Terra Resources

Vision for Future Exploration: Geophysics and Gold

B. Bourne, ASEG-PESA Melbourne, 13th August, 2013

Outline

- Gold Trends
- Challenges
- Gold Model Types
  - Carlin
  - Greenstone
  - Porphyry
  - HS Epithermal
- Research
- Future
- Summary

Gold Trends


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Gold Price (daily) since Aug 2012
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1-Aug
15-Aug
29-Aug
12-Sep
26-Sep
10-Oct
24-Oct
7-Nov
21-Nov
5-Dec
19-Dec
2-Jan
16-Jan
30-Jan
13-Feb
27-Feb
13-Mar
27-Mar
10-Apr
24-Apr
8-May
22-May
5-Jun
19-Jun
3-Jul
17-Jul
31-Jul
Gold Price USD
Gold Price AUD

Gold Discoveries since 1995

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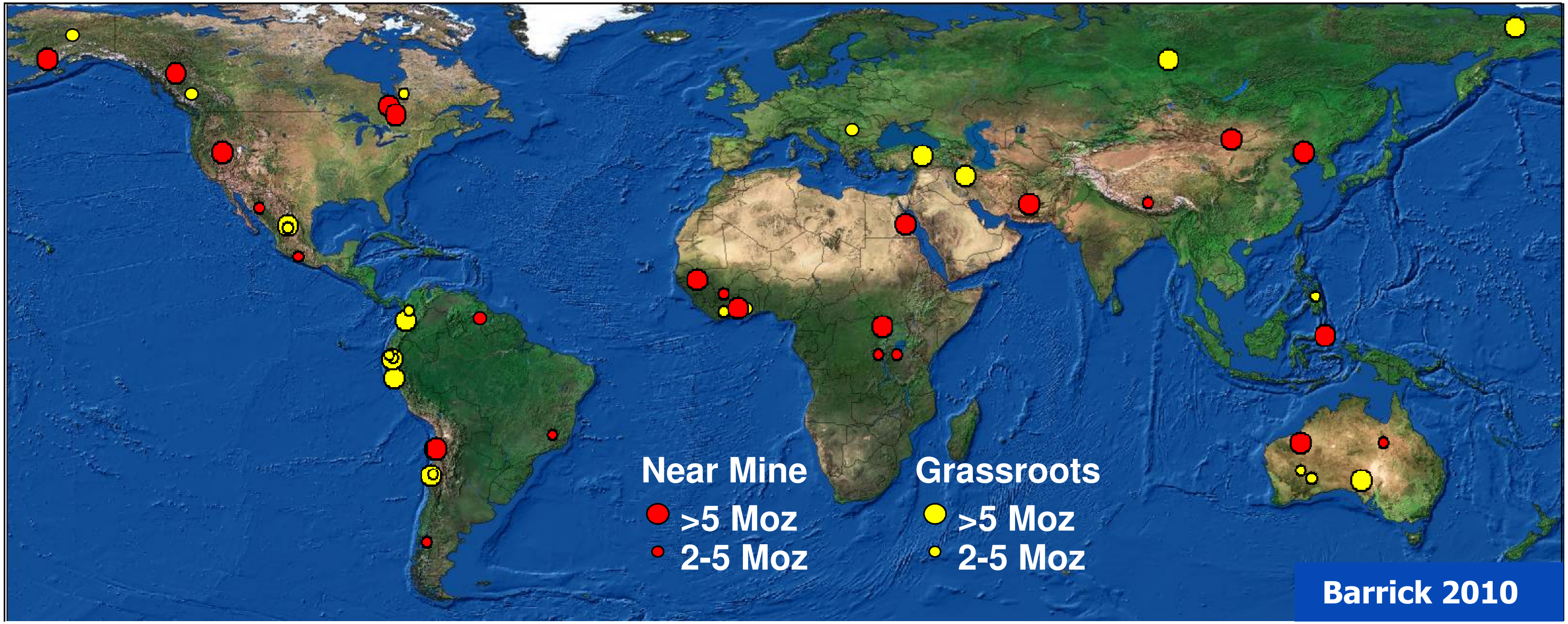
- Looking at +2Moz deposits:
- 52 discoveries for 580 Moz (6 are >20 M oz)
- 26 grassroots, 26 near-mine
- Only 10 in production
  - 4 grassroots, 6 brownfields
- We discover but
  - Few get to production
  - Takes longer



Discovery trends

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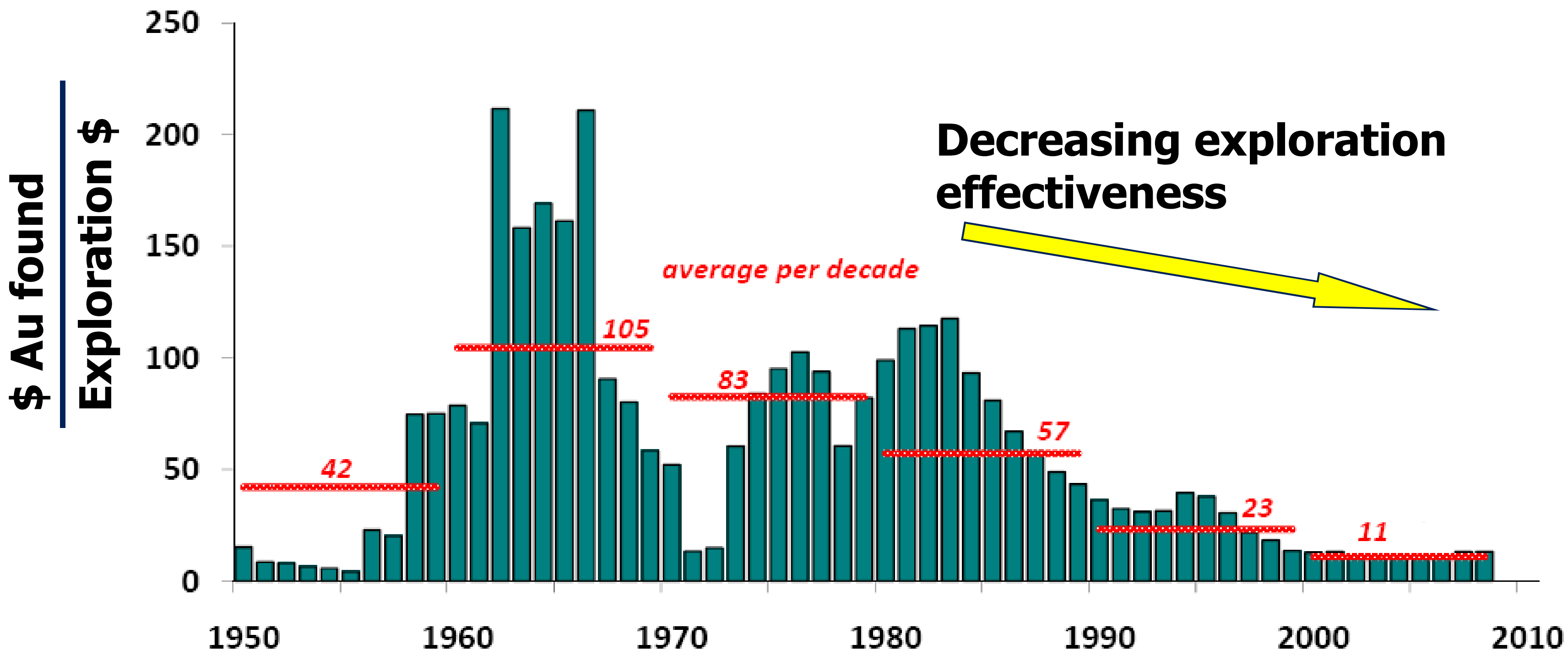
- Discovery rates down
- Discovery cost up
- Effectiveness down

→

- Increasing maturity
- Shrinking of search space



From McKeith 2009

World class discoveries required

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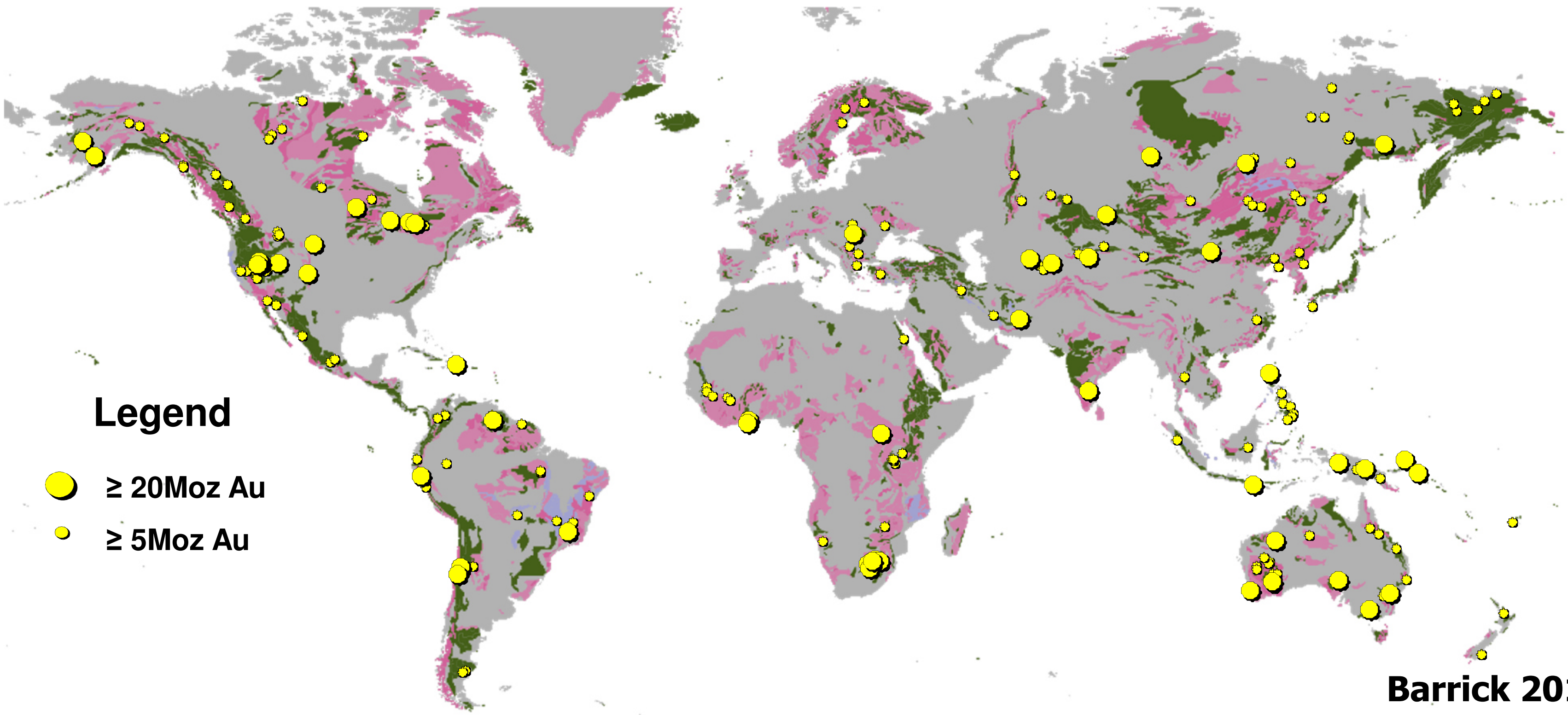
- Long life, high margin, high throughput deposits
- 20% biggest deposits = 80% production or resources
- Those are rare!
- Gold: 55 deposits >20 Moz
  - ~45 producing or mined
  - ~10 in the pipeline



Barrick 2010

Exploration Challenge Maturity

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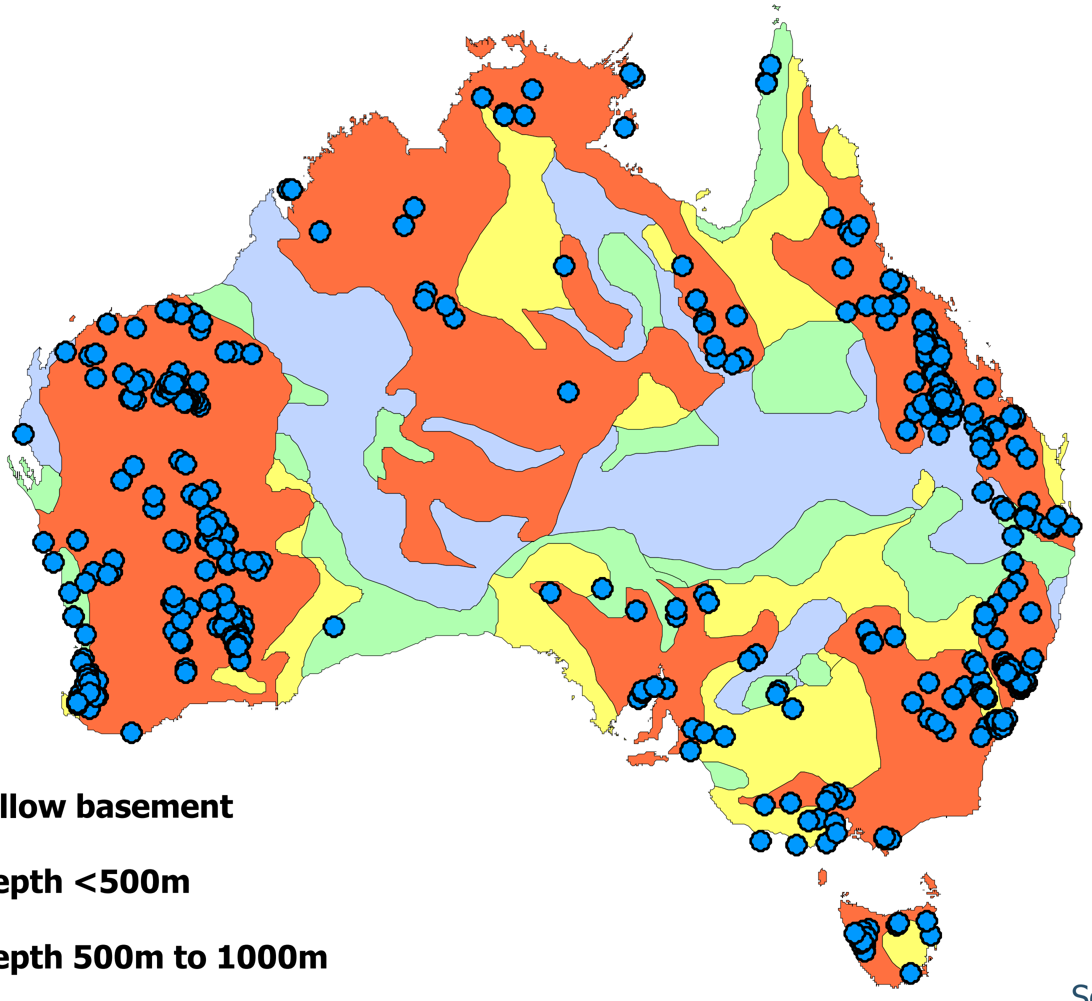
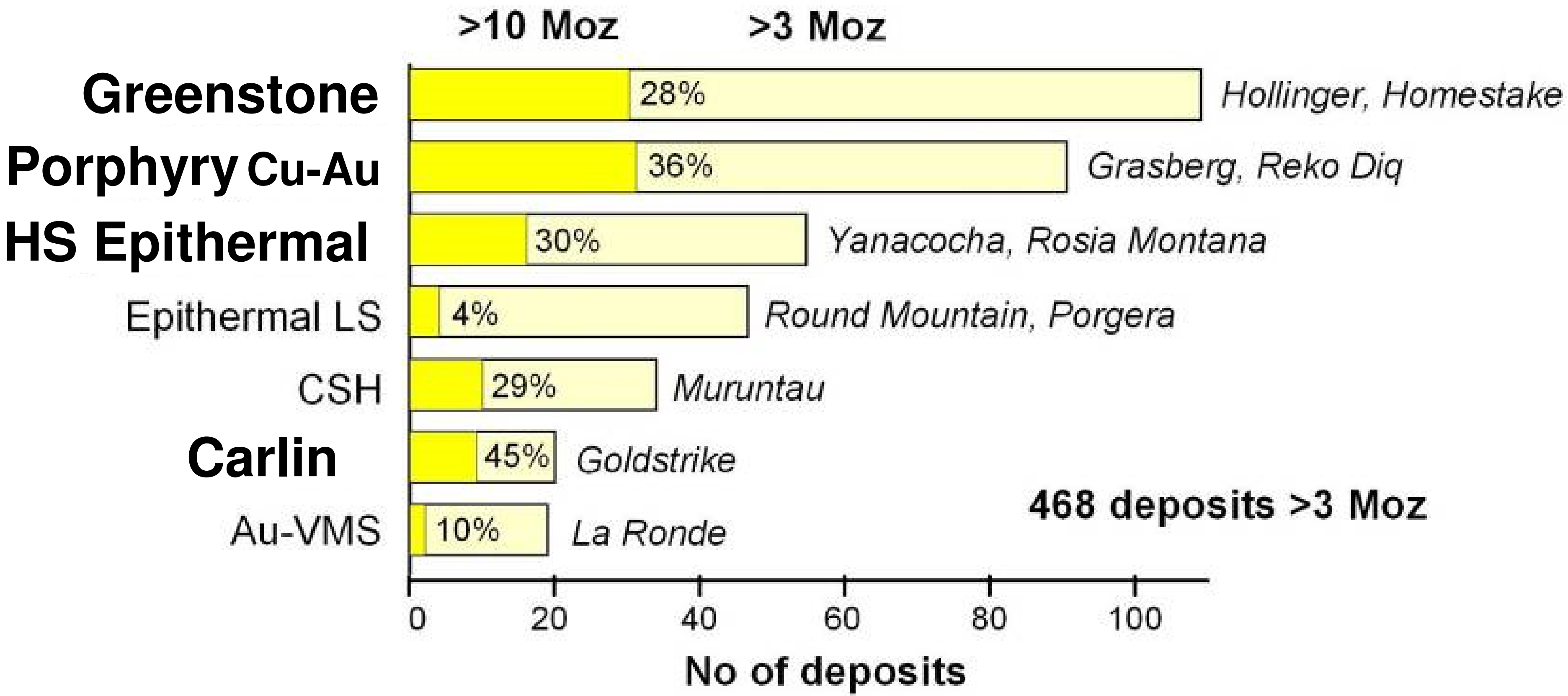


- Outcrop Shallow basement
- Basement depth <500m
- Basement depth 500m to 1000m
- Basement depth > 1000m
- Mineral Deposits

Source:
Geoscience Australia
Intierra

Targeting the Best Models

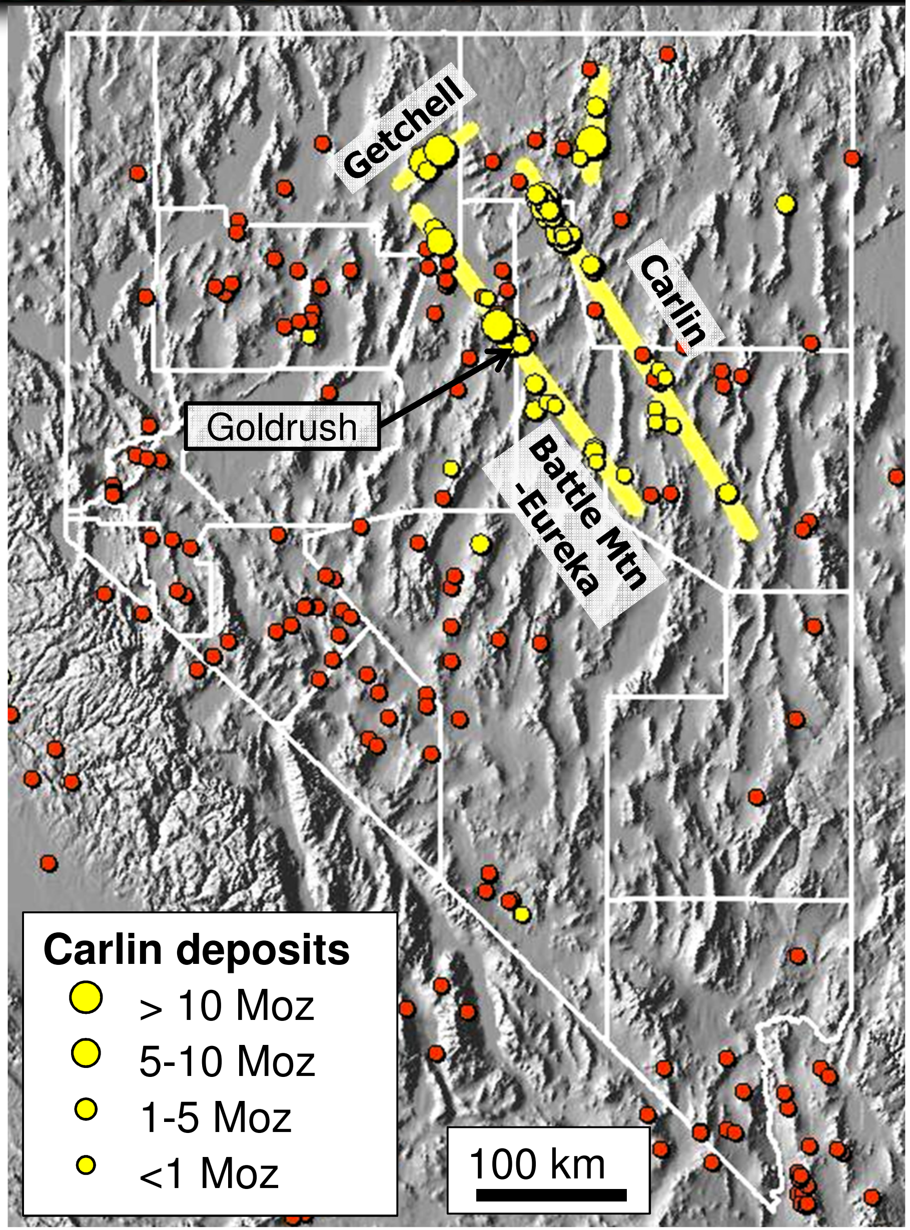
- Preferred target types:
  - High deposit abundance
  - Highest % of population >10 Moz deposits
  - Good economics and mineability



Nevada Hot Spot

- +250 Moz in Carlin deposits in area 200 x 400km
- ~5% of world Au production
- Distributed along "Trends"

Top 5	Moz Au	g/t
Goldstrike	**55**	**8.6**
Getchell-TR	**26**	**7.1**
Gold Quarry	24	1.2
Twin Creeks	17	2
Goldrush	**14**	**4.2**



Mineralization characteristics

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- Au with fine dissem. pyrite
  - Au-As in rims (*main ore stage*)
  - Later realgar, orpiment, stibnite (*late ore stage*)
  - Au-As-Tl-Sb-Hg association
- Forms as wallrock replacement or breccia matrix

Silicified silty micrite, Cortez Hills; 25 g/t Au

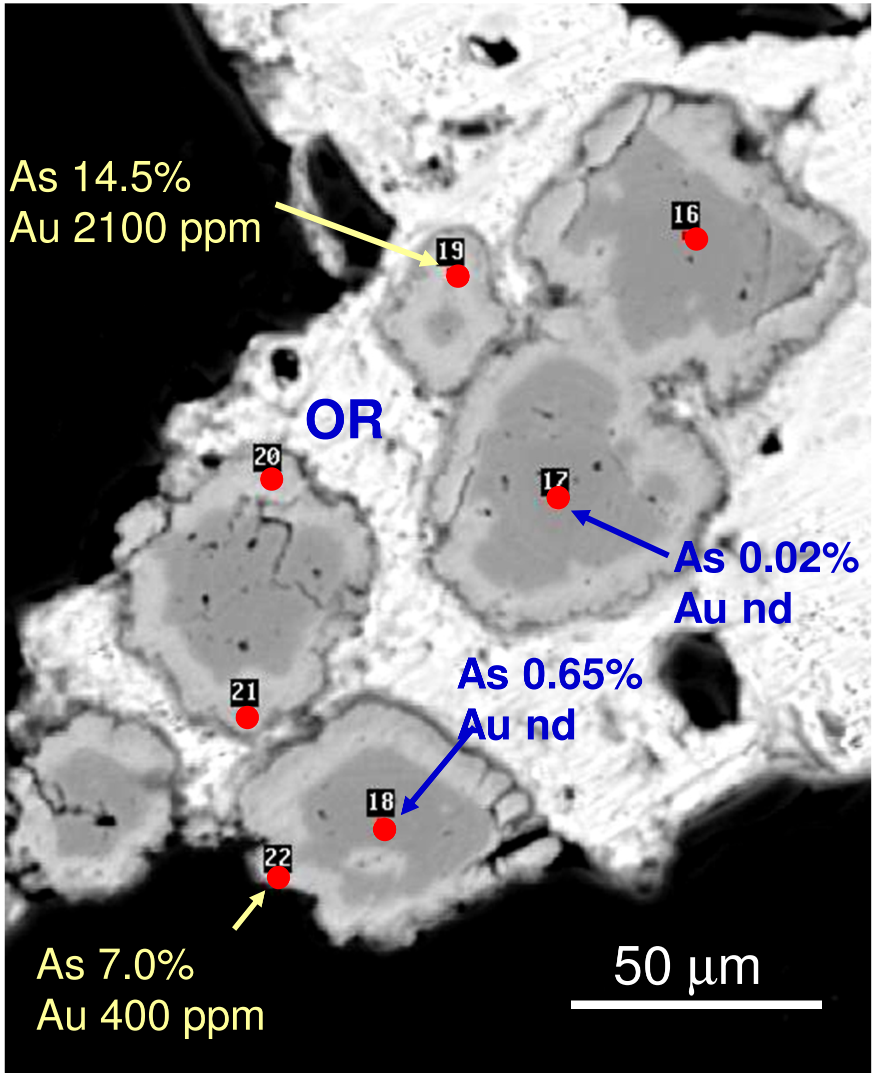

Photo courtesy of Jean Cline

Deposit characteristics

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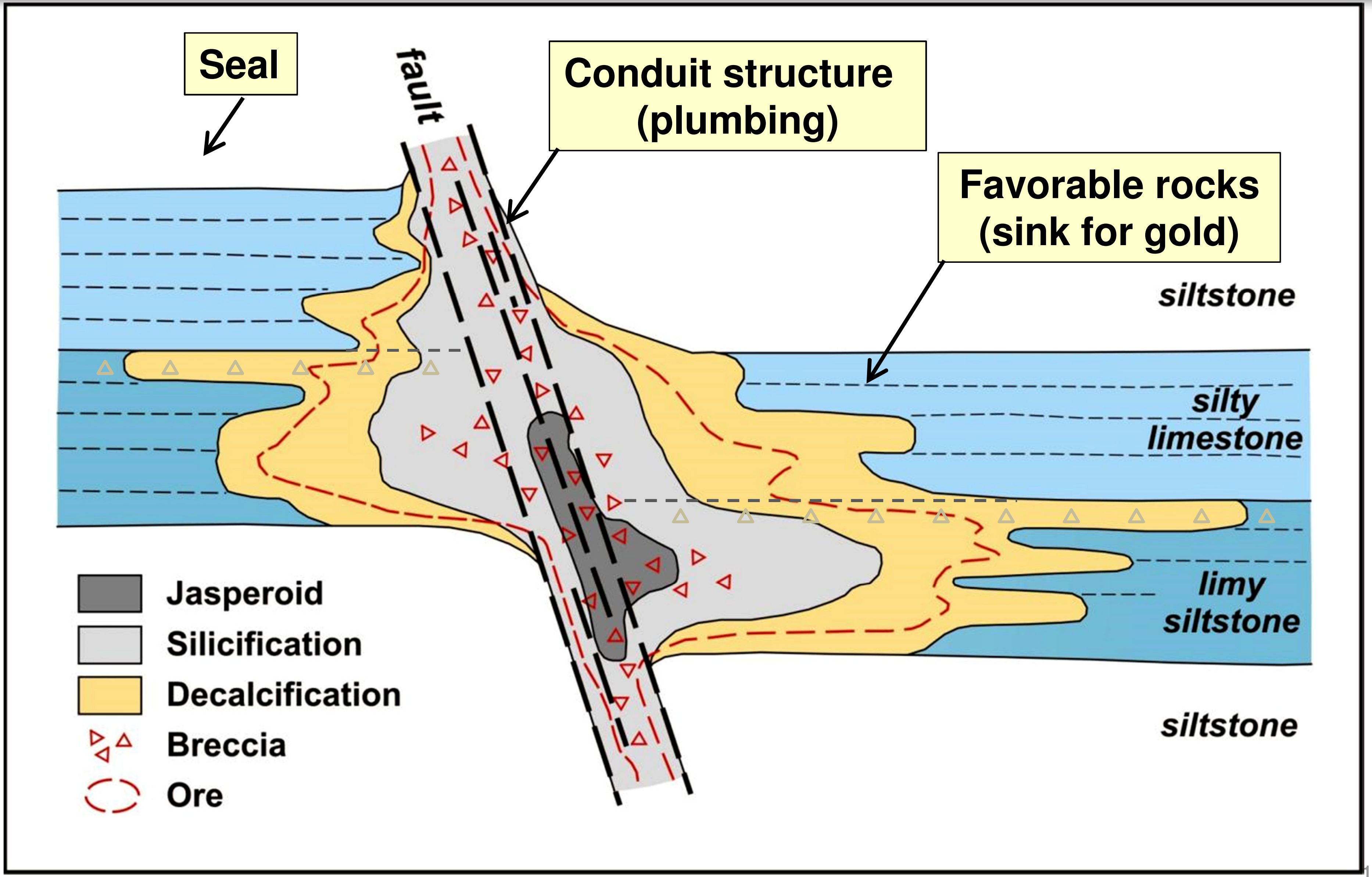

Carlin - Petrophysics

- No geophysical "silver bullet" for Carlin-style gold mineralization
- Petrophysical **GENERALIZATIONS** of typical Great Basin rocks:

Physical Property / Rock type	Magnetization	Density	Conductivity	Chargeability
Paleozoic Lower Plate Carbonates	L	M-H	M	M
Paleozoic Upper Plate Siliciclastics	L	M	M	L
Pen-Perm overlap sediments	L	M	M	L
Mesozoic Intrusive stocks	M - H	M	M	L
Tertiary/Quaternary Alluvium/Colluvium	L	L	H	L
Tertiary/Quaternary Volcanics	H	M	M	L

- Overprinting structural, alteration and metamorphic events inherently causes **highly variable** petrophysical properties

Carlin- Petrophysics

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- Geophysical applications in the Great Basin require:
  - Specific **petrophysical studies**
  - understanding of **geologic controls on mineralization**
- Recent Great Basin examples:
  - Gravity: Project A ★
  - Hardrock Seismic: Cortez ★
  - IP/Resistivity: Bald Mountain ★

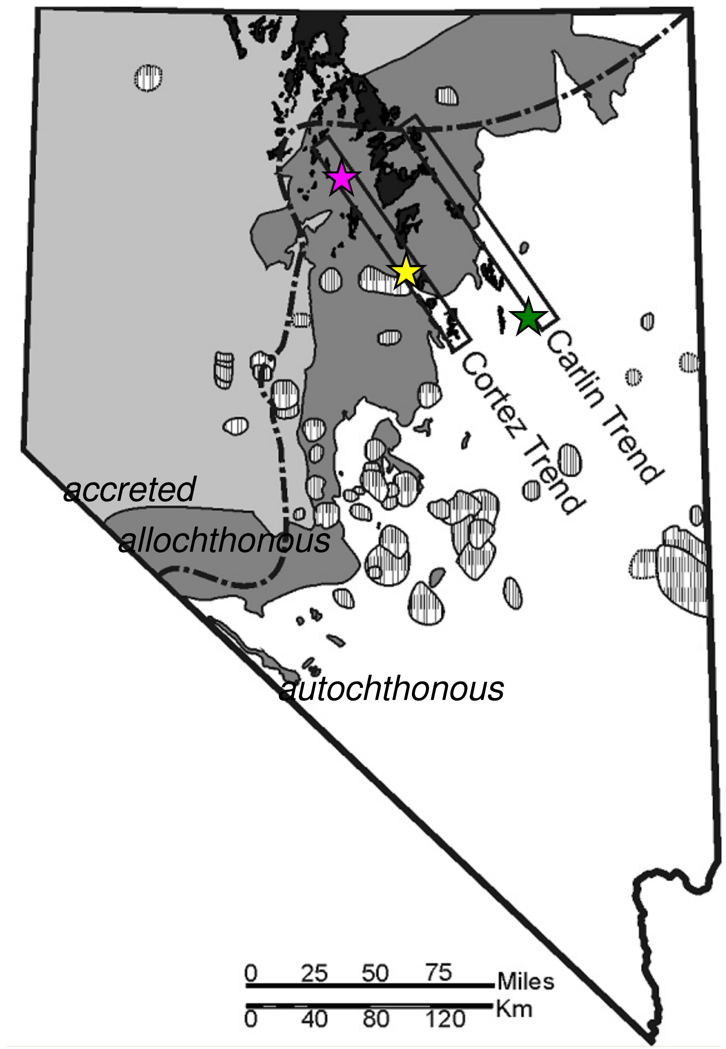

Image from M. Jackson, 2010

Detailed Gravity

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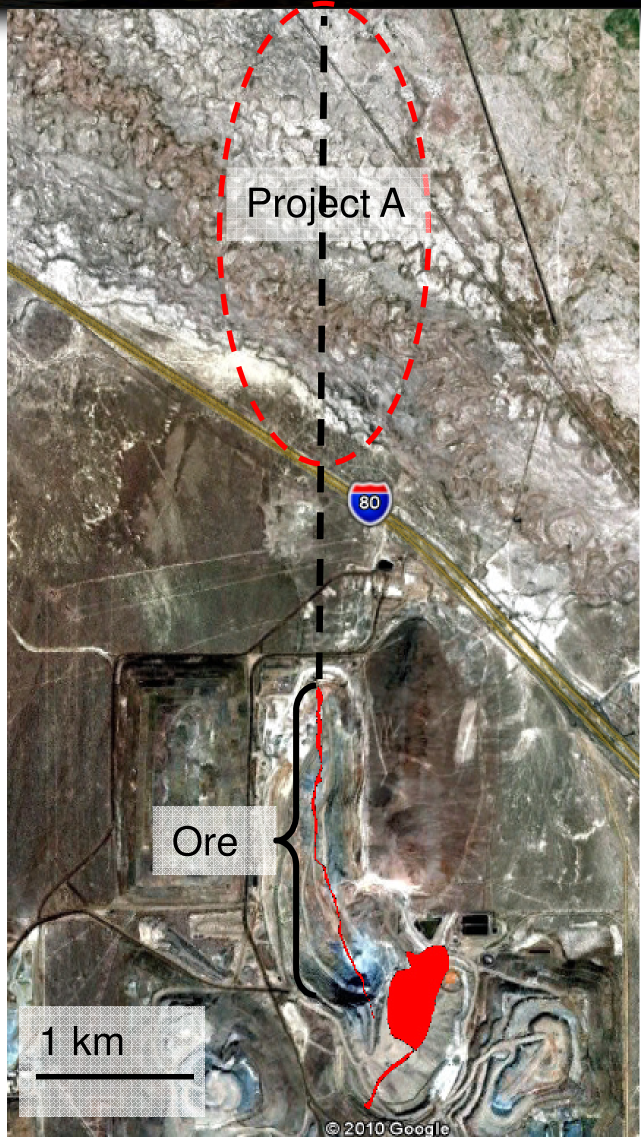
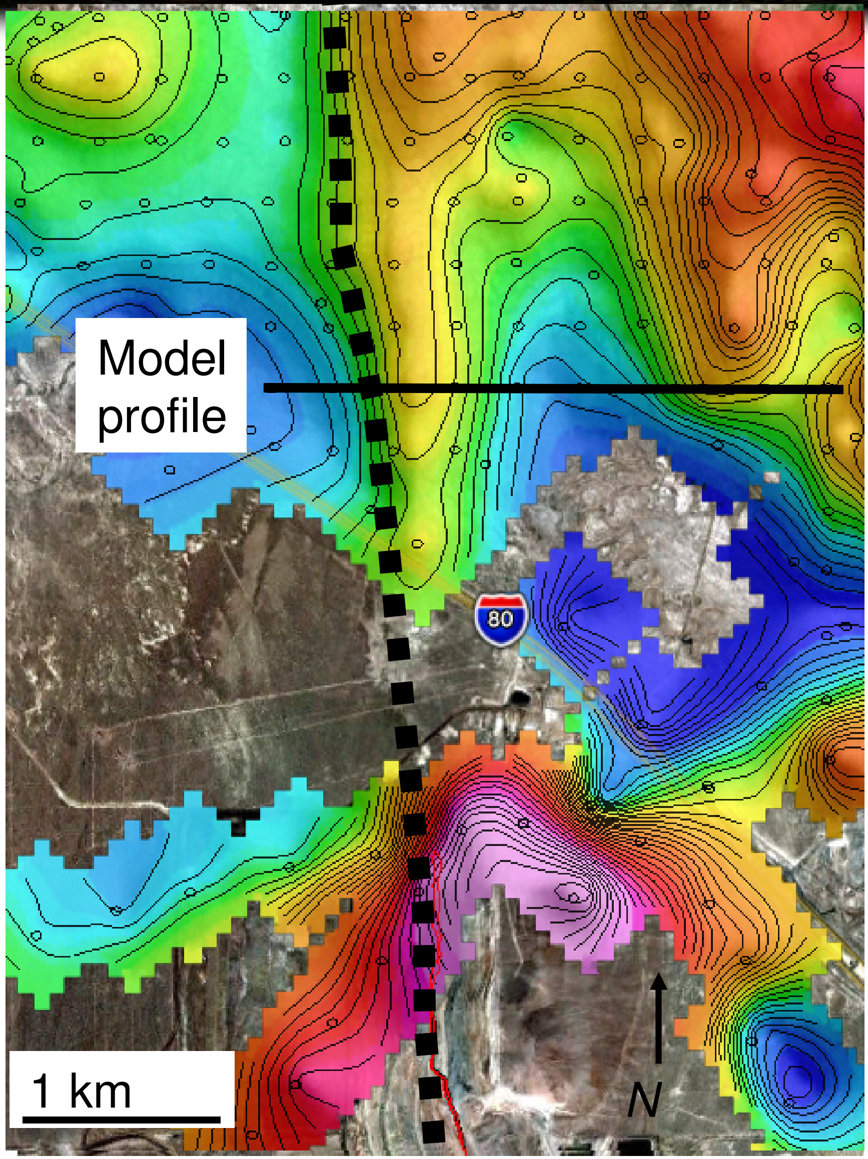
- Gravity for Great Basin exploration
  - Map **denser** Lower Plate vs Upper Plate
  - Map **alteration and metamorphism**
    - Decalcification=low, Hornfelsing=high
  - Map bedrock structure **beneath cover**
- Project A example
  - Immediately north of mine
  - Ore is structurally controlled on high-angle (75º W) fault
  - Use gravity to map extension of mineralised structure
- Pediment cover greater than 150m
  - 300m gravity station spacing



Google Earth image over Project A

Detailed Gravity – Project A

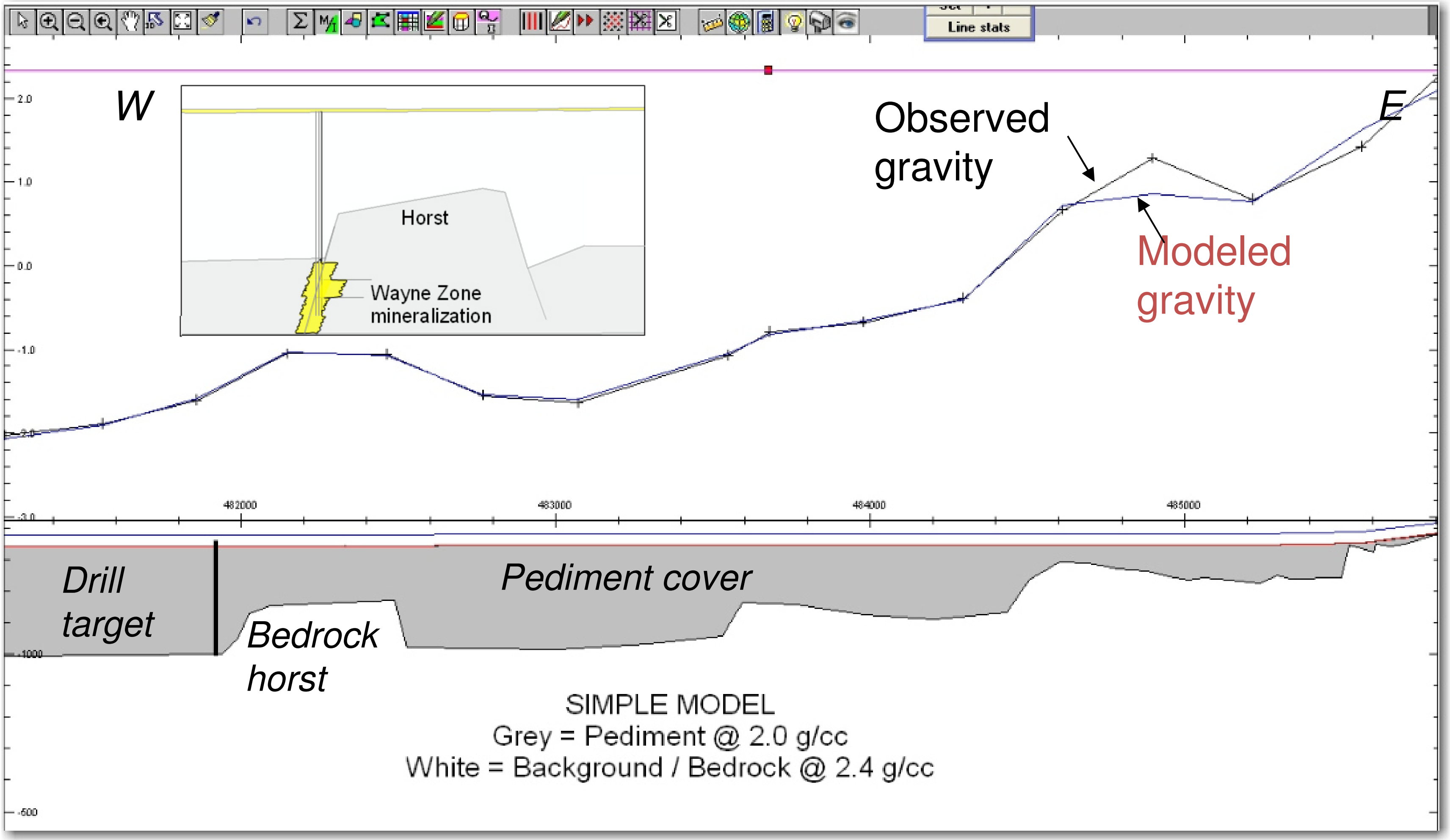


Residual gravity data over Project A

- Residual gravity highlights density contrasts in upper 500m
- Defines bedrock horst beneath alluvial pediment
  - 1500ft wide, 3 miles long
- 2D gravity modeling to quantify geometry and offset
  - Simple 2-layer earth model
    - Bedrock (2.4 g/cc)
    - Alluvium (2.0 g/cc)

Detailed Gravity – Project A

- Simple two-layer* 2D gravity model (Encom ModelVision)



*Tertiary Basalt layers of unknown thickness are not accounted for in modeling

Carlin – Hardrock Seismic

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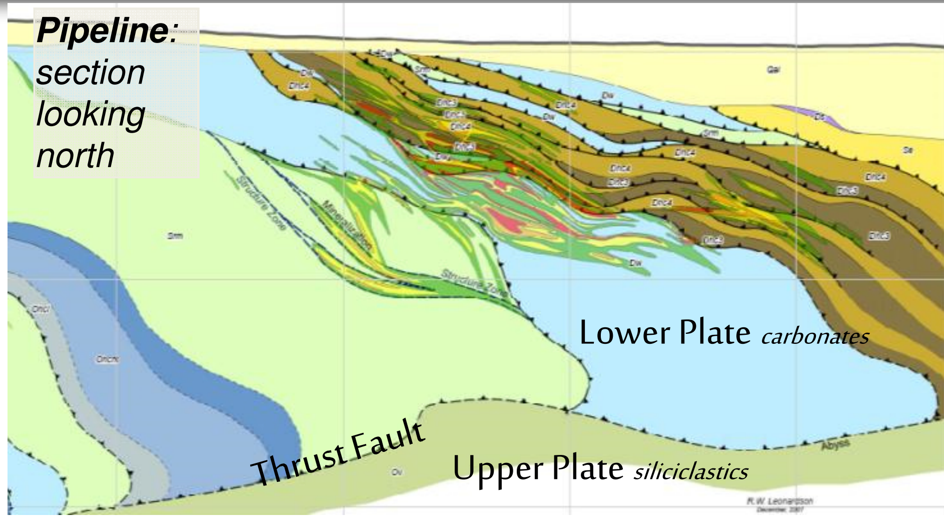
- Geology
  - Carbonate stratigraphy
  - Low-angle architecture
  - Thrusting and stacking
  - ***Au in antiform structure***
- Petrophysics
  - Density & velocity contrast between
    - lithologies
    - deposition facies
    - structure
- Hardrock Seismic
  - Acquisition:
    - High resolution & frequency
    - 10m receiver, 20m shot
    - At least 120 fold
    - 3D acquisition in 2011,2012
  - Processing:
    - Statics corrections for topography
    - Huge velocity contrasts in near-surface



Hardrock Seismic - Cortez

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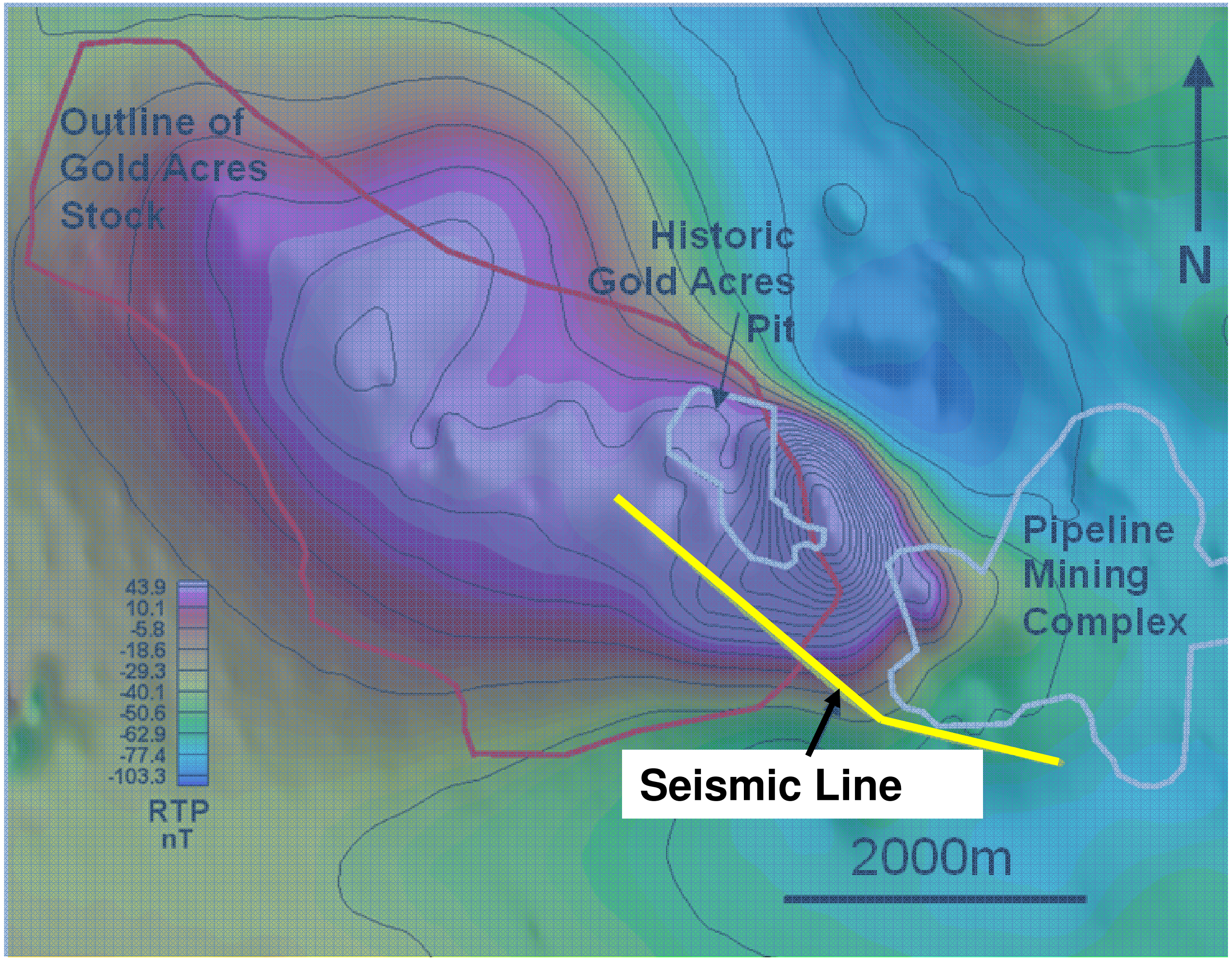
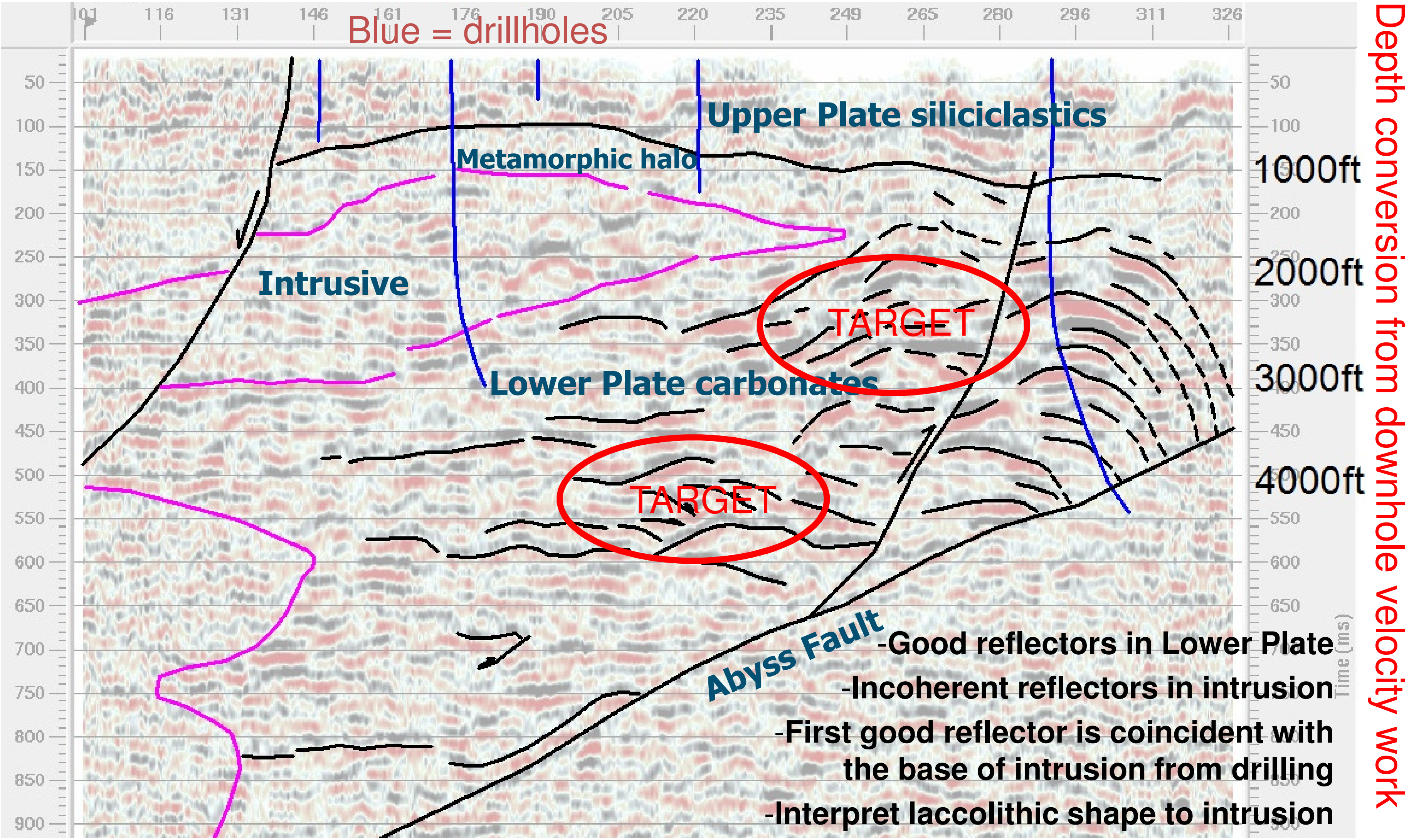
- Location of Gold Acres seismic line



Hardrock Seismic - Cortez

Terra Resources



- Good reflectors in Lower Plate
- Incoherent reflectors in intrusion
- First good reflector is coincident with the base of intrusion from drilling
- Interpret laccolithic shape to intrusion

Induced Polarization

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- Pyrite and Arsenopyrite will have an IP response
- ….BUT so does geological ‘noise’:
  - Diagenetic pyrite that is not associated with mineralization
  - Graphitic ‘black’ shales
  - Remobilized carbon outbound of contact metamorphic aureole
- Use of IP in the Great Basin is limited and applied on case by case basis depending on geologic setting
- Innovative applications of traditional IP techniques
  - Distributed array systems
  - 3D inversion
  - Downhole IP experiments
  - AMIRA P1058 Spectral Induced Polarization for 3D Mineral Discrimination

IP - Bald Mt example

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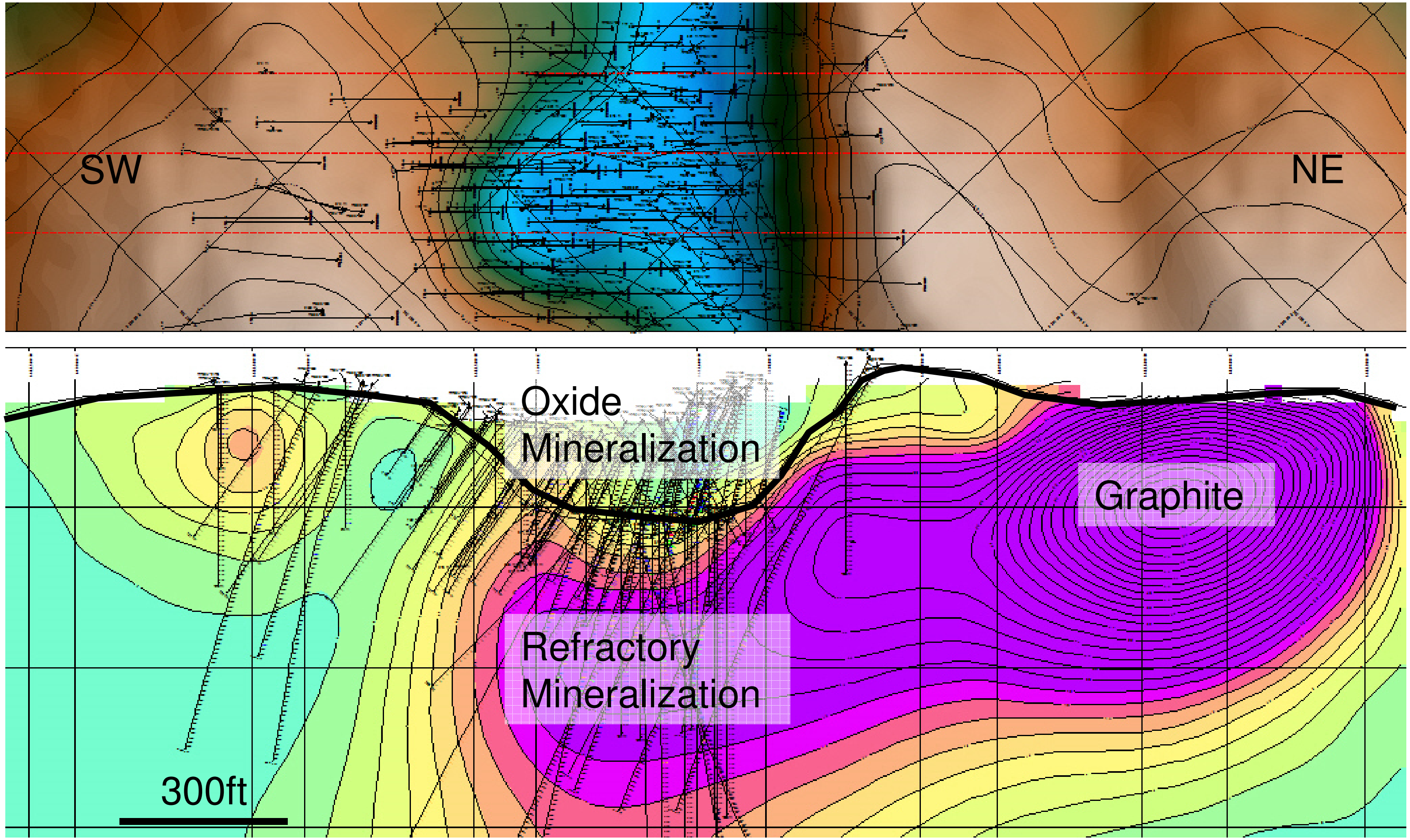
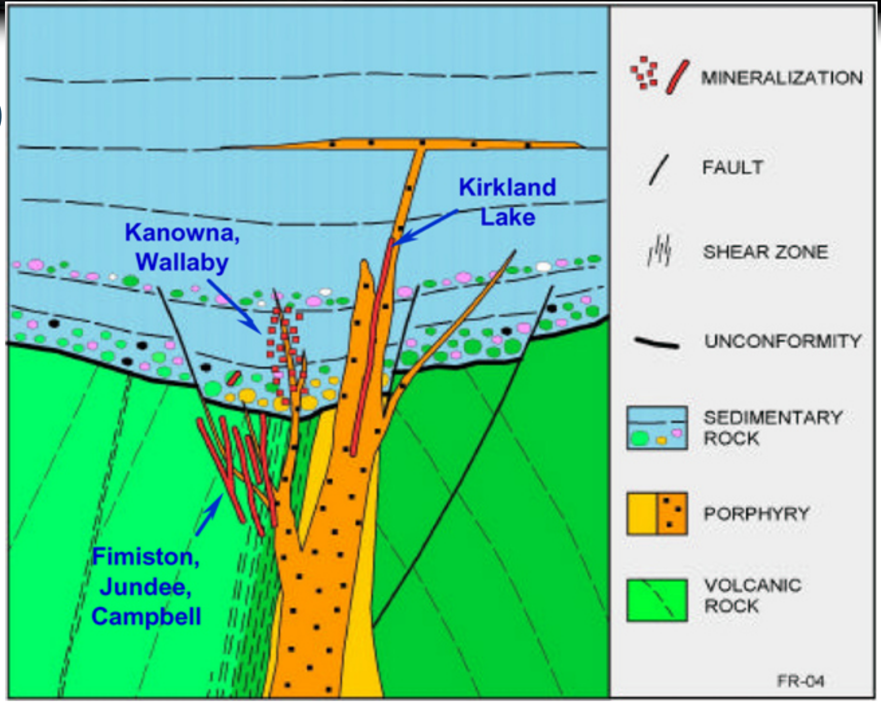
- RBM dipole-dipole IP Survey



Greenstones

- Geology
  - Greenstone stratigraphy (includes seds)
  - Sediment hosted sulphide-rich end member
  - Near volcanic sequence or porphyry
  - ***Au associated with sulphides***

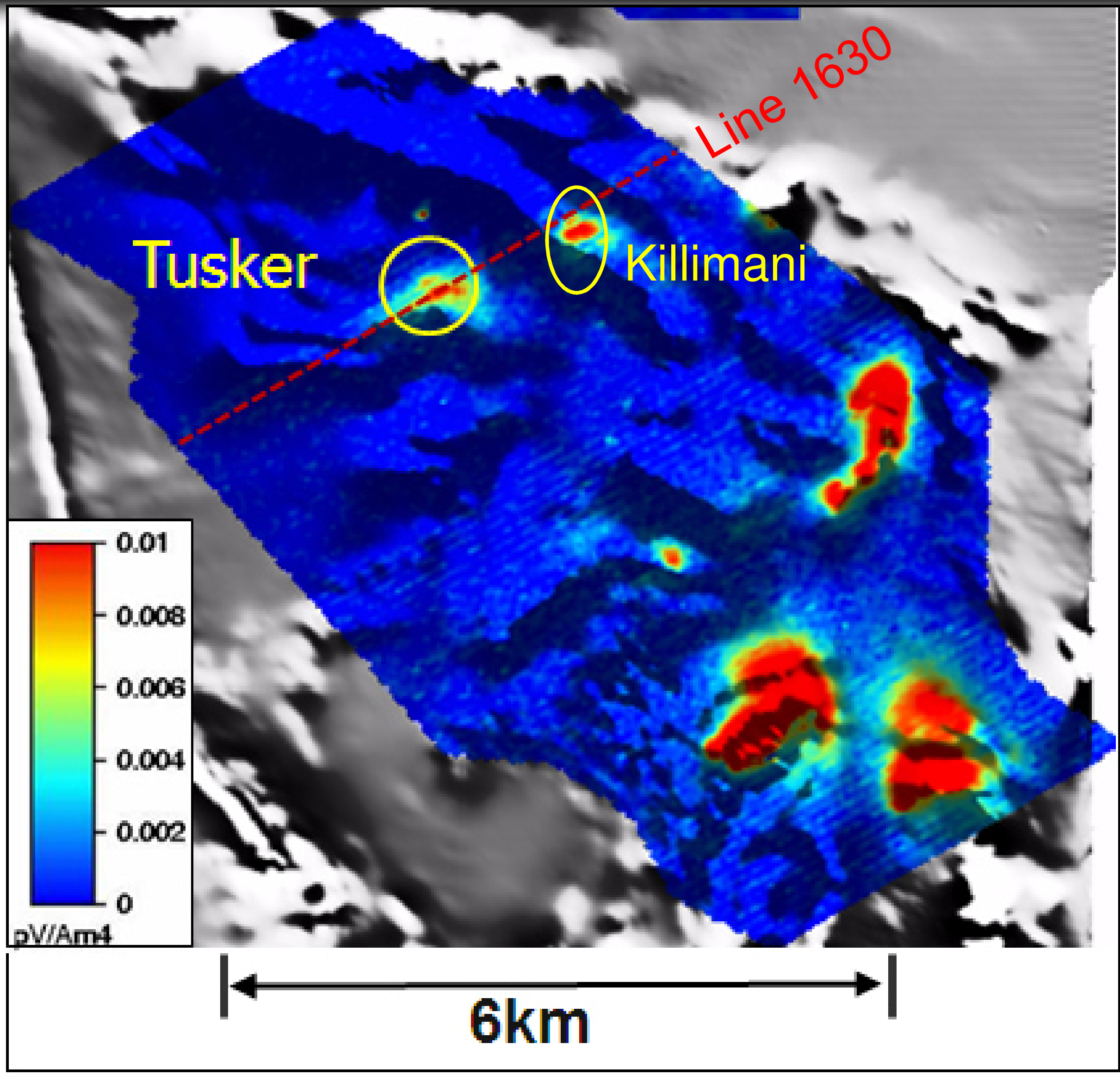


- Petrophysics
  - Resistivity contrasts
    - Disseminated sulphides
    - More resistive host
  - Density, magnetic contrasts (in strat.)
- Airborne EM
  - Acquisition:
    - High resolution (50/100m line spaced)
    - Target late time conductive responses
  - Processing:
    - Channel amplitude maps
    - 1D transforms and inversions routine

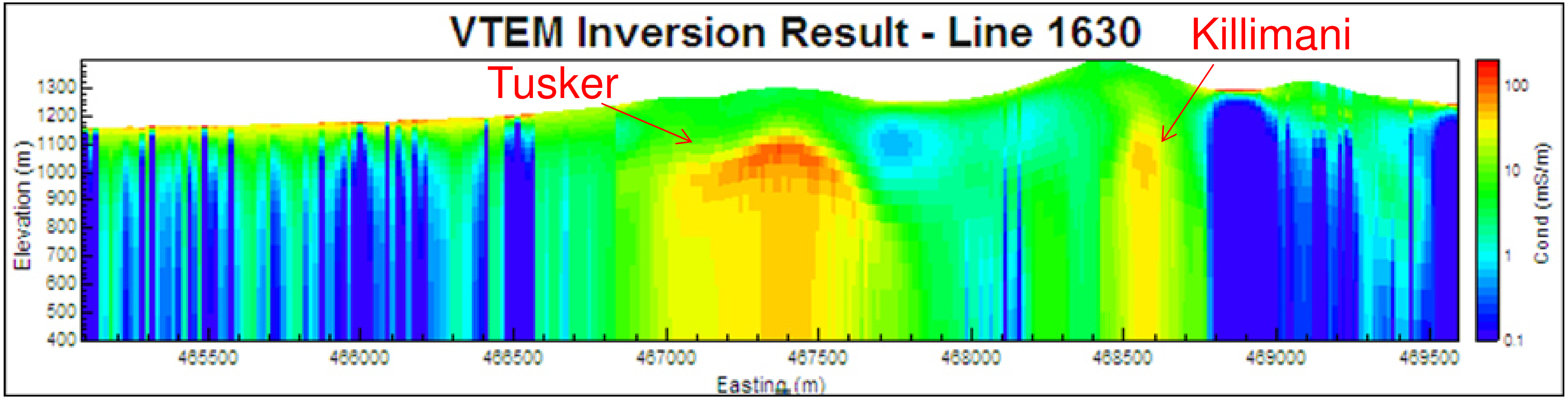
VTEM system

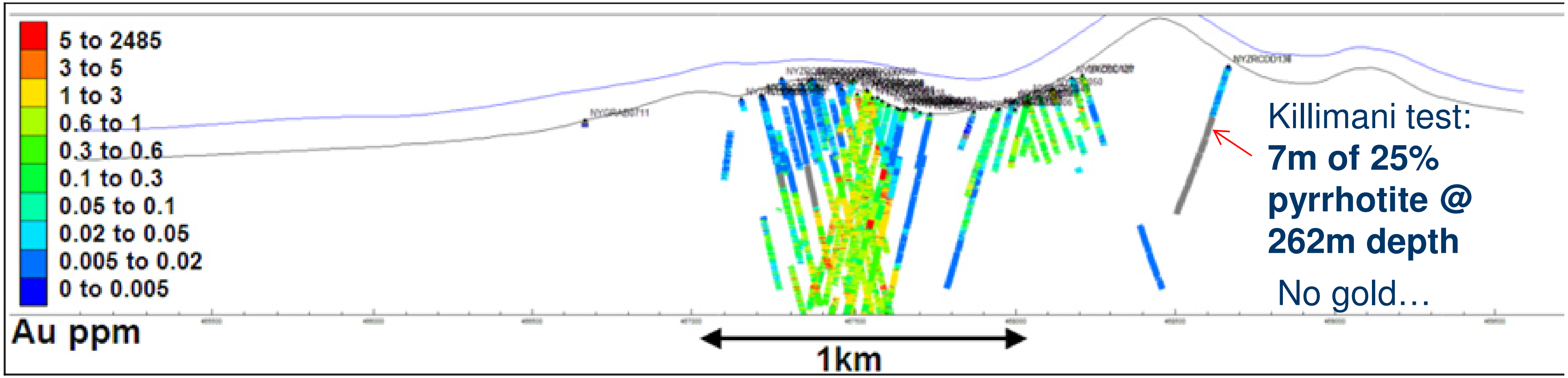
Greenstone – Airborne EM Example

- Helicopter time domain VTEM surveys
- Late time channel data (8.9 ms) shown
- Draped over greyscale magnetics (RTP 1VD)
- Tusker 4.54Moz @ 1.5g/t Au (2009) – Sulphidised BIF
- Killimani anomaly identified as another sulphide response



Greenstone – Airborne EM Inversion (1D)





Porphyry – Various Methods

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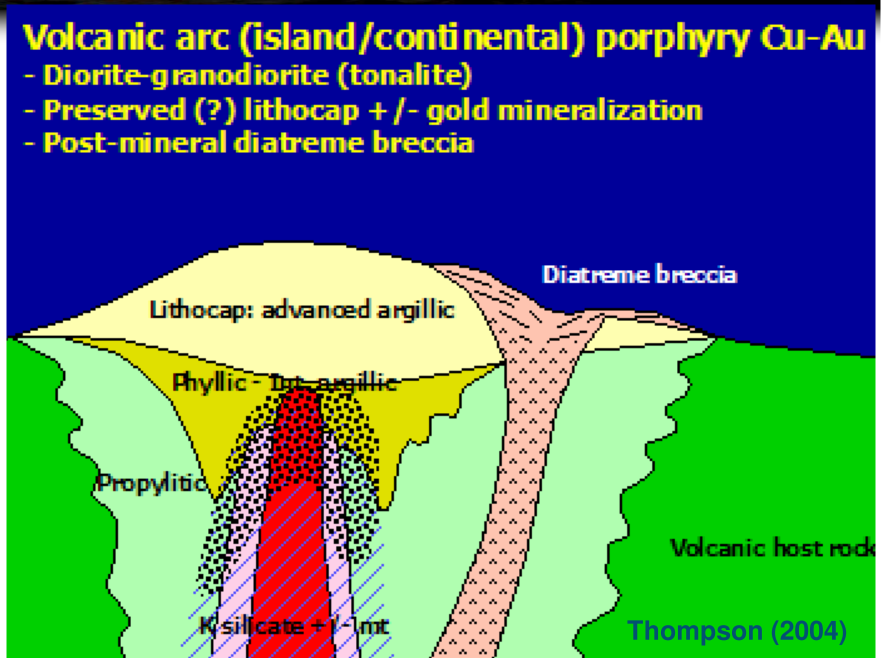
- Geology
  - Porphyries form in various settings
  - Usually at convergent plate margins
  - Commonly hosted in volcanics or sediments
  - ***Au in centre of porphyry system***
- Petrophysics
  - Magnetic, electrical & potassium contrasts
    - Alteration zonation
    - Response varies depending on host
    - Disseminated sulphides
- Various geophysical methods
  - Acquisition:
    - 1) Regional airborne mag & radiometrics
    - 2) Follow-up airborne EM
    - 3) IP/resistivity methods (100-200m dipoles)
  - Processing:
    - Channel amplitude maps
    - 1D/2D/3D transforms and inversions



AEROTEM IV system

Porphyry – Geological Cross Section

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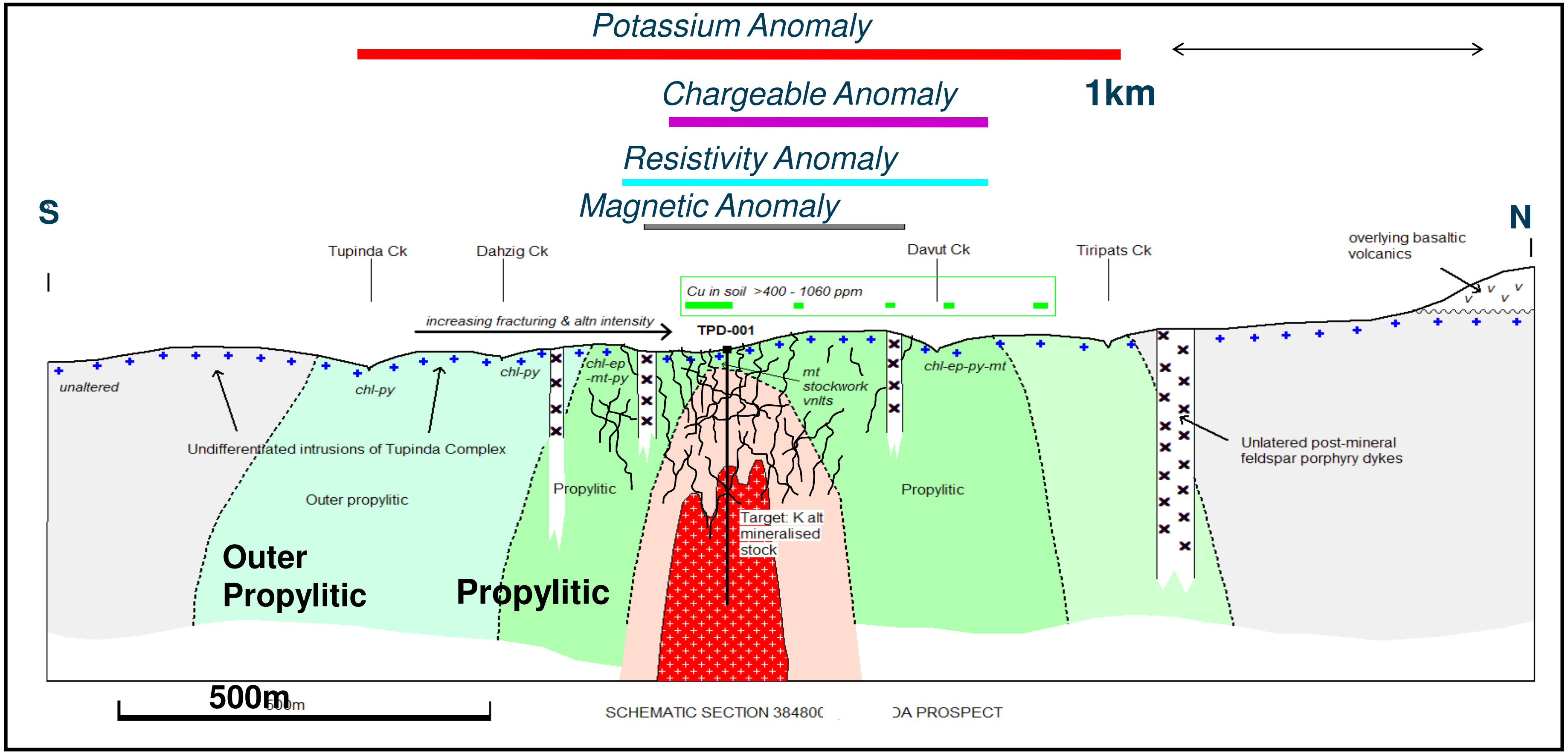
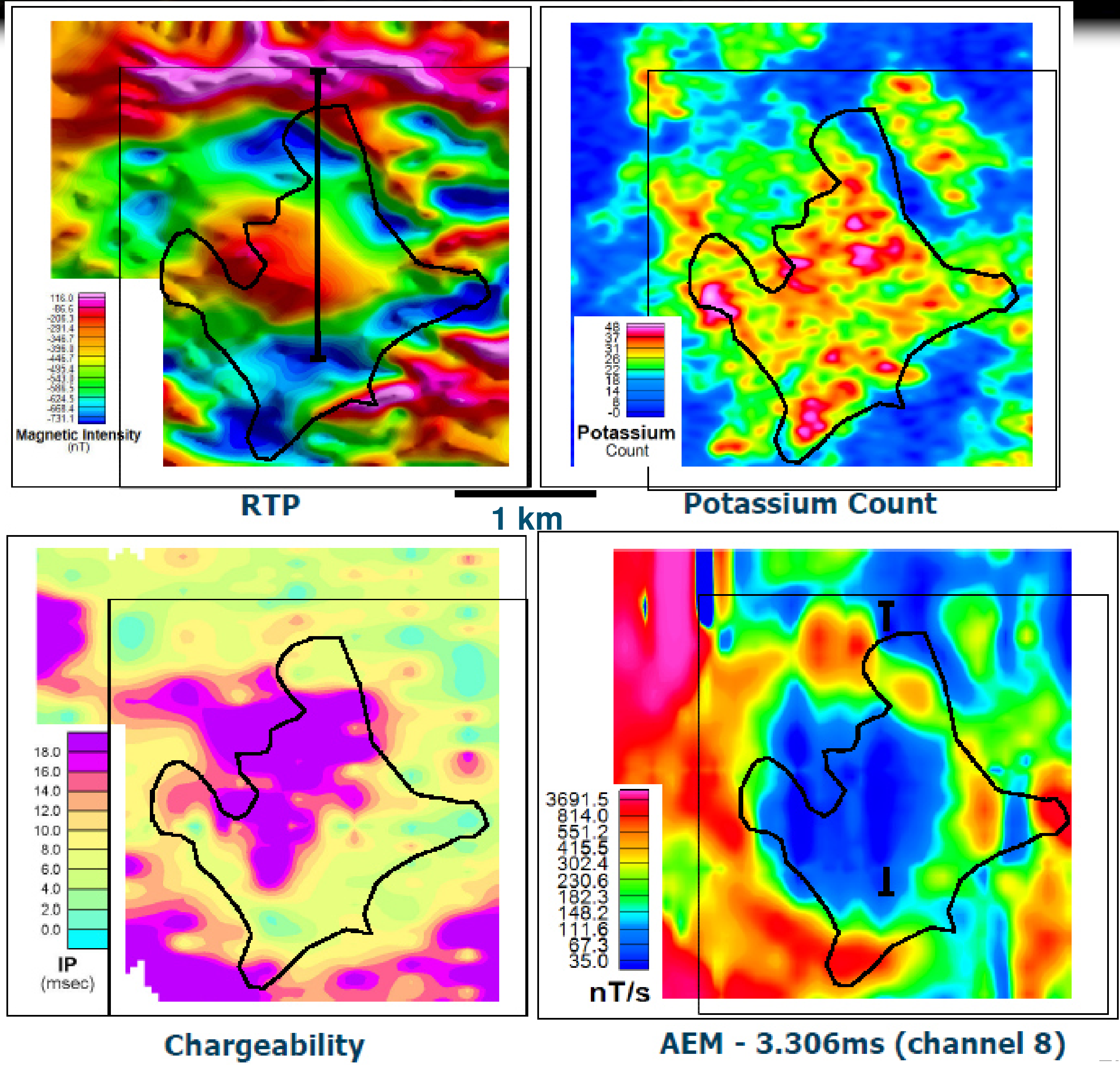


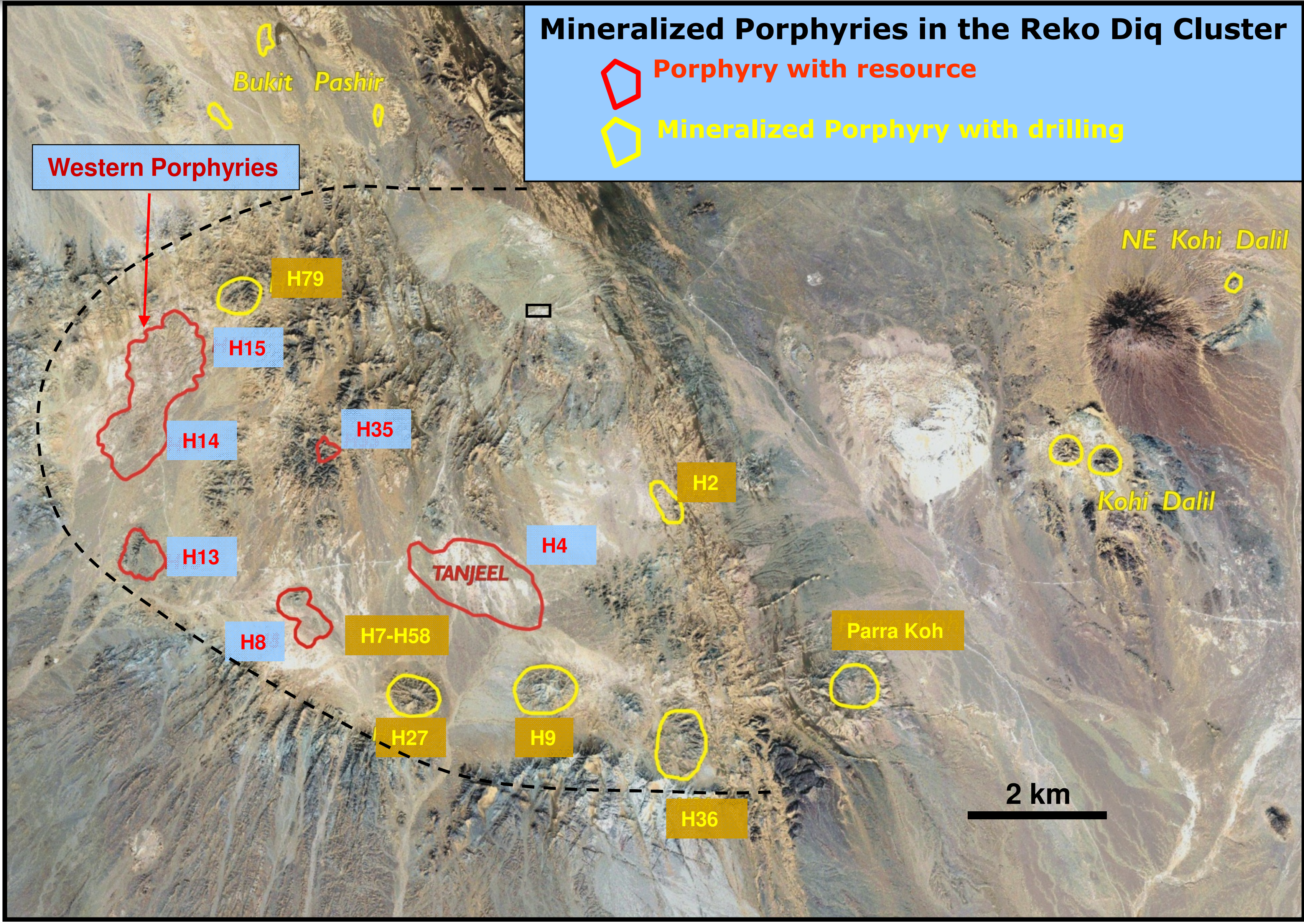
Porphyry – Integrated Example

- K-silicate core
  - magnetic
  - resistive
- Phyllic alteration
  - resistive
  - chargeable
- Propylitic alteration
  - chargeable
  - magnetic
- Outer propylitic alteration
  - Potassium anomaly



Reko Diq Project : Porphyry Centre's

ANTOFAGASTA PLC   TETHYAN COPPER COMPANY LIMITED   Terra Resources



Ground EM on Tanjeel (H4)
Channel 15 (990 usec)

ANTOFAGASTA PLC
TETHYAN COPPER COMPANY LIMITED
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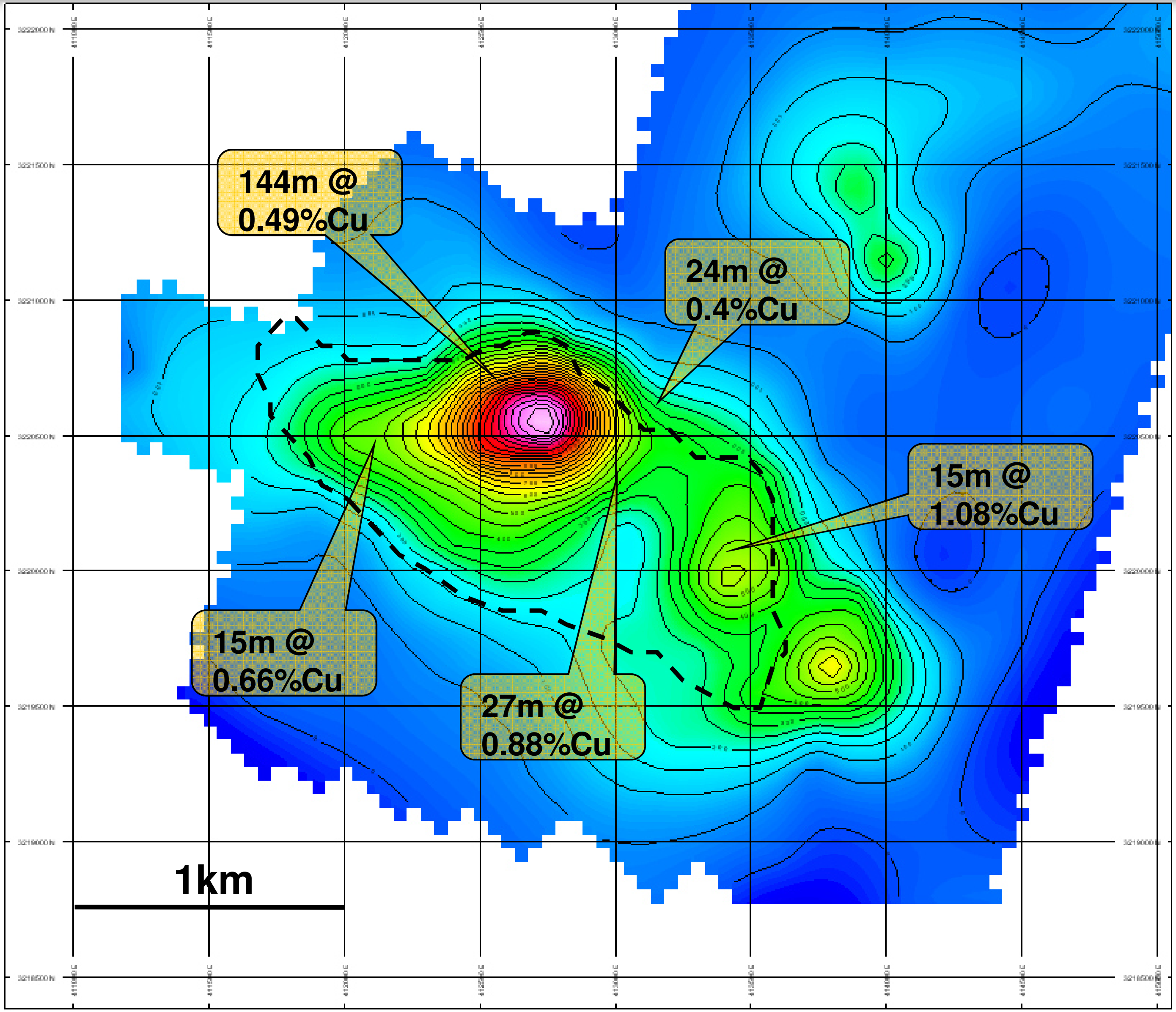

Ground EM on Tanjeel (H4)
Channel 15 with Cu Grade

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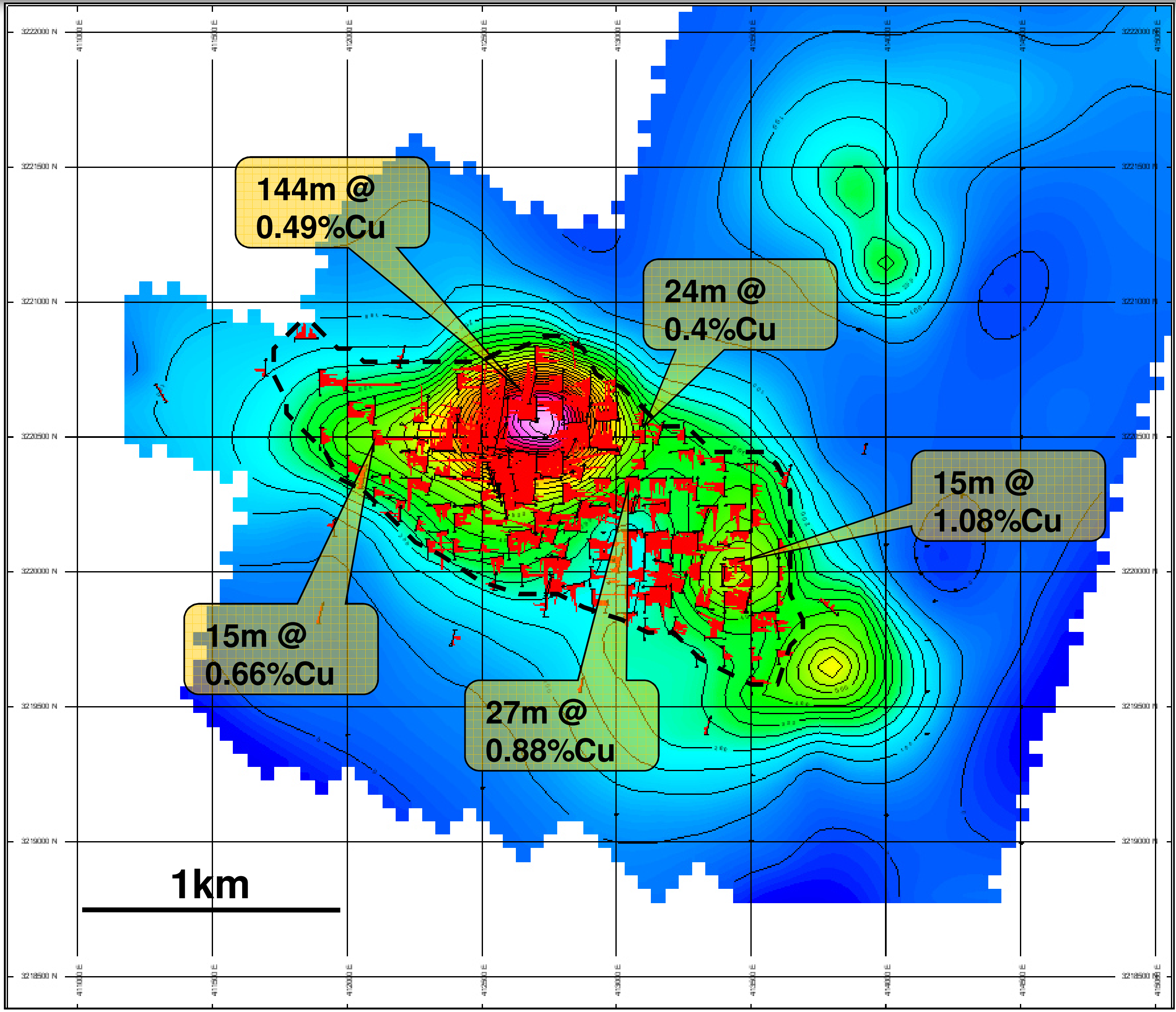
Terra Resources



Research – Image Processing

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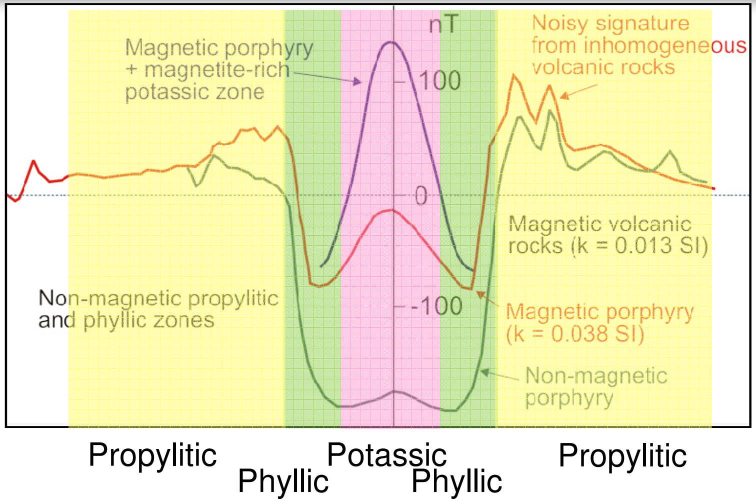
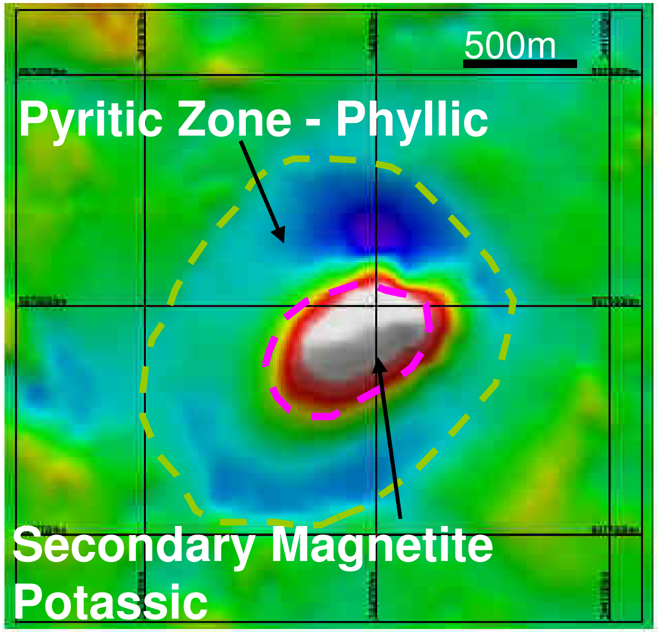
Porphyry Filter

- Automatically detect and quantify porphyry magnetic signatures via user defined application of porphyry target model
- Research agreement between UWA-CET and Barrick signed in 2008 to sole-fund “Porphyry Texture Filter”
- Cu-Au rich porphyry focus
- Magnetic coverage available over most projects – capitalise on investment
- Rapid objective analysis of large datasets
- Discrimination within highly magnetic terrains and under cover





Modified from Clark - AMIRA P700

Research – Image Processing Example

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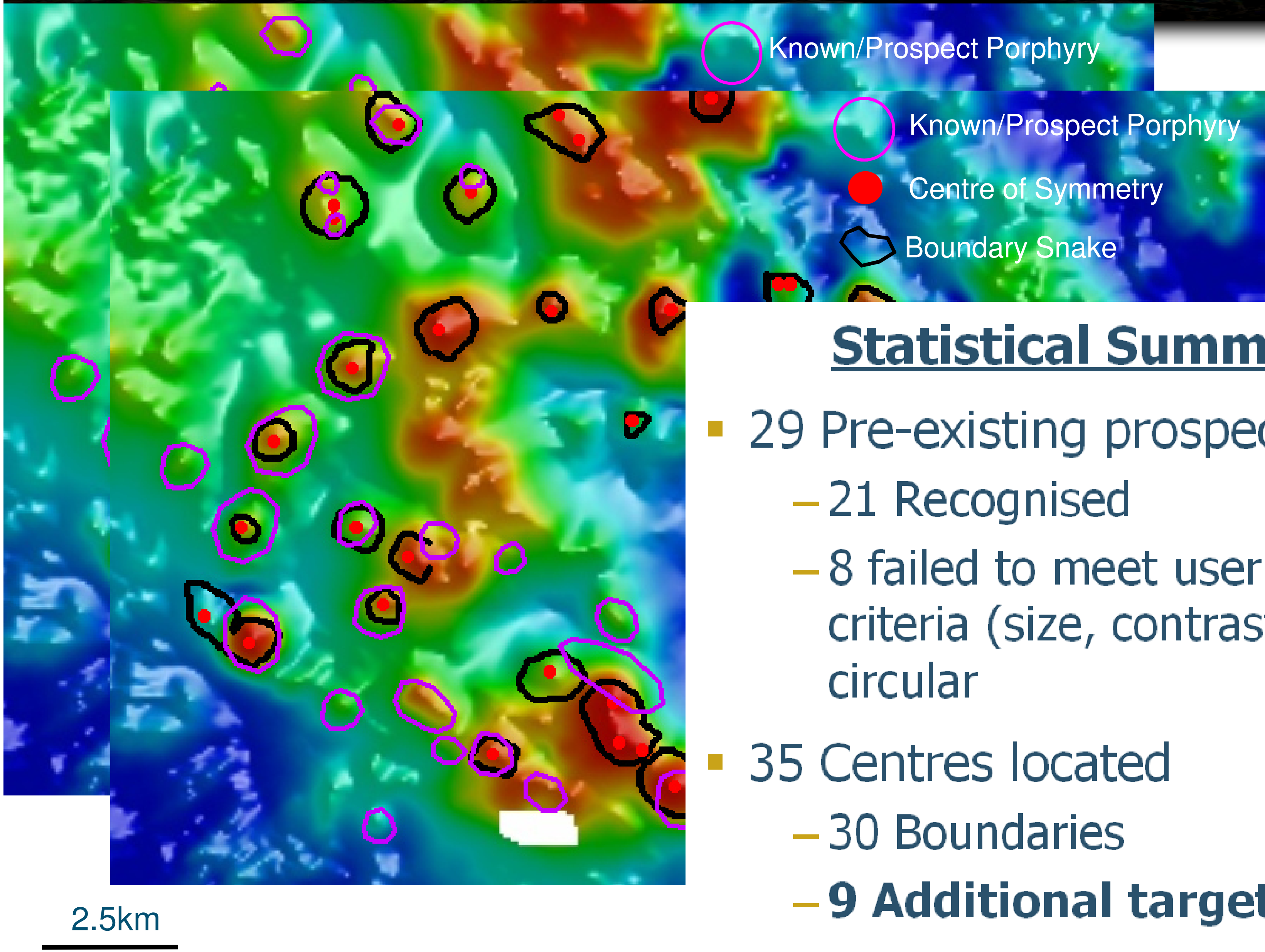

Statistical Summary

- 29 Pre-existing prospects
  - 21 Recognised
  - 8 failed to meet user defined criteria (size, contrast, not circular
- 35 Centres located
  - 30 Boundaries
  - **9 Additional targets**

Epithermal (HS) – CSAMT

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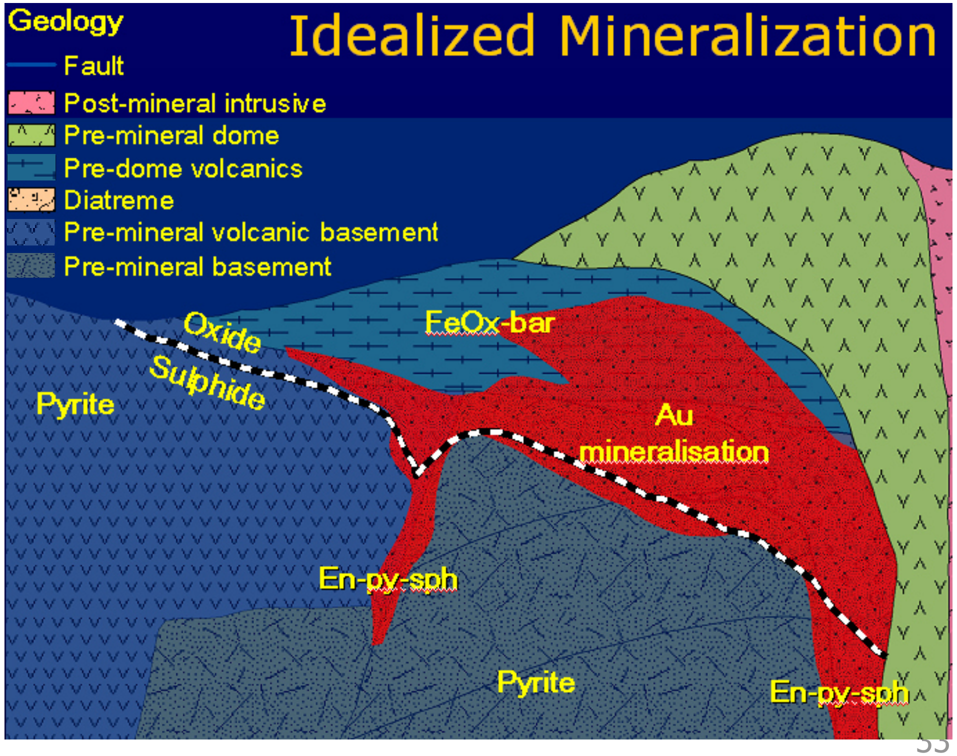
- Geology
  - Diatreme dome complexes with associated volcanics
  - Pre, syn and post mineral diatremes
  - Pre-mineral domes can be unaltered and overlying
  - Large advanced argillic alteration zones (100's km^2)
  - Topographic highs of silicic alteration
  - ***Au in vuggy silica core***

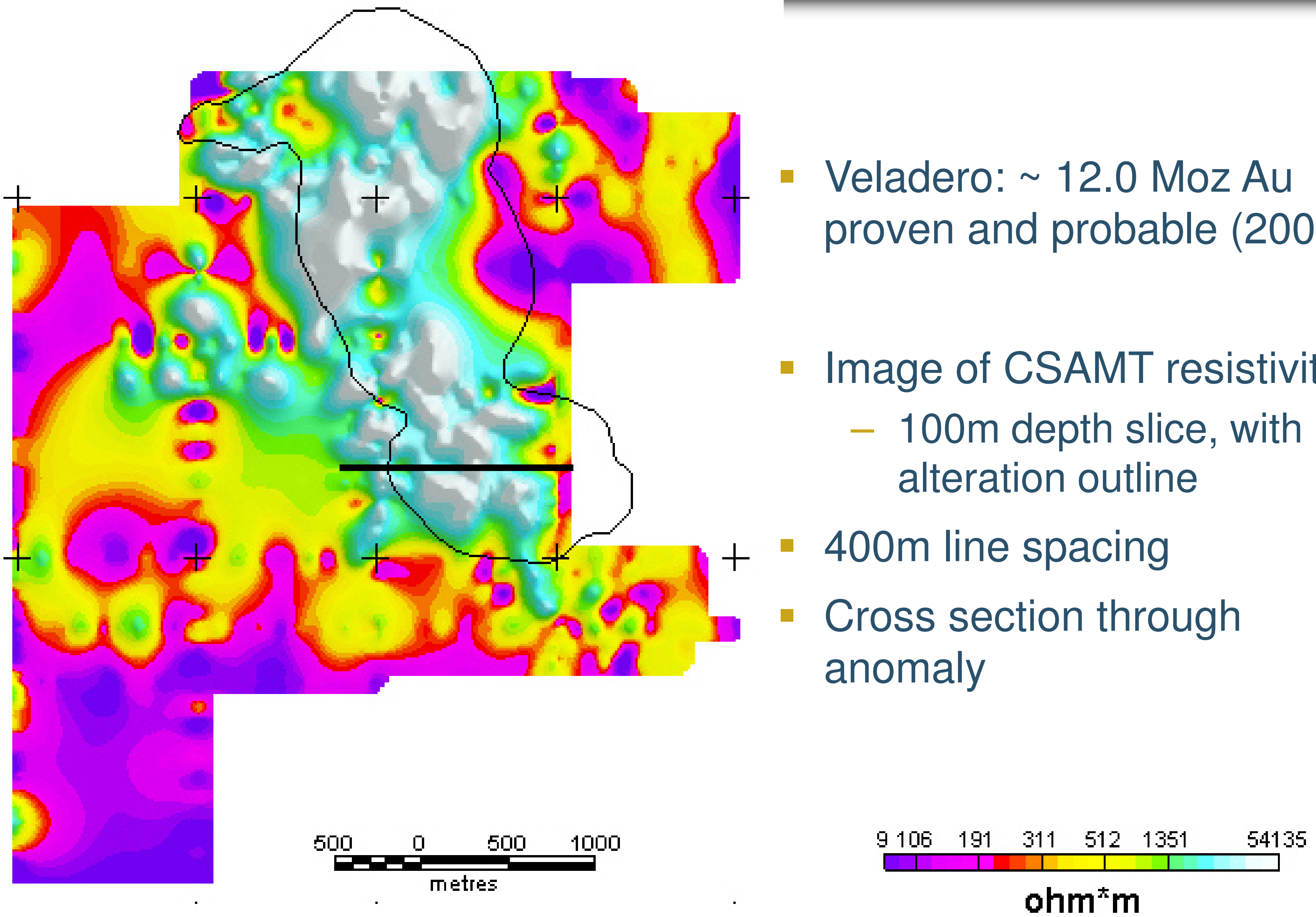
Vuggy silica

- Petrophysics
  - Resistive, massive vuggy silica core
  - Magnetite depletion
  - Chargeable alteration halo
- Resistivity methods
  - Acquisition:
    - IP/res (100-200m dipoles)
    - CSAMT
  - Processing:
    - Amplitude maps, depth slices
    - 1D/2D inversions



Epithermal (HS) – CSAMT Example

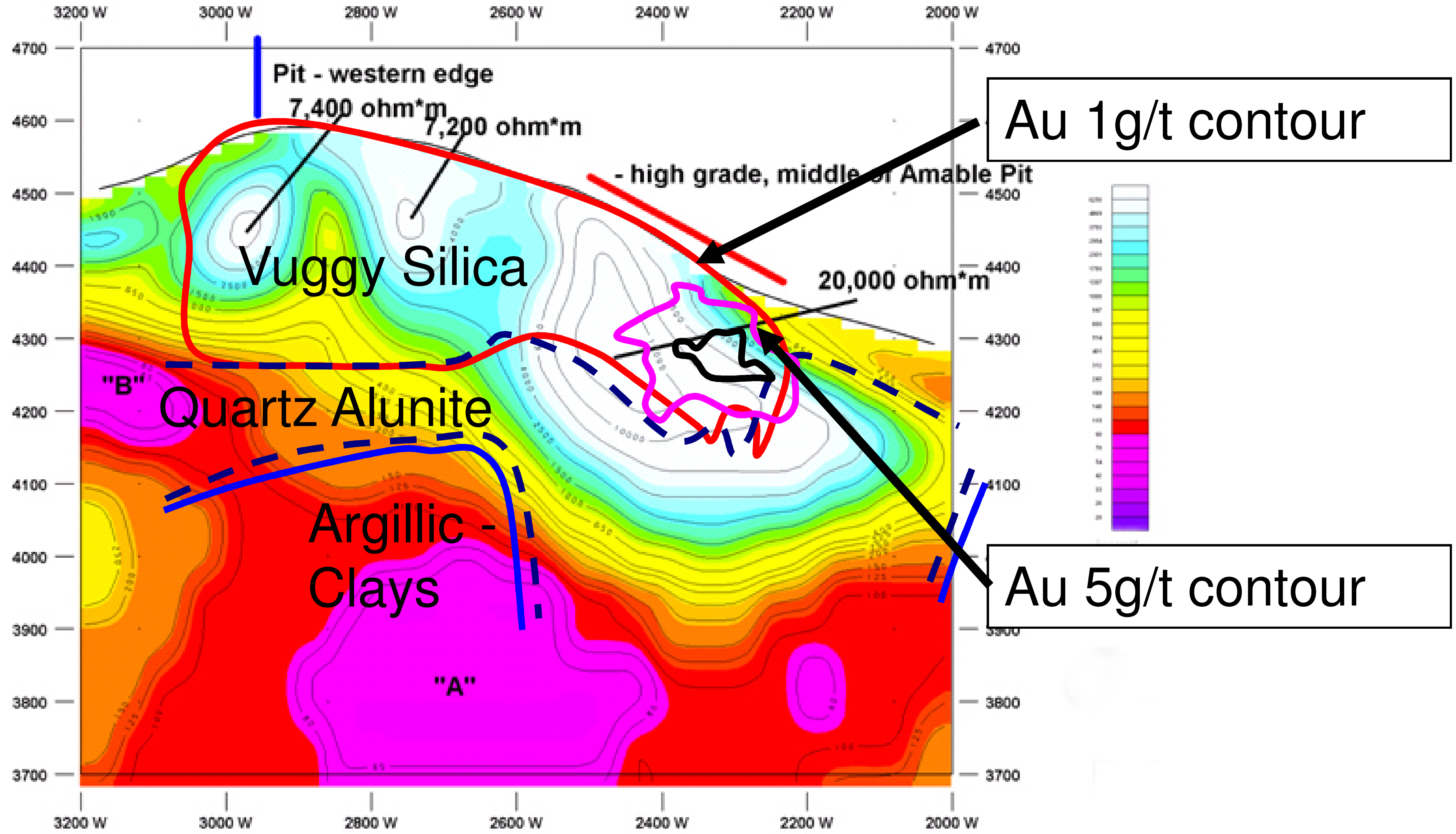
Terra Resources



- Veladero: ~ 12.0 Moz Au proven and probable (2009)
- Image of CSAMT resistivity
  - 100m depth slice, with alteration outline
- 400m line spacing
- Cross section through anomaly

Epithermal (HS)- CSAMT Example

Terra Resources



Pushing the Frontiers

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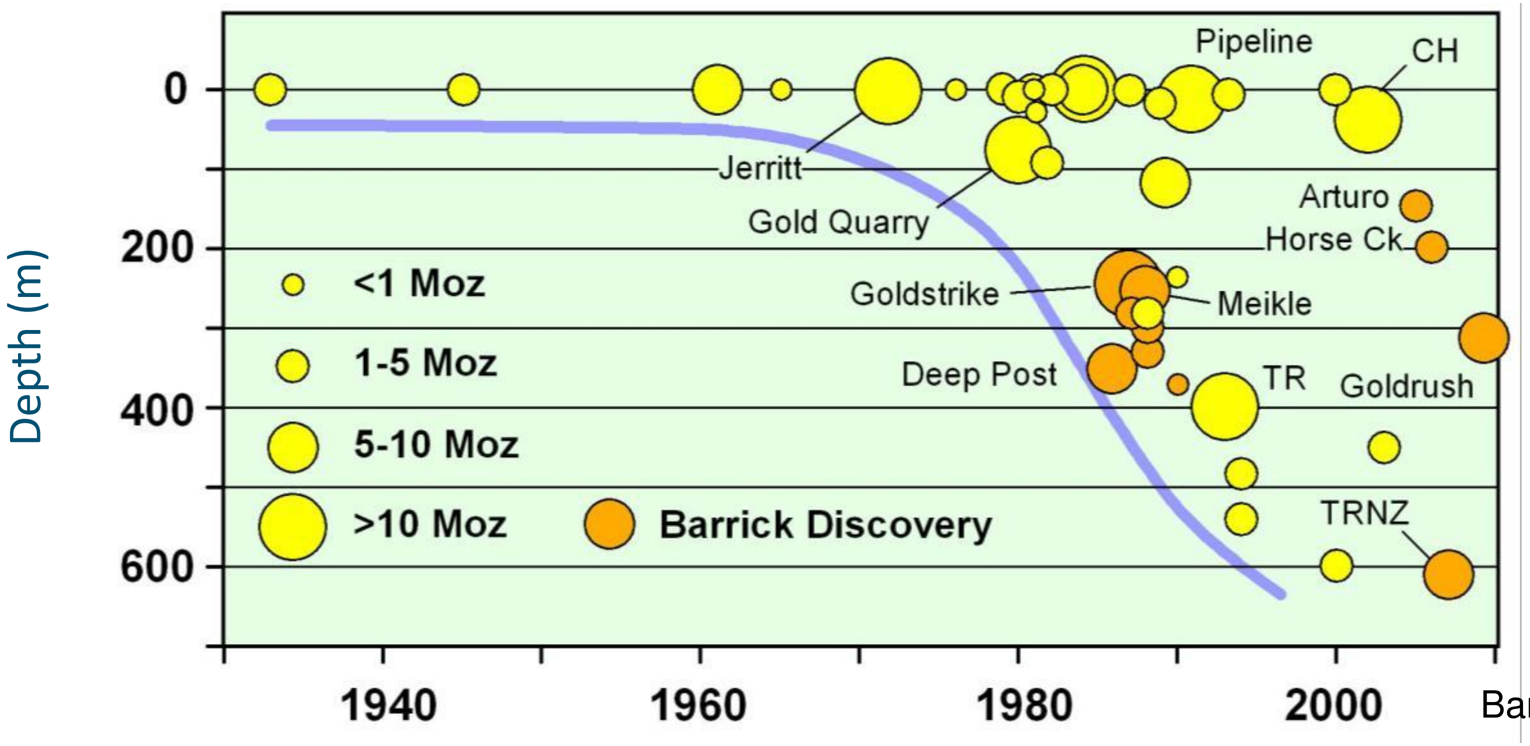
- Near-mine success for deep discoveries
- Need to extend success to all our frontiers
  - At depth, under cover, in remote areas

Carlin discoveries in Nevada (near-mine)



Barrick 2012

Where to Look - Targeting

- Understand fundamental controls on mineral systems, deposit formation and distribution through time

- Collaborative research to improve understanding of mega-scale terrains and giant mineral systems footprints combined with Government precompetitive raw data

- Direct Targeting is company responsibility not broad collaborative research – Company competitive advantage.

Vision for Exploration - Geophysics

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- Petrophysical analysis performed on all drill core or routinely determined down hole.
- All deep exploration boreholes with strategic value preserved (cased) and exploited using off hole geophysical techniques (eg VSP, gravity, magnetics)
- Routine use of high resolution 3D seismic for mineral exploration - basement mapping
- Routine use of multi-component sensor technology for airborne acquisition (eg EM, magnetics, gravity)
- "Array" style acquisition for ground geophysical surveys. Multiple sensors deployed and acquire data simultaneously.
- Routine 3D inversion of all geophysical data with joint inversion (geology or other geophysical data) common practice.

Advances: Acquisition

- Distributed array electrical methods
  - Multiple source-receiver combinations
  - Reduce non-uniqueness in inversions
  - Higher interpretability, more accurate
- 3D Hardrock Seismic
  - 3D seismic best for complex 3D geology
  - A lot more affordable in past decade
  - Wireless receivers + built-in GPS receivers for formidable terrain
- Airborne gravity
  - Noise levels **down**
  - Acquire data in rugged areas…or over competitor ground ;)
  - Helicopter platform now available

Advances: Processing and Inversion

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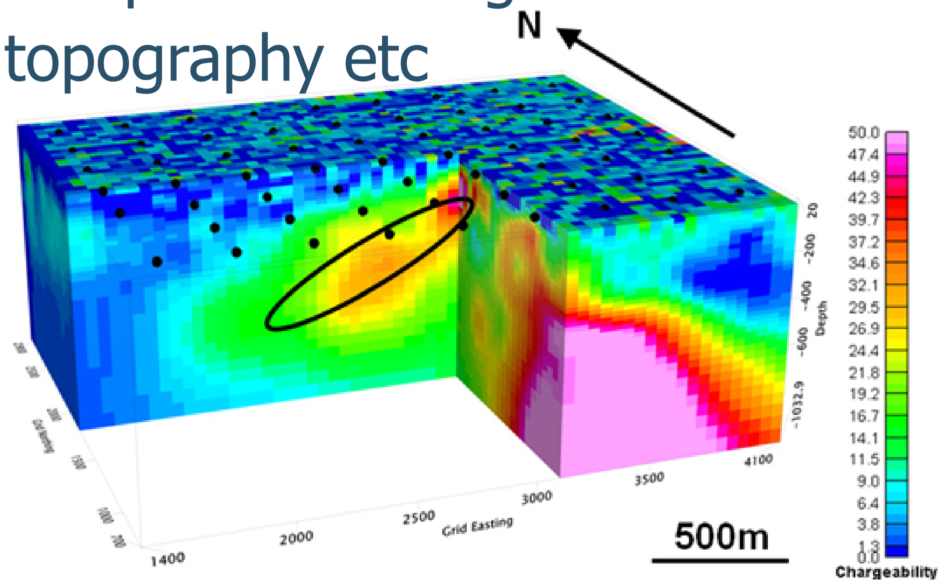
- Able to use office PC's, instead of blades/cluster.
  - Processing with 64-bit machines, +++Gb RAM
- Forward modeling for 3D survey planning
  - 3D seismic / 3D MT station planning to best 'illuminate' target
- 3D inversion
  - Faster algorithms, continuous updates through research
  - More complex meshing for topography etc
  - Example: Round Mt, NV
  - 3D survey acquisition
  - Gold Hill 3D IP inversion
  - 3D replicated 2D results



Advances: 3D Interpretation

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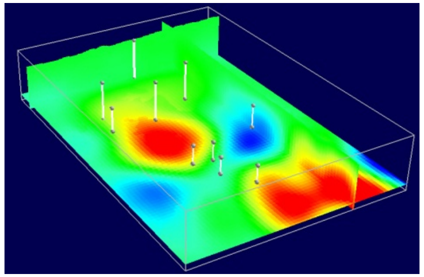
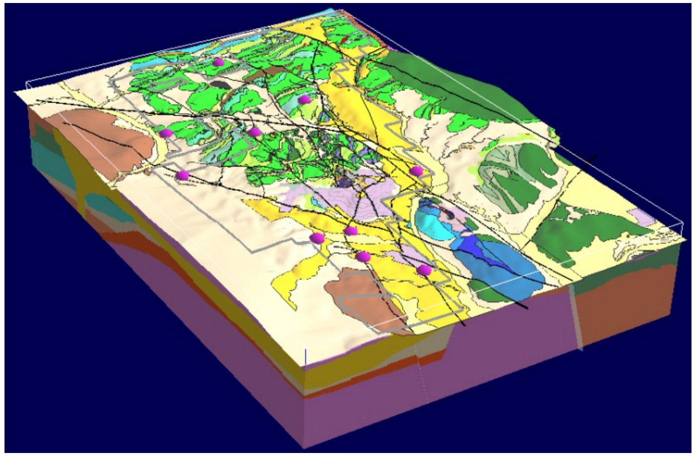
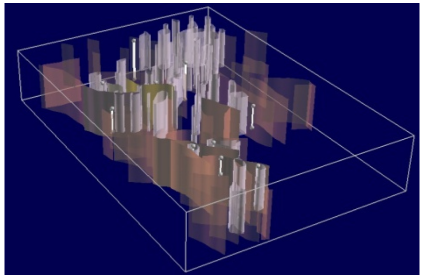
- Integration of geophysical, geochemical and geologic data
- Common earth models populated with multidisciplinary data



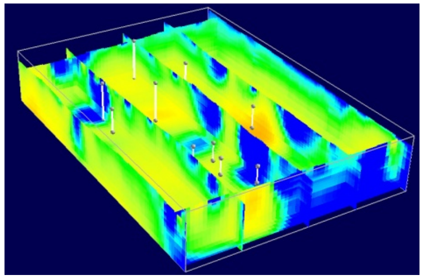
3-D INVERTED GRAVITY

3D model for Dee property

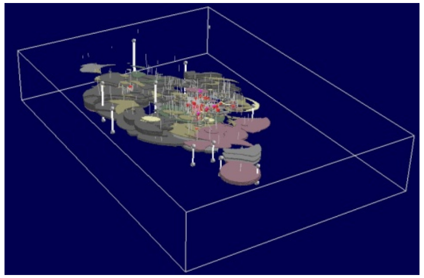




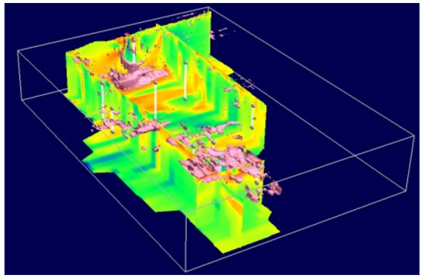
SURFACE ANOMALIES



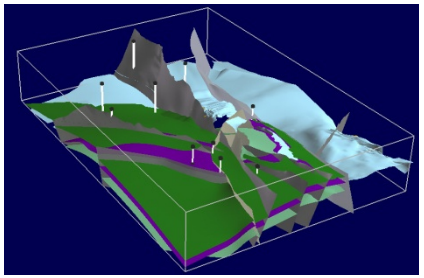
3-D INVERTED MAGNETICS



DRILLHOLE ALTERATION AND GEOCHEMISTRY



MT INVERSIONS



GEOLOGY

From J. Katseanes (Barrick)

Conclusions

- Barrick Gold
  - Leading gold producer, with largest reserves
  - Support Universities, professional affiliate groups and research
  - Preferred model type greenstone, epithermal, Carlin and porphyry Cu-Au

- Carlin: Hardrock Seismic
  - Seismic suits the carbonate stratigraphy, having low-angle structural control on architecture and good acoustic impedance contrasts between lithologies and deposition facies
  - Hardrock seismic requires high spatial resolution (10m receiver, 20m shot) and frequency and higher fold (120+)

- Greenstone: Airborne EM
  - Sediment hosted sulphide-rich end member is better suited to electromagnetic (EM) techniques
  - Conductive near-surface response usually identifies centre of the system

Conclusions (cont)

- Porphyry Cu-Au: Integrated Methods
  - Magnetics/ radiometrics to map potassic alteration is well known
  - Potassic core can be either conductive in sulphide-rich systems, or resistive in sulphide-poor systems, depending on host
  - Outer phyllic/ propylitic alteration is chargeable, magnetite destructive and is often resistive

- High Sulphidation Epithermal: CSAMT
  - Resistivity data can effectively map the typical alteration of advanced argillic with vuggy silica (resistive), advanced argillic with quartz alunite (moderate resistor), to argillic with intense clay (conductive, chargeable)
  - Magnetite depletion and chargeable alteration also system indicators

Summary

- Demand for resources will increase
- Maturity in shallow search space, forcing us deeper
- Discovery success rates expected to remain low
- Risk – increasingly important in choice of where to explore, technical risk will eventually increase
- Tools need further development and in some cases step change to improve exploration success rates
- Integrated exploration will be the key in the next round of discoveries – geophysics will be key
- Geoscientists – remember fundamental geology and boots on the ground

Terra Resources

Vision for Future Exploration: Geophysics and Gold

B. Bourne, ASEG-PESA Melbourne, 13th August, 2013