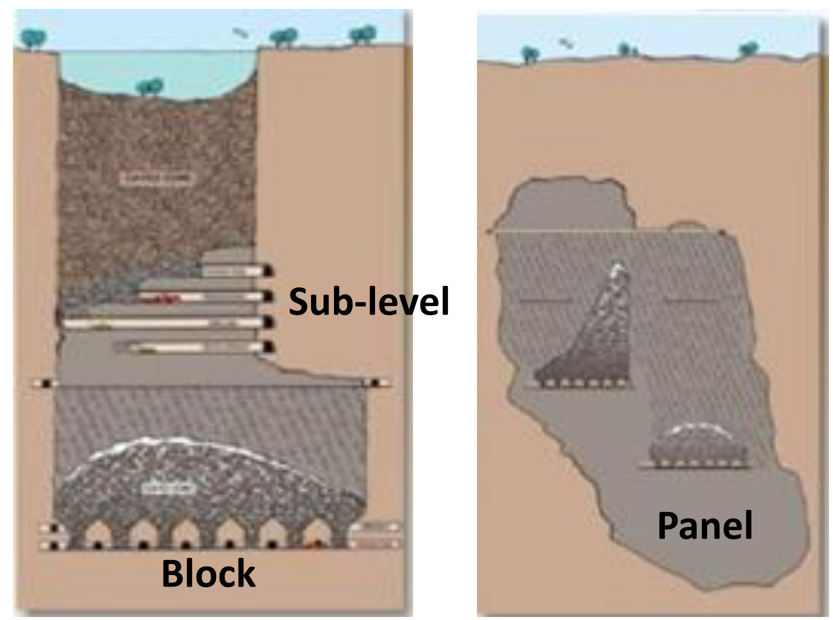




- **On supplying the growing demand for mineral resources while replacing the major mines that will close**
- **By increasing the number of 'Major' and 'Giant' discoveries**
- **To do this we need to explore deeper**
- **Which means we need to understand what is an ore deposit at depth**
- **BUT WE NEED TO FOCUS ON FIRST DISCOVERING AN "ORE SYSTEM"**

Thinking “Deeper”





(Images Source: Newcrest)

- Opens up a relatively poorly explored “Greenfield” region, down to at least 2,000 m depth
- Which should contain many more deposits than discovered so far
- Exploring deeper requires knowing the different methods of mining underground, particularly caving
- AND UNDERSTANDING THE DEPOSIT LIMITS TO THE METHODS

What is Caving?

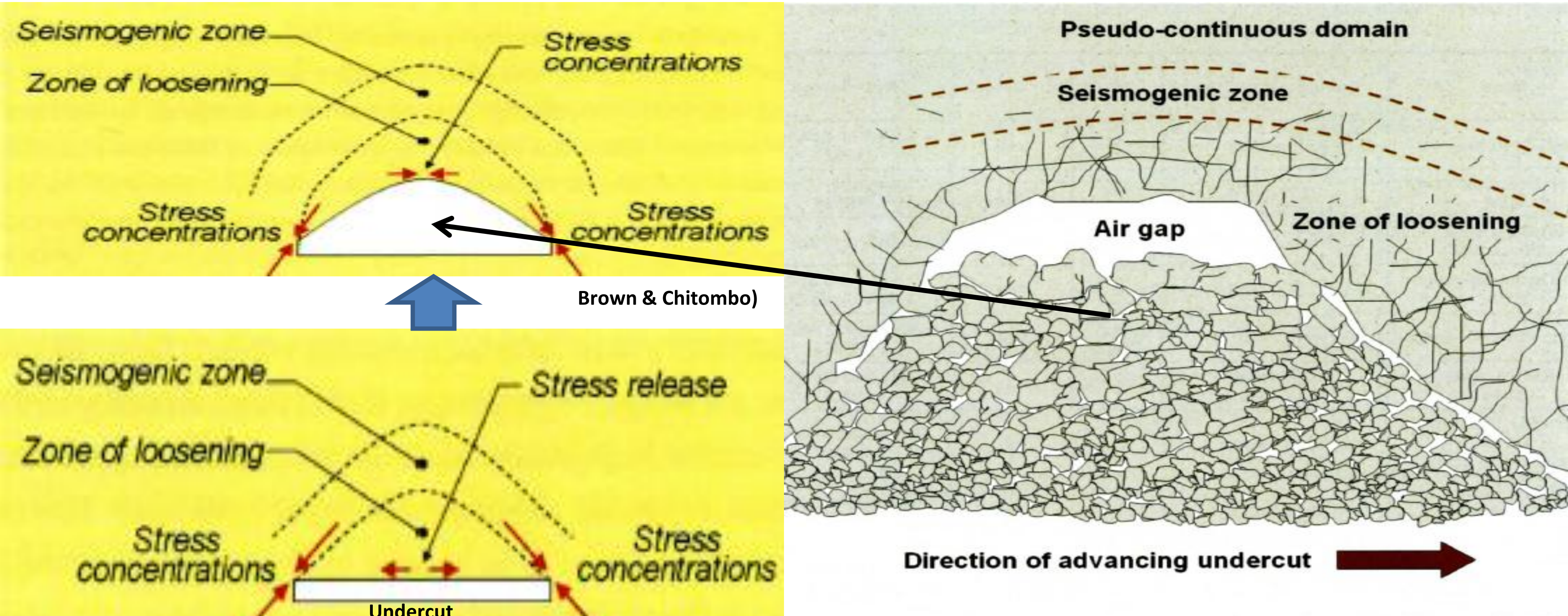


Figure 12: Conceptual model of caving (after Duplancic & Brady 1999)

- **Caving occurs because of gravity and induced stress in ore that has been undercut by removing ore**
- **UNFORTUNATELY, NOT ALL ROCK CAN BE CAVED, ECONOMICALLY**

- **Unlike open pit mining, CAVING IS UNFORGIVING – a failure usually cannot be recovered**
- **A cave may stall because of cave roof asymmetry, for example**

Caving Advantages

- **Much reduced environmental impact**
  - **Surface opening is limited to surface subsidence**

versus

  - **No waste pile from extracting ore**

  - Removes possibility for failure of waste stored on surface

- **There is also the possibility of further reducing the impact**
  - **By relocating surface ore processing plant**

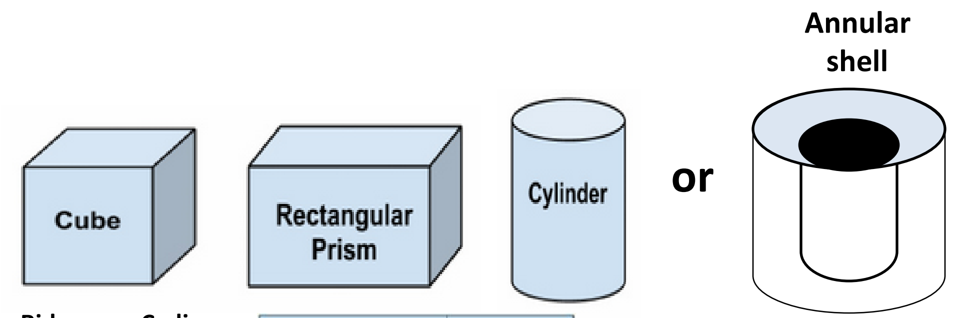
  - To deep underground

  - **By removing need for surface storage of tailings**

  - Using cemented tailings stored in surface subsidence void

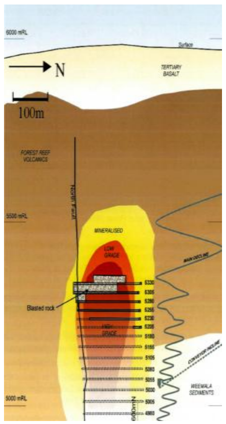
Some Caving Challenges

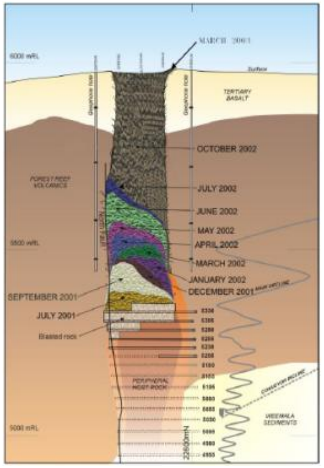
- Caving requires an ore deposit with a regular geometrical shape, without internal waste to dilute the ore grade

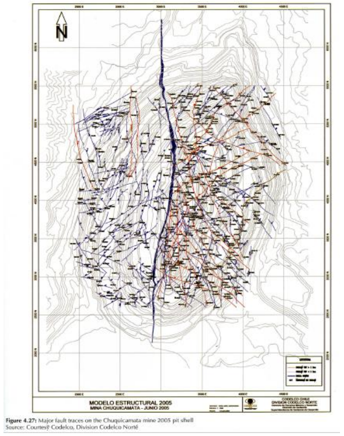


- Faulting within an ore deposit will affect performance of the cave, but this usually can be managed

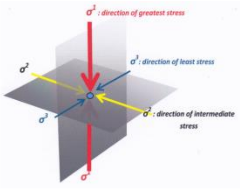
Ridgeway, Cadia

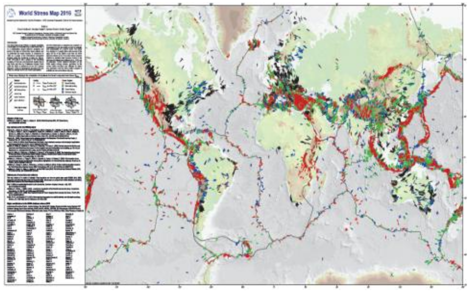


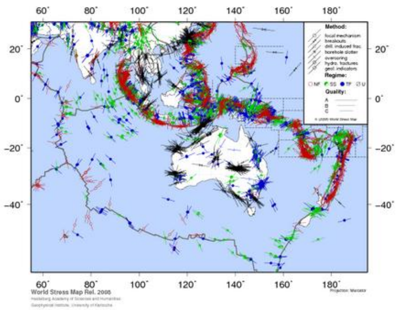




- The caving process uses gravity and operates better where
 in situ stress is low



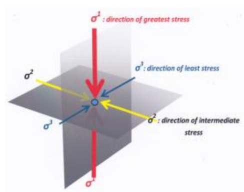




Source: GFZ Data Services

Other Caving Challenges

- Some aspects of caving work better with low horizontal stress



Courtesy: G. Chitombo

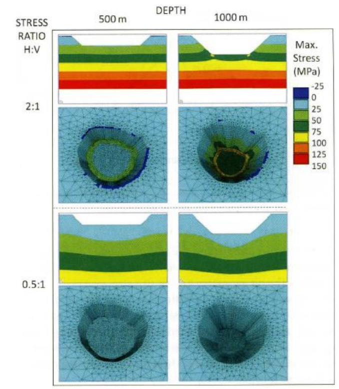
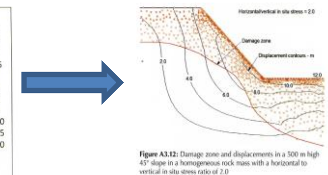
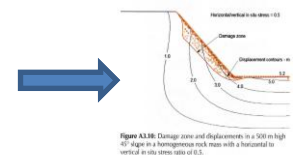


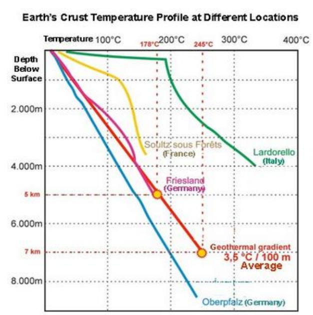
Figure A3.7: 3D modelling showing the effect of pit depth and stress ratio on the stresses induced in the rock mass surrounding an open pit with 45° slopes

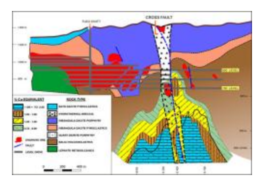


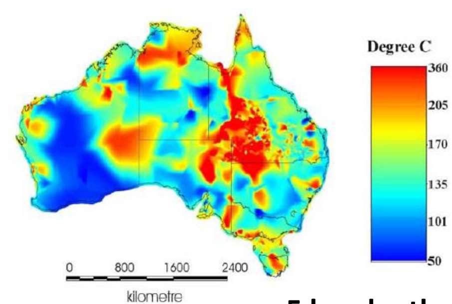


Read & Stacey, 2009

- High rock temperature is a mining issue, e.g., Resolution & Far South East deposits

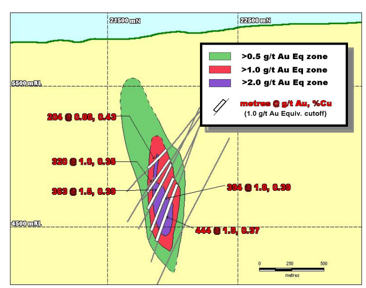


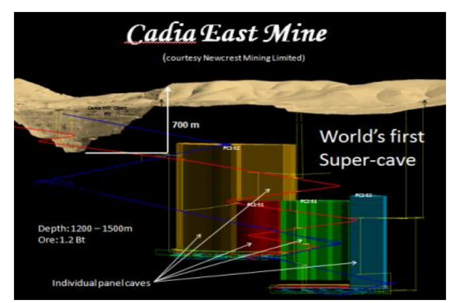


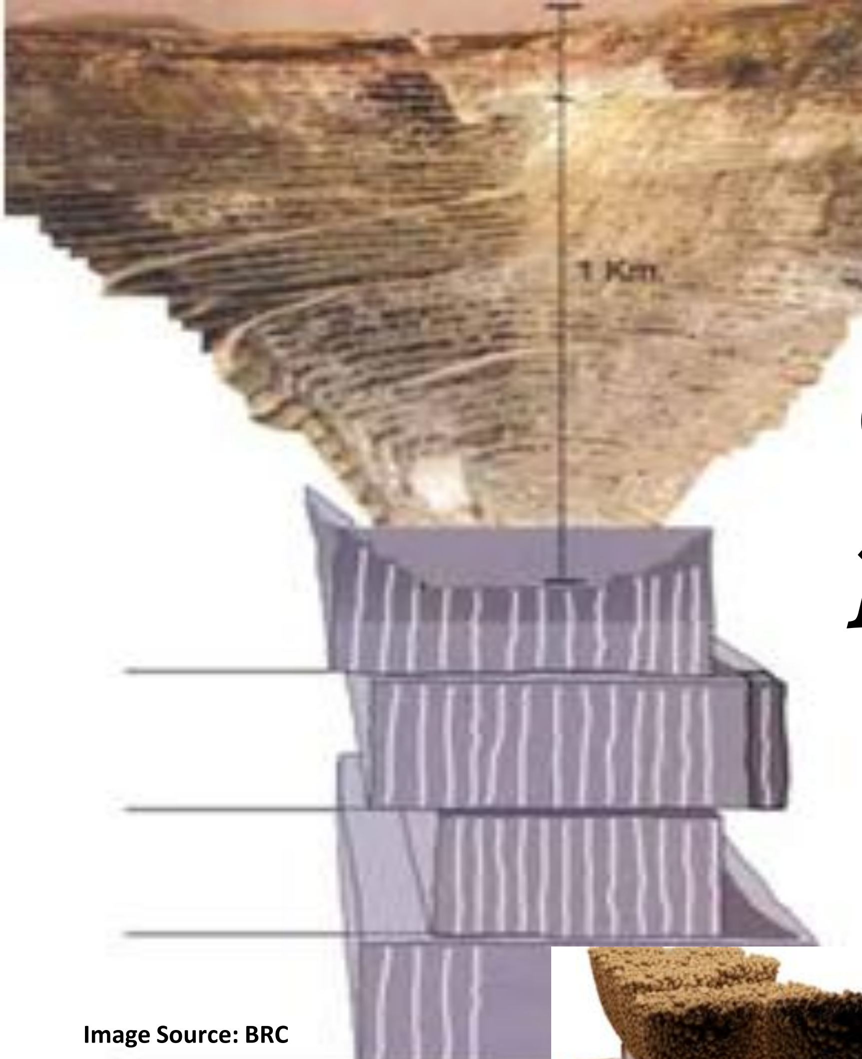


5 km depth

- As with open pit mining, caving economics may be enhanced by starting mining in high grade; but not always







Caving is extending to present deep open pits

A pit depth of >1,000m may be too deep for open pit mining to continue

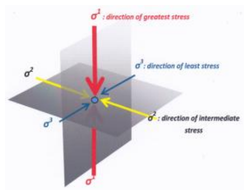
These mines are unlikely to be deepened and mining will cease

Unless there is sufficient ore remaining that can be caved

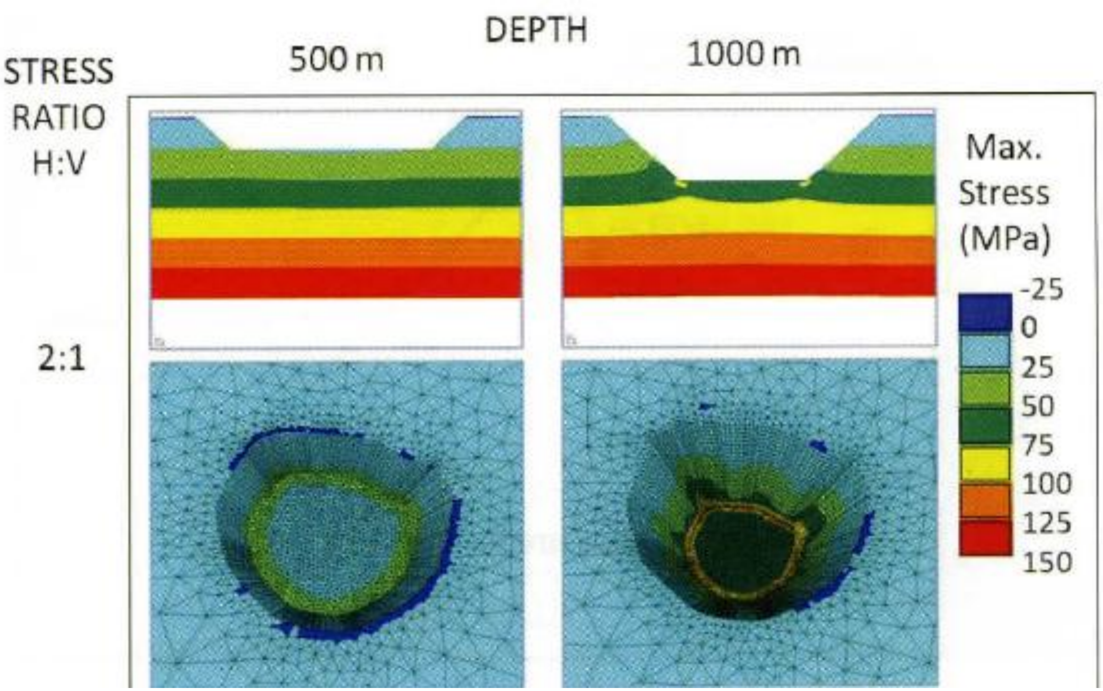
Image Source: BRC

Possible Difficulty for Caving

Caving works better with low horizontal stress, but a high horizontal stress will induce caving, also



If open pit mining is stopped because of a high in situ Hz:V stress ratio, this ratio may impact the suitability of the deposit for cave mining – on the production level, for example



Source: Read & Stacey

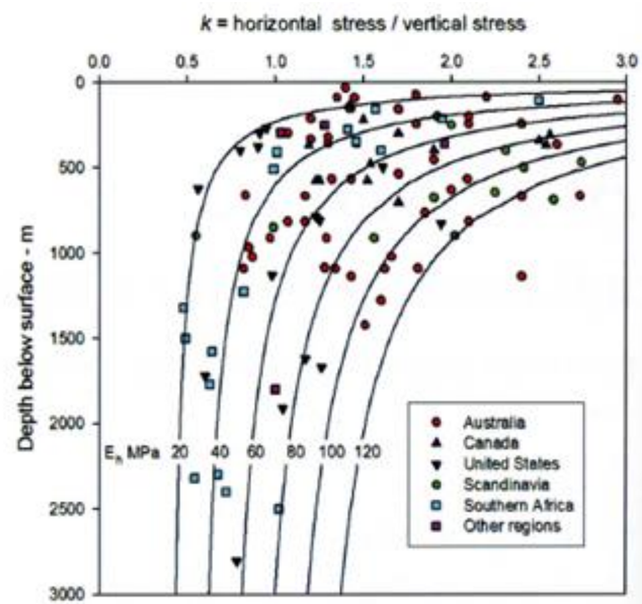


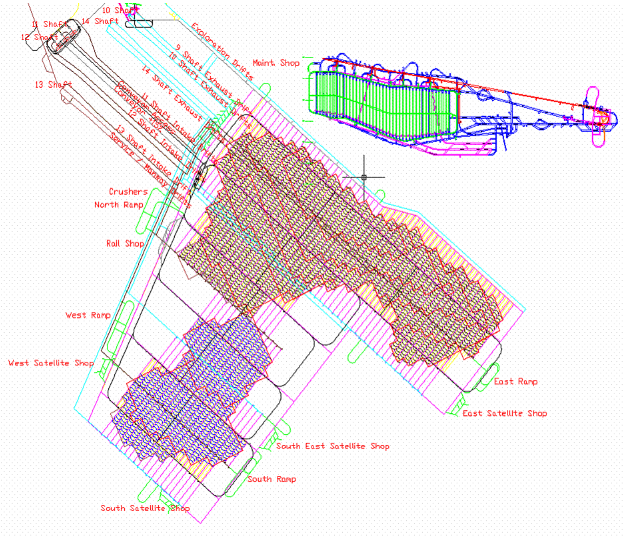
Figure A3.2: Measurements of horizontal stress in different regions of the world
Source: After Hoek & Brown (1980b)

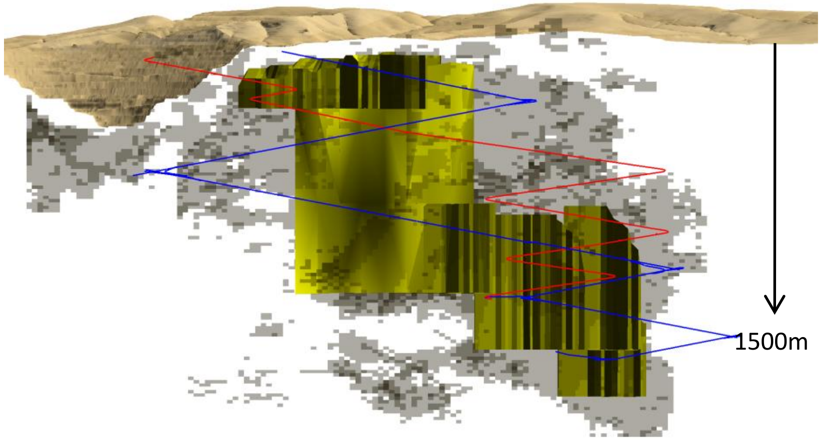
Likely Scale Comparison

(Courtesy G. Chitombo)

- **Contemporary cave**
  - **Footprint : 200 m x 200 m**
  - **Block height: < 500 m**
  - **Production: 10,000 – 40,000 tpd**
  - **Undercut level : < 1,000 m deep**

- **Supercave**
  - **2,000 m x 2,000 m**
  - **>500 – 800 m**
  - **70,000 – 100,000 tpd (single panel)**
  - **>1,500 – 2,000 m deep**





Massive Rock Caves

There are few natural breaks in this core, but these rocks cave

Two Different Operating Mines

Two Different Planned Mines

(Brown & Chitombo, 2007)

Figure 15: Orebody cores from some current and planned BPC mines

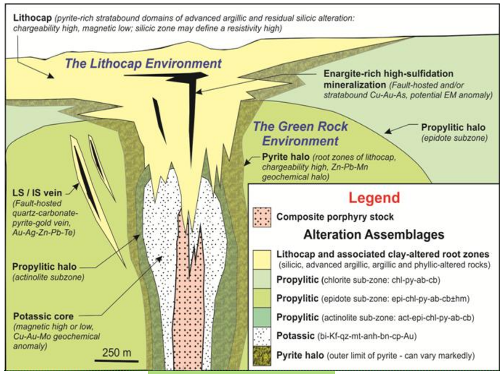
Caving produces surface subsidence

Future Exploration Needs?

A deeper-discovery exploration approach

- *A discovery business model that is understood and strongly supported by senior corporate management, which accepts the need for consistent funding, time and a focus on caving*

- **Ore deposit models that reduce discovery risk by more accurately forecasting proximity to possible ore using:**
  - *geological attributes*
  - *geochemical signatures*
  - *geophysical techniques*



(Cooke, et al)

- ***Cheaper discovery drilling technology/capability***

Deep Exploration Technologies

Coiled tubing drilling: Objective of $50/m cost & fast penetration rate

Deeper Discovery Exploration

Re-focusing the Model for Caving

- **The present model is basically modern prospecting –** *we target ore using different ways of "observing" than did old-time prospectors* **– so far usually for mining by open pit**
- ***The present model will continue to be effective in seeking shallow deposits for open pit mining***
- **Discovering deeper ore bodies to be mined by caving, however, requires a refocusing of the exploration model**
- ***This is needed to avoid wasted expenditure in discovering deposits that cannot be mined for known and predictable reasons***

Present model

Observation

↓

Pattern

↓

Hypothesis

↓

Drilling

↓

Discovery?

A Mining-focused Model

- **Because of the extra uncertainty about location with a deep deposit, we need to first discover a larger target –** *which may contain a deposit that can be mined*
- **This means we should explore to first discover a potential "Ore System"**
- **To achieve this we need to "observe" with an "Ore System" in mind –** *in the hope that it may host an ore deposit*
- **When drilling we need to identify risks to mining if we were to discover a deposit**
- **High mining risk will downgrade a target**

Proposed model

Observe for "System"

↓

Apply target scale

↓

Identify mining risk

↓

Widely-spaced drilling

↓

Discovery?

Re-focused Model – Mining Risk

- **The model is re-focused on discovering ore deposits that will be exploited using one of several underground mass mining methods**
- *These methods impose constraints on the type of deposit that can be mined economically*
- **The constraints are mostly related to geology and the physical characteristics of a deposit**
- *Some, however, are the result of the non-selective nature of this mining method*
- **The absence of internal waste is almost always a pre-requisite for applying this mining method**

Proposed model

Observe for "system"

↓

Apply target scale

↓

Identify mining risk

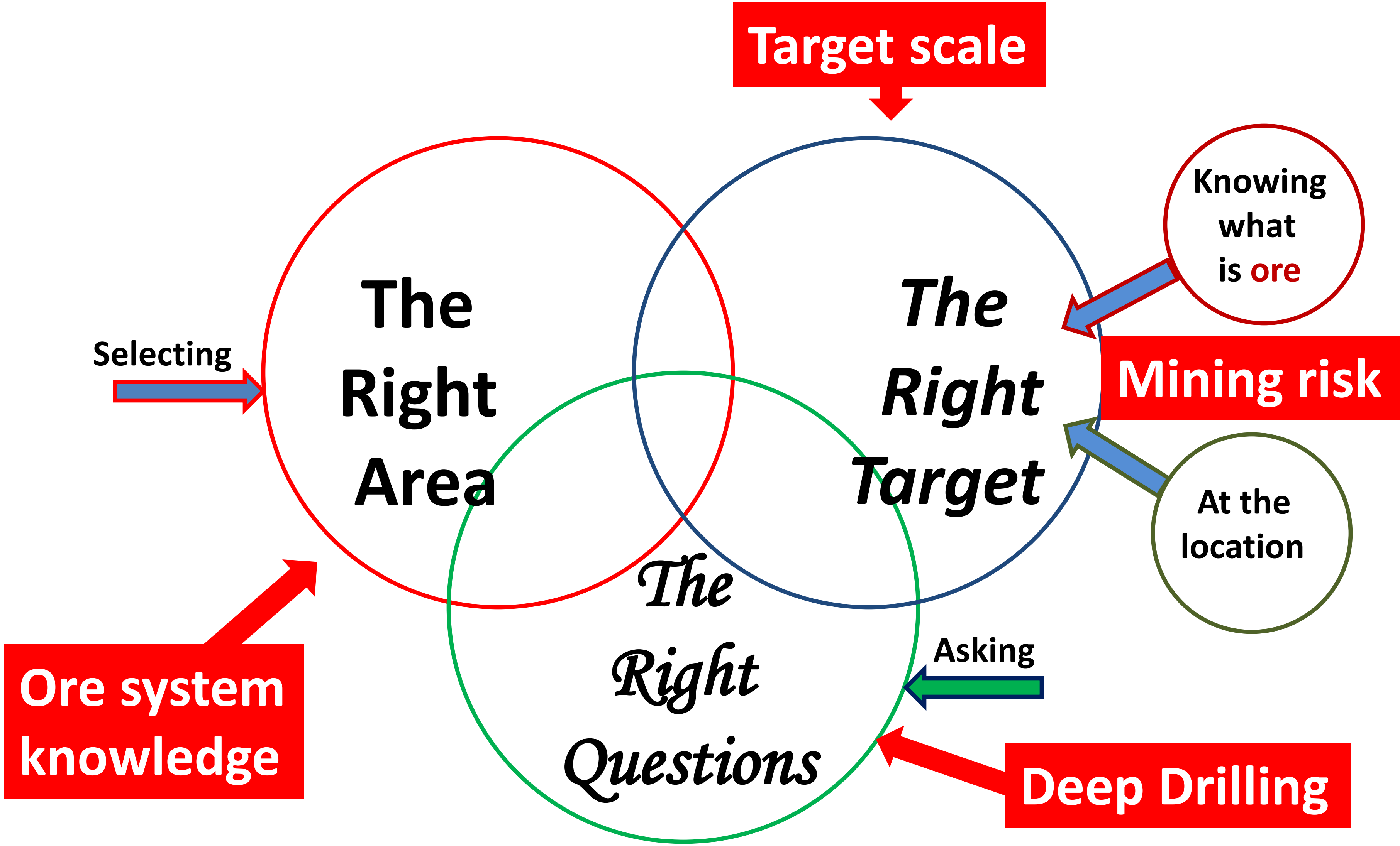
↓

Widely-spaced drilling

↓

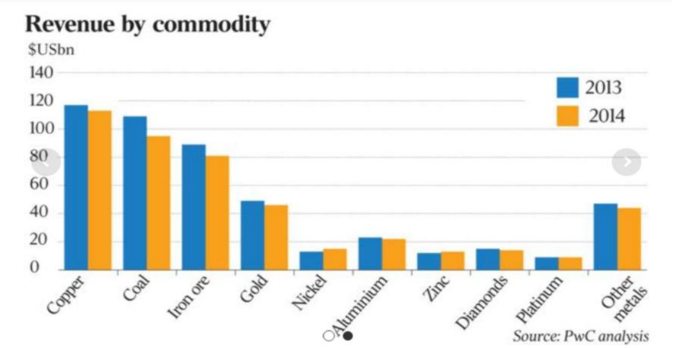
Discovery

Future Exploration Model



Future Targets?

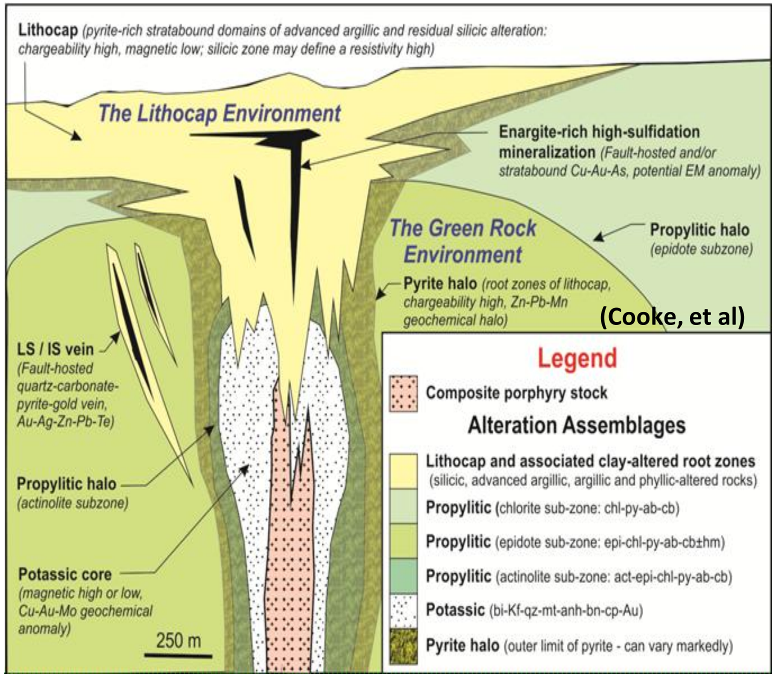
- **The target will depend on company size**
- ***Copper, coal, iron ore, and gold produce the most revenue***
- **Of the metals, Cu plus Au are by far those most sought after presently**
- ***Porphyries are possibly the easiest Cu + Au deposits to discover***
- **Drilling below or near a porphyry open pit is the obvious place to explore for a deeper porphyry Cu ± Au deposit**
- ***However, deeper Au*** *(and other metal)* ***deposits with suitable grade, tonnage, geometry, etc. may also be amenable to caving***

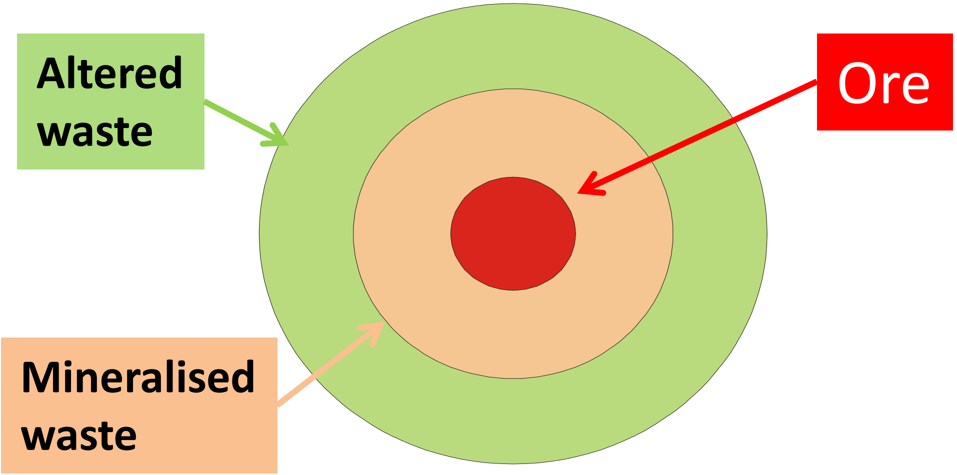


Revenue by commodity. *Source:* TheAustralian

A Porphyry "Ore System"

- **The basic ingredients are:** potassic (ore-bearing), phyllic (pyrite halo) & propylitic alteration, arranged in roughly concentric shells; with, possibly, an upper advanced argillic alteration overprint
- **A deposit may have a barren core**
- **The mining counterparts are:** ore and mineralised waste, altered waste, and overprinting waste, if present





- Drilling will intersect one of the 3D-dartboard rings, laterally and vertically
- **It will also produce evidence of leakage from ore, if recognisable**
- The task is to follow the clues

Porphyry Model – Target Scale

- **Porpyhry deposits are large: volumetrically and in horizontal and vertical dimensions**
- *They are characterised by having continuity of mineralisation throughout the deposit, except where impacted by post-mineral intrusions or faulting*
- Horizontal dimensions are relatively equal and can range from <200x200 m to >1,000x1,000 m
- *The vertical dimension can range from <500 m to >1,500 m*
- **Also, they have a large "footprint" which means widely-spaced discovery drilling can be used –** *e.g., a hole spacing of 500 – 1,000 m*

Proposed model

Observe for "system"

↓

Apply target scale

↓

Identify mining risk

↓

Widely-spaced drilling

↓

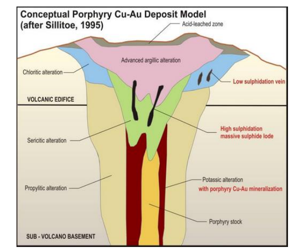
Discovery

Porphyry Discovery Process

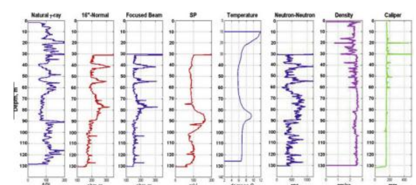
Achieve two objectives: ***1.Locate a possible ore system at depth***

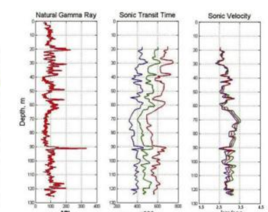
2. Indicate ore potential in the system

- **Role of Surface Mapping**
  - Identify associated mineralisation, e.g., epithermal, skarn, etc.
  - Indicate possible alteration halo assemblages, e.g., propylitic/chloritic, phyllic/sercitic, advanced argillic
  - Detect evidence of ore-leakage, e.g., veining

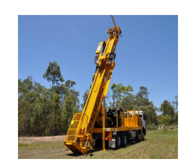


- **Role of Geochemistry**
  - Possibly to provide evidence for a permissive alteration halo
  - Support leakage interpretation
- **Role of Geophysics**
  - Identify possible ore system
  - Collect engineering data by applying relevant down-hole geophysical logging technology, as used in coal exploration





- **Role of Ore Deposit Models**
  - Identify the halo to possible ore by providing better description of this aspect of the ore system
- **Role of Drilling**
  - Prospecting to locate possible ore system, cheaply
  - Conventional deposit delineation & definition

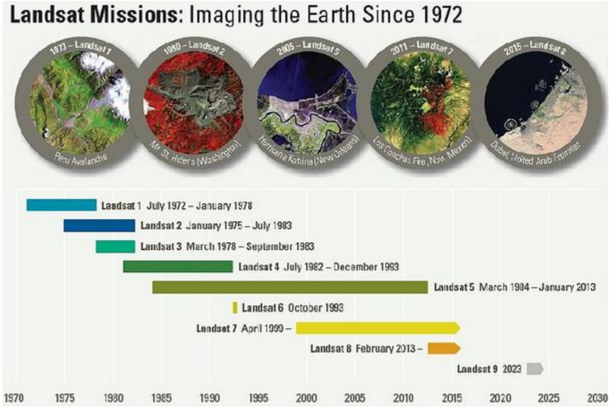


Mapping Tools

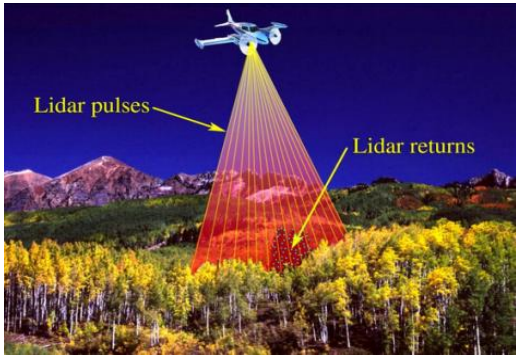
- **Model-focused geological mapping is essential, in my opinion**
- **Enhanced through the use of airborne technology**
- **The focus of mapping is to locate surface evidence of ore leakage – no matter however meagre or subtle**
- **Drilling on the basis of this evidence is crucial to discovery**

Geology Pick

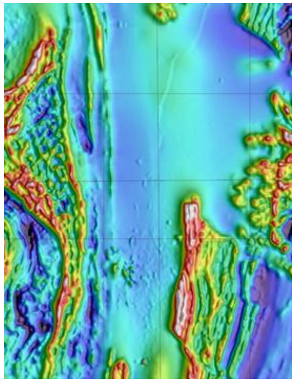
Satellite Imagery



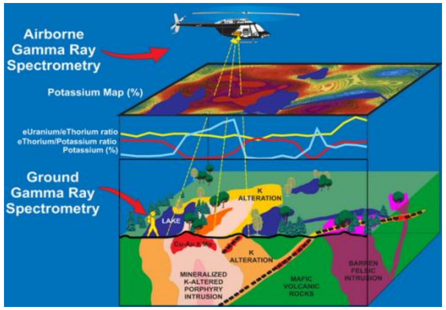
LIDAR Surveying



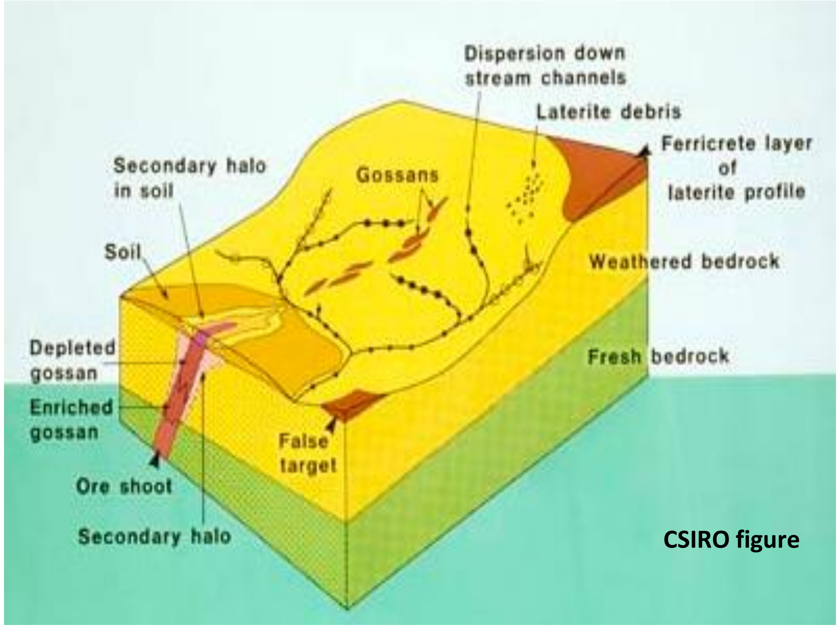
Aeromagnetics



Radiometrics



Geochemical Tools



- **In areas of outcrop:**
  - The present sampling media & technology will require change

Stream sediment

Soil

Rock & Talus

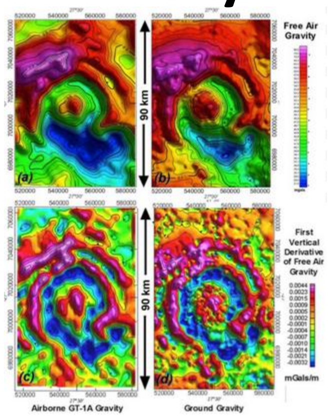
  - Change will be required in:
    - The media fraction collected & analysed
    - The definition of anomalous
  - This will require research to identify deep ore signatures
  - Focus on recording deposit leakage

- **In covered areas:**
  - Base-of-cover sampling is required
  - Using cheap drilling

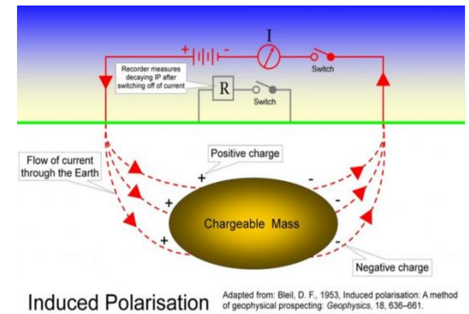
Geophysical Tools

- **Airborne (fixed-wing & helicopter) & ground surveys can be useful:**
  - in areas of outcrop
  - and in areas of consolidated or unconsolidated cover

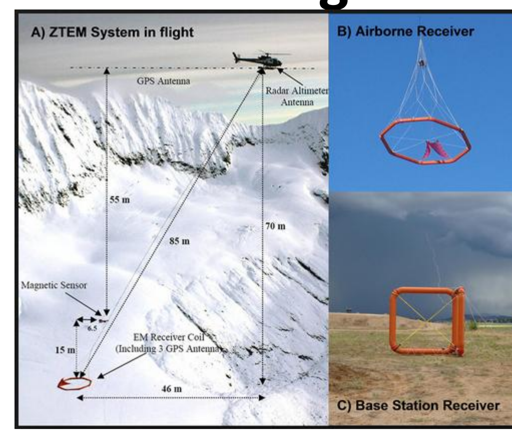
Gravity



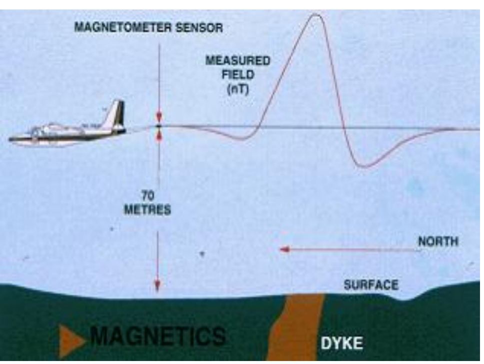
IP



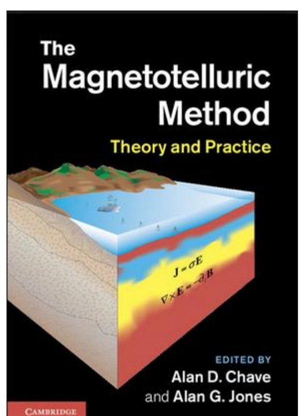
Electromagnetics



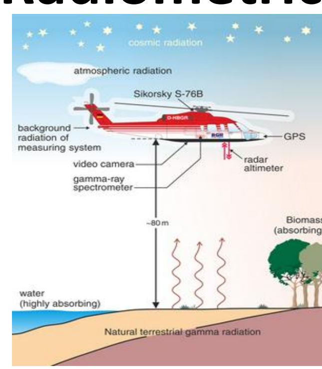
Magnetics



Magnetotellurics



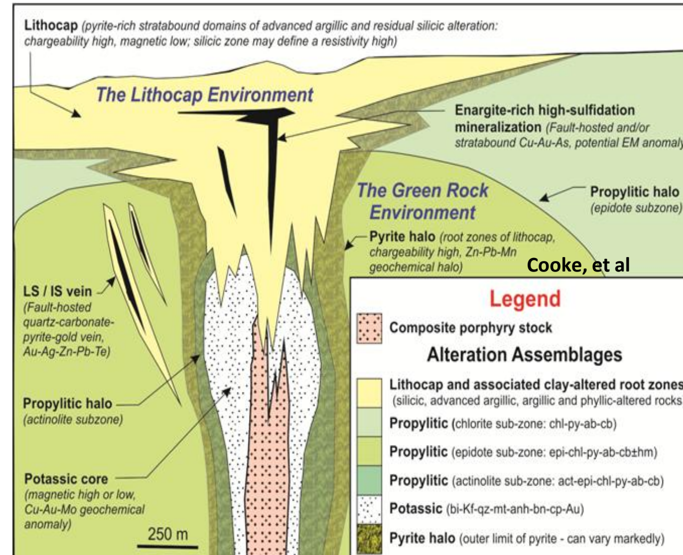
Radiometrics

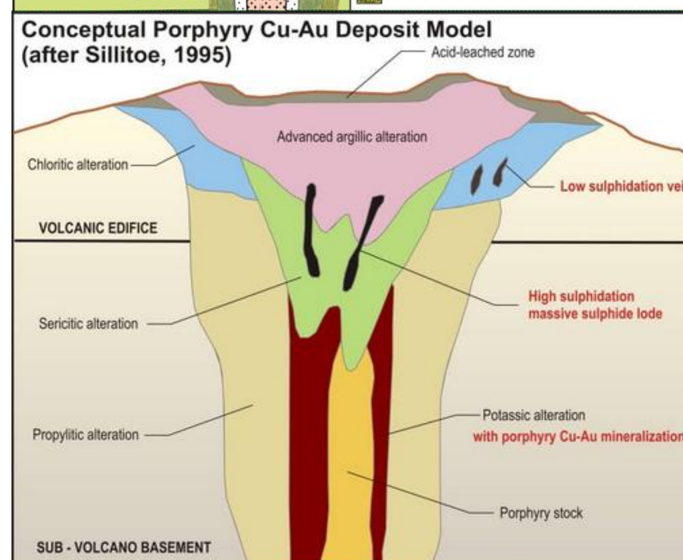


The objective is to locate a possible "Ore System"

Ore Deposit Models

- **Expanded research effort into porphyry alteration is required, focused on:**
  - propylitic alteration zone
  - phyllic alteration zone
  - advanced argillic overprint (lithocap) zone
- **To assist in identifying possibly productive, porphyry alteration systems**
- **Research is required into how to identify and characterise “leakage” from a porphyry ore deposit, located at ± 1,000 m depth**





Drilling Tools

- **PROSPECTING**
  - **Unconsolidated cover**


Aircore



Rotary

  - **Consolidated cover & outcrop**

Multi-purpose

Diamond core

Coiled tubing

- **DISCOVERY & DELINEATION**

Diamond core

Multi-purpose core

Geophysical logging

Exploring under Cover & Risk

- **THE RISK IS LOW TO UNACCEPTABLE**

- **<u>Low-risk</u> is where evidence of mineral potential (**e.g., mine, vein extension or alteration**) is recognised on the edge of thin cover (**sand dune, mesa, etc.)



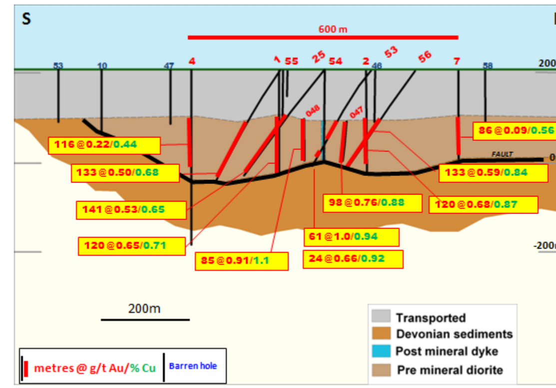
- **<u>High-risk</u> is where evidence of mineral potential is absent and cover is thick and consolidated**

- **<u>Unacceptable risk</u> is where the target is to be caved and the cover includes a known aquifer, which would flood the mine when breached by subsidence**

Two Example Discoveries

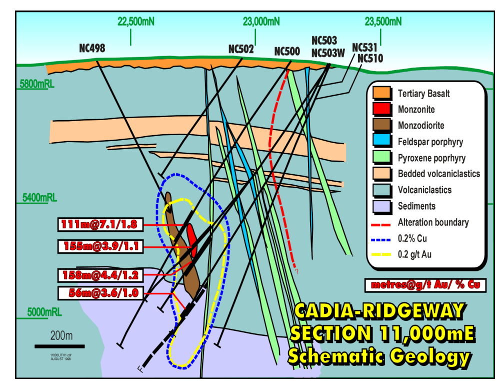
- **Unconsolidated cover:**

  Marsden porphyry Cu-Au deposit in NSW, Australia

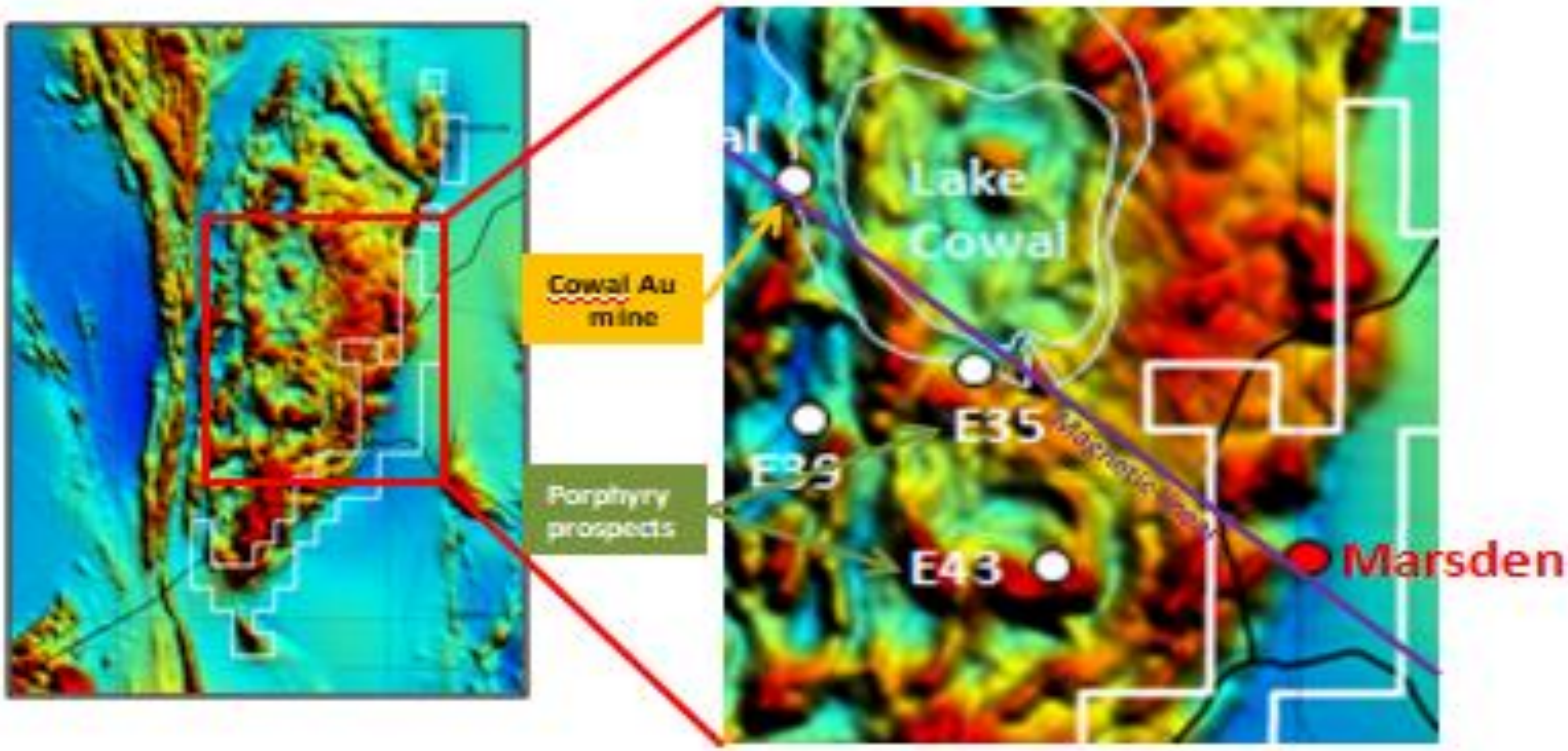


- **Basalt cover:**

  Ridgeway porphyry Au-Cu ore deposit at Cadia, NSW

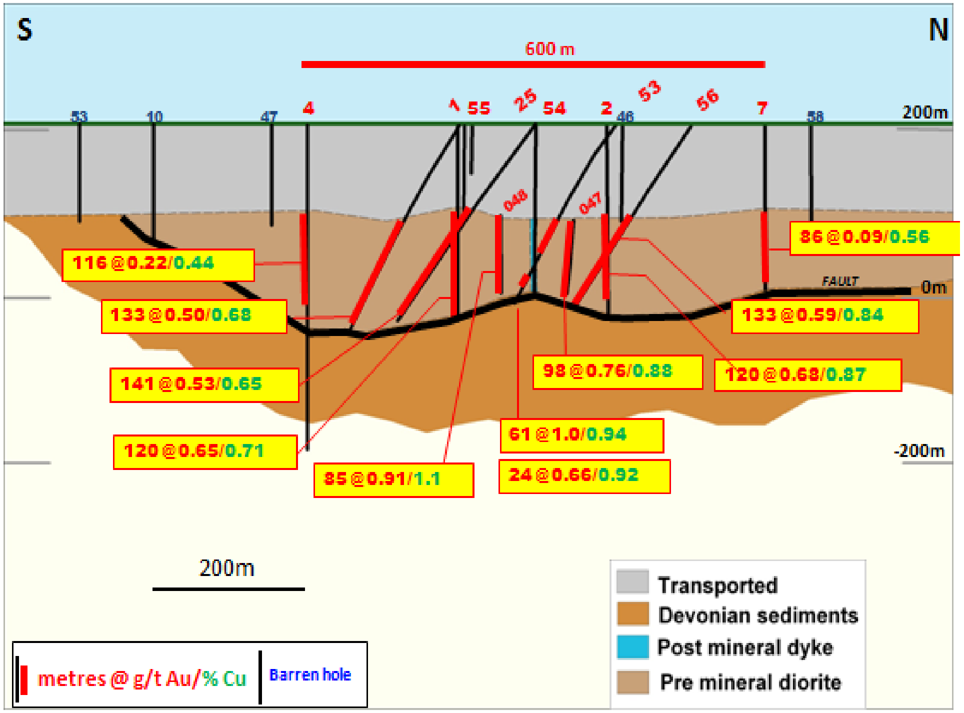


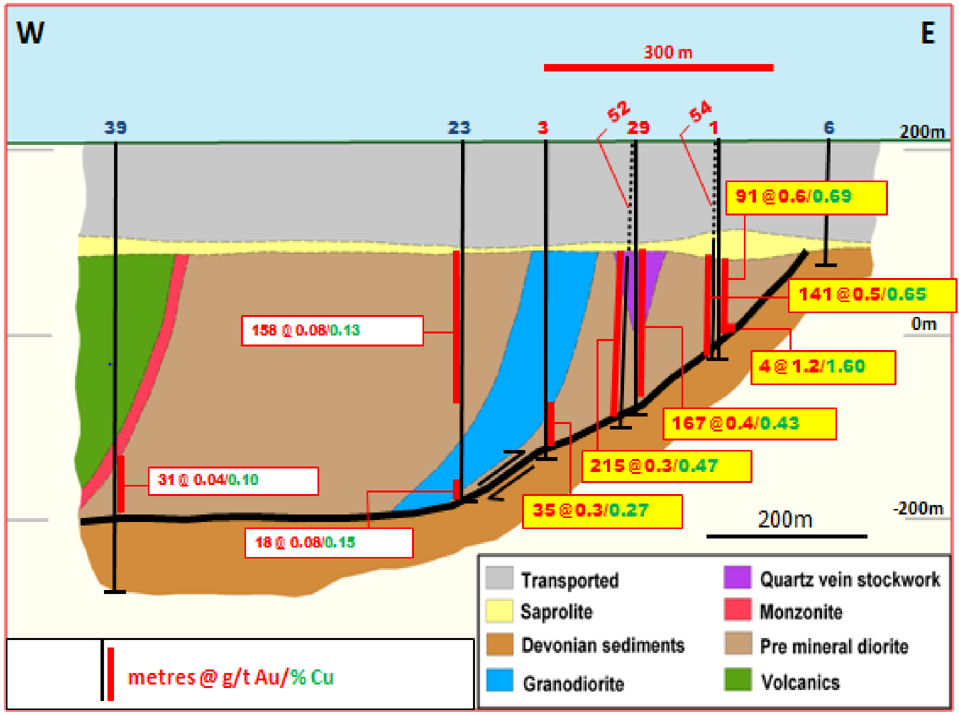
Unconsolidated – Marsden



- 500 x 1,000 m offset pattern aircore drilling investigated extension of a magnetic linear trend, from a mineralised region into an area of possibly deep, recent fluvial cover
- One hole recorded 15 m @ 1.2 g/t Au & 0.47 % Cu beneath 100 m of transported fluvial cover

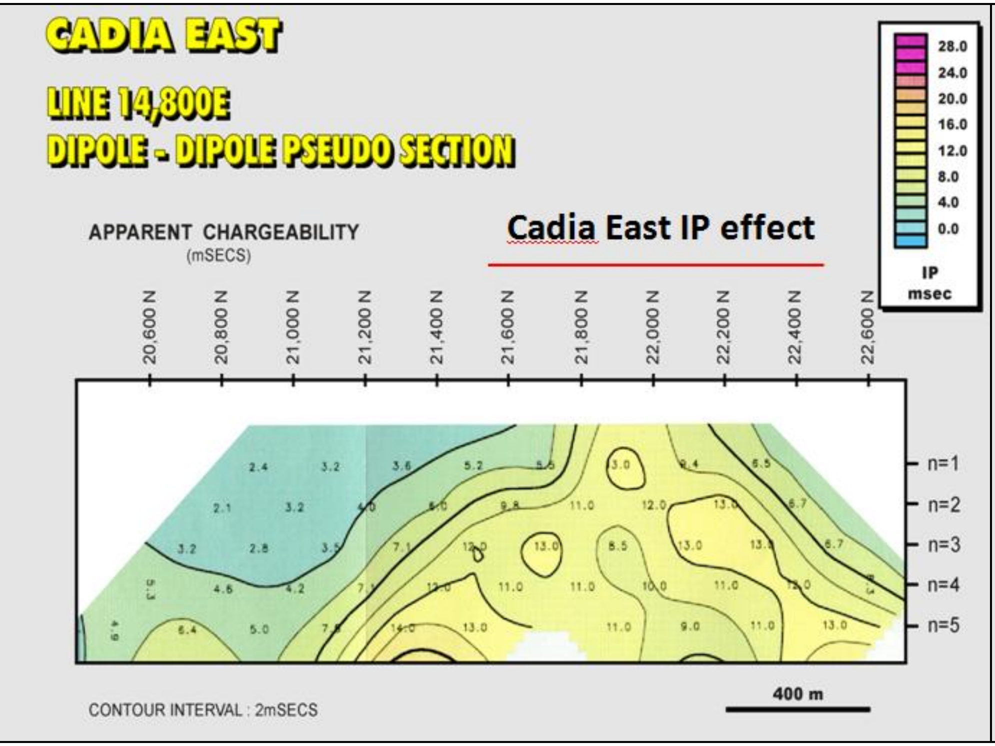
Marsden Core Drilling

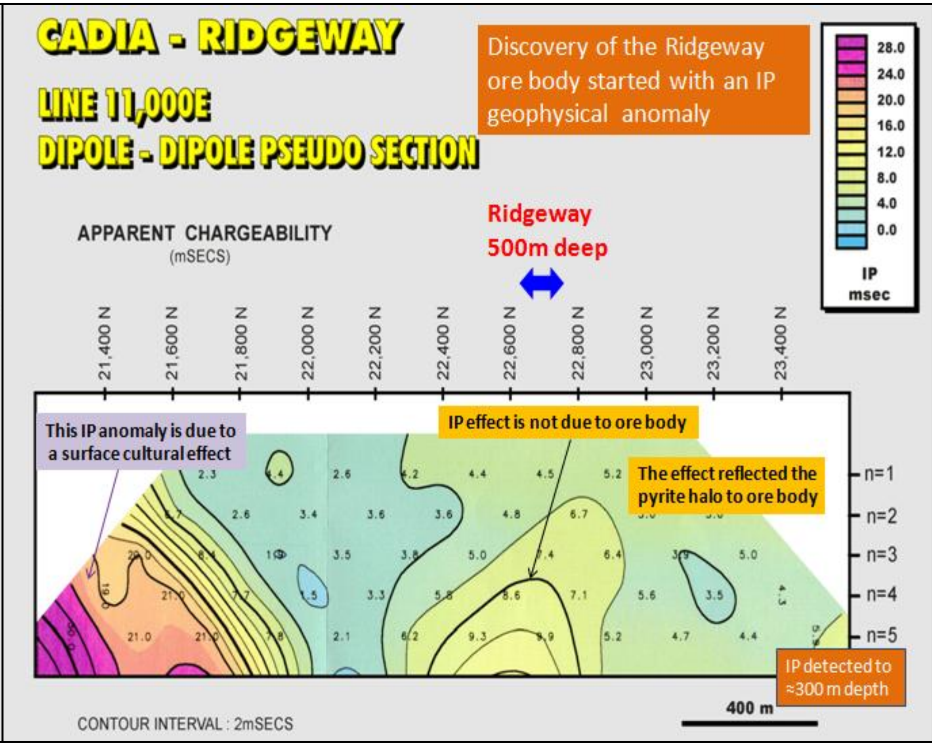




- Core drilling recorded intervals of porphyry-style mineralisation and up to 85 m @ 0.90 g/t Au & 1.1 % Cu
- Mineralisation is truncated by a west-dipping reverse fault – the remainder lies to the west!

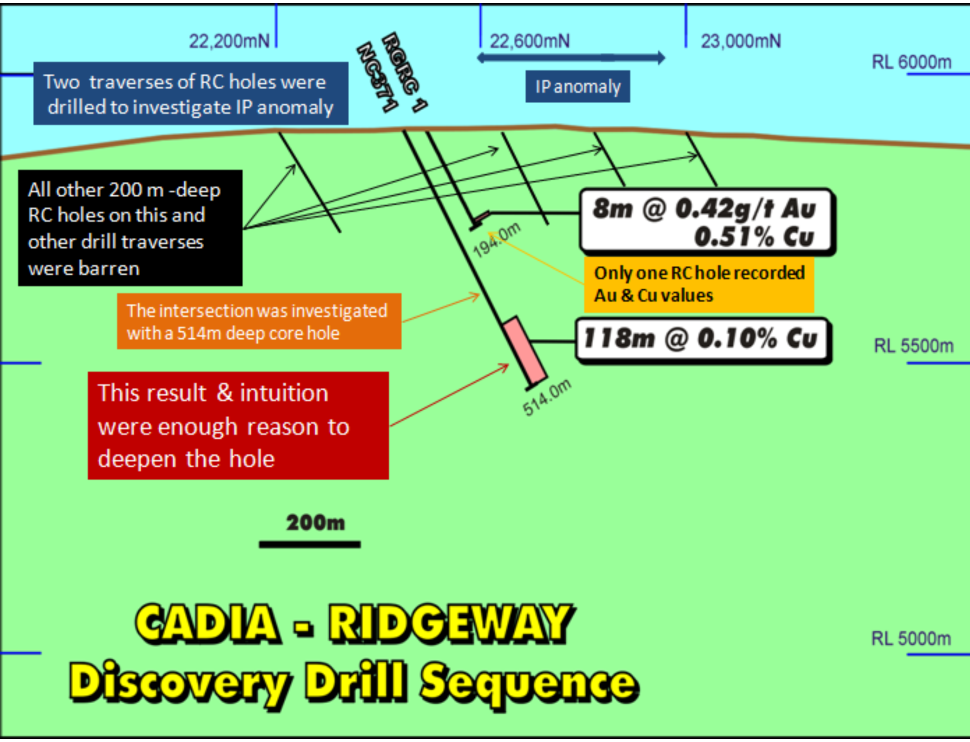
Basalt cover – Ridgeway

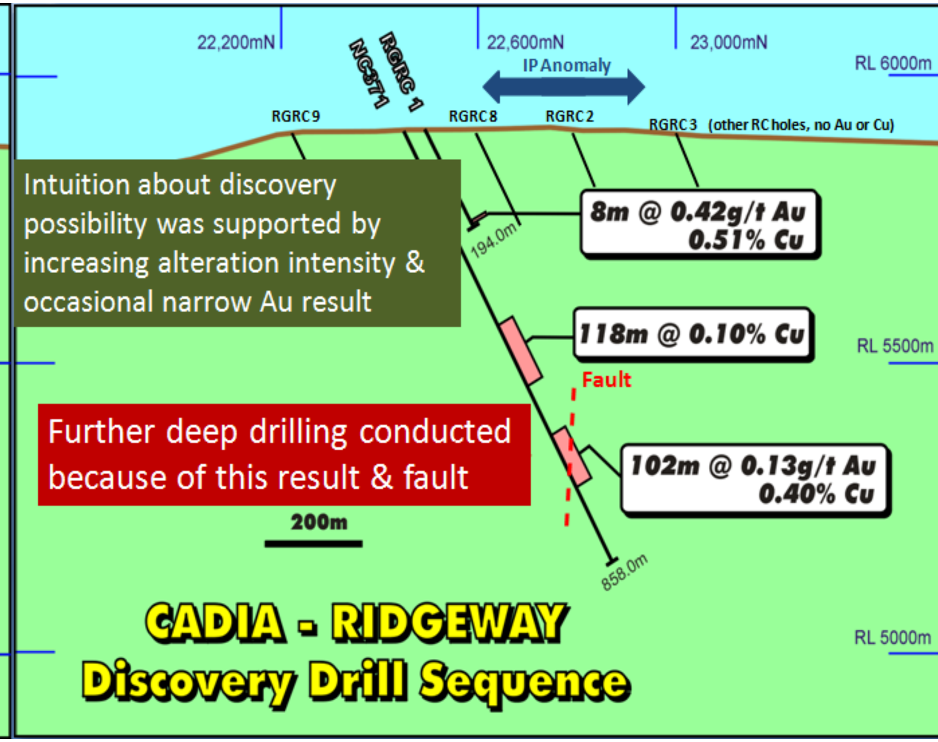




- **An IP survey using a 200 m dipole-dipole array was trialled over the outcropping Cadia Hill and covered Cadia East deposits**
- **At Cadia East, a well-defined chargeability anomaly was detected beneath 200 m of post-mineral siltstone cover**
- **In an area of Tertiary basalt cover a weaker and much smaller chargeability anomaly was detected**
- **The IP anomaly was investigated with two traverses of 200 m-deep angled RC holes**

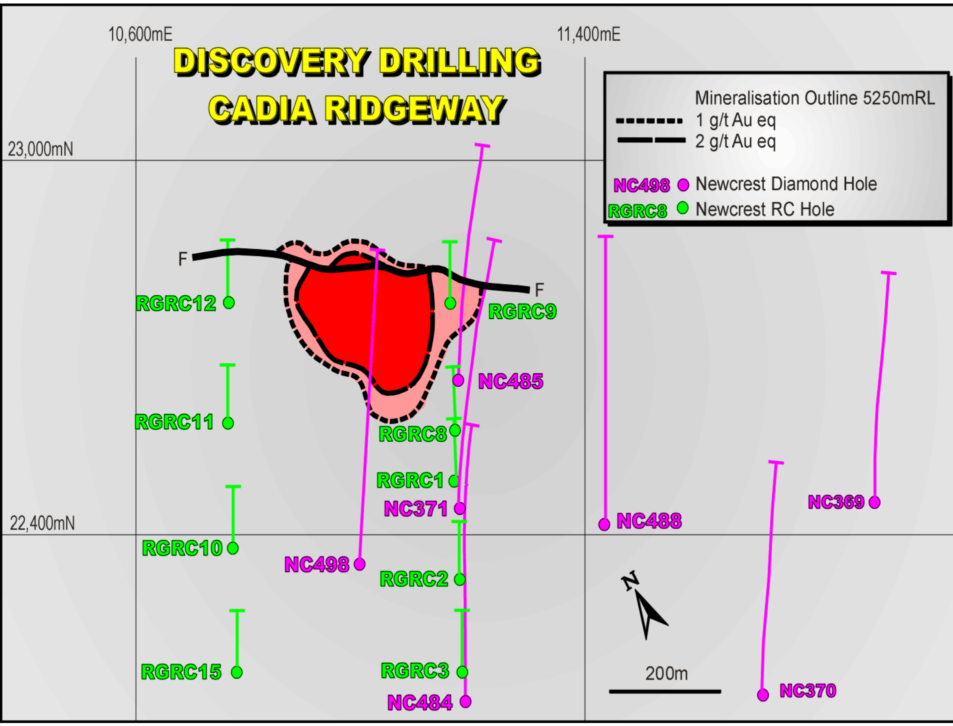
Ridgeway Discovery Drilling

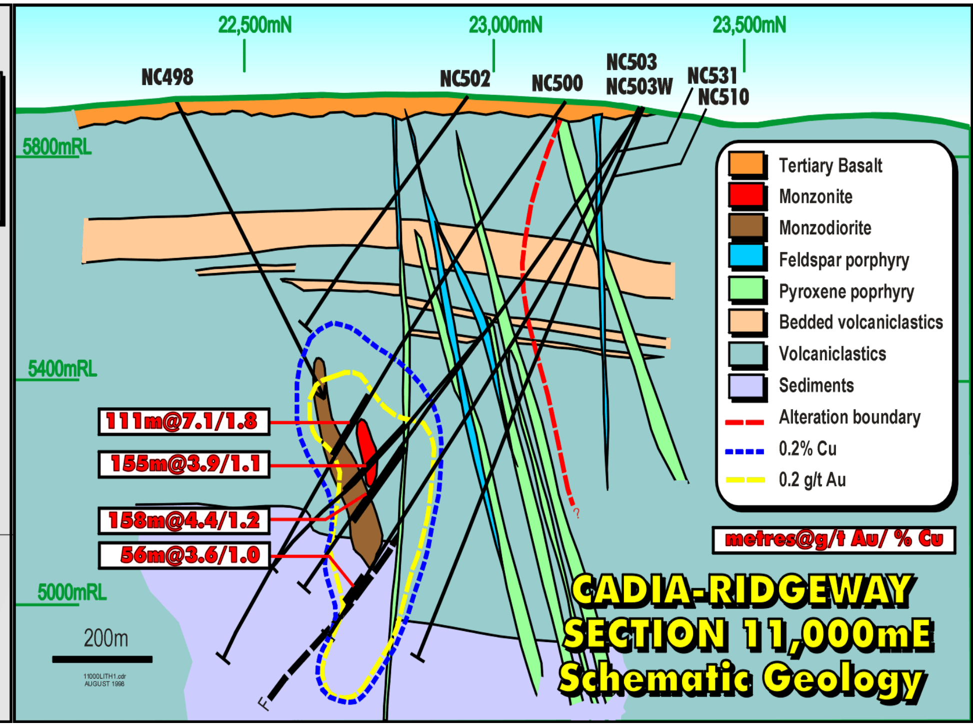




- The IP chargeability anomaly, 8m @ 0.4 g/t Au & 0.5 % Cu in one RC hole and Zn anomalism in another hole, plus pyritic (>0.5 vol. %) propylitic alteration was tested with a ‘wildcat’, 514 m-deep core hole
- The hole recorded 118 m @ 0.1 % Cu with several 1 m intervals of >1.0 g/t Au, plus one 2 m interval @ 10 g/t Au
- Deepening produced 102 m @ 0.1 g/t Au & 0.4 % Cu with chalcopyrite-bearing quartz veins, truncated by a fault
- Below the fault, 3 m @ 4.4 g/t Au and 3 m @ 0.3 % Cu were recorded
- Four deep core holes were drilled to investigate these results and increased alteration “reddening” and intensity

Ridgeway Discovery

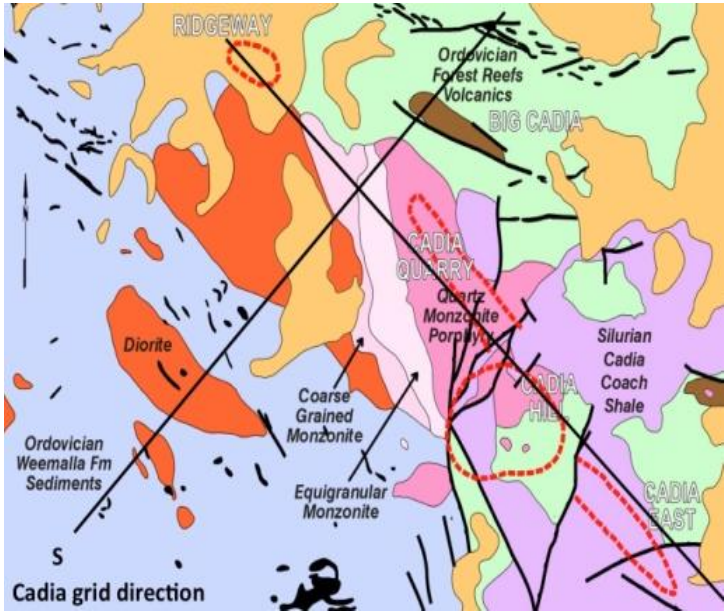


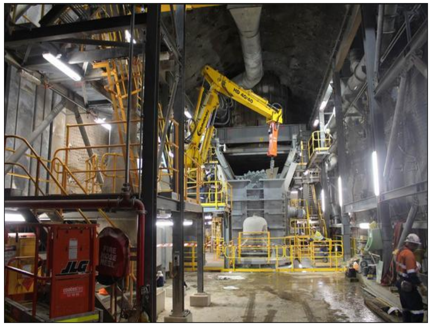


- The higher grade Au intersections and the 3 m @ 0.3 % Cu were vertical, and probably lateral, ‘leakage’ from the Ridgeway deposit
- Discovery came with the fourth hole – 145 m @ 4.3 g/t Au & 1.2 % Cu, plus 84 m @ 7.4 g/t Au & 1.3 % Cu
- The top of the deposit was located 500 m below surface, beneath 20 – 80 m of basalt cover

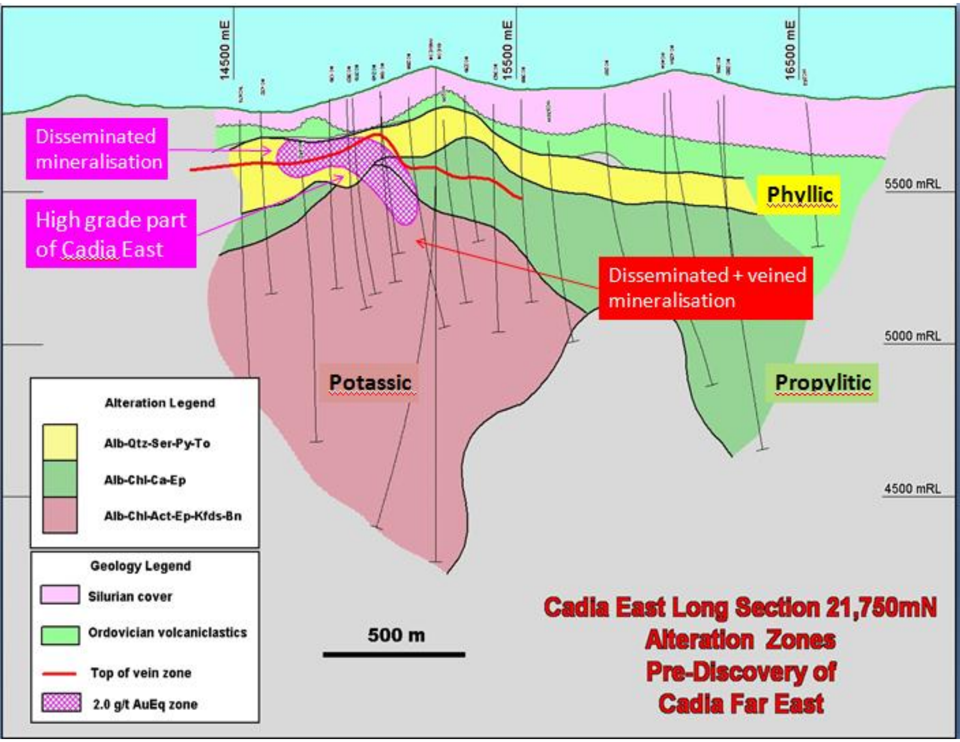
- **Basic components to discovery were:**
  - IP anomaly detected the pyritic alteration halo
  - Propylitic and ‘red rock’ alteration increased in intensity with depth
  - Drill-hole intersections leading up to drilling the four holes were interpreted as evidence of ‘leakage’ from a possible ore deposit

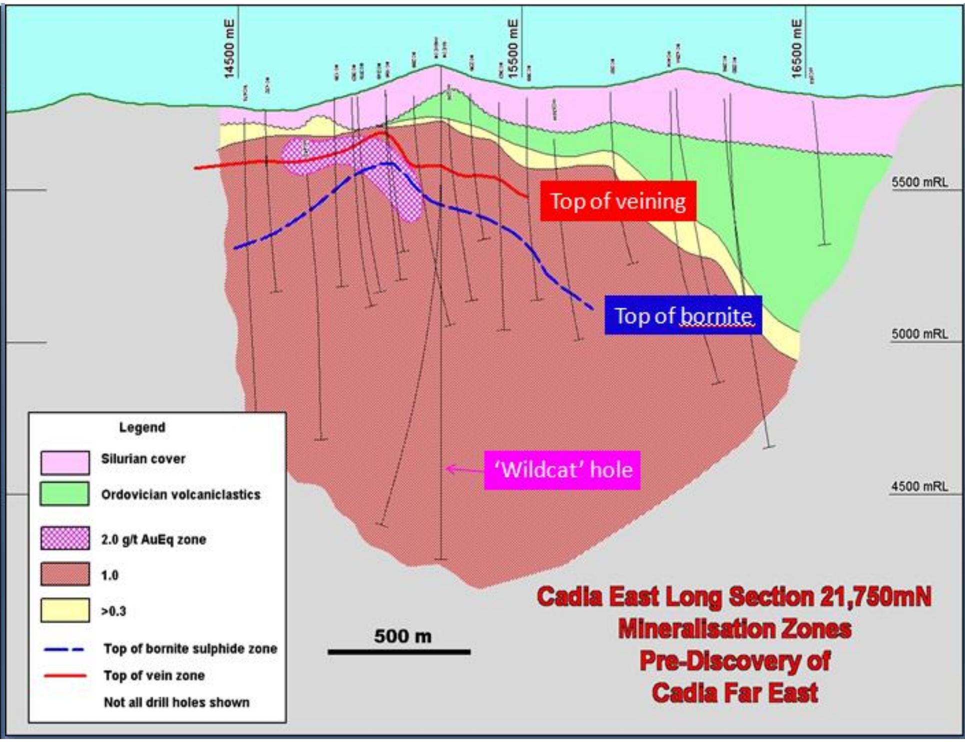
Discovery of Cadia Far East





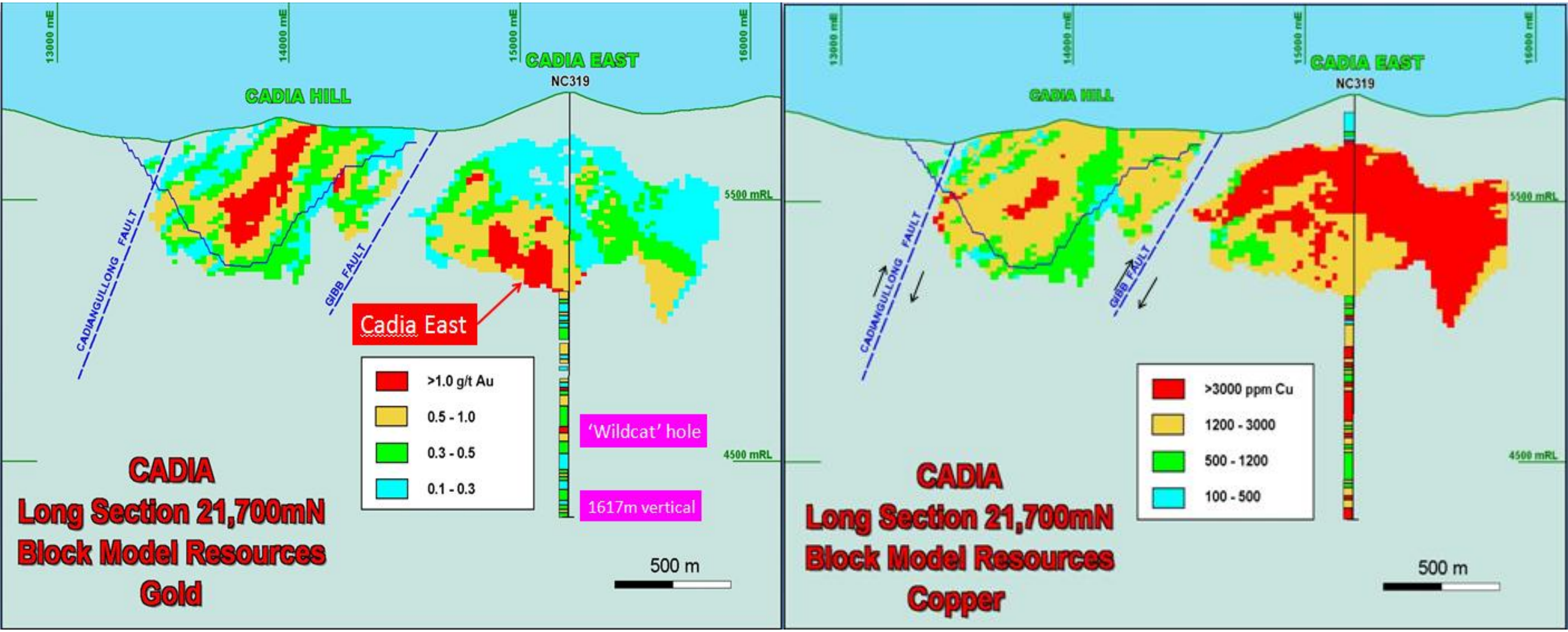
Cadia East Mineralisation



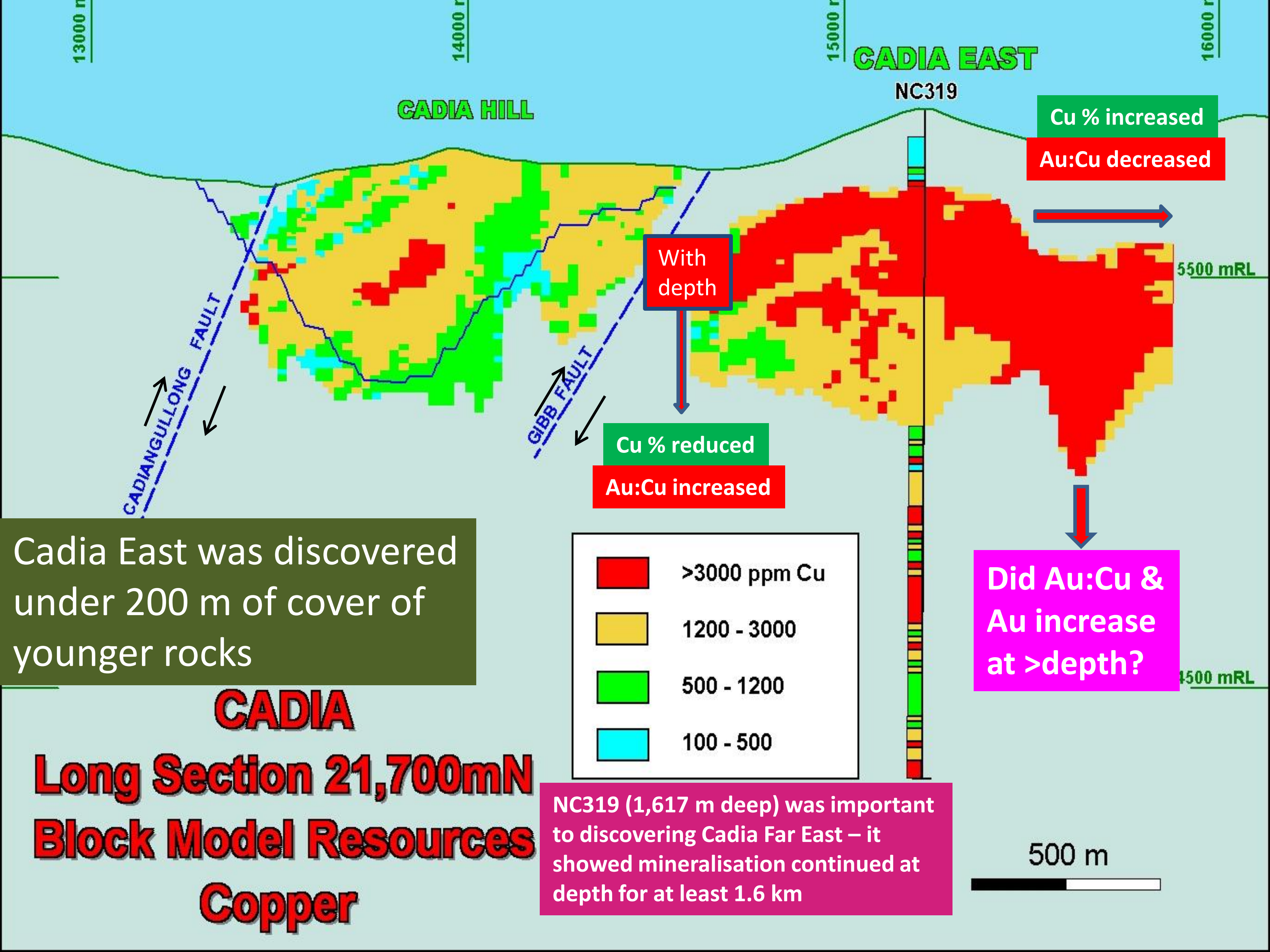


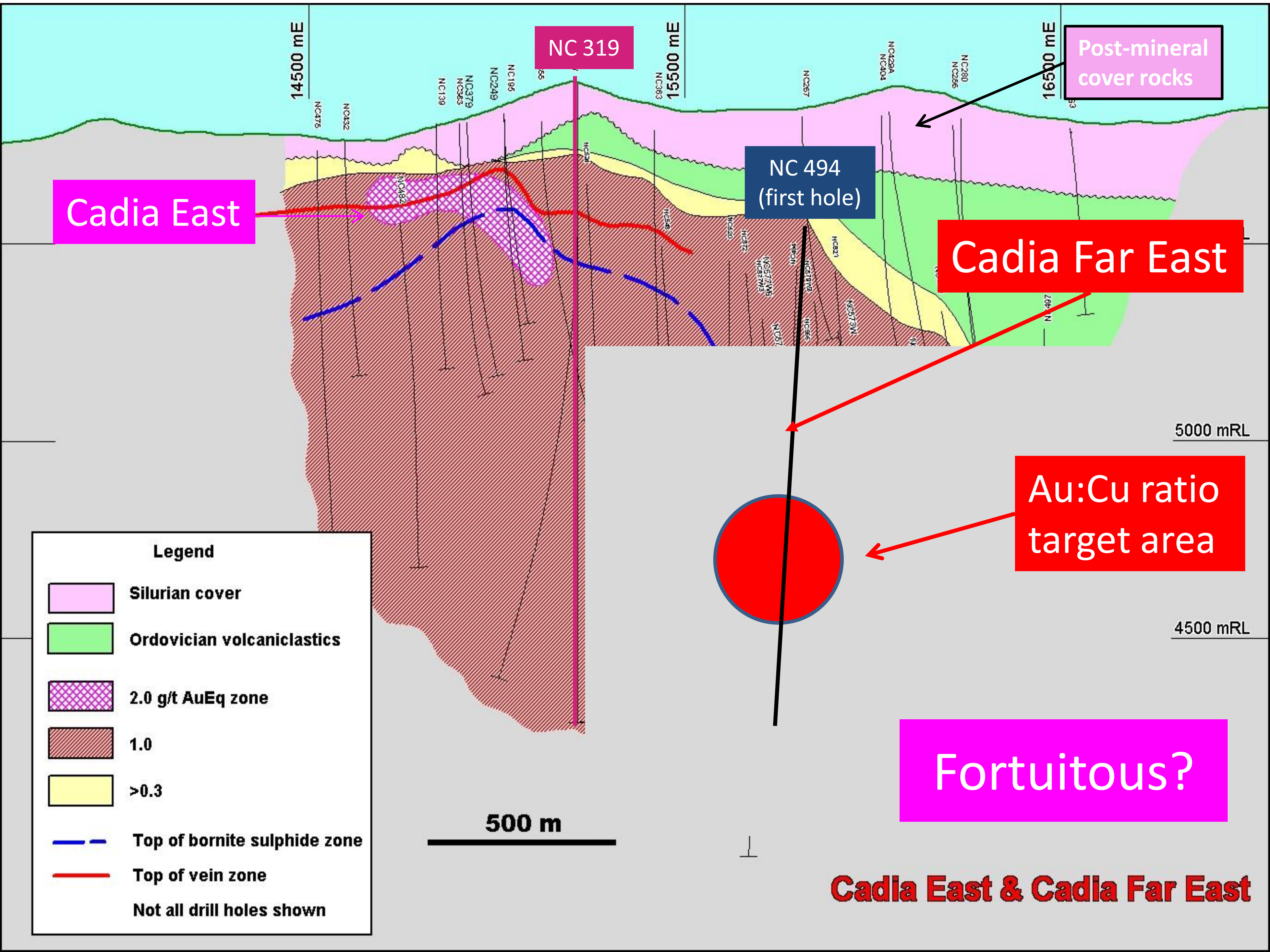
- **Disseminated and vein controlled Au-Cu mineralisation discovered at Cadia East is hosted in a flat-lying volcanic succession, to the vertical limit of drilling at the time of discovery**
- **Chalcopyrite is the dominant Cu sulphide in the upper part of the mineralised zone, passing into bornite-dominant mineralisation at depth**

Cadia East Gold and Copper

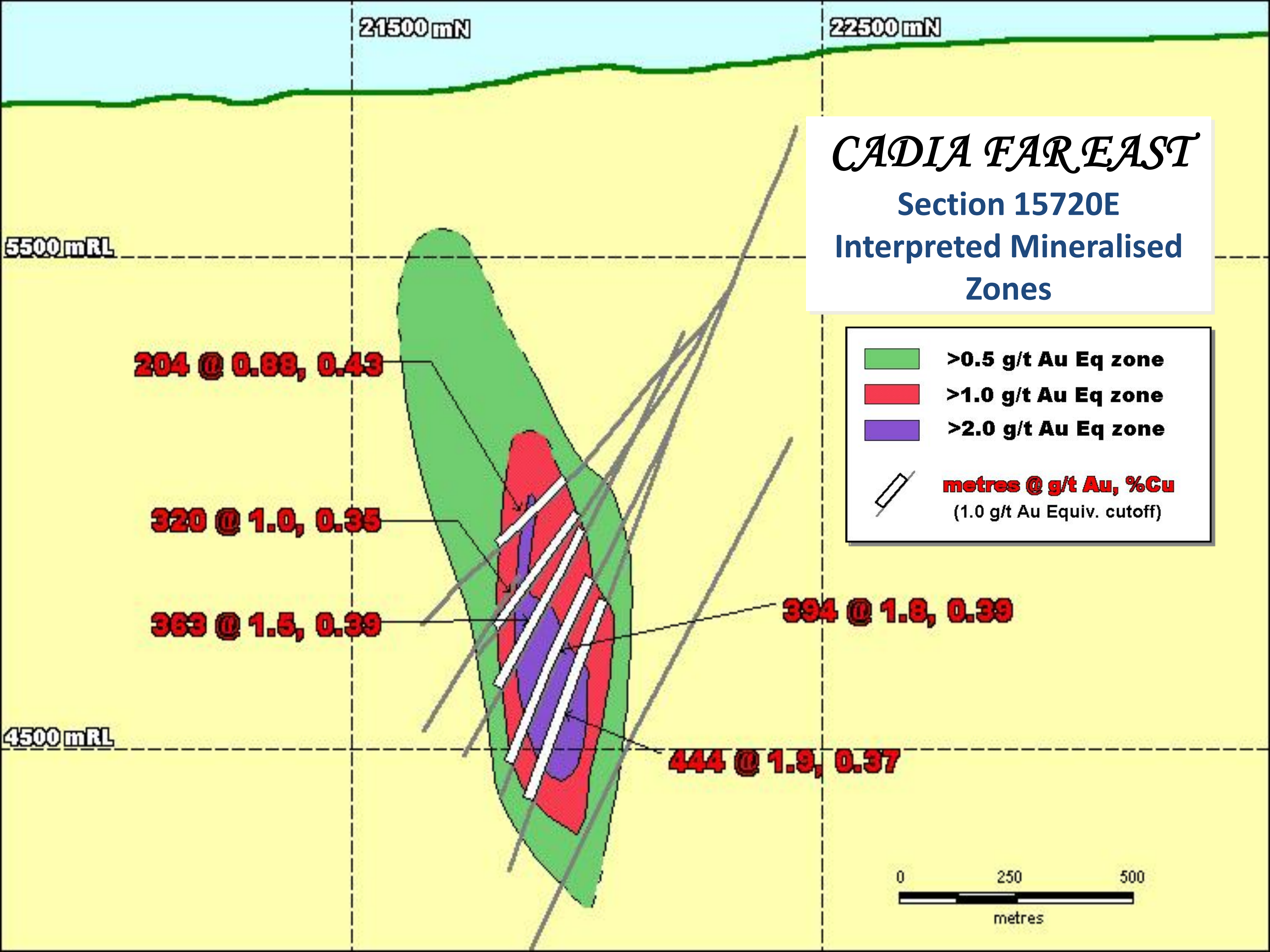


- **At Cadia Hill and in the Cadia East deposit Au is the dominant economic metal, with a well-defined zoning of grade apparent in both deposits**
- **The correlation between Au and Cu is well defined at Cadia Hill, whereas at Cadia East the pattern is different**


13000 m
14000 m
15000 m
16000 m
CADIA EAST
NC319
CADIA HILL
Cu % increased
Au:Cu decreased
With depth
5500 mRL
4500 mRL
CADIANGULLONG FAULT
GIBB FAULT
Cu % reduced
Au:Cu increased
Cadia East was discovered under 200 m of cover of younger rocks
>3000 ppm Cu
1200 - 3000
500 - 1200
100 - 500
Did Au:Cu & Au increase at >depth?
CADIA
Long Section 21,700mN
Block Model Resources
Copper
NC319 (1,617 m deep) was important to discovering Cadia Far East – it showed mineralisation continued at depth for at least 1.6 km
500 m



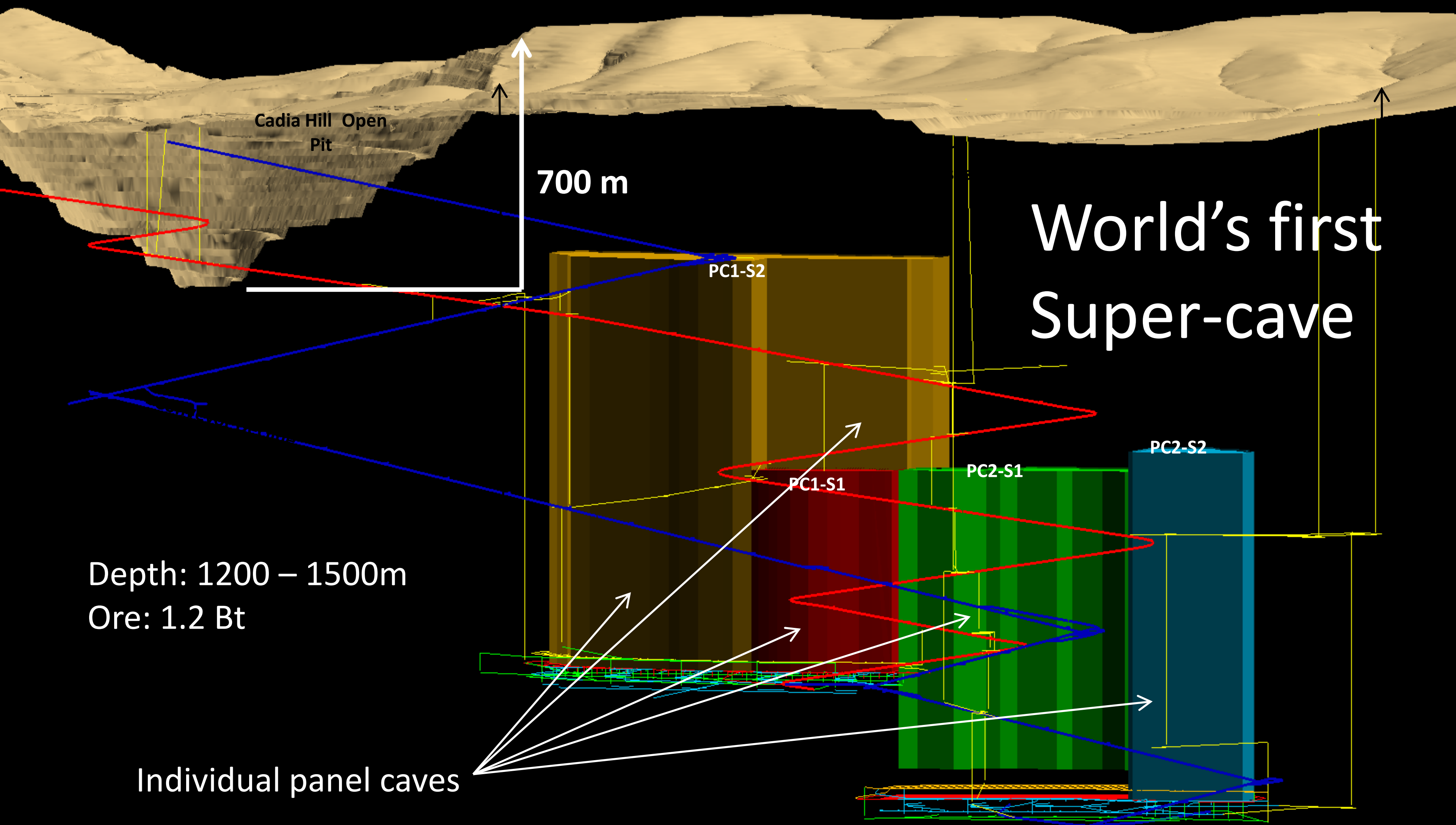
14500 mE
15500 mE
16500 mE
NC 319
Post-mineral cover rocks
NC 494 (first hole)
Cadia East
Cadia Far East
5000 mRL
4500 mRL
Au:Cu ratio target area
Fortuitous?
Legend
Silurian cover
Ordovician volcaniclastics
2.0 g/t AuEq zone
1.0
>0.3
Top of bornite sulphide zone
Top of vein zone
Not all drill holes shown
500 m
Cadia East & Cadia Far East



CADIA FAR EAST
Section 15720E
Interpreted Mineralised Zones
21500 mN
22500 mN
5500 mRL
4500 mRL
204 @ 0.88, 0.43
320 @ 1.0, 0.35
363 @ 1.5, 0.39
394 @ 1.8, 0.39
444 @ 1.9, 0.37
>0.5 g/t Au Eq zone
>1.0 g/t Au Eq zone
>2.0 g/t Au Eq zone
metres @ g/t Au, %Cu
(1.0 g/t Au Equiv. cutoff)
0
250
500
metres

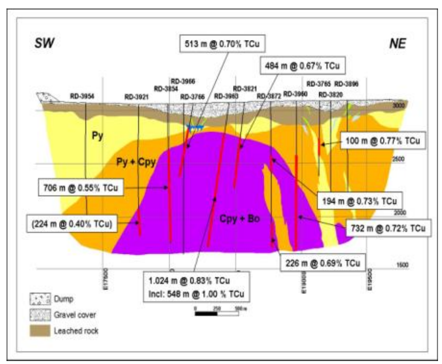
Cadia East Mine

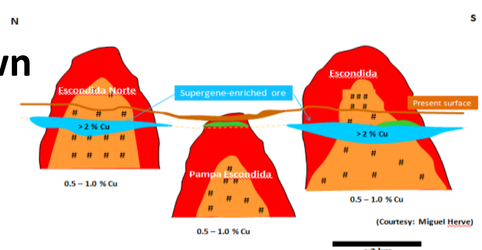
(courtesy Newcrest Mining Limited)




Ridgeway
Big Cadia skarn
Cadia Quarry
Cadia Hill
Cadia East

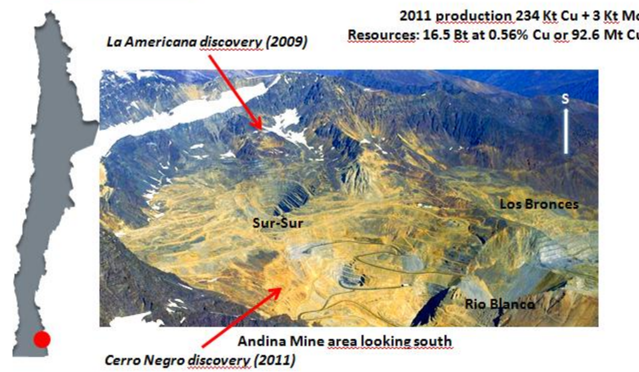
Other Deeper Discoveries





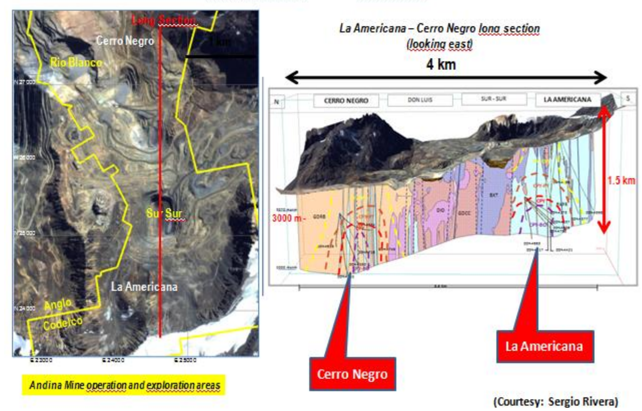
- Pampa Escondida deposit: discovered in an area where 136 sterilisation holes were drilled to 250 m depth, on average
- One 389 m-deep hole had “porphyry alteration” with cpy + bn over final 97 m
- Deeper drilling intersected the Pampa Escondida deposit between the known Escondida and Escondida Norte ore deposits

Andina Mine, Chile



La Americana & Cerro Negro

(deep porphyry Cu-Mo discoveries)



- At Andina, recognition of bornite at depth in previously-drilled deep holes led to discovery of the La Americana and Cerro Negro deposits with deeper drilling

Some Concluding Remarks

Follow Sig Meussig's canons:

- Look for ore, not mineralisation
- To find an ore body, you need to drill holes
- There needs to be room for the ore

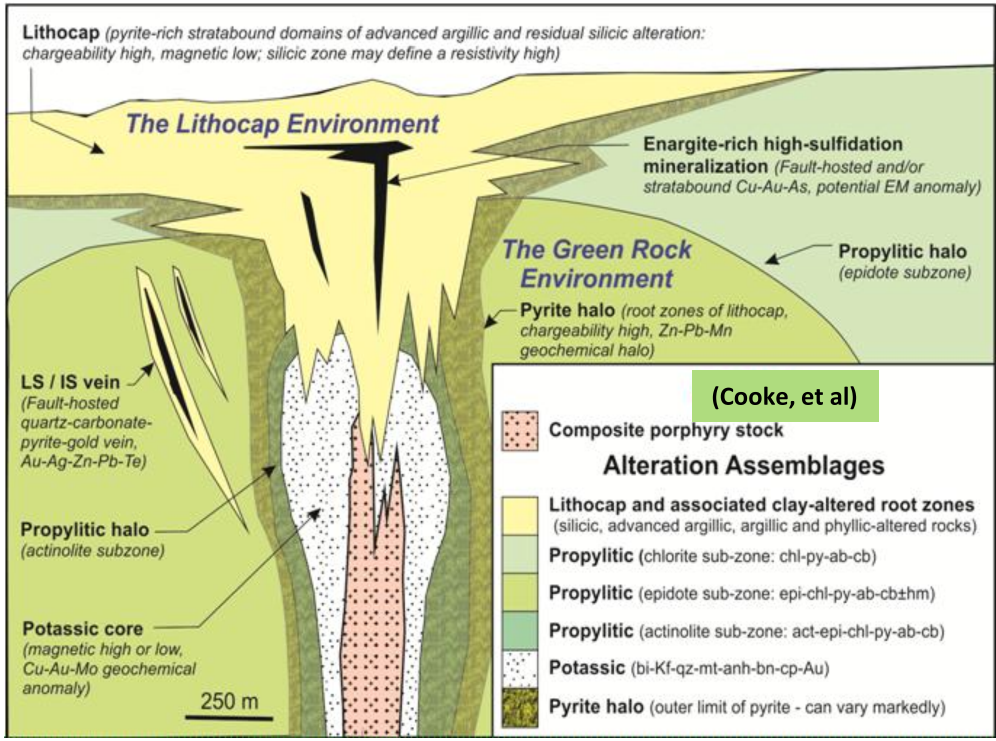
Deeper is the new Greenfield

- Deeper only means >300 m depth
- In seeking underground mining targets, know what is required for mining

- **Above all, Drill Holes!** *(The worst outcome of drilling is failure to discover ore, which is essentially guaranteed in exploration, anyway!)*

One way to discover a Porphyry

- **Start in a known porphyry district**
  - *Or in a known epithermal district*
    - *Particularly high-sulphidation, but also low-sulphidation*
- Don't discount possibly nearer-surface types of deposit, e.g., skarn?
- *Understand the size of an ore target*
  - It will have a plan area of >200x200 m
- *Understand the size of a deposit's hydrothermal alteration "footprint"*
  - It will have a plan area of many km²



- Design the discovery programme accordingly
- **Use widely-spaced discovery holes, e.g., 0.5 –1 km**
- **Investigate weak alteration & veins**

Keep it simple – *1.* find a large alteration system, *2.* detect metal anomalism, *3*. drill a sufficient number of deep holes – vertical holes are fine

Drilling for Geology is OK

A Drilling Rig is only a very large geology hammer

Thinking this way makes it easier to drill deep holes


Thankyou