2012 SEG

Distinguished Lecture

Society of Economic Geologists (SEG)

- *Established in 1920, the SEG is committed to "Advancing Science and Discovery."*
- *Goals:*
  - *Sponsor Scientific Investigations*
  - *Disseminate Results*
  - *Support the Profession Globally*

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Society of Economic Geologists (SEG)

- ***International Society***
  - ***Members in 100 Countries***
  - ***71% of Members are from outside the USA***
- ***Member Affiliation:***
  - ***60% Industry (50/50 Corporate/Self-Employed)***
  - ***20% Academia & Government***
  - ***20% Students***

SOCIETY OF ECONOMIC GEOLOGISTS
FOUNDED 1920

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Society of Economic Geologists (SEG)

- ***Peer Networking***
  - ***6,500 Members – online directory***
- ***SEG Publications***
  - ***Economic Geology***
  - ***SEG Newsletter***
  - ***Special Publications & Reviews***
- ***Foundation Student Programs***
  - ***Research Grants, Fellowships, Field Trips***
  - ***Student Mentoring Program***
  - ***Student Chapter Program***

(60 active student chapters in 22 countries)

Society of Economic Geologists (SEG)

- *Professional Development*
  - *Conferences, Short Courses, and Field Trips*
    - *SEG Traveling Lecturers*
      - *Distinguished Lecturer*
      - *International Exchange Lecturer*
      - *Thayer Lindsley Lecturer*
      - *Regional VP Lecturer*
      - *Honorary Lecturers*

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Crucial Challenges to Discovery and Mining

Tomorrow's Deeper Ore Bodies

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Lecture Objectives

- Focus on mass mining
- Identify some challenges
- Link discovery & mining
- Show “deep’’ is difficult/ but possible

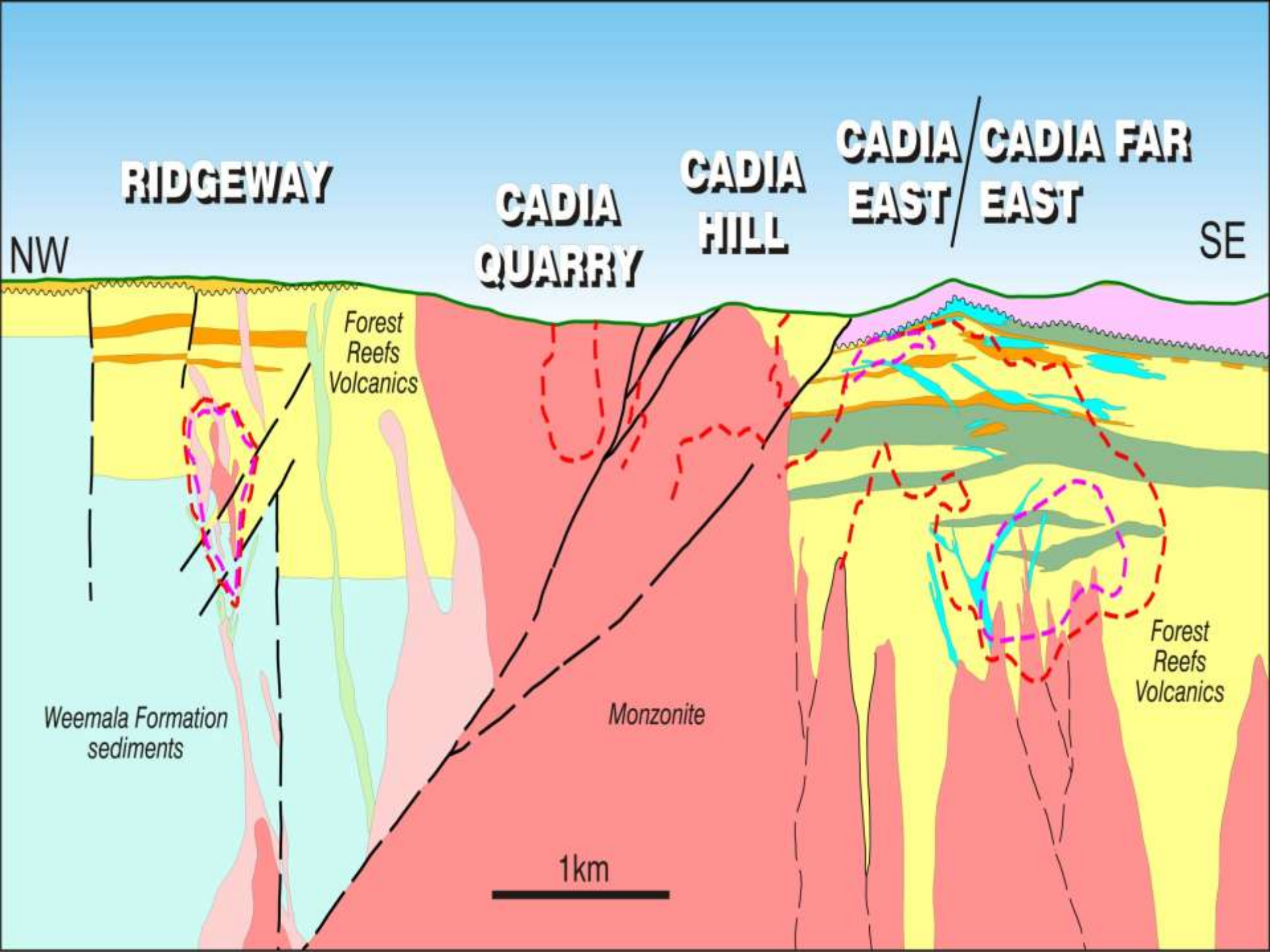
Content

- ‘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


RIDGEWAY
CADIA QUARRY
CADIA HILL
CADIA EAST
CADIA FAR EAST
NW
SE
Forest Reefs Volcanics
Weemala Formation sediments
Monzonite
Forest Reefs Volcanics
1km

‘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

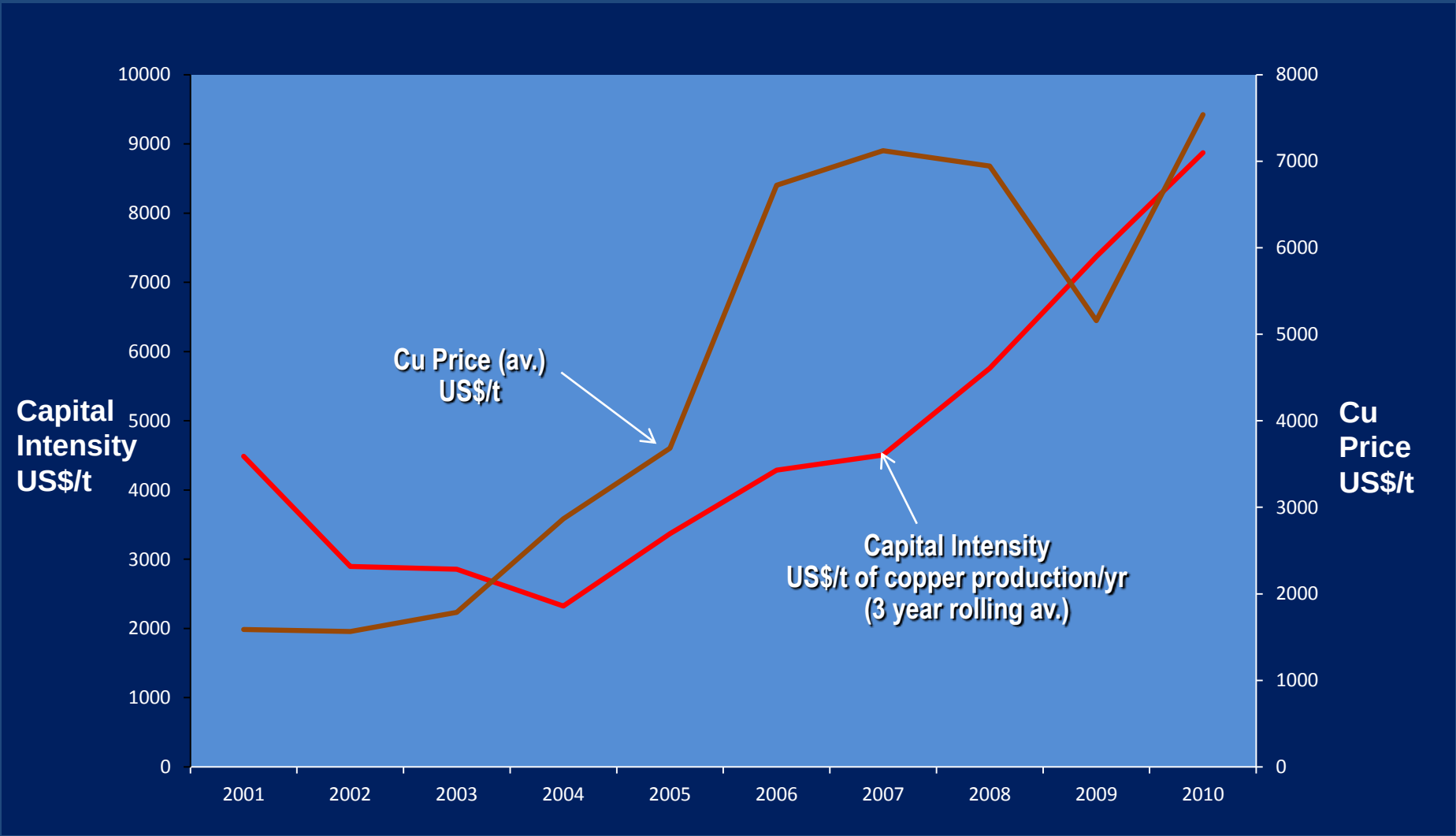
Some Mining Effects

- 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'

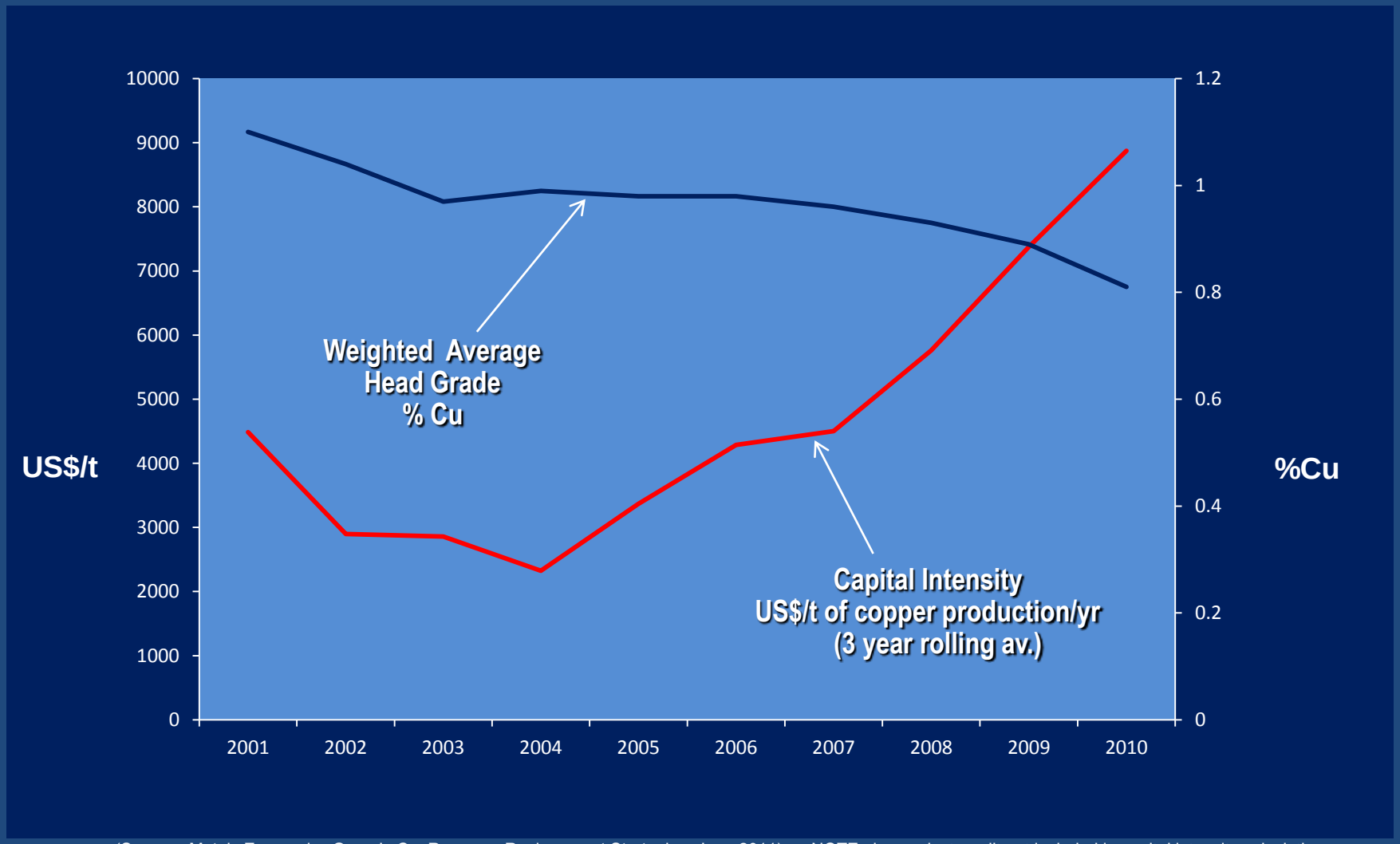
- 'State Capitalism'
- Increasing world influence
- "The world's ten biggest oil-and-gas firms, measured by reserves, are all state-owned" – *The Economist, January 2012*

Capital Intensity vs Cu Price for New Cu Mines, 2001 - 2010



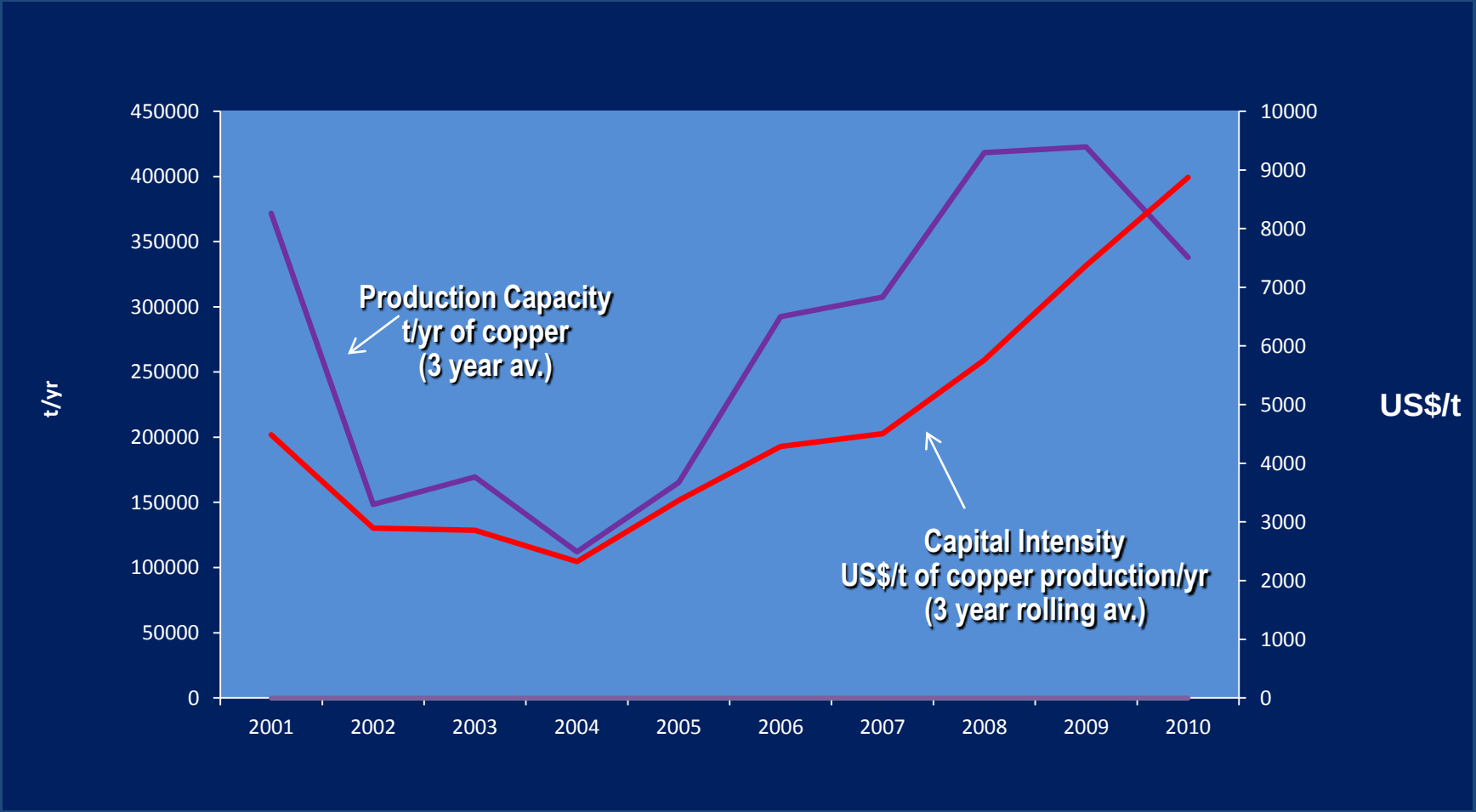
(Source: Metals Economics Group's Cu Reserves Replacement Strategies, June 2011) NOTE: by-product credit not included in capital intensity calculation

Capital Intensity vs Cu Mine Head Grade, 2001 - 2010



(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

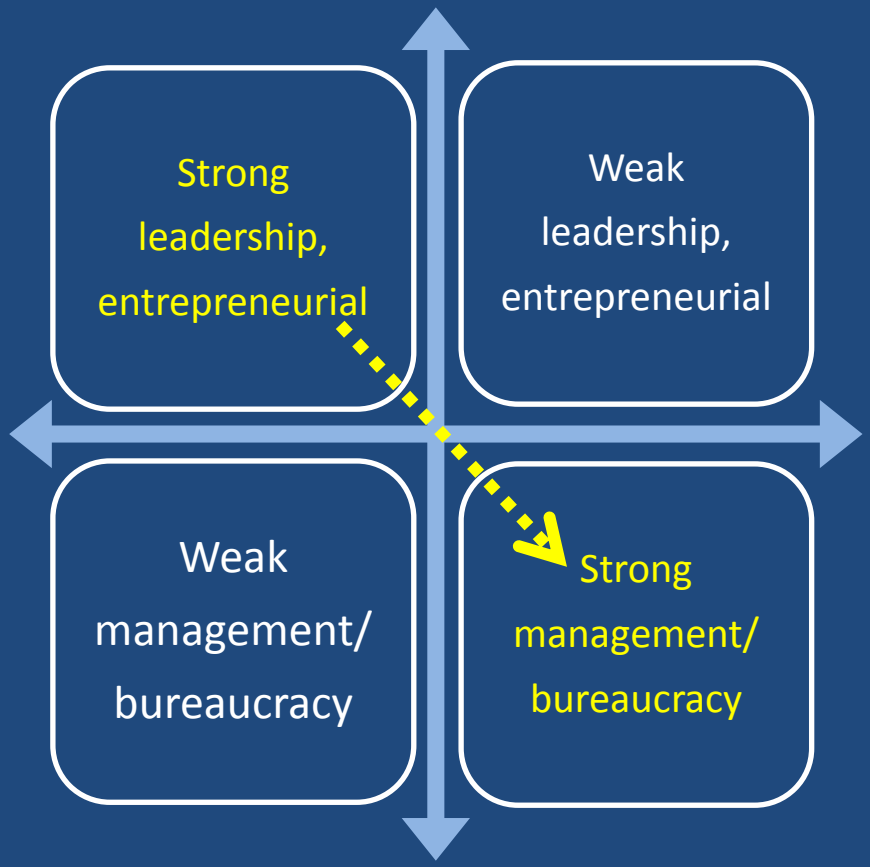
Some Copper Examples

- 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

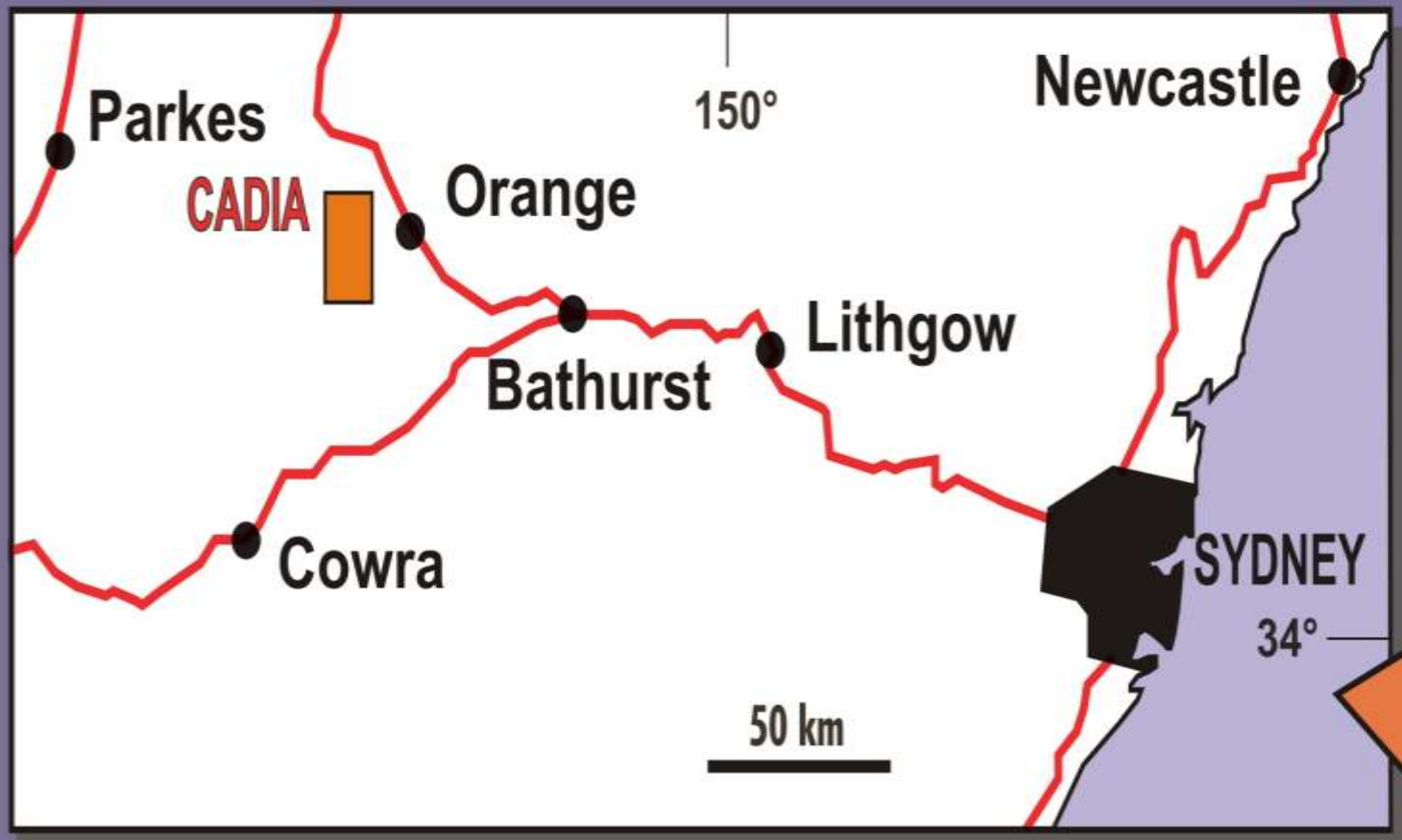
- ‘Easy’ to make ?
- Surface/near-surface – prospecting
- ‘Good’ geology often important
- Some were ‘Deep Earth’

A Prior Discovery Model

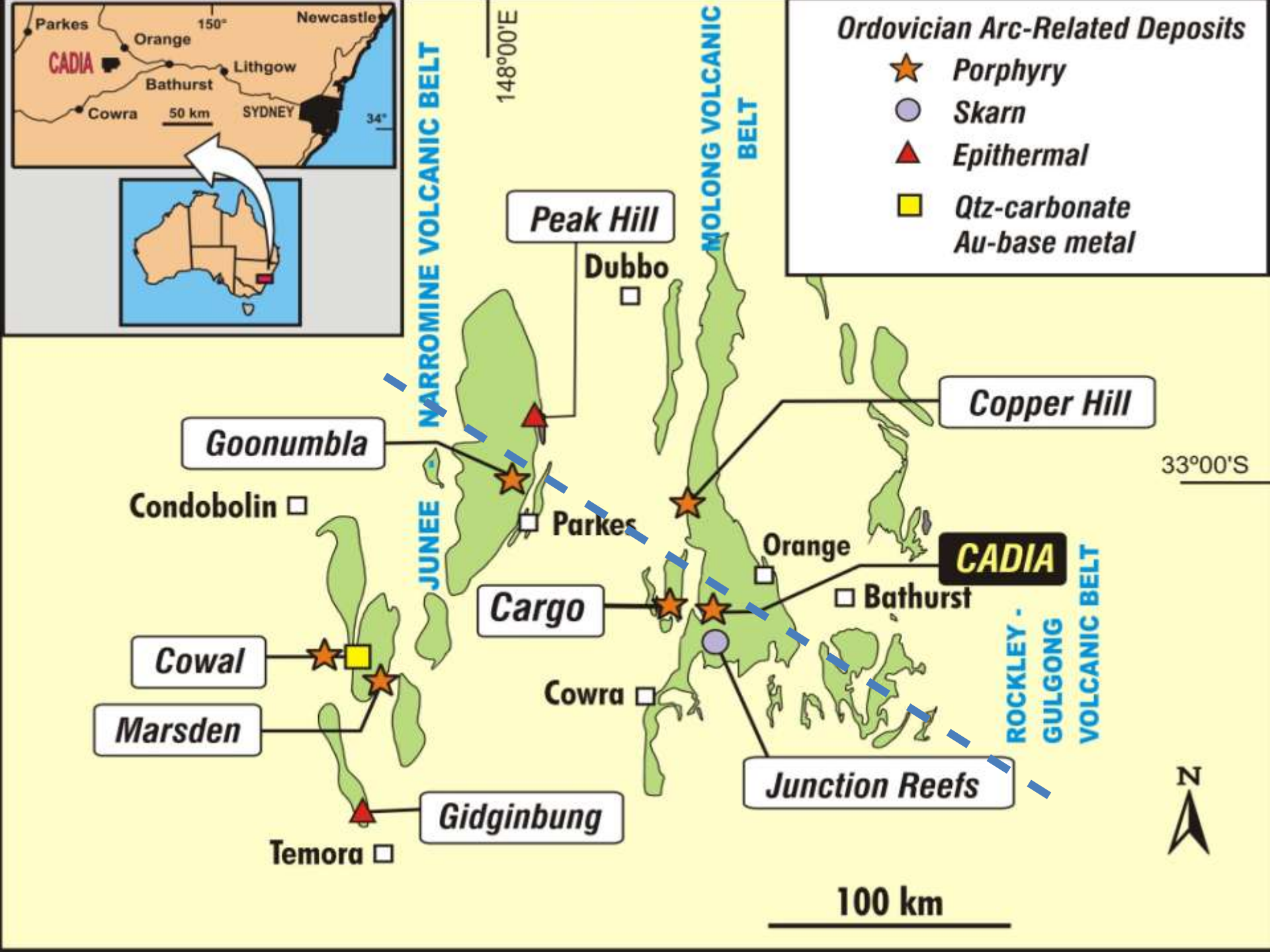
- "Where best to look – shadow of the headframe" – Sig. Muessig, Getty
- Why – "the closer to ore, the lower the risk" – Sig. Muessig, Getty

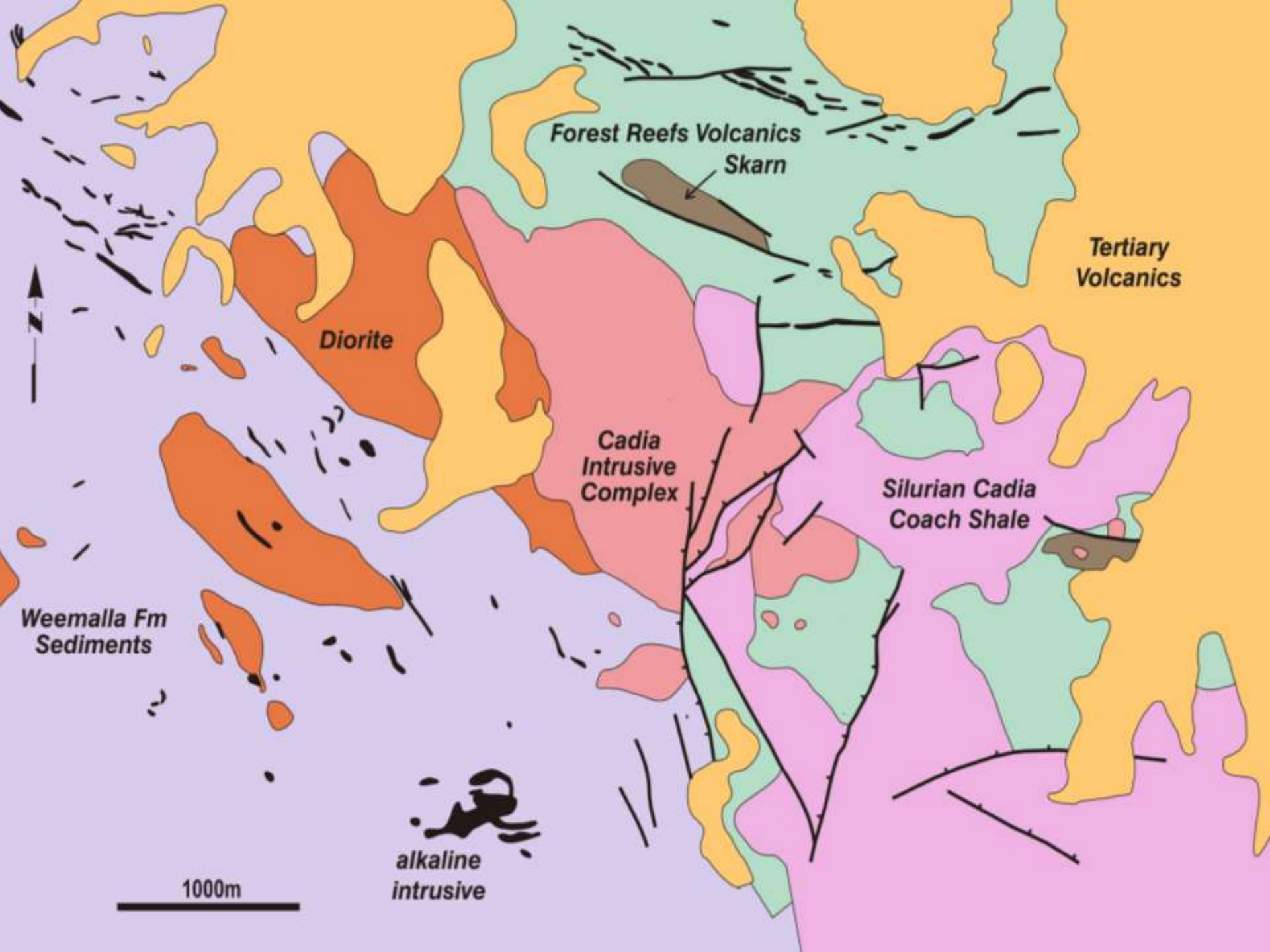
An Example: Cadia Hill

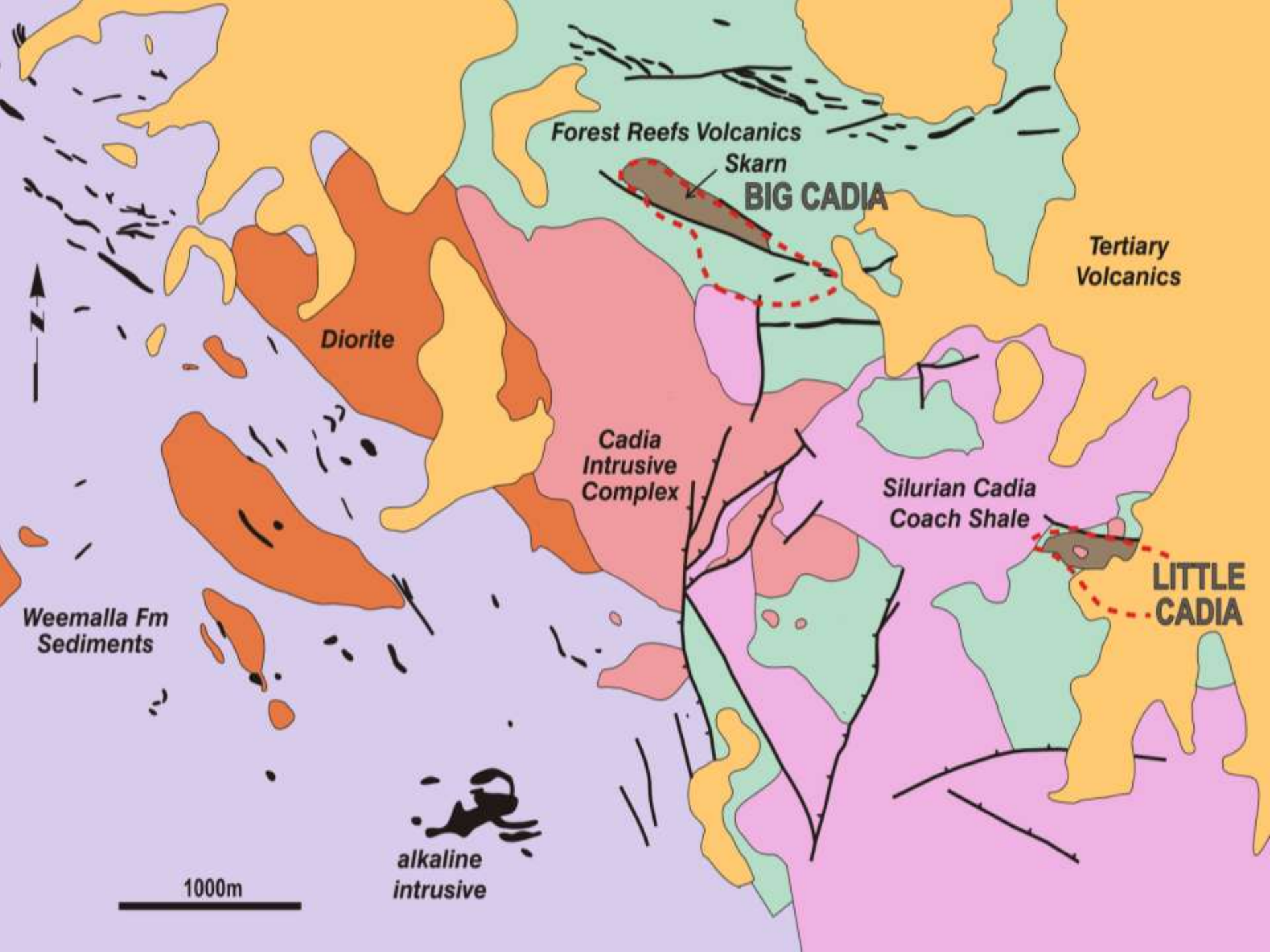
- ‘Old-fashioned’ & ‘easy’?
- Surface prospecting
- Influenced by people, time, gold price and geological thinking



CADIA PROJECT
New South Wales


Parkes
150°
Newcastle
Orange
CADIA
Lithgow
Bathurst
Cowra
50 km
SYDNEY
34°
148°00'E
NARROMINE VOLCANIC BELT
MOLONG VOLCANIC BELT
Ordovician Arc-Related Deposits
Porphyry
Skarn
Epithermal
Qtz-carbonate
Au-base metal
Peak Hill
Dubbo
Copper Hill
Goonumbla
33°00'S
Condobolin
Parkes
Orange
CADIA
Bathurst
JUNEE
Cargo
Cowal
Cowra
Marsden
ROCKLEY - GULGONG VOLCANIC BELT
Junction Reefs
Gidginbung
Temora
N
100 km


Forest Reefs Volcanics
Skarn
Tertiary
Volcanics
Diorite
Cadia
Intrusive
Complex
Silurian Cadia
Coach Shale
Weemalla Fm
Sediments
alkaline
intrusive
1000m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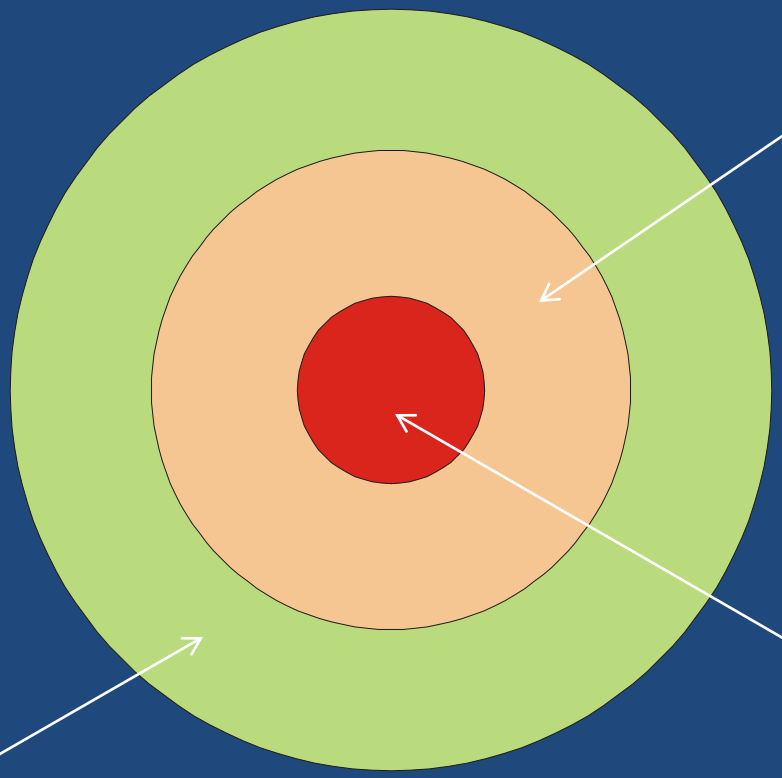
CADIA
Weemalla Fm
Sediments
alkaline
intrusive
1000m

“Lateral” Comparison

- Ok Tedi porphyry Au/Cu deposit
- Skarn & Ok Tedi porphyry – yes
- Skarn & Cadia porphyry – why not?
- Supporting evidence – where?

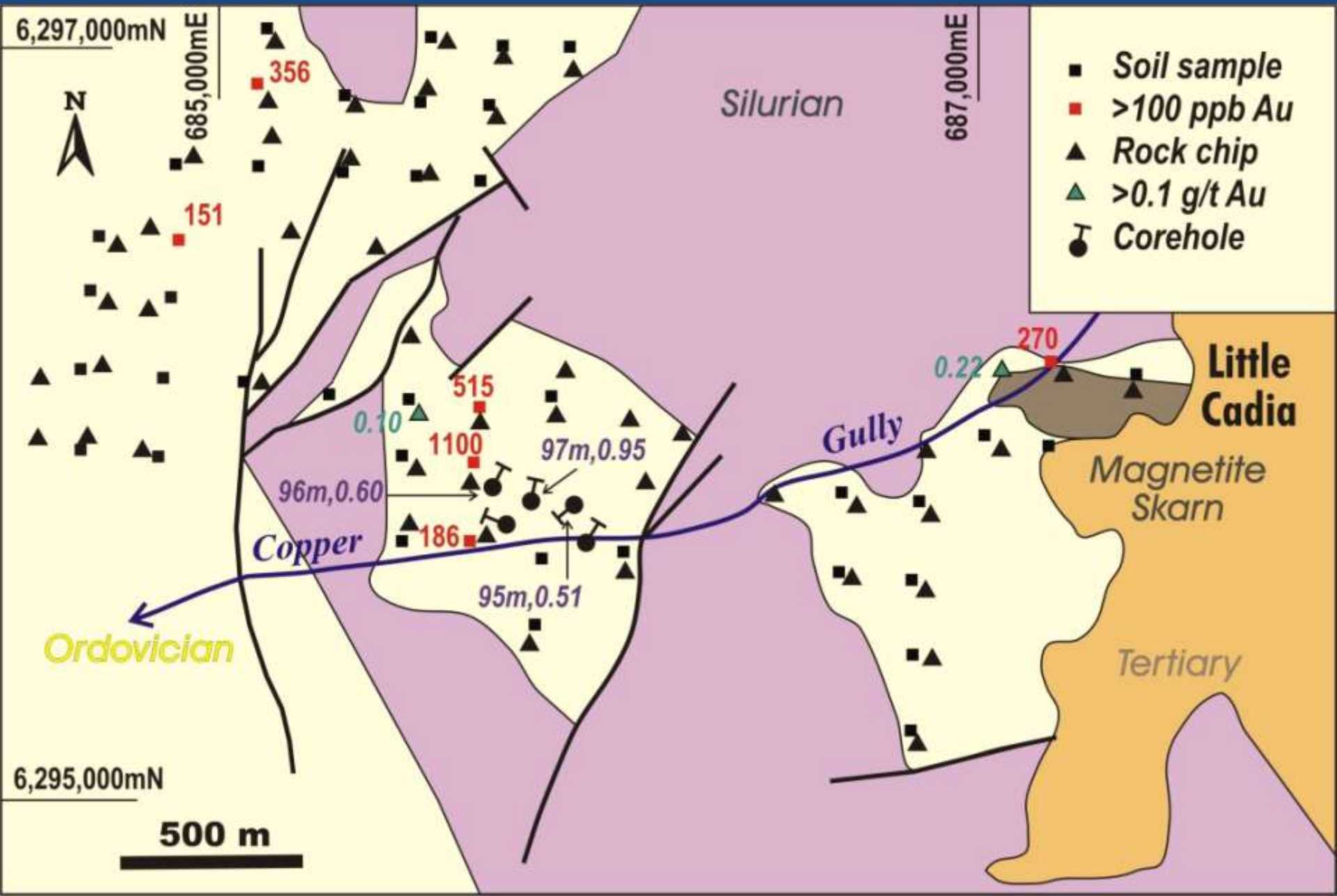
“Lateral” Thought



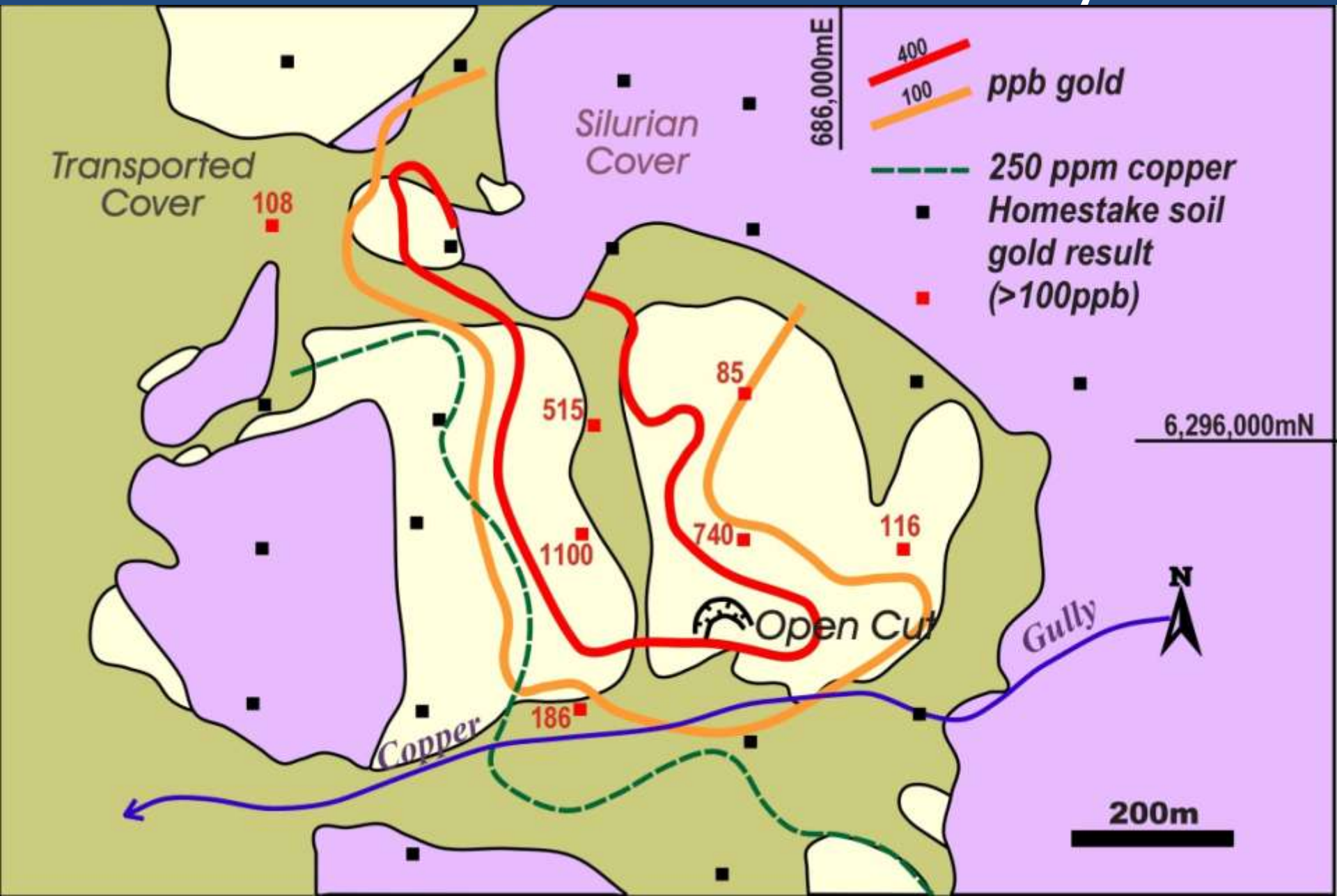
3D dartboard

Western Cadia Hill – prior to discovery

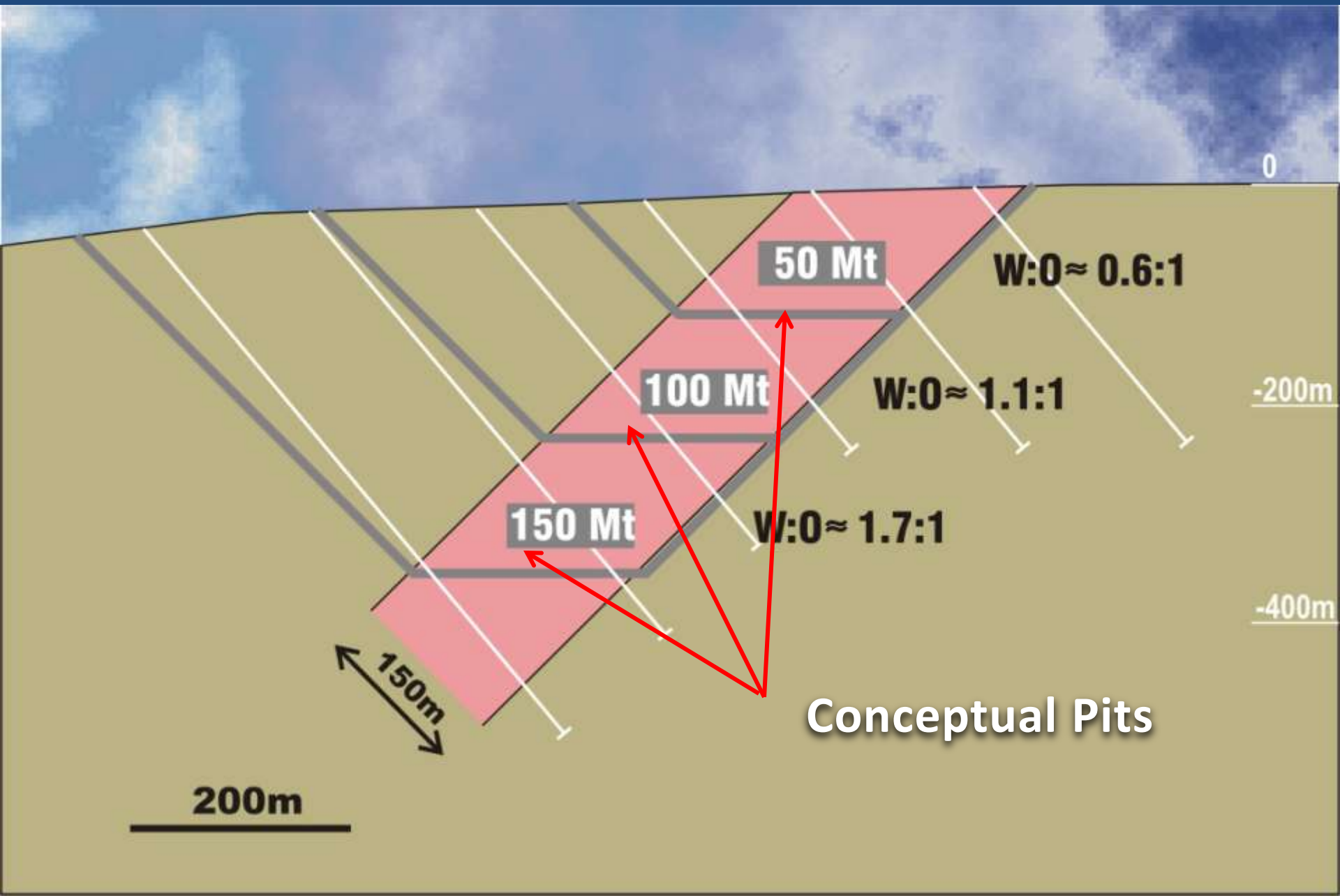
Cadia Hill: Pre-Newcrest Exploration



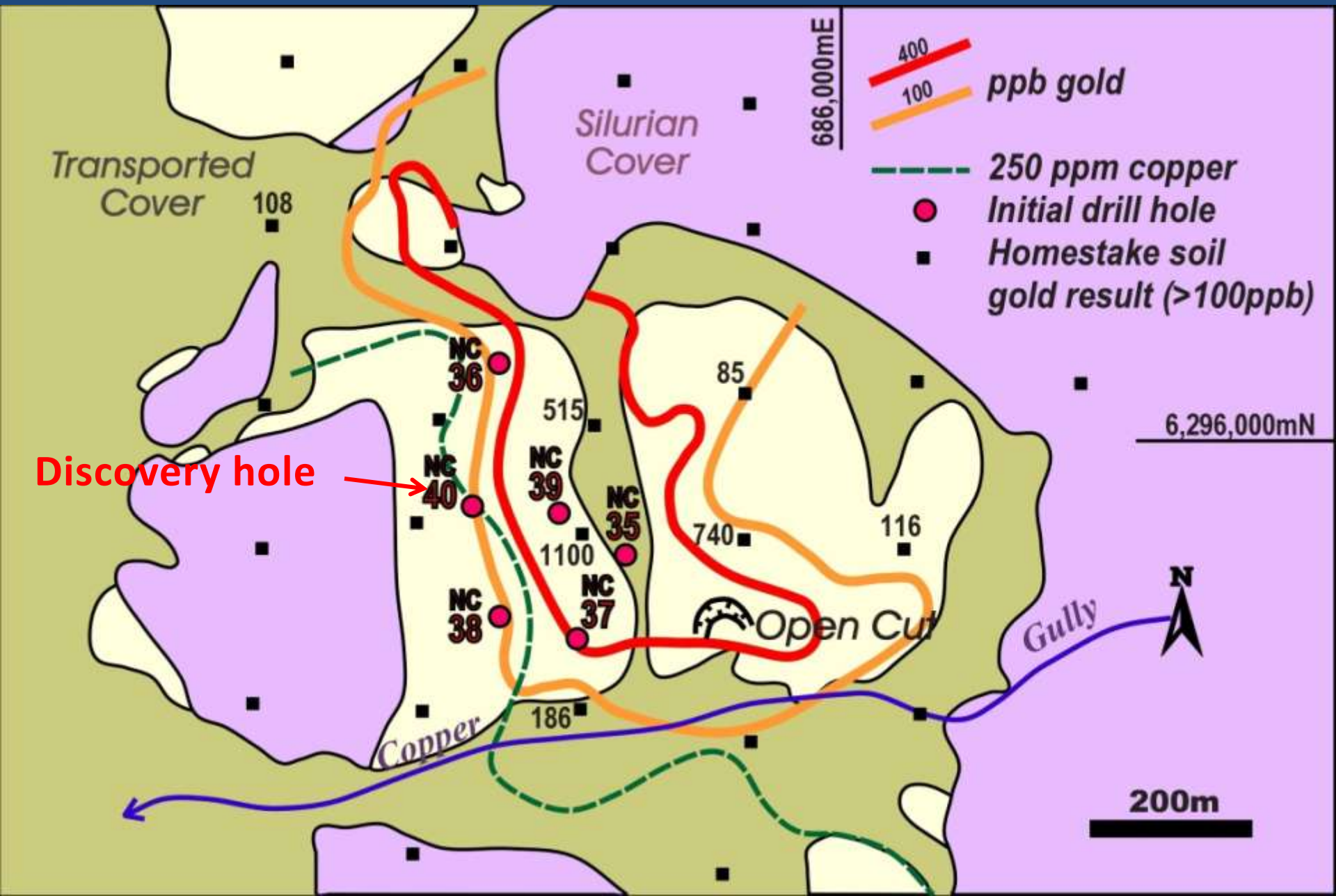
Cadia Hill: Soil Geochemistry



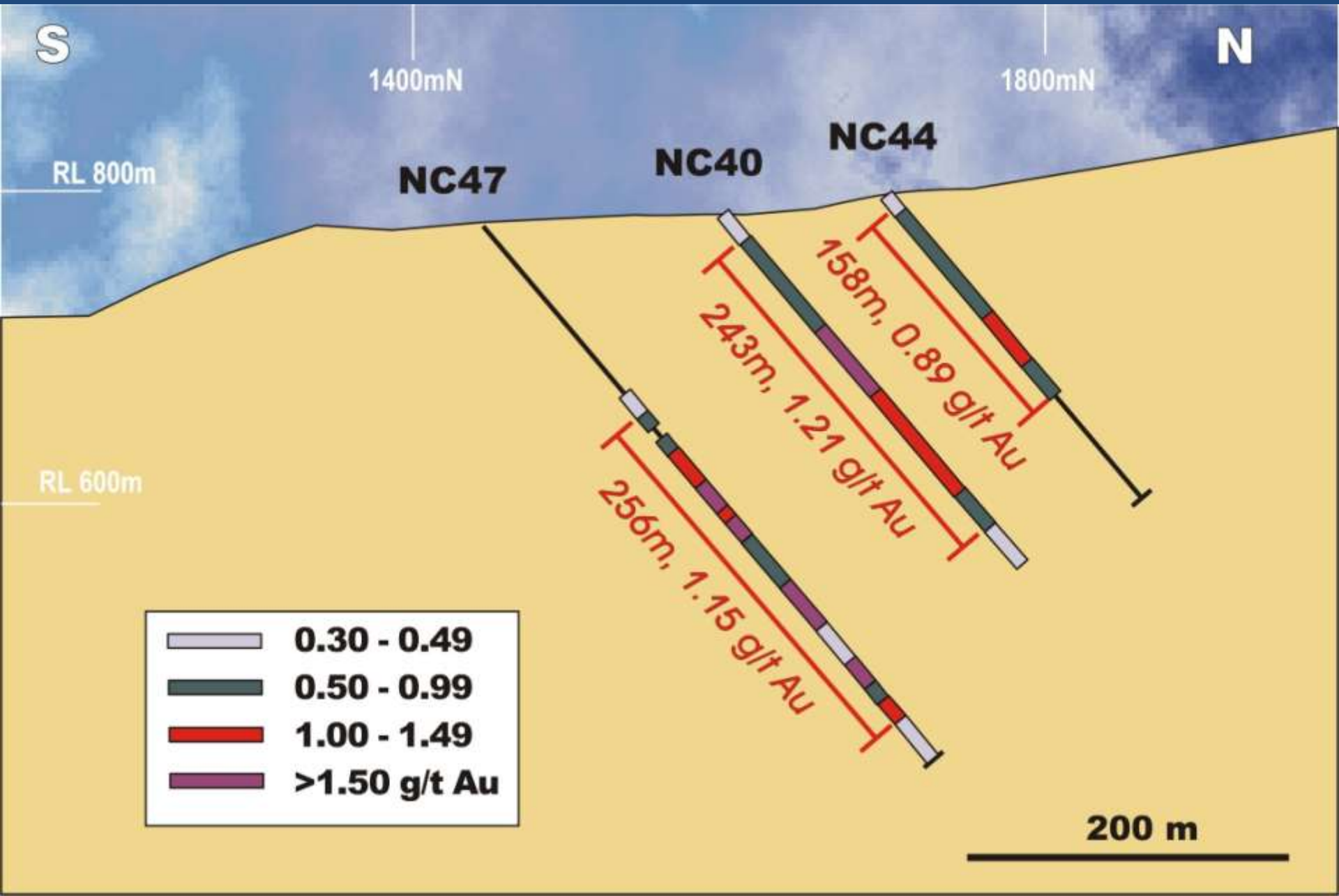
Cadia Hill: Exploratory Drilling Concept



Cadia Hill: Discovery Drilling

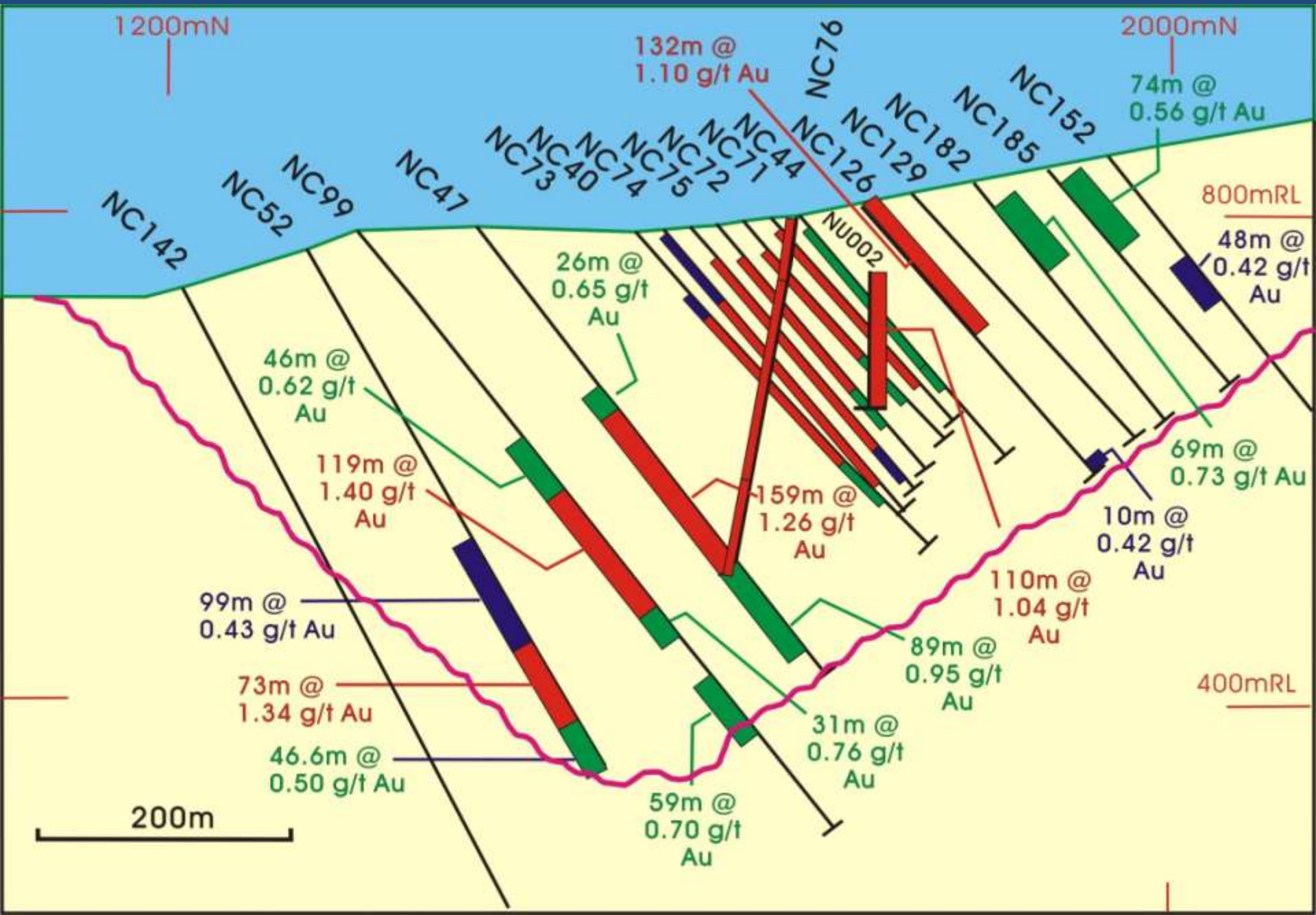


Cadia Hill: Section 14,020E



Cadia Hill Core - hole NC38

Cadia Hill: Section 14,020E – Gold Intersections




Ridgeway
subsidence zone
Ridgeway
decline portal
Cadia Hill
open cut

‘Deep Earth’ Discoveries

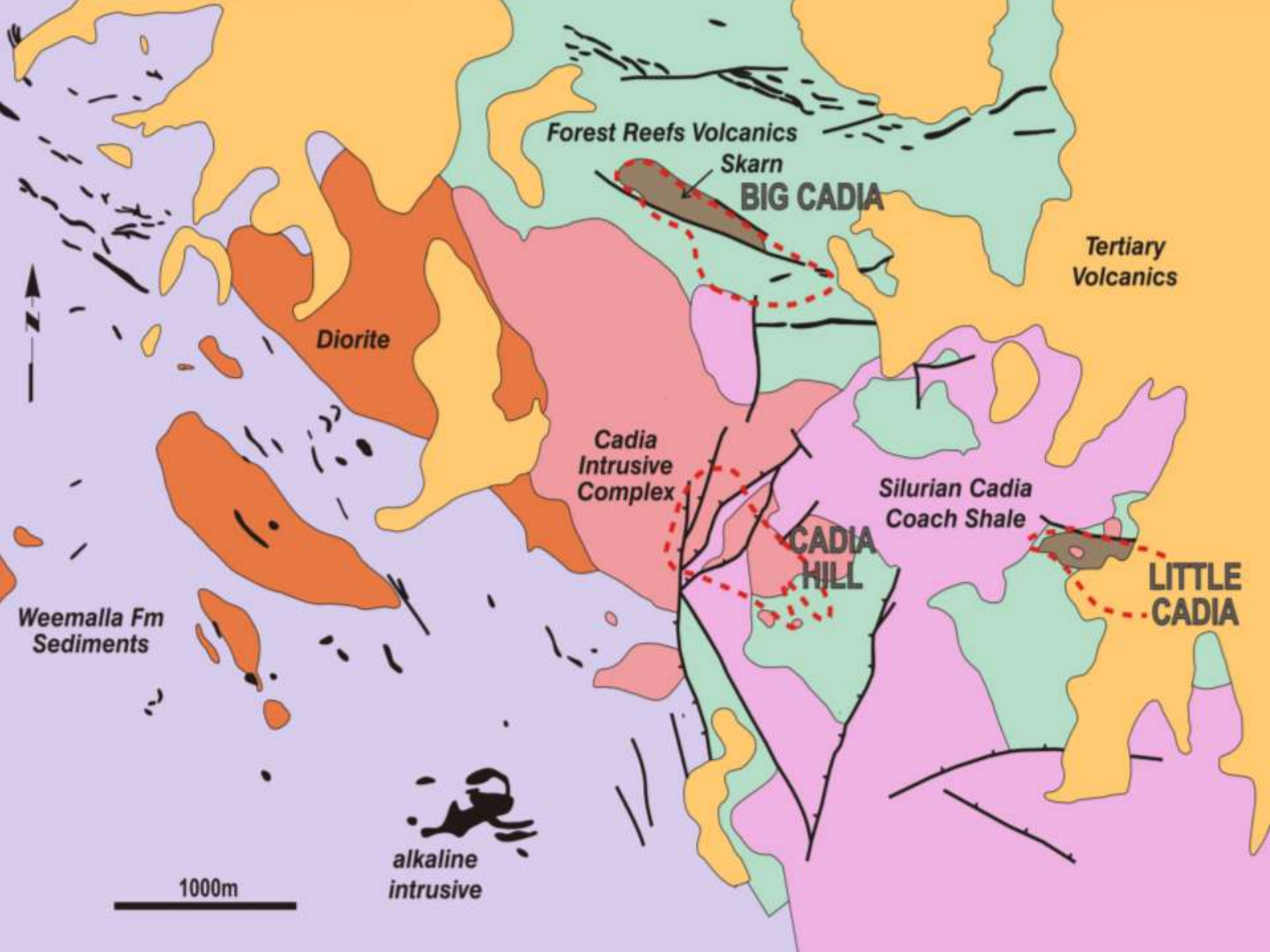
- More difficult & less ‘obvious’
- Much greater depth
- Possibly lower grade
- Need to be much larger

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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Skarn
BIG CADIA
Tertiary
Volcanics
Diorite
Cadia
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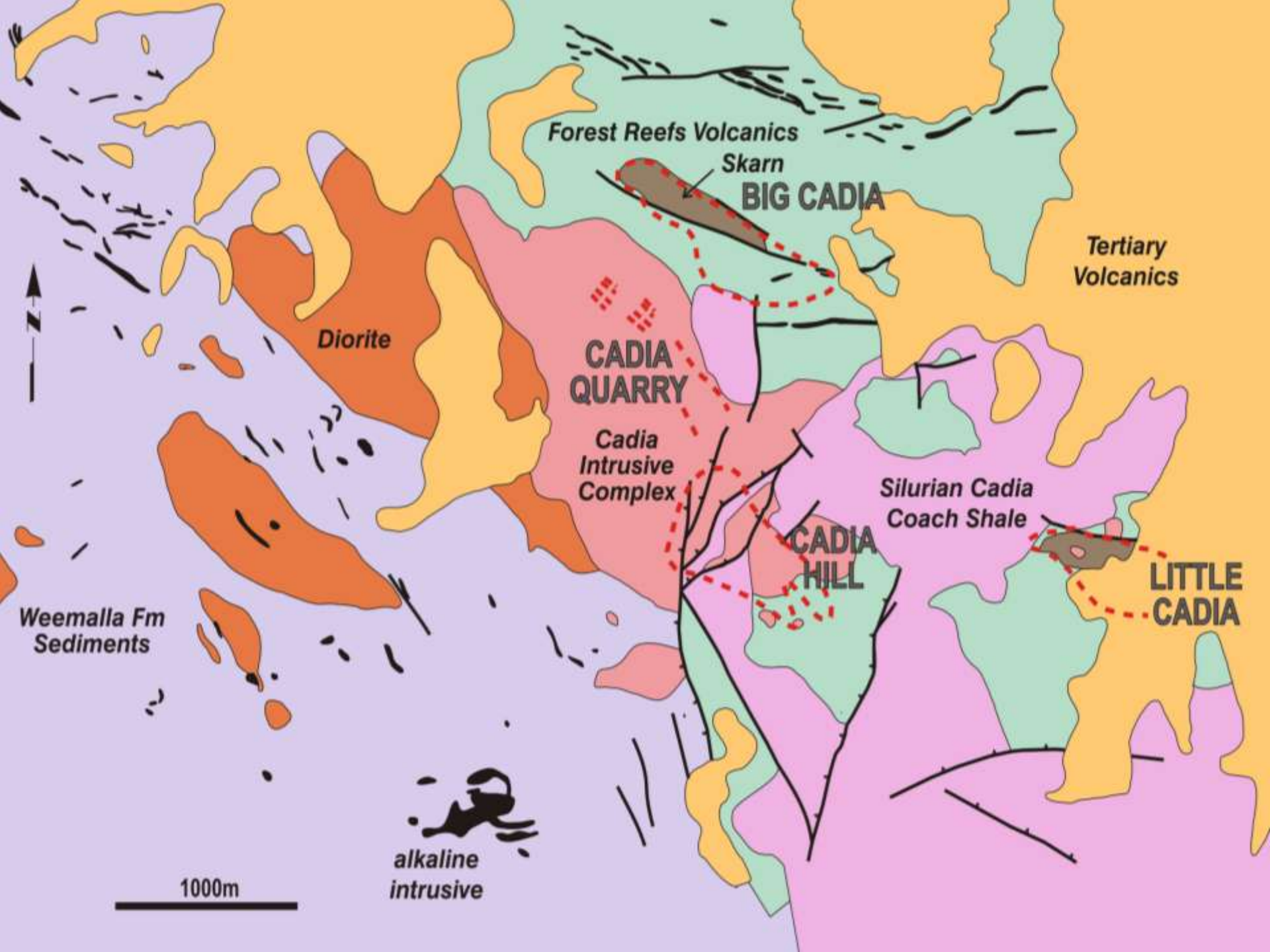
Complex
Silurian Cadia
Coach Shale
CADIA
HILL
LITTLE
CADIA
Weemalla Fm
Sediments
alkaline
intrusive
1000m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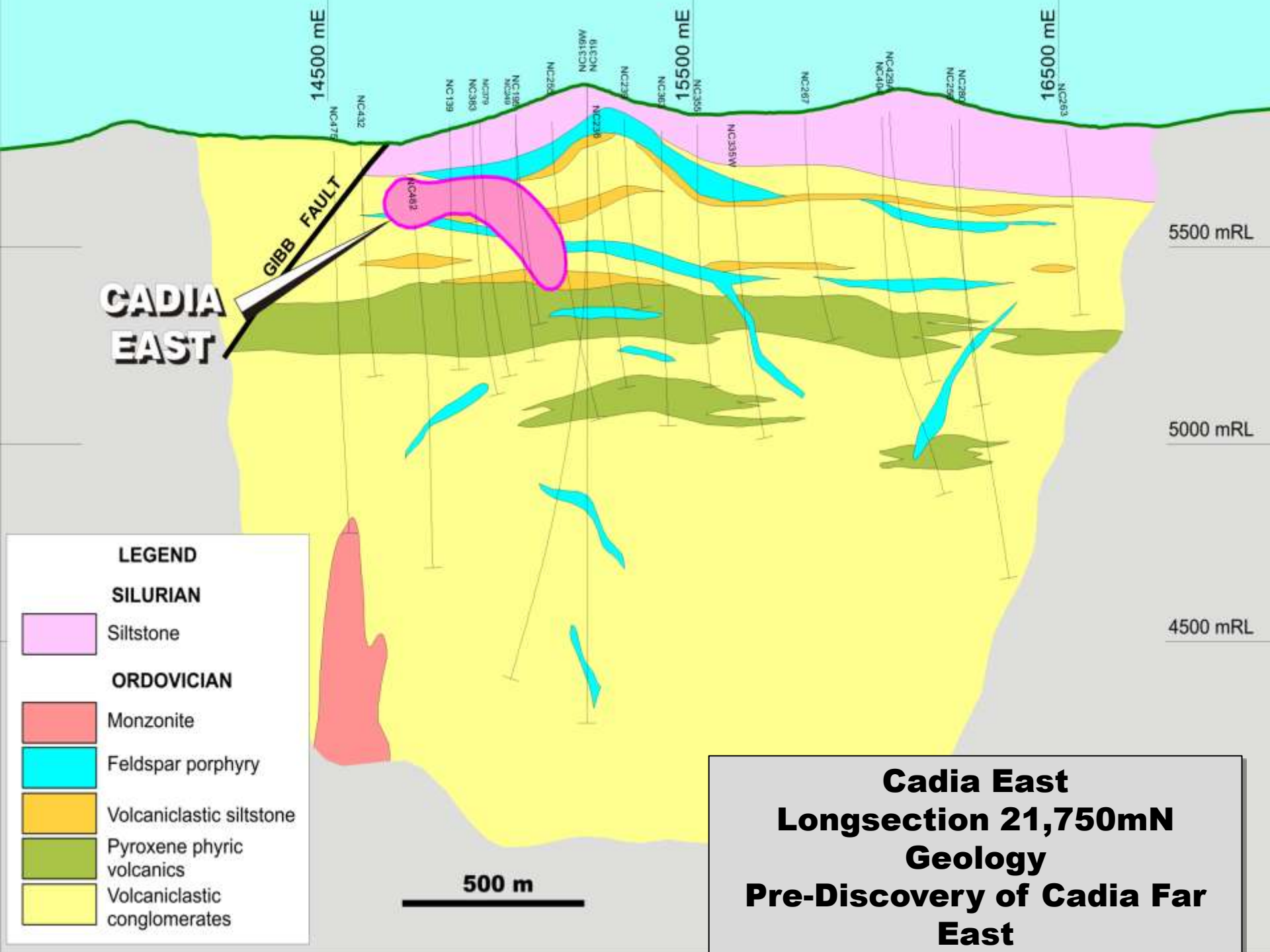
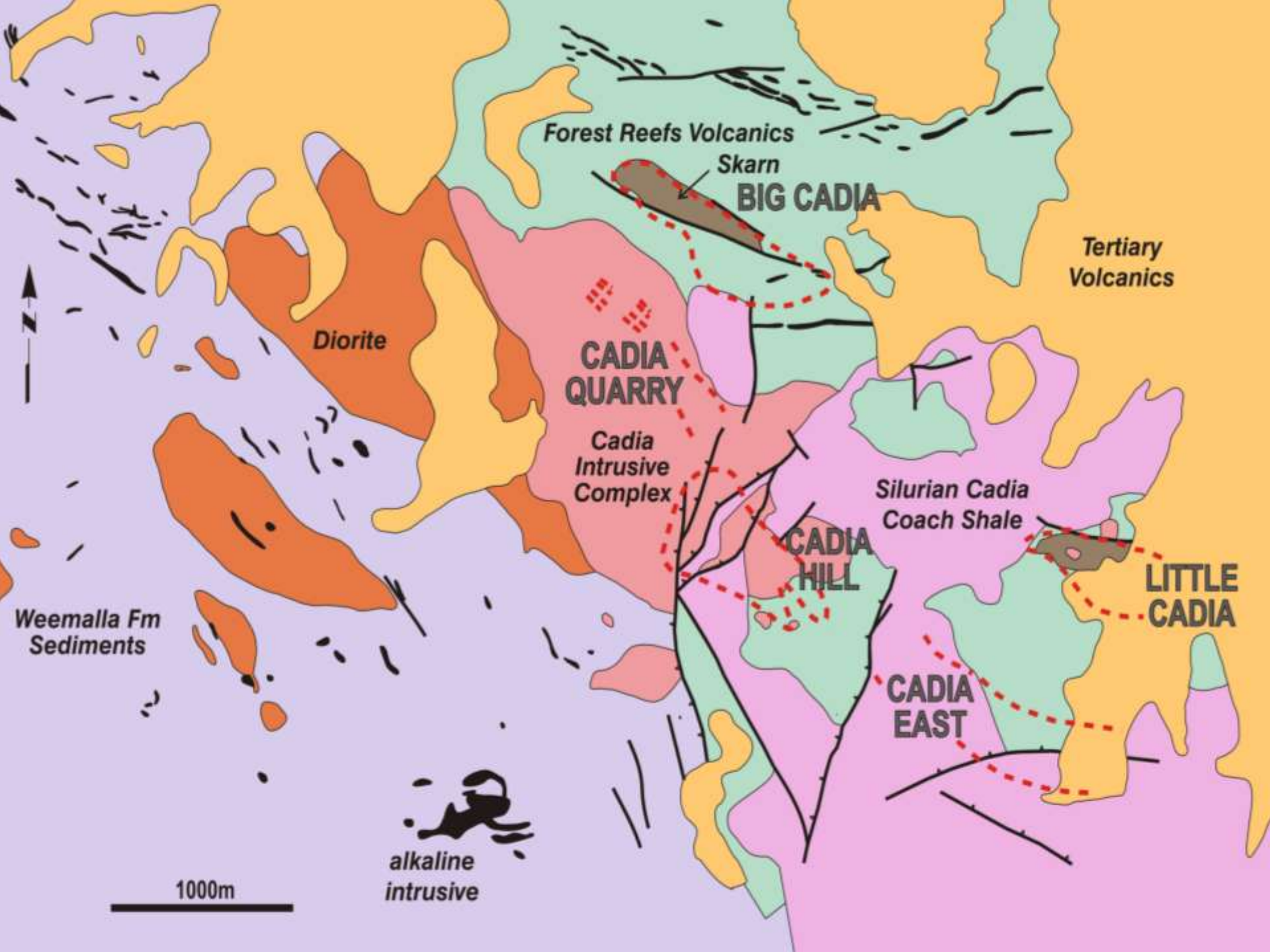


Cadia East
Longsection 21,750mN
Geology
Pre-Discovery of Cadia Far East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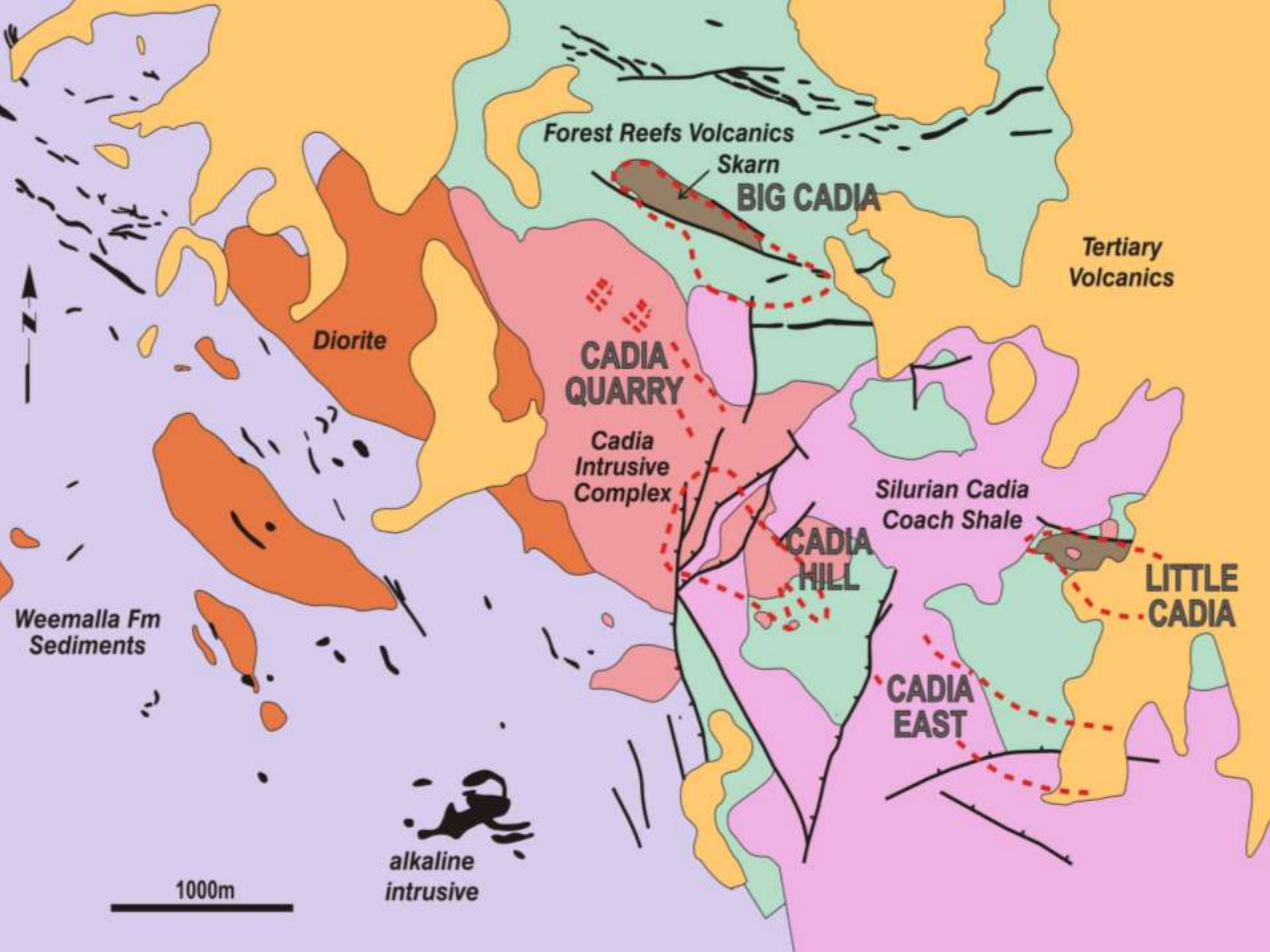
1000m

IP Traversing

- Trialled over Cadia Hill/East
- 200 m dipole-dipole array
- Deep low-order chargeability responses
- Possibly good for 200 m cover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EAST
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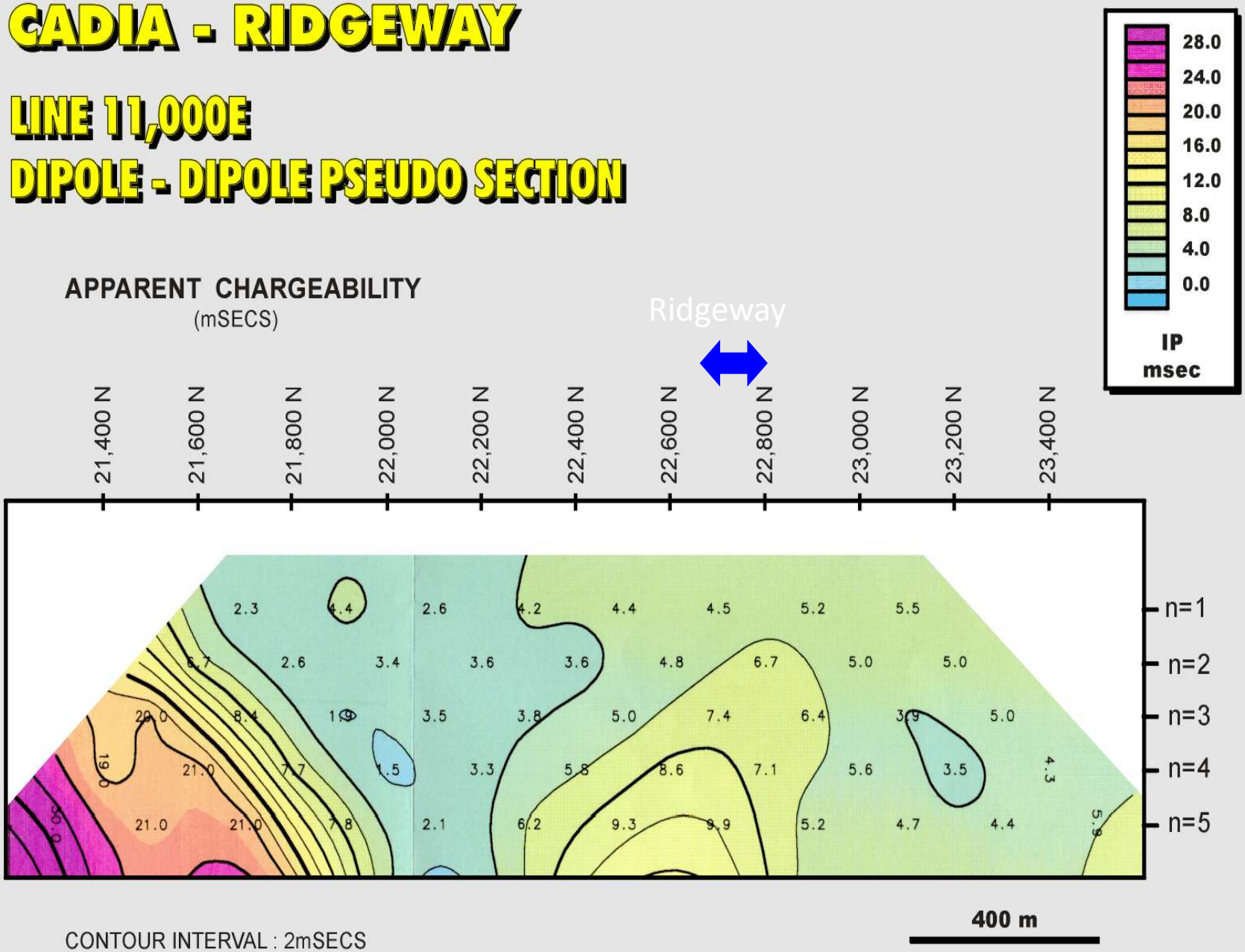
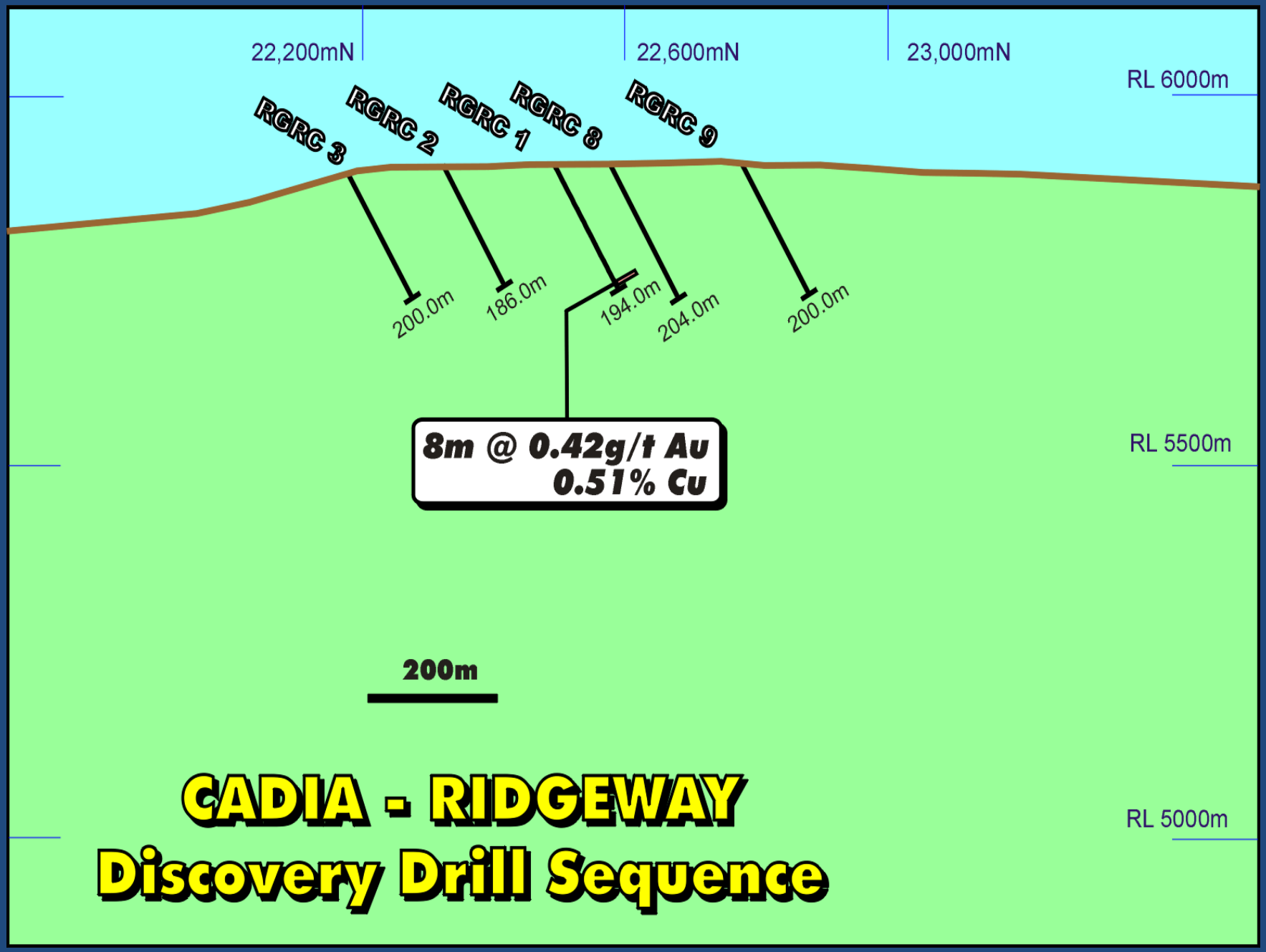
1000m

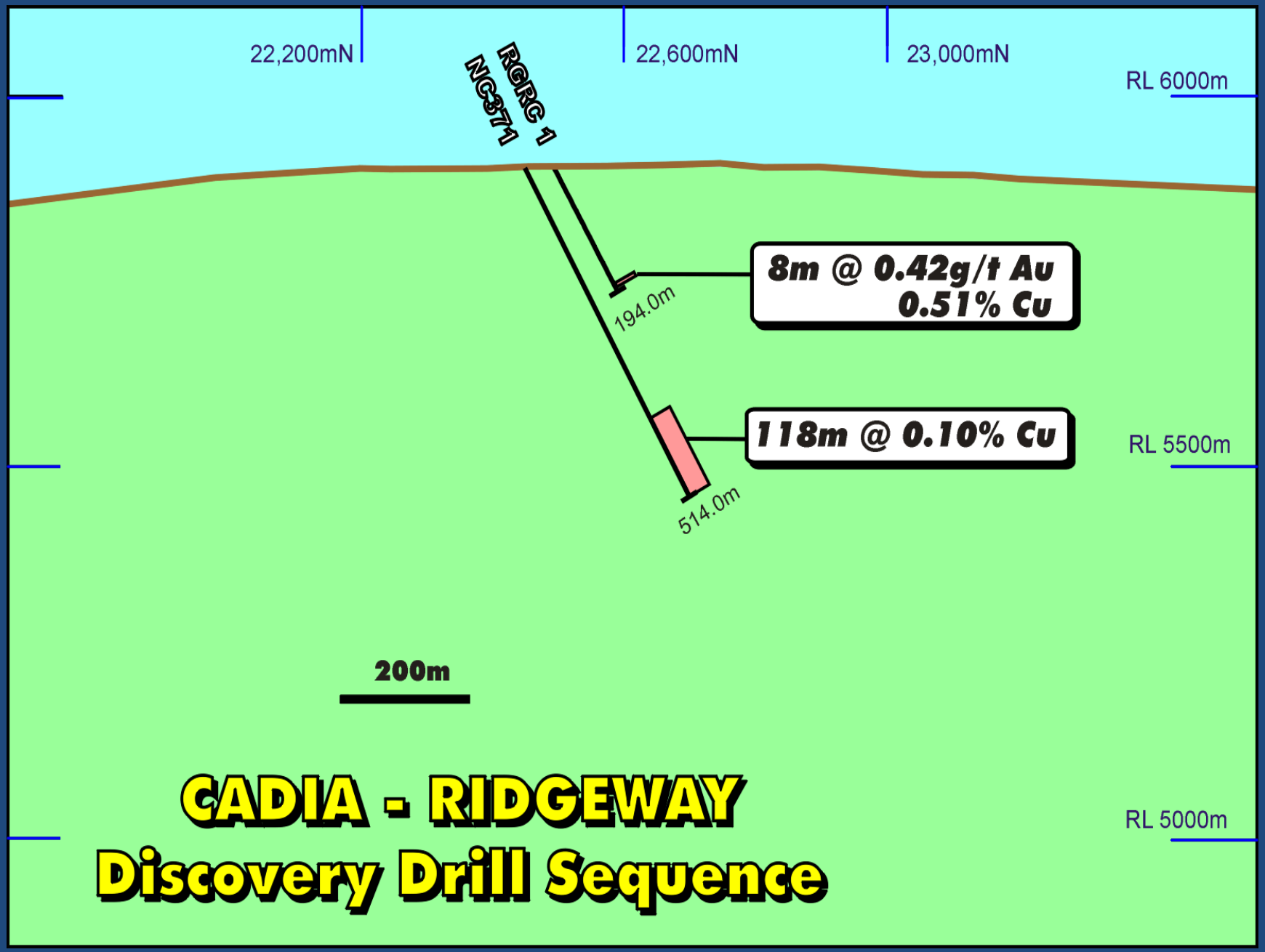
CADIA - RIDGEWAY

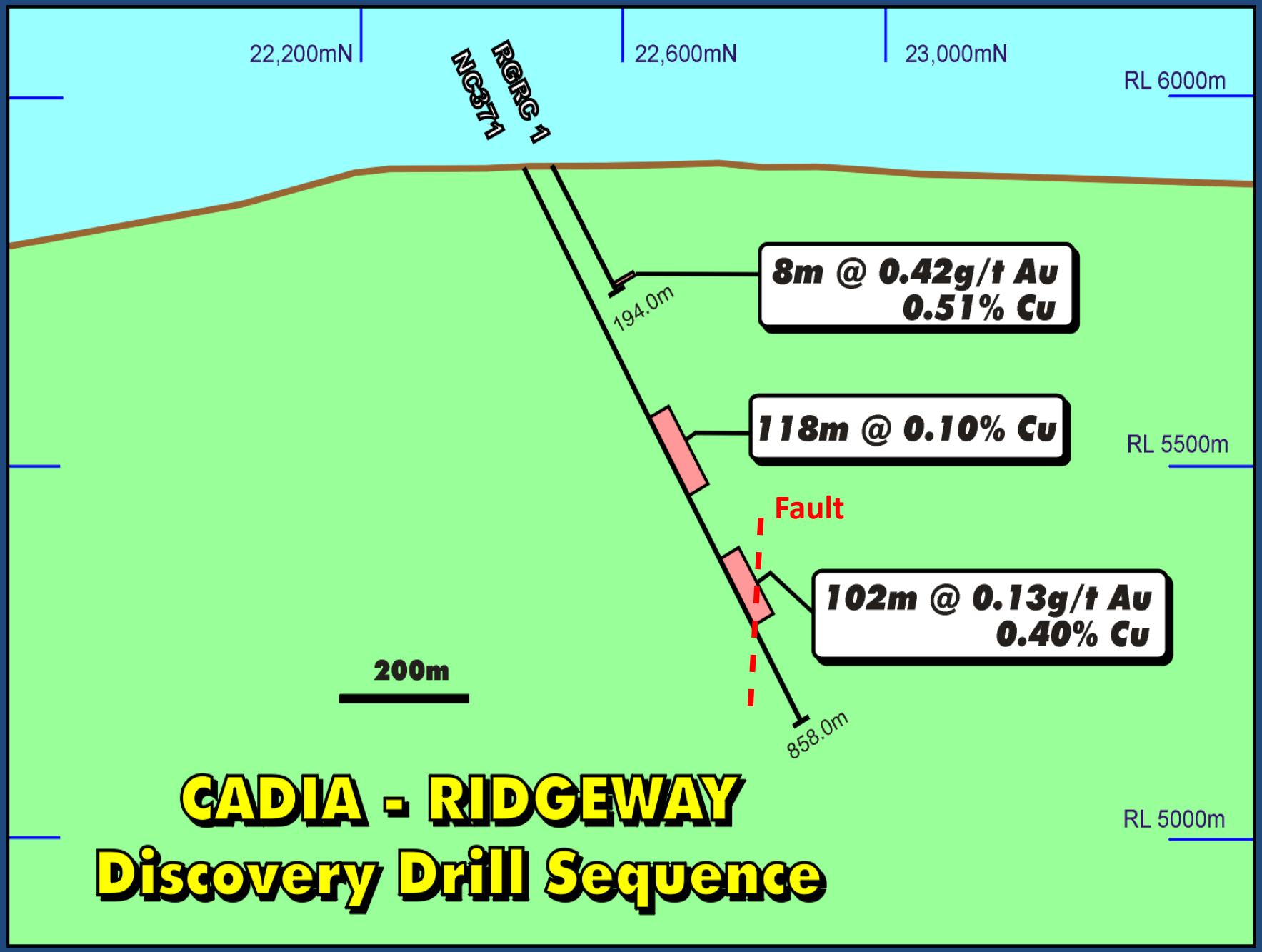
LINE 11,000E
DIPOLE - DIPOLE PSEUDO SECTION

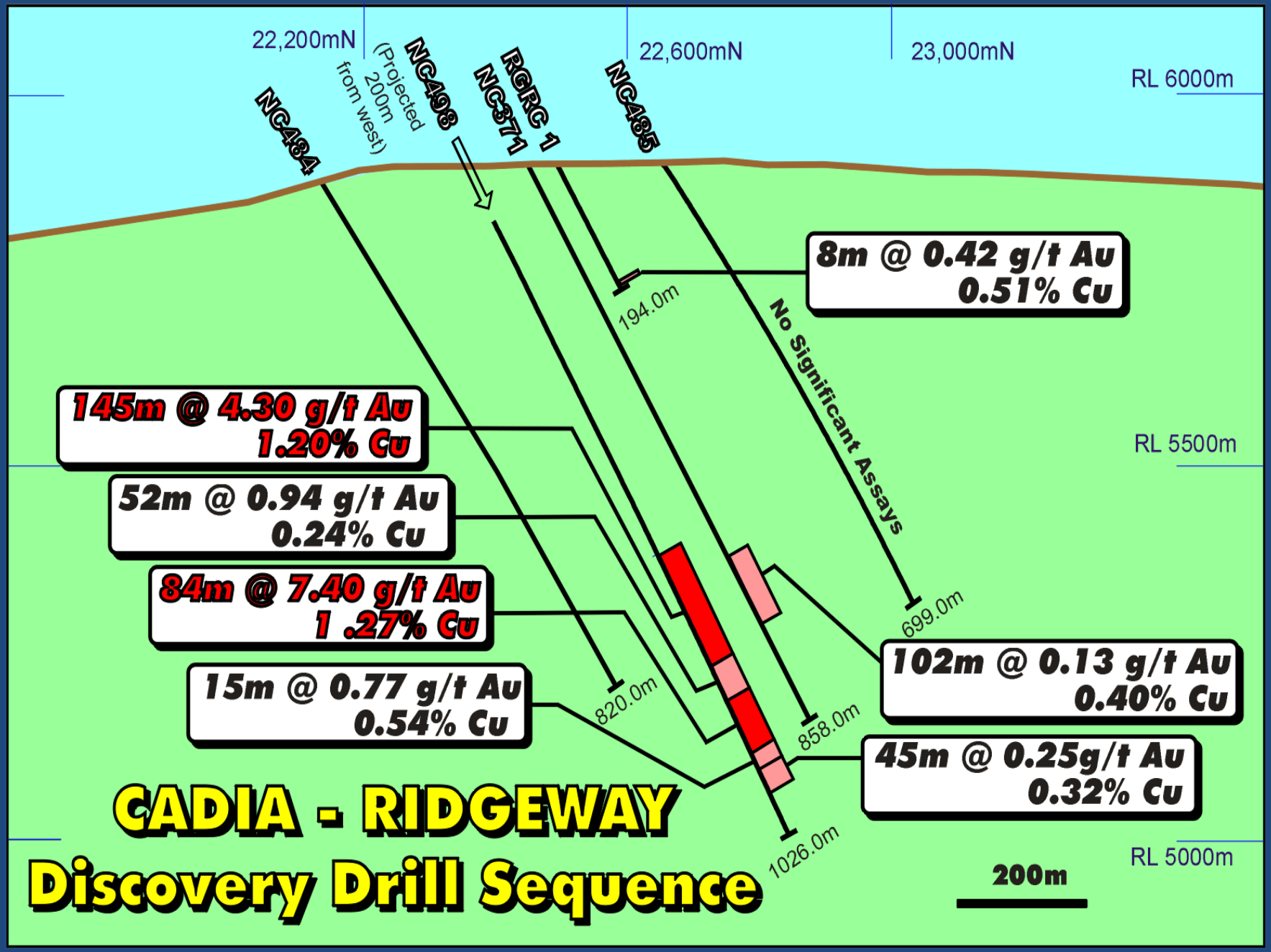


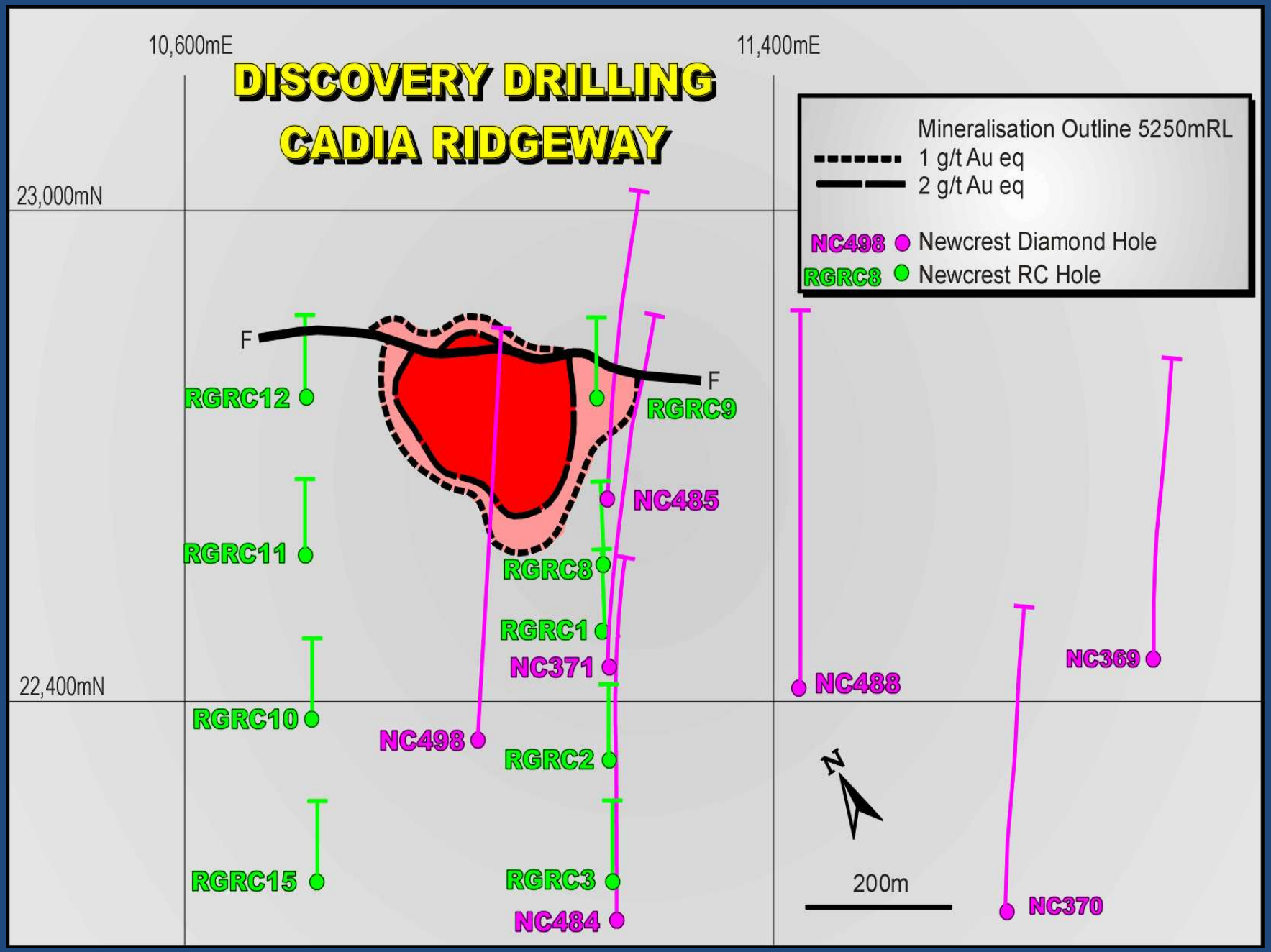


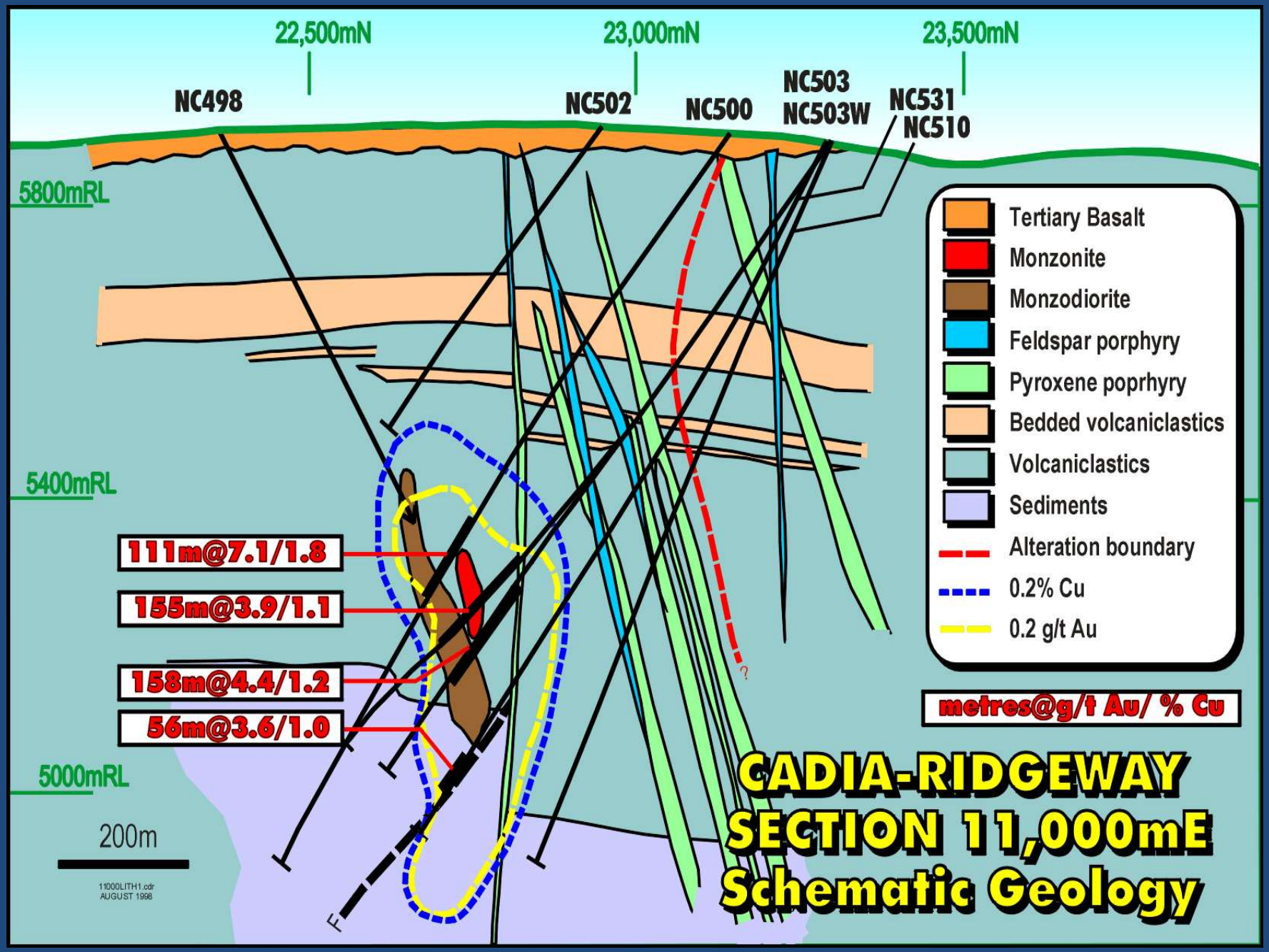
CADIA - RIDGEWAY
Discovery Drill Sequence


22,200mN
22,600mN
23,000mN
RL 6000m
RGRC 1
NC371
194.0m
8m @ 0.42g/t Au
0.51% Cu
118m @ 0.10% Cu
RL 5500m
514.0m
200m
RL 5000m
CADIA - RIDGEWAY
Discovery Drill Sequence


22,200mN
22,600mN
23,000mN
RL 6000m
RGRC 1
NC371
194.0m
8m @ 0.42g/t Au
0.51% Cu
118m @ 0.10% Cu
RL 5500m
Fault
102m @ 0.13g/t Au
0.40% Cu
200m
858.0m
RL 5000m
CADIA - RIDGEWAY
Discovery Drill Sequence


22,200mN
22,600mN
23,000mN
RL 6000m
RL 5500m
RL 5000m
NC484
NC498
(Projected 200m from west)
NC371
RGRC 1
NC485
8m @ 0.42 g/t Au
0.51% Cu
194.0m
No Significant Assays
145m @ 4.30 g/t Au
1.20% Cu
52m @ 0.94 g/t Au
0.24% Cu
84m @ 7.40 g/t Au
1 .27% Cu
15m @ 0.77 g/t Au
0.54% Cu
820.0m
699.0m
102m @ 0.13 g/t Au
0.40% Cu
858.0m
45m @ 0.25g/t Au
0.32% Cu
1026.0m
200m
CADIA - RIDGEWAY
Discovery Drill Sequence


DISCOVERY DRILLING
CADIA RIDGEWAY
10,600mE
11,400mE
23,000mN
22,400mN
Mineralisation Outline 5250mRL
1 g/t Au eq
2 g/t Au eq
NC498 Newcrest Diamond Hole
RGRC8 Newcrest RC Hole
F
F
RGRC12
RGRC9
NC485
RGRC11
RGRC8
RGRC1
NC371
NC488
NC369
RGRC10
NC498
RGRC2
N
RGRC15
RGRC3
NC484
200m
NC370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23,000mN
23,500mN
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NC502
NC500
NC503
NC503W
NC531
NC510
5800mRL
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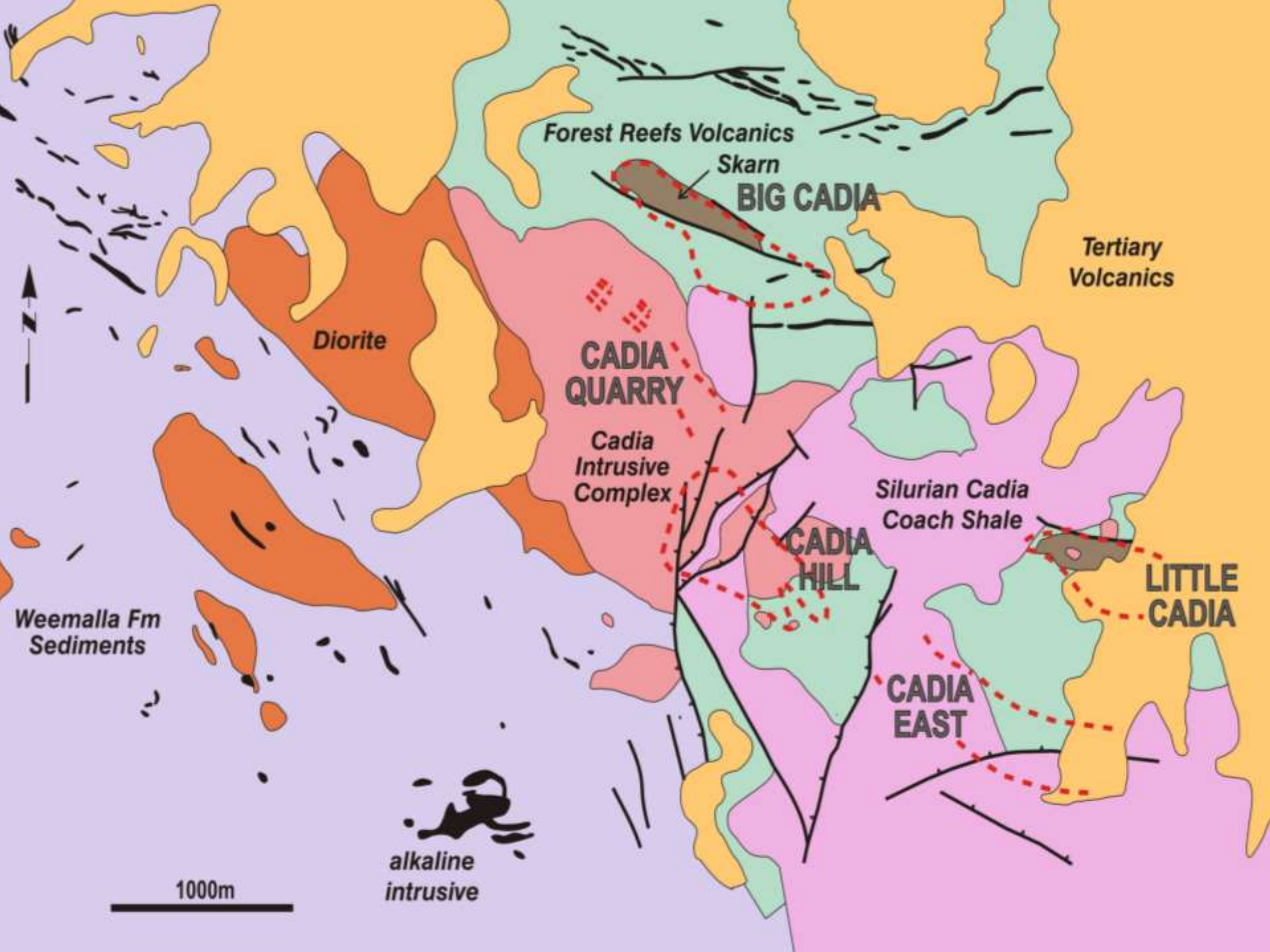
5000mRL
111m@7.1/1.8
155m@3.9/1.1
158m@4.4/1.2
56m@3.6/1.0
200m
11000LITH1.cdr
AUGUST 1998
Tertiary Basalt
Monzonite
Monzodiorite
Feldspar porphyry
Pyroxene poprhyry
Bedded volcaniclastics
Volcaniclastics
Sediments
Alteration boundary
0.2% Cu
0.2 g/t Au
metres@g/t Au/ % Cu
CADIA-RIDGEWAY
SECTION 11,000mE
Schematic Geology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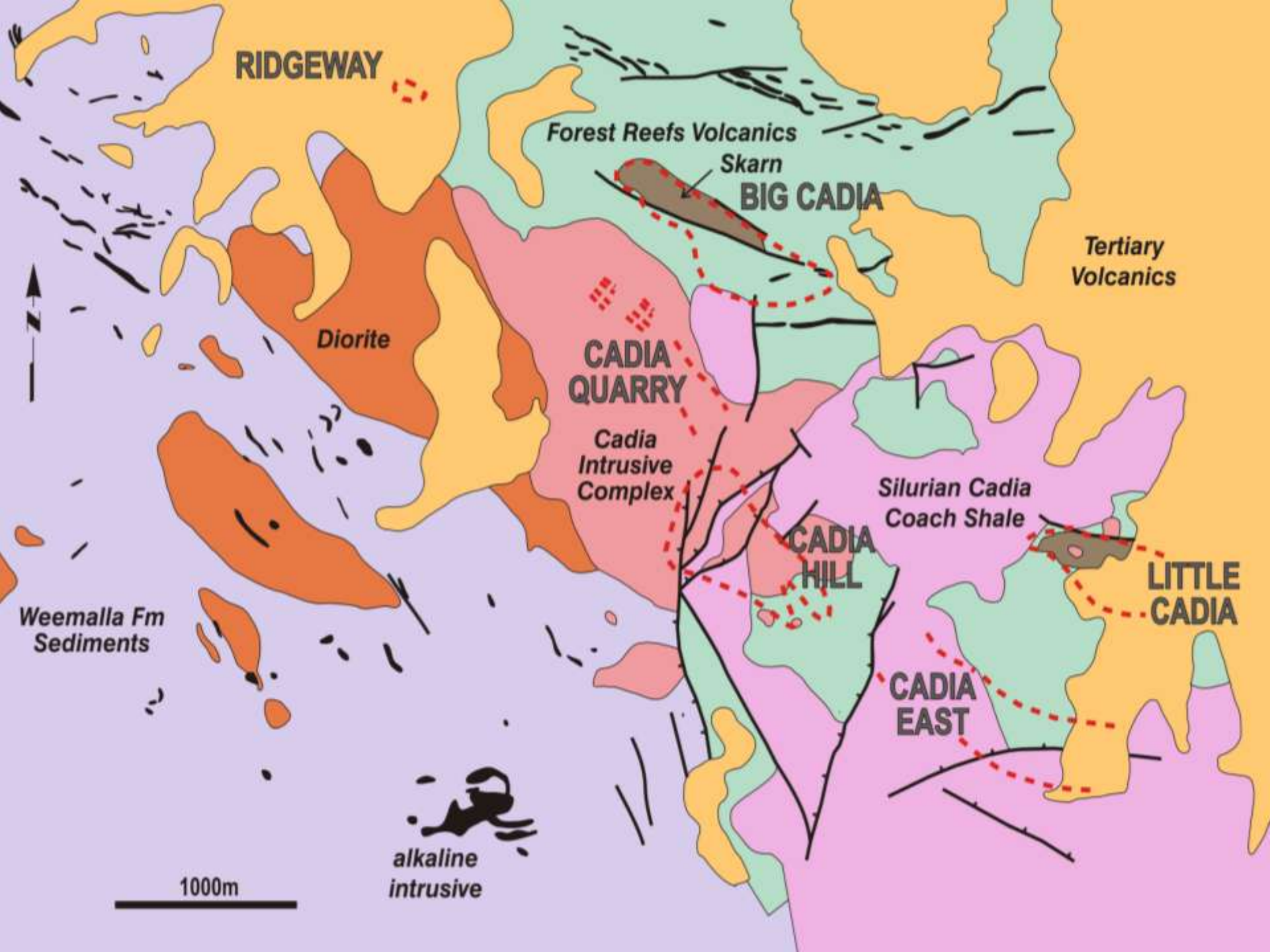
RIDGEWAY
Forest Reefs Volcanics
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Tertiary
Volcanics
Diorite
CADIA
QUARRY
Cadia
Intrusive
Complex
Silurian Cadia
Coach Shale
CADIA
HILL
LITTLE
CADIA
Weemalla Fm
Sediments
CADIA
EAST
alkaline
intrusive
1000m


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:

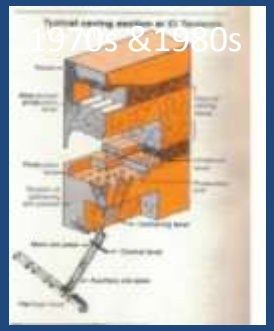
  > 3.0 M tpd.

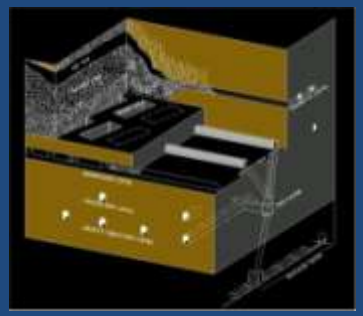
Potential Size Increase

- Ore treated: by up to x3
- Waste removed: more than x4
- Total moved: 1.8 billion tonnes per year

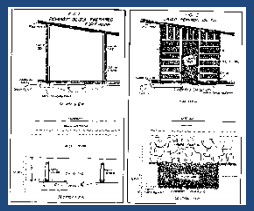
Evolution of Cave mining

(Courtesy of Chitombo, 2011)





1898
First Block Cave
Pewabic Mine (Iron Ore)



Grizzly and slusher systems

Weak rocks and shallow depths

Contemporary caves

Strong rocks at moderate depths

Emergence of Super-caves

Massive footprints

Lower grades

Deep deposits

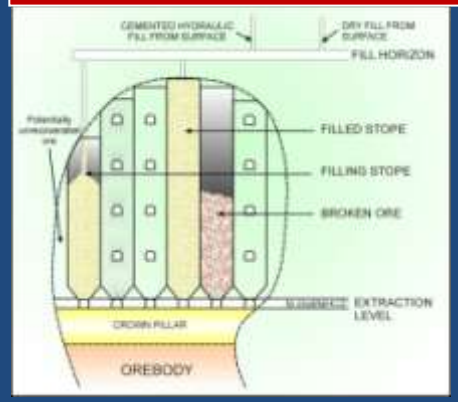
Panel caving

Beyond Super-caves

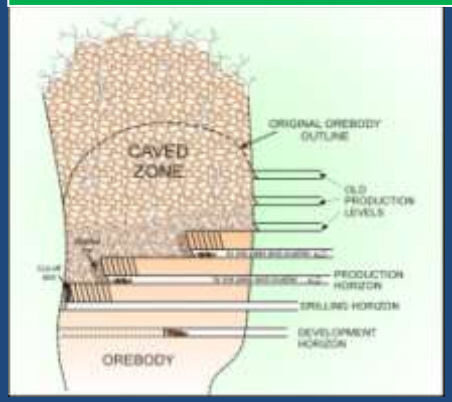
In-situ metal recovery ??

Cost Comparison

Sublevel Stoping (SLS)



Sublevel Caving (SLC)

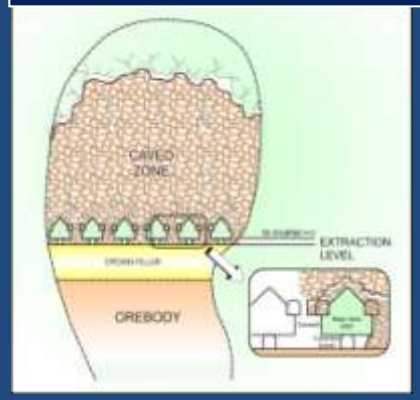


Mining cost reduction

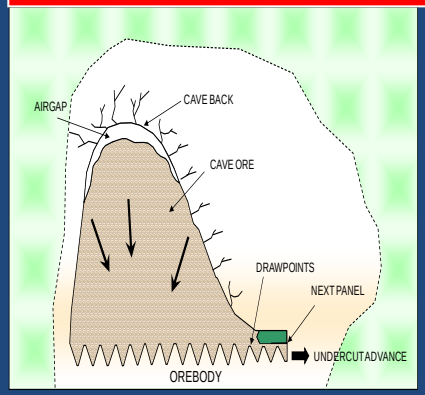
~50%

~50%

Block Caving (BC)



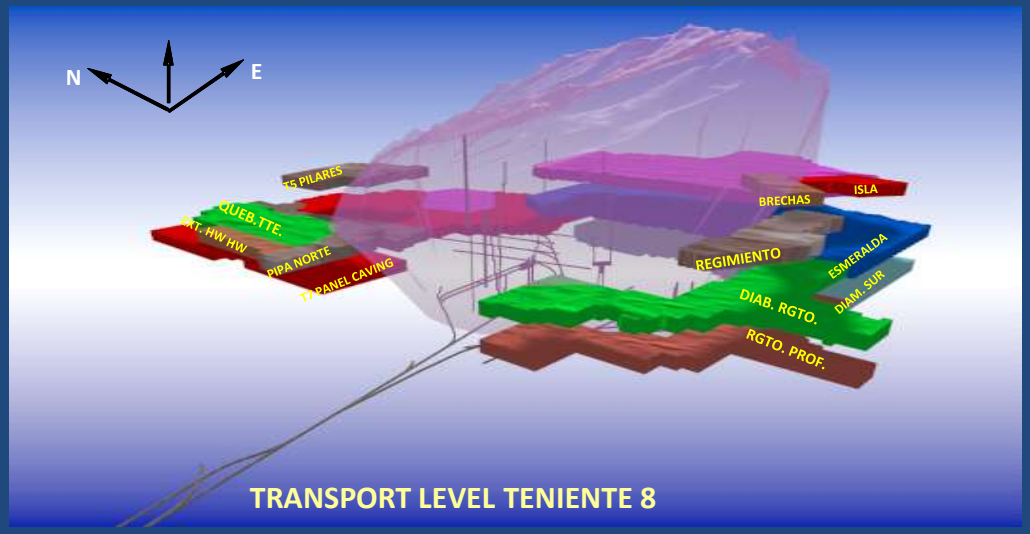
Panel Caving (PC)

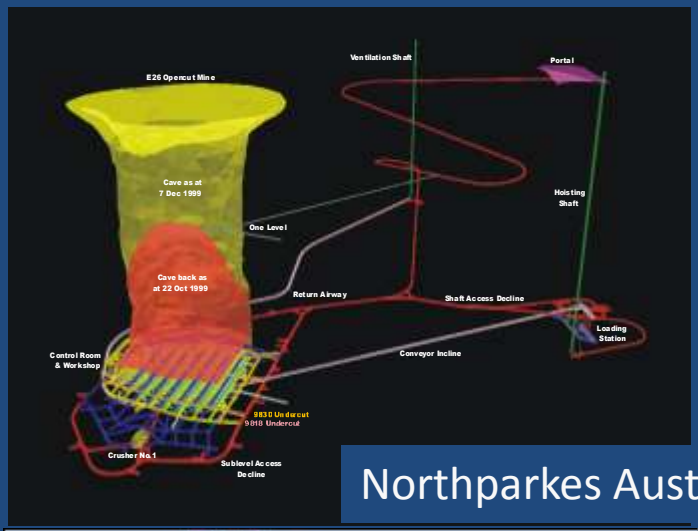


Lower Capital Costs

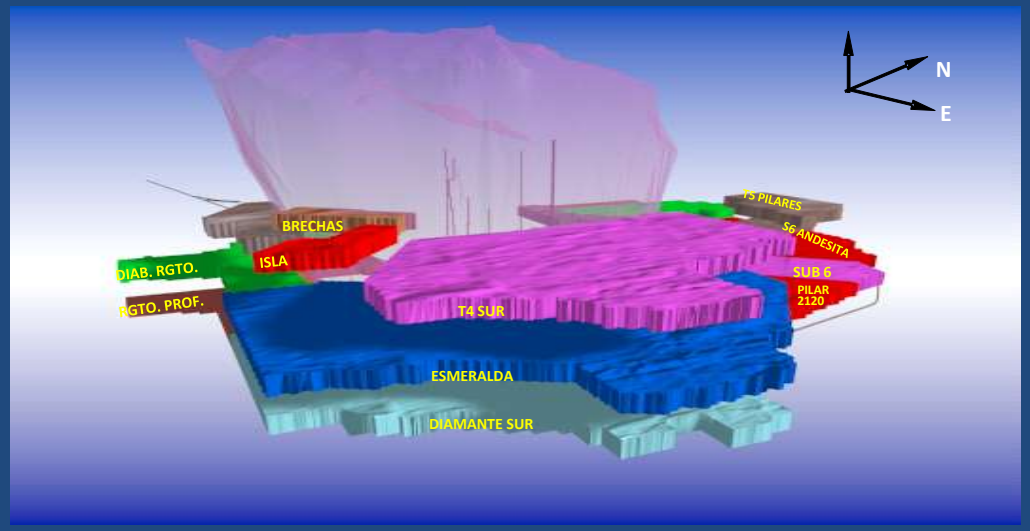
After Flores 2011

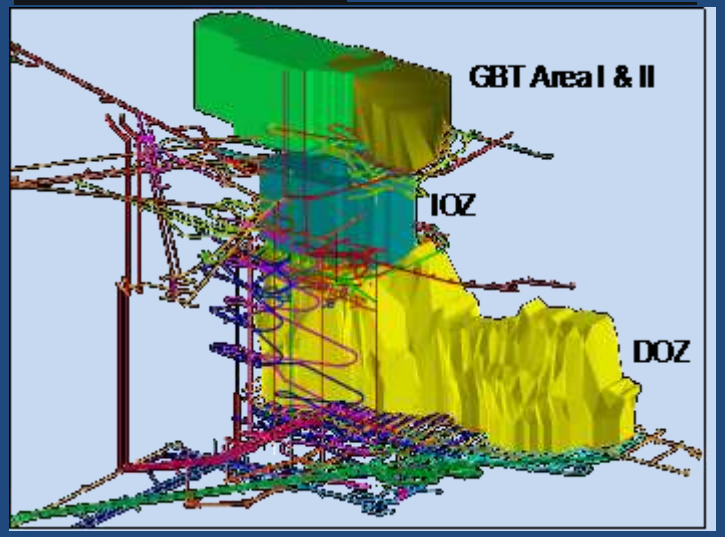
Some Current Caving Styles





Northparkes Australia

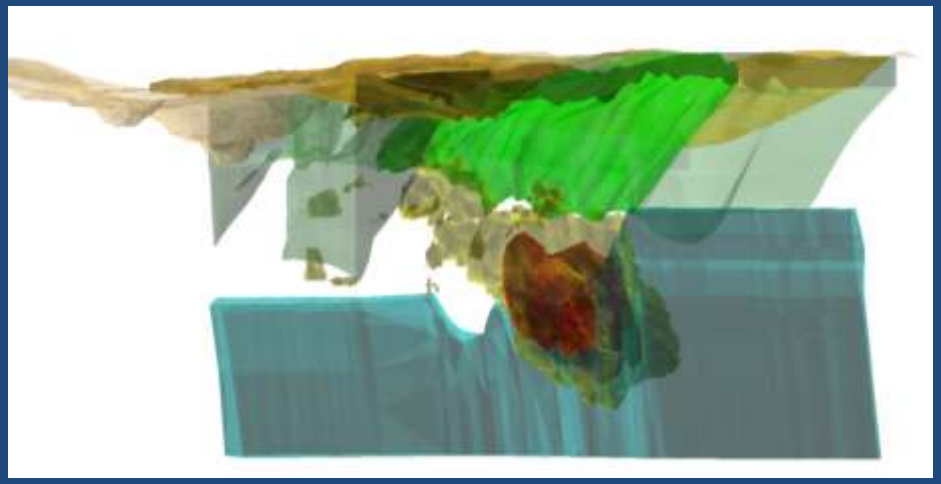




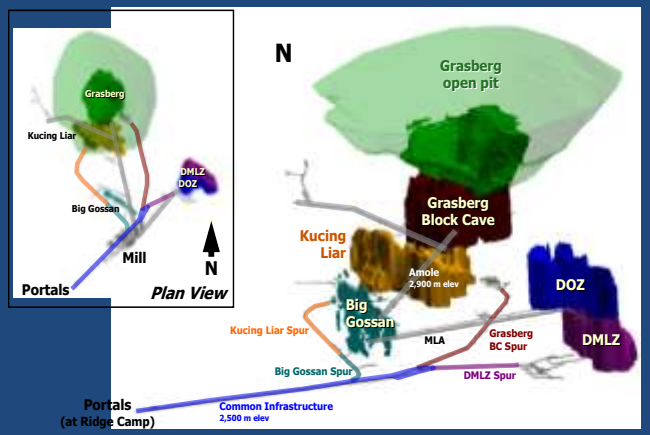
El Teniente Chile (courtesy Chitombo, 2011) **Grasberg Indonesia**

Possible Super-caves

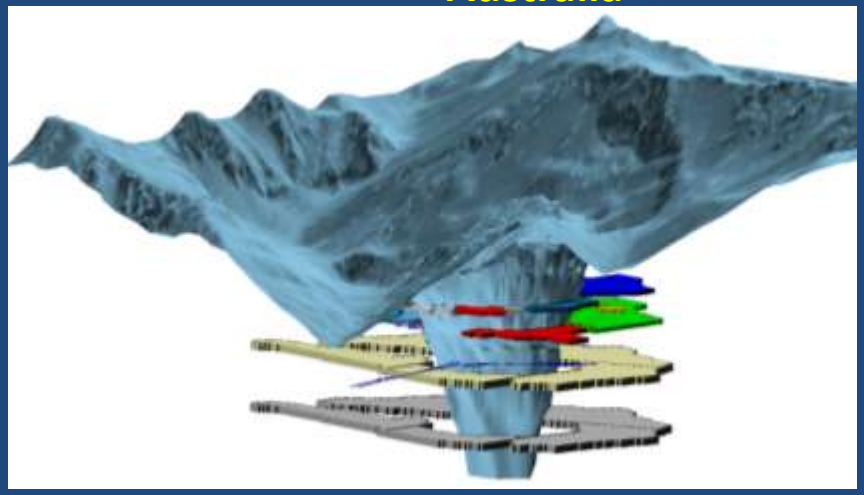
(Courtesy Chitombo, 2011)



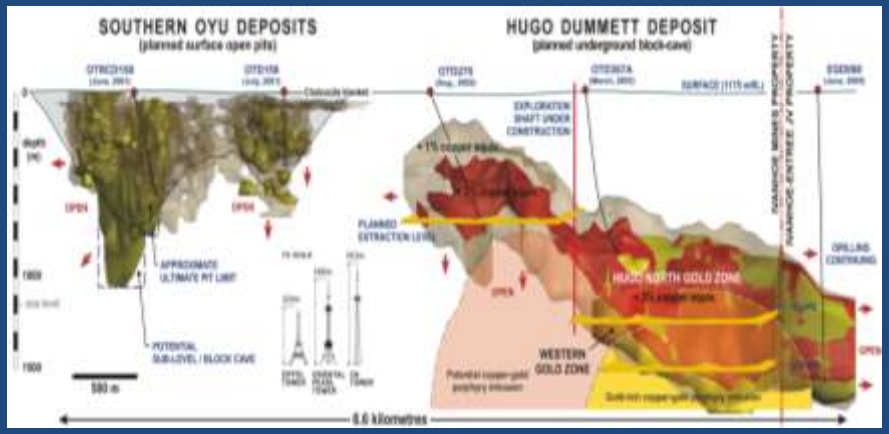
Australia



Indonesia



Chile



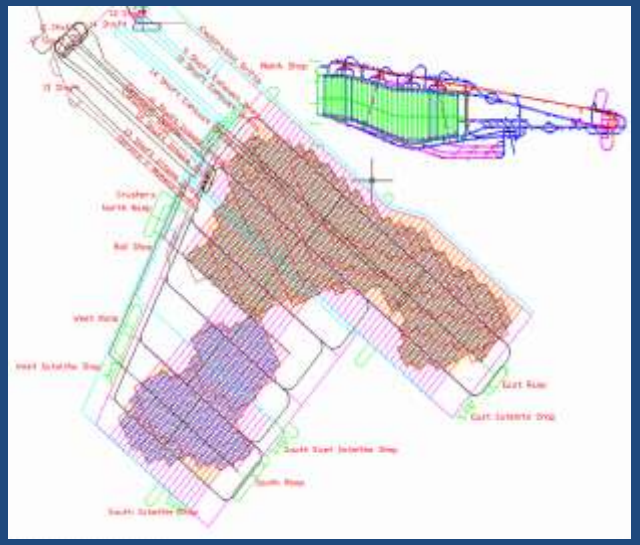
Mongolia

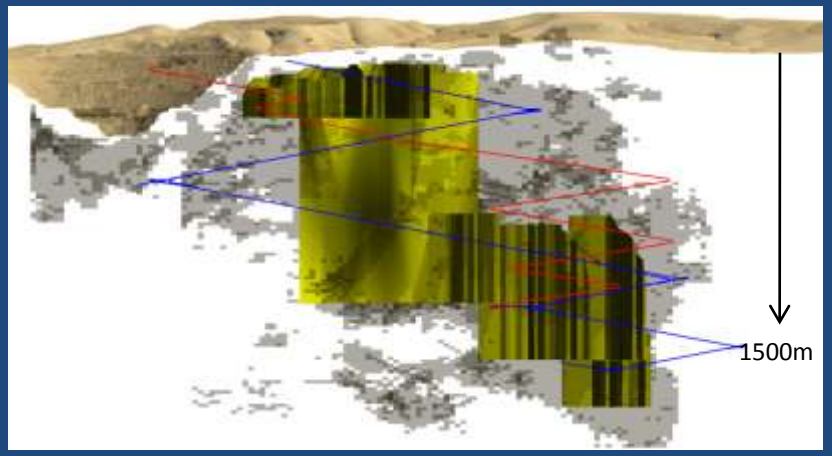
Likely Scale Comparison

(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



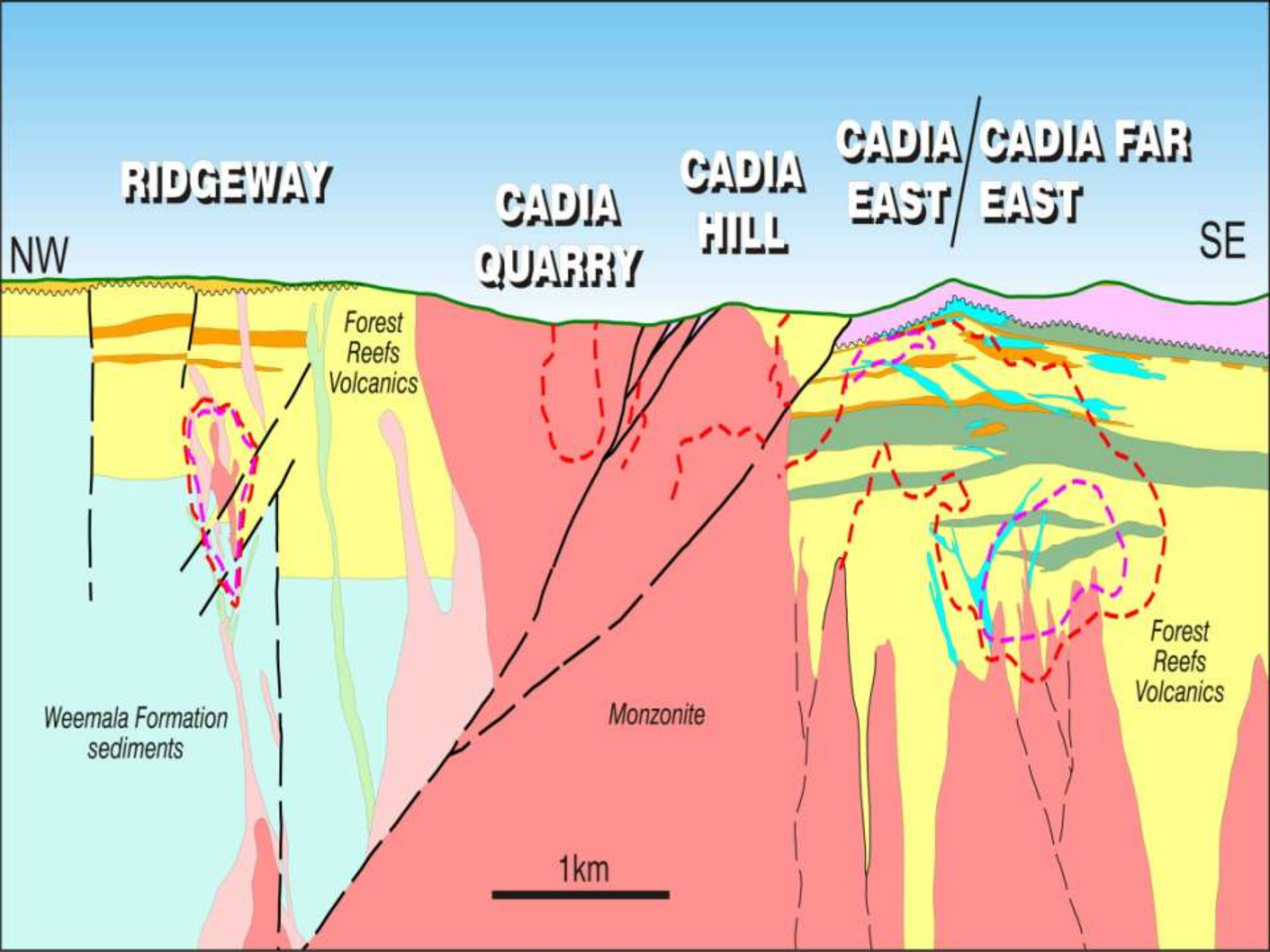


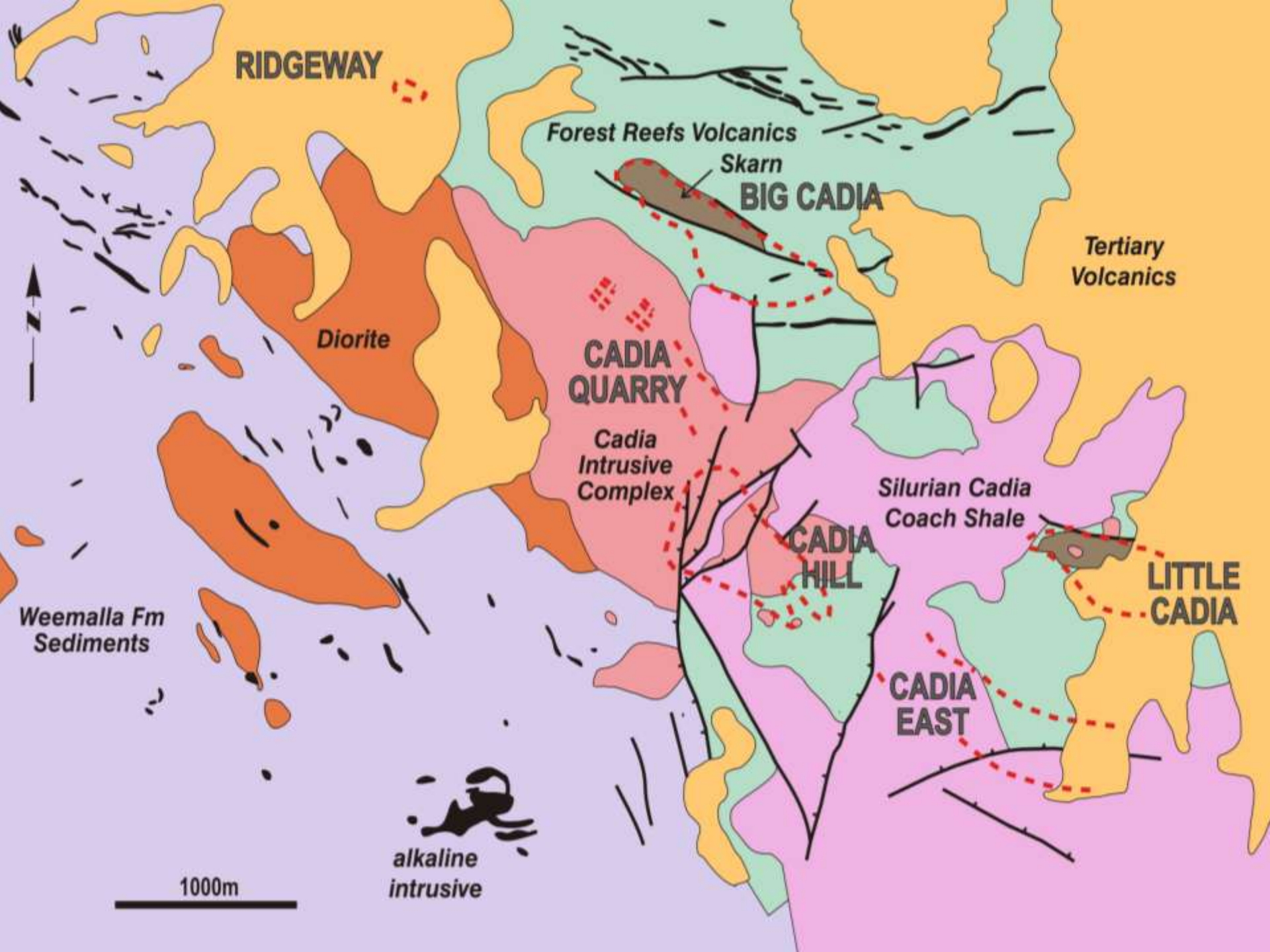
‘Deep Earth’ Environment

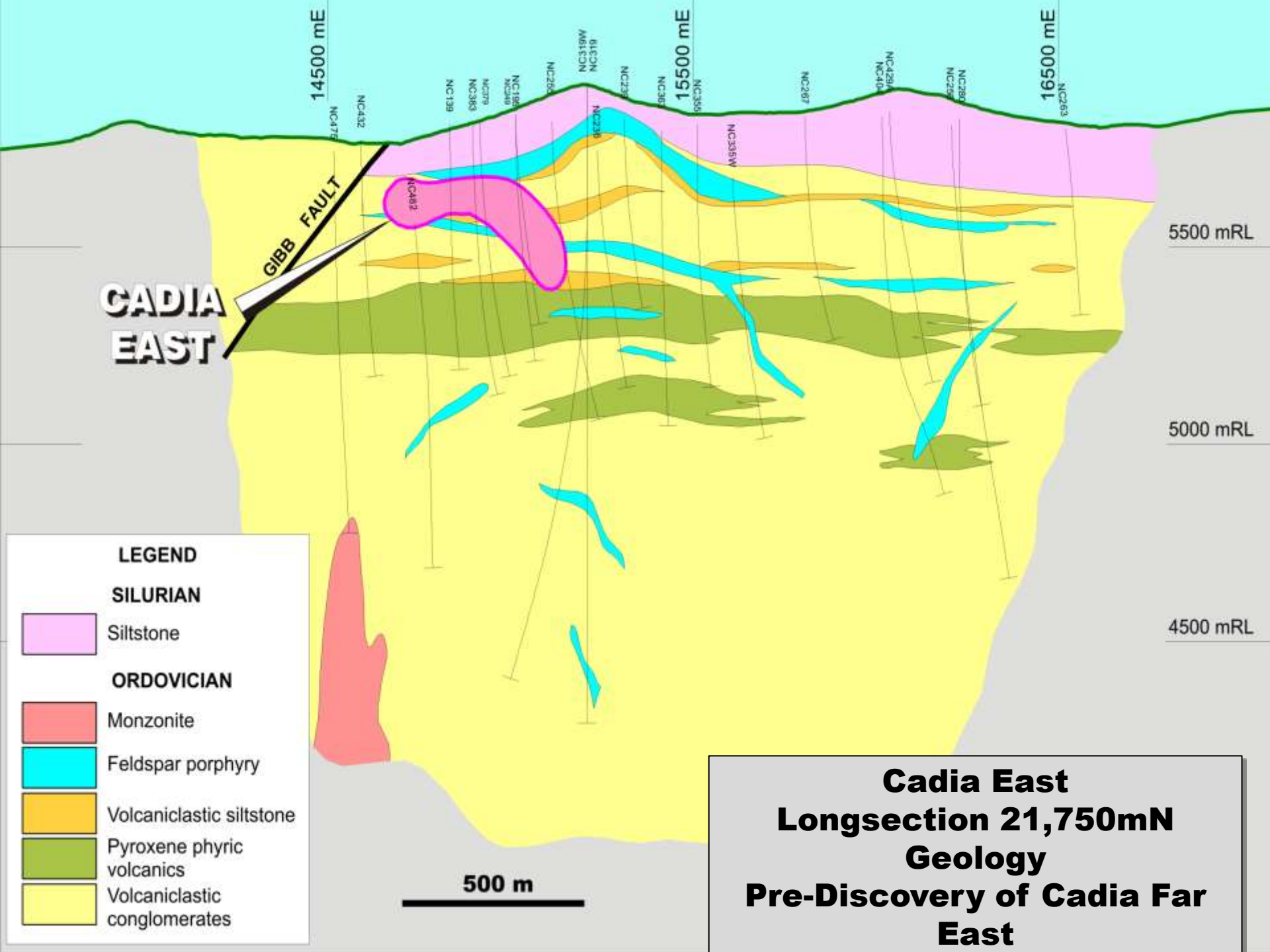
- >500 m – >1000 m to top of ore
- Obscuring post-mineral rocks
- Science-based risk-taking essential
- Robust deposit-halo models needed
- Geophysics for ‘sulfur’ anomaly

Cadia Far East Deposit

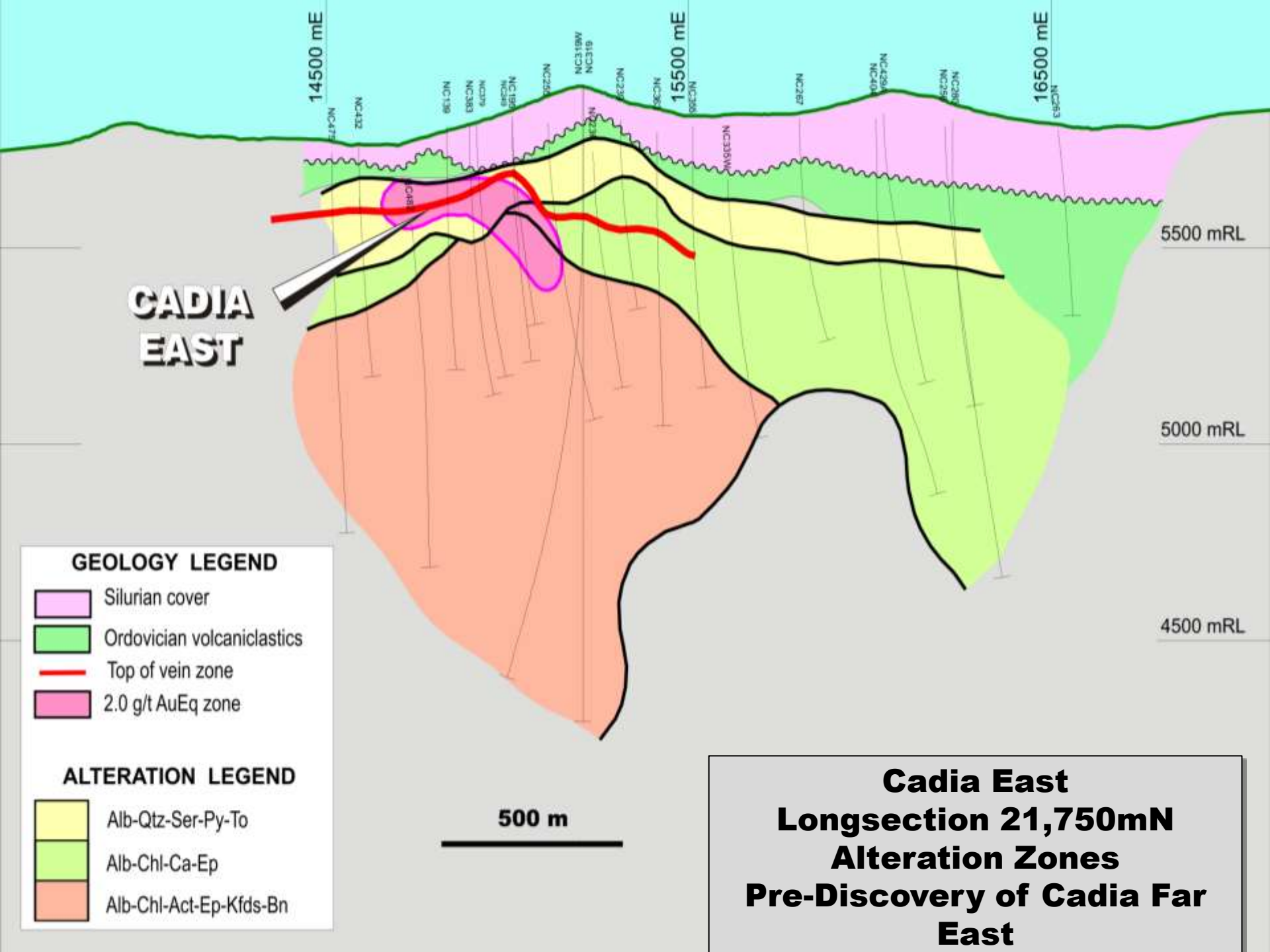
- 800 m to ore body top
- 100 – 200 m of post-mineral rock
- ‘asking good questions’ and ‘testing these’ - *Tedder, 2001*
- Technical key was Au:Cu vector


RIDGEWAY
CADIA QUARRY
CADIA HILL
CADIA EAST
CADIA FAR EAST
NW
SE
Forest Reefs Volcanics
Weemala Formation sediments
Monzonite
Forest Reefs Volcanics
1km

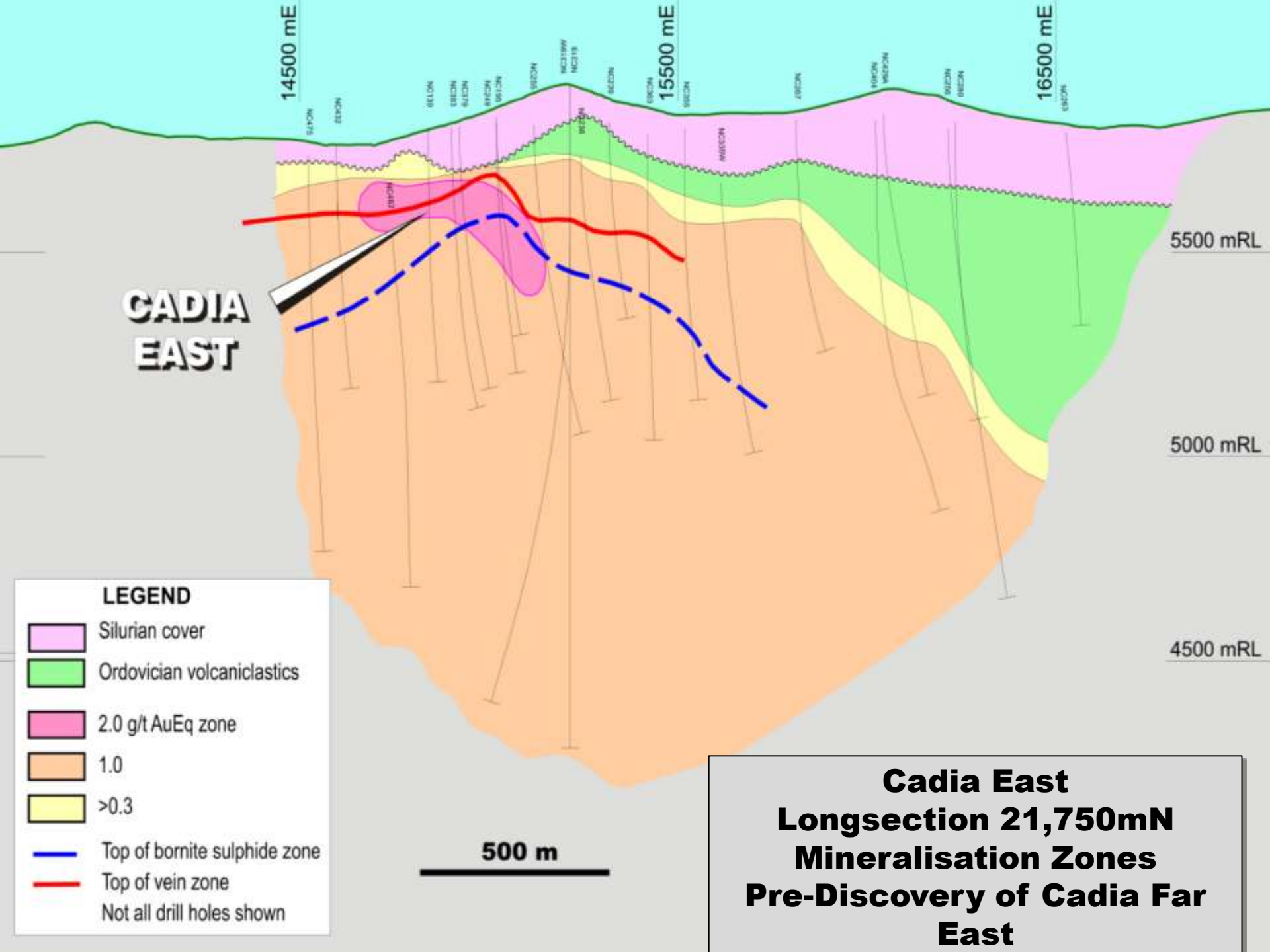

RIDGEWAY
Forest Reefs Volcanics
Skarn
BIG CADIA
Tertiary
Volcanics
Diorite
CADIA
QUARRY
Cadia
Intrusive
Complex
Silurian Cadia
Coach Shale
CADIA
HILL
LITTLE
CADIA
Weemalla Fm
Sediments
CADIA
EAST
alkaline
intrusive
1000m



Cadia East
Longsection 21,750mN
Geology
Pre-Discovery of Cadia Far East



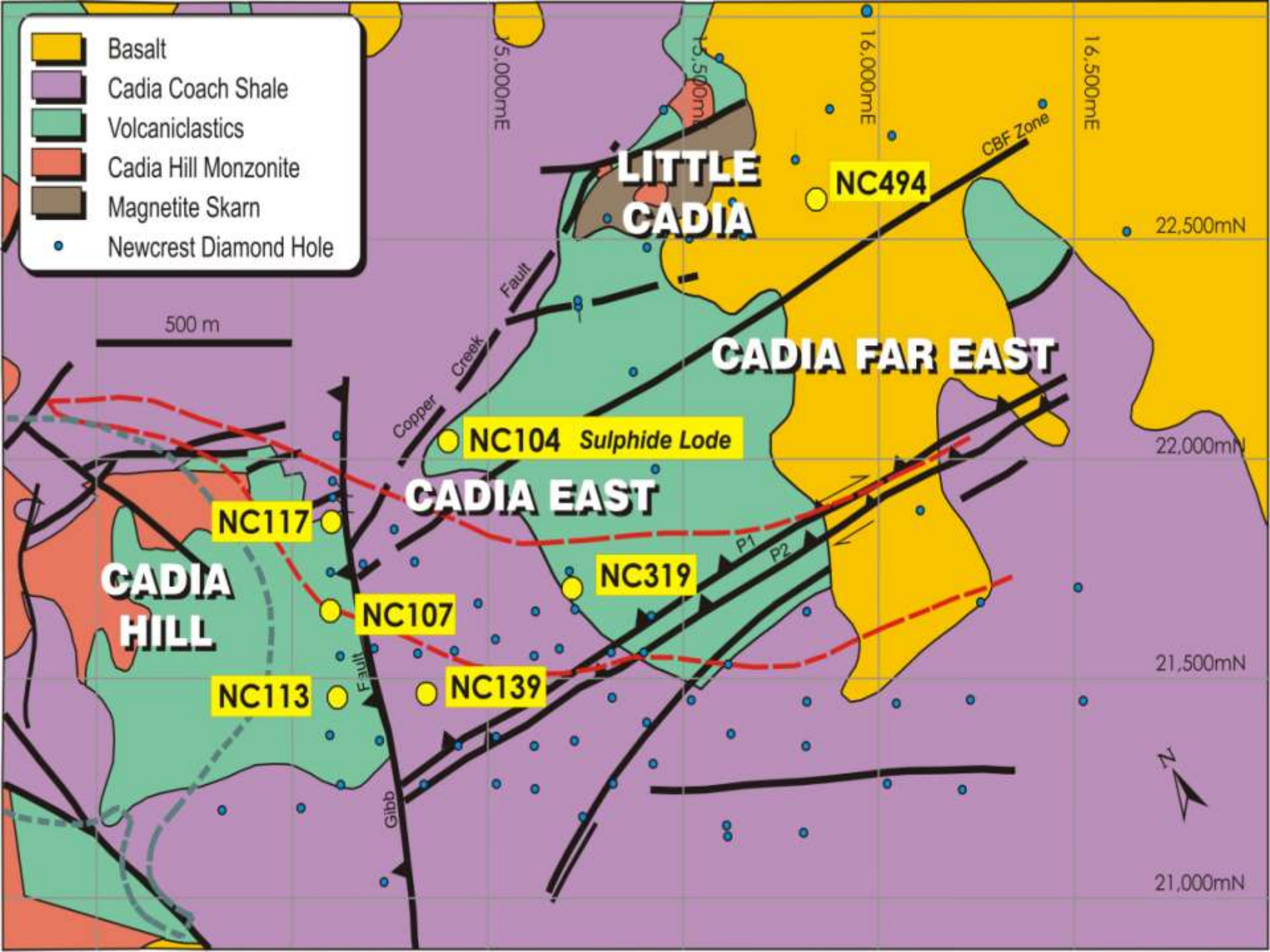
Cadia East
Longsection 21,750mN
Alteration Zones
Pre-Discovery of Cadia Far East

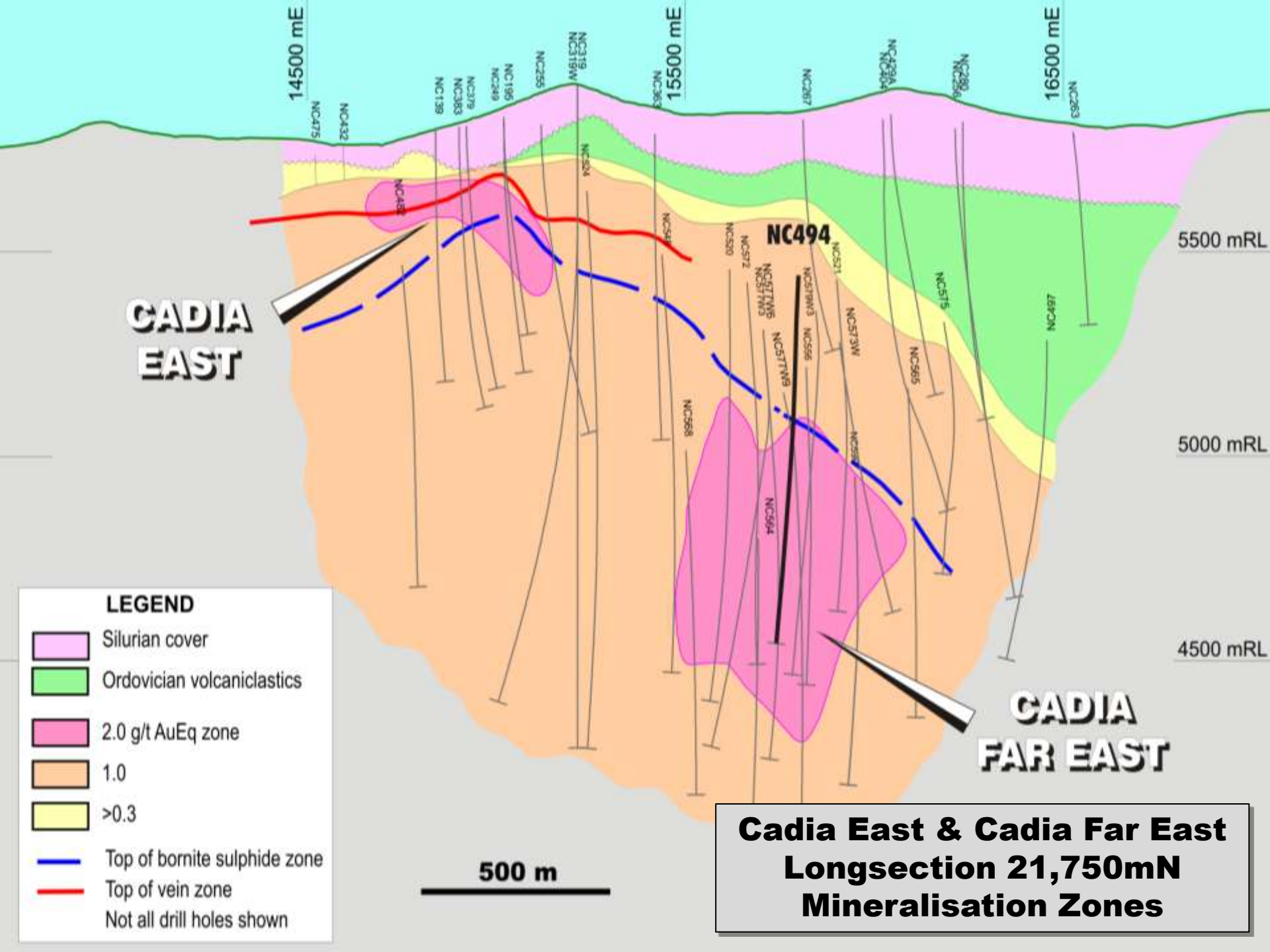


Cadia East Longsection 21,750mN Mineralisation Zones Pre-Discovery of Cadia Far East

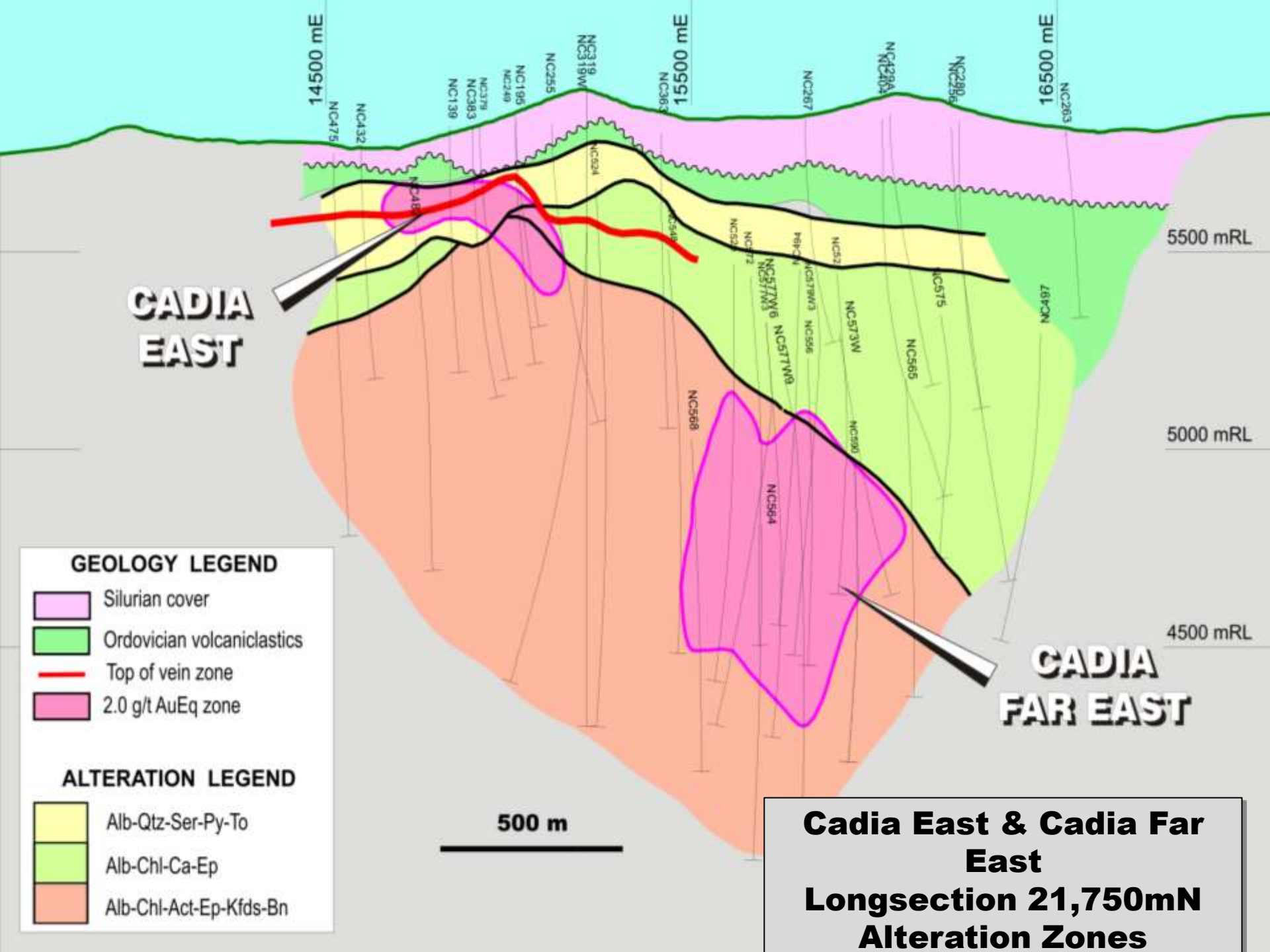
Cadia Far East Beckons

- > 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

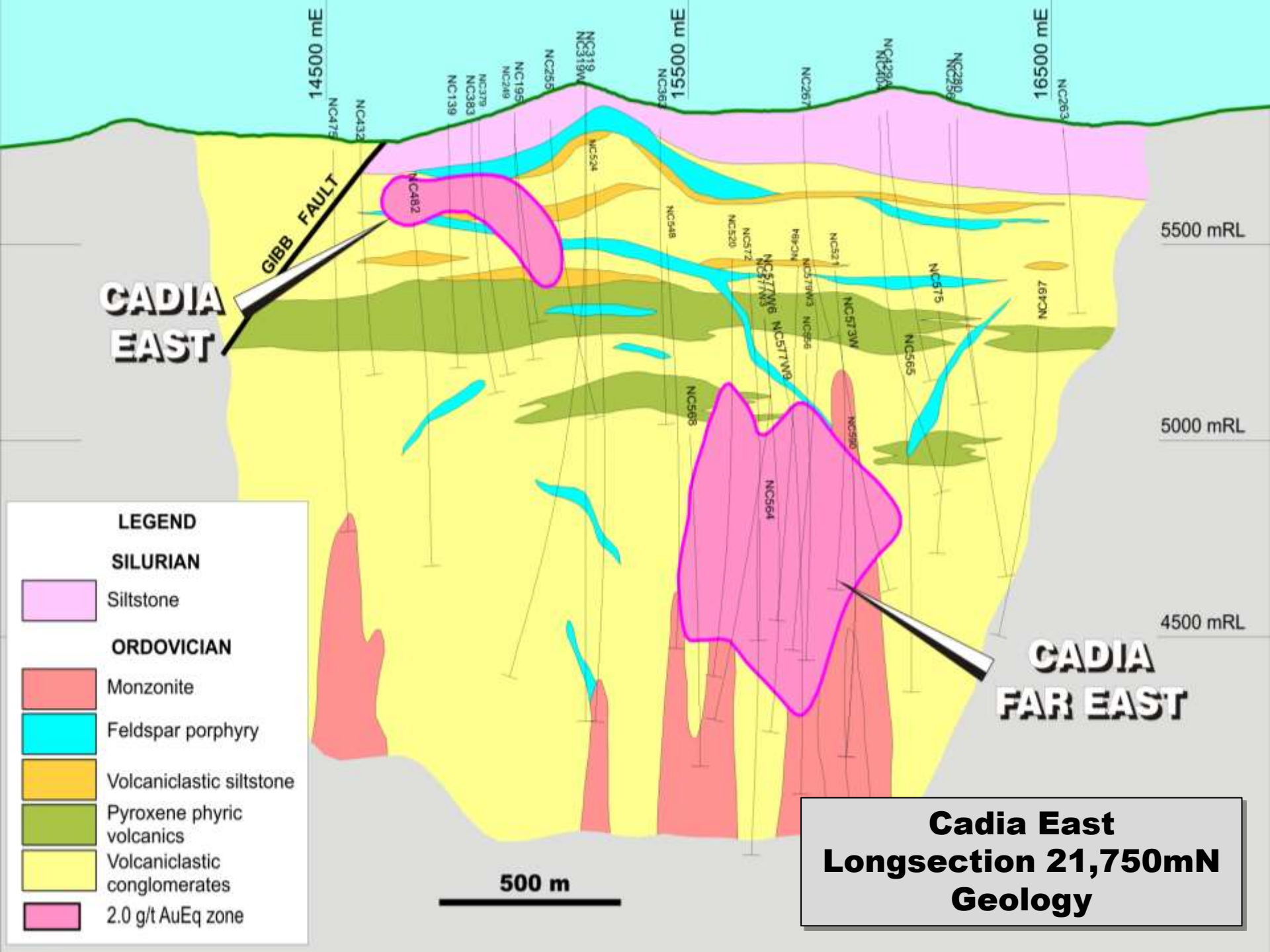

Basalt
Cadia Coach Shale
Volcaniclastics
Cadia Hill Monzonite
Magnetite Skarn
Newcrest Diamond Hole
500 m
15,000mE
15,500mE
16,000mE
16,500mE
22,500mN
22,000mN
21,500mN
21,000mN
LITTLE CADIA
NC494
CBF Zone
CADIA FAR EAST
Copper Creek Fault
NC104
Sulphide Lode
CADIA EAST
NC117
CADIA HILL
NC107
NC319
P1
P2
NC113
NC139
Gibb Fault
N



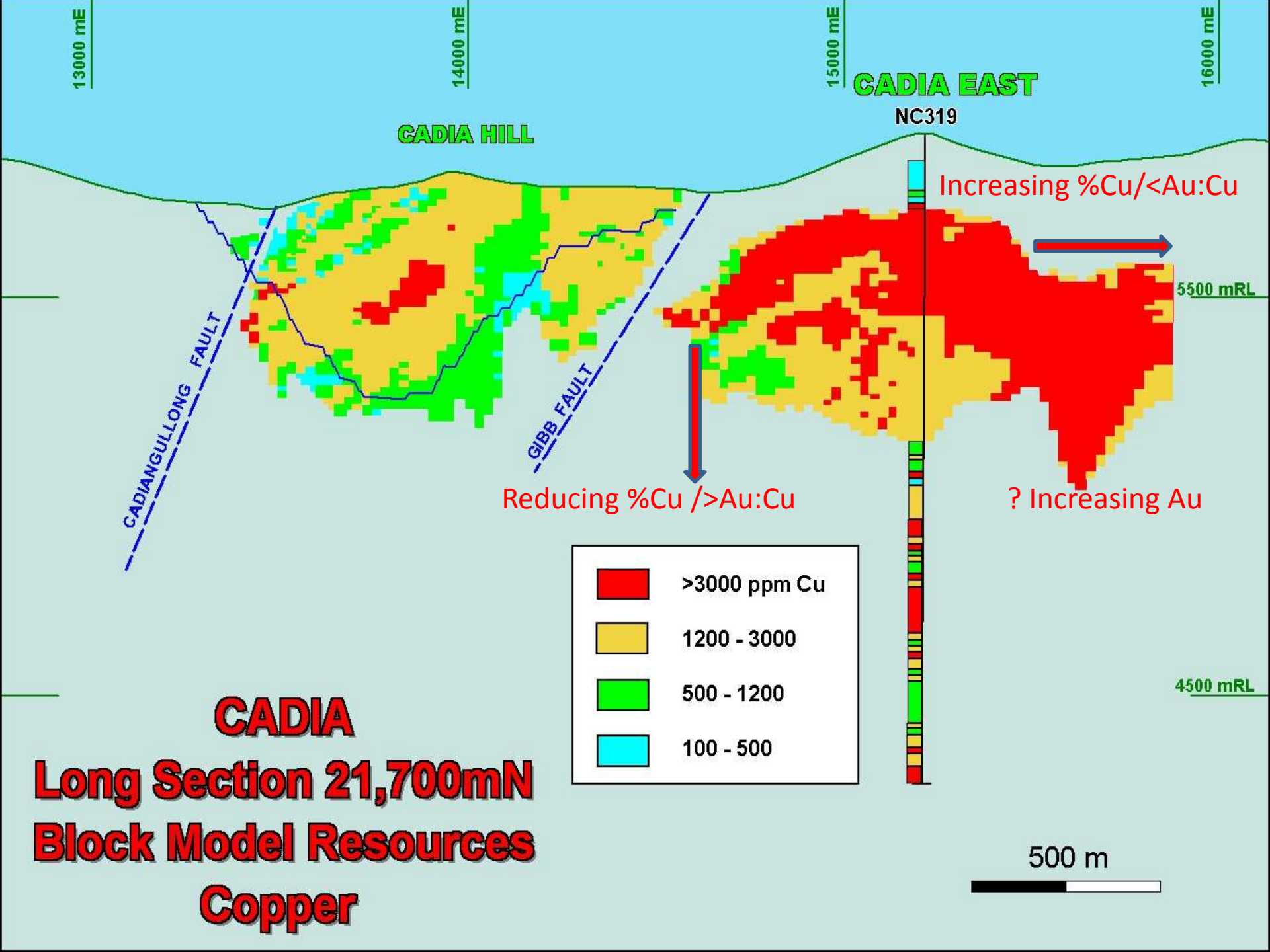
Cadia East & Cadia Far East Longsection 21,750mN Mineralisation Zones

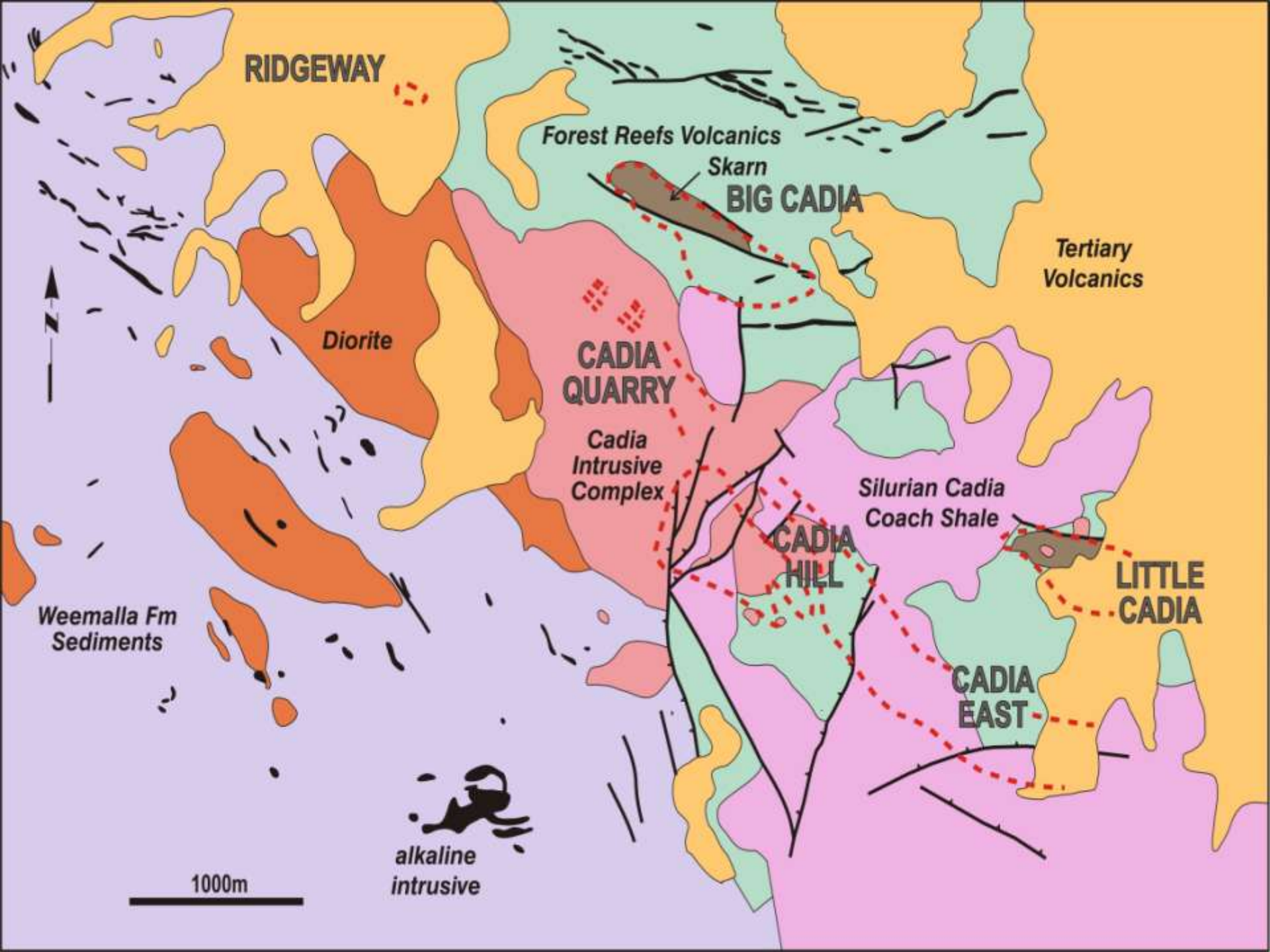


Cadia East & Cadia Far East
Longsection 21,750mN
Alteration Zones



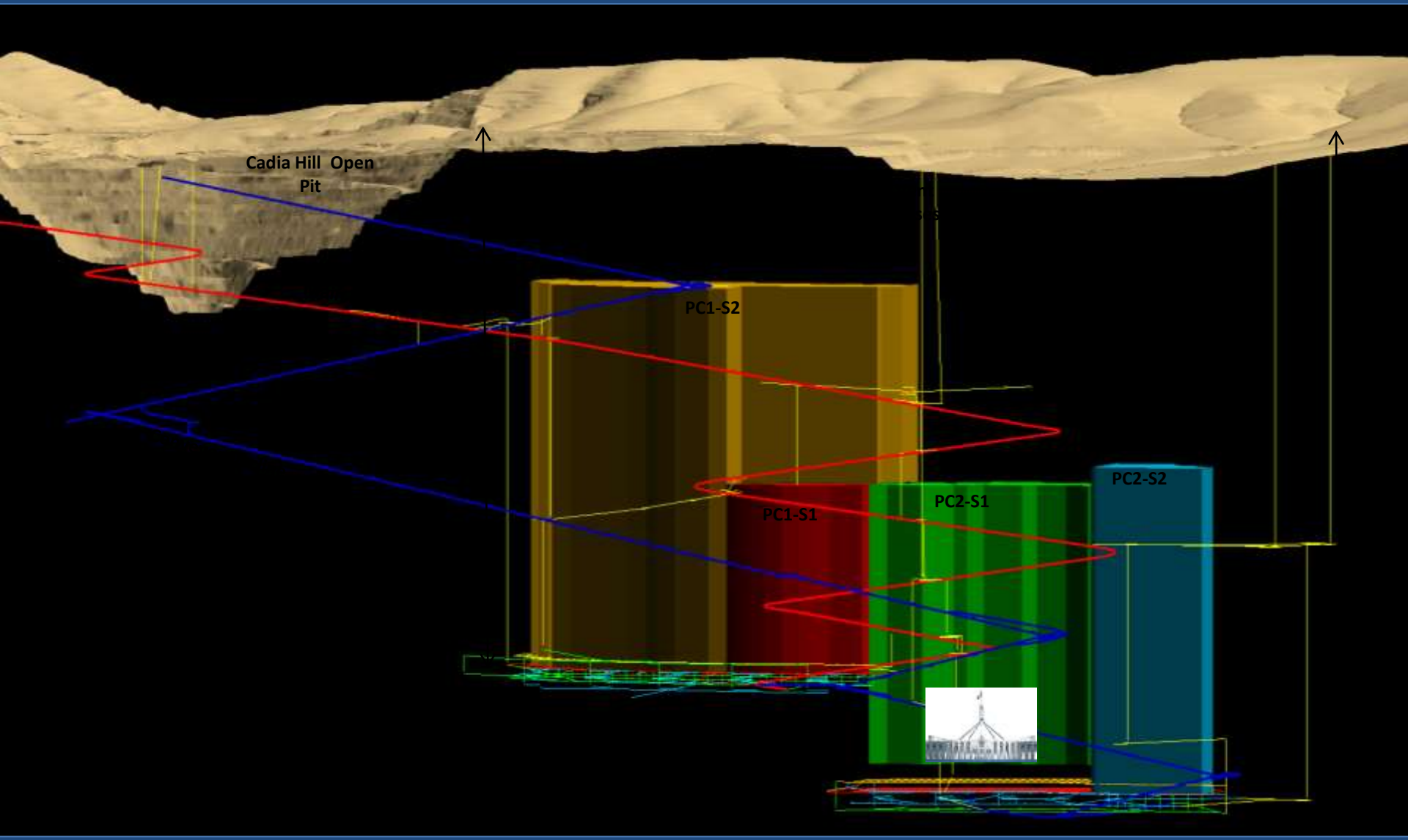
Cadia East Longsection 21,750mN Geology


13000 mE
14000 mE
15000 mE
16000 mE
CADIA EAST
NC319
CADIA HILL
Increasing %Cu/<Au:Cu
5500 mRL
4500 mRL
CADIANGULLONG FAULT
GIBB FAULT
Reducing %Cu />Au:Cu
? Increasing Au
>3000 ppm Cu
1200 - 3000
500 - 1200
100 - 500
500 m
CADIA
Long Section 21,700mN
Block Model Resources
Copper


RIDGEWAY
Forest Reefs Volcanics
Skarn
BIG CADIA
Tertiary
Volcanics
Diorite
CADIA
QUARRY
Cadia
Intrusive
Complex
Silurian Cadia
Coach Shale
CADIA
HILL
LITTLE
CADIA
Weemalla Fm
Sediments
CADIA
EAST
alkaline
intrusive
1000m

Cadia East Mine Configuration

(courtesy Newcrest Mining Limited)




Ridgeway
subsidence zone
Ridgeway
decline portal
Cadia Hill
open cut
Cadia East
decline portal
N
1,000 m

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

- Society of Economic Geologists
- Newcrest Mining Limited
- W H Bryan Mining and Geology Research Centre, University of Qld
- 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)