Magnetic effects of alteration in mineral systems

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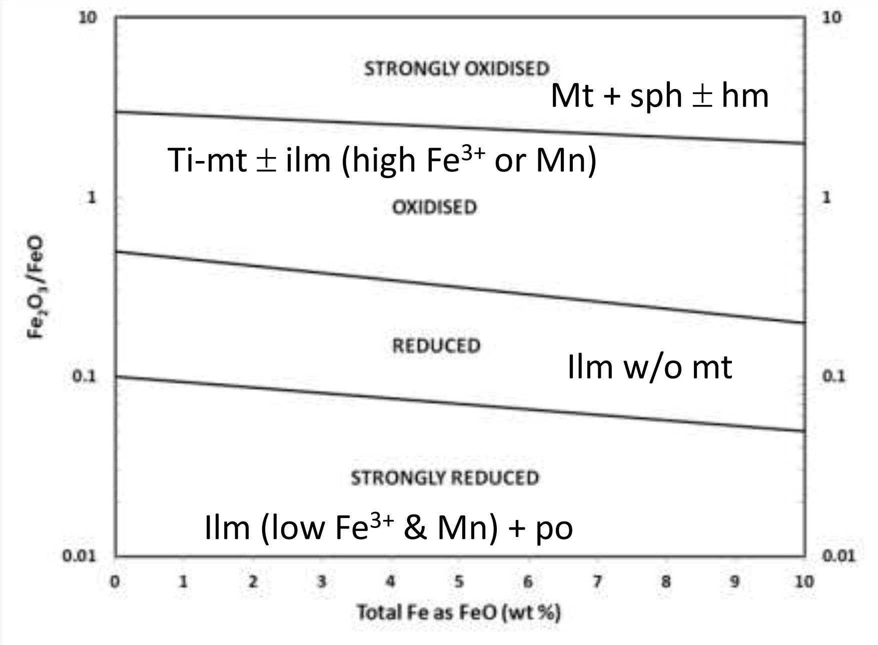
Workshop 8: "Improving Exploration with Petrophysics: The Application of Magnetic Remanence and Other Rock Physical Properties to Geophysical Targeting"

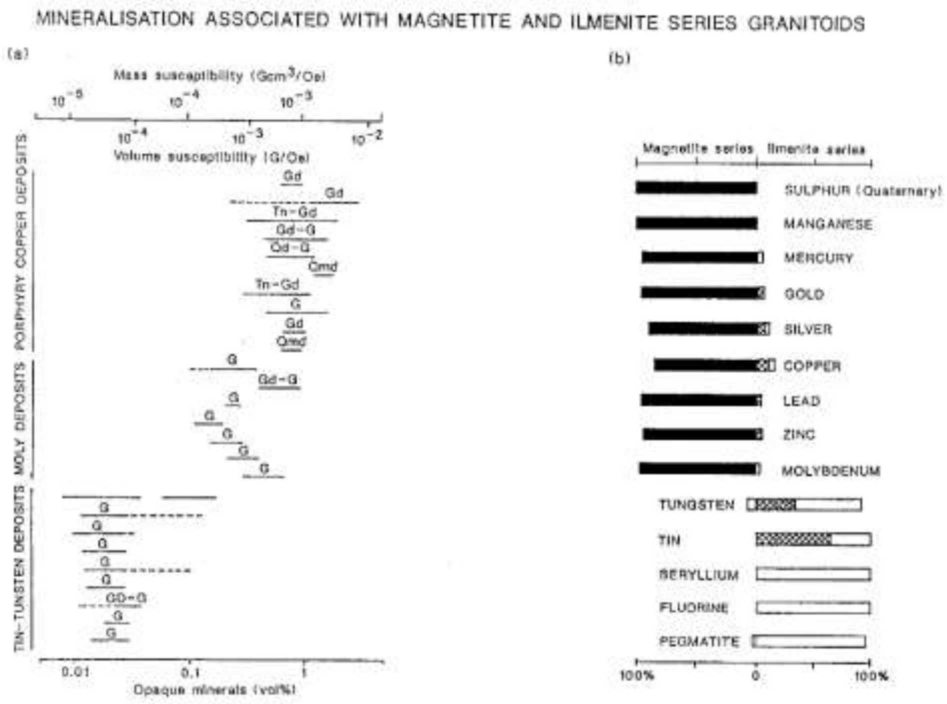
Outline of talk

Key reference: Clark, D.A., 2014. Magnetic effects of hydrothermal alteration in porphyry copper and iron-oxide copper–gold systems: A review, Tectonophysics, 624-625, 46-65.

1. Magnetic petrology of igneous intrusions associated with mineralisation
   - Importance of oxidation state
   - Influence of host rocks on alteration zoning
   - Alteration in porphyry copper systems
2. Predictive magnetic exploration models
3. Exploration criteria

Importance of oxidation state





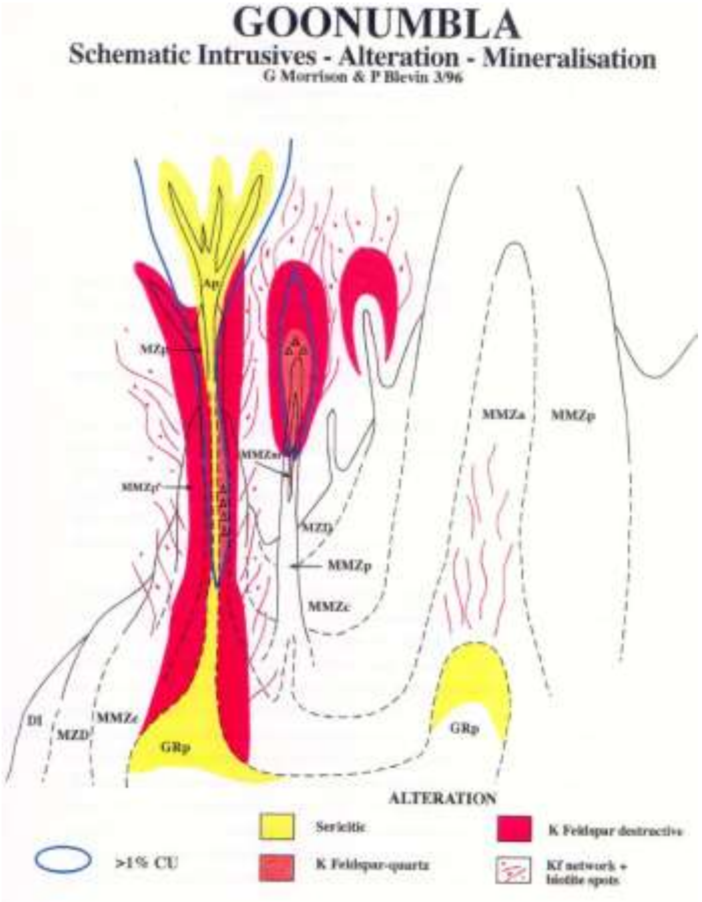
Importance of oxidation state

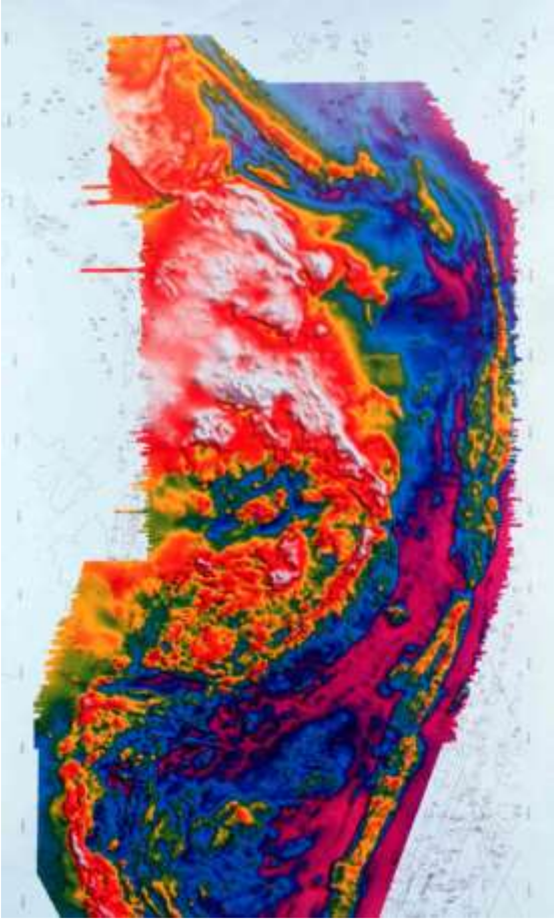
- Significant differences in magnetic susceptibility, at equivalent degrees of differentiation, are found for mantle-derived (M-type) intrusions, found typically in island arcs, and I-type granitoids in continental arcs.
- Intrusions associated with gold-rich porphyry copper deposits are more oxidized than those associated with gold-poor porphyry copper deposits, and accordingly contain more abundant igneous (titano)magnetite and produce greater quantities of hydrothermal magnetite during early potassic alteration.
- An empirical association between Au-rich (> 0.4 g/t) porphyry copper deposits and abundant magnetite in the potassic core has been documented by Sillitoe and others. The corresponding magnetic signatures also differ profoundly, with more prominent anomalies associated with gold-rich porphyry copper deposits than with gold-poor deposits

Redox state of iron in rocks is a useful indicator of hydrothermal alteration.

- Studemeister (1983) pointed out that the redox state of iron in rocks is a useful indicator of hydrothermal alteration. Large volumes of fluid or high concentrations of exotic reactants, such as hydrogen or oxygen, are required to shift Fe^{3+}/Fe^{2+} ratios.
- When reactions associated with large water/rock ratios occur, the change in redox state of the rocks produces large changes in magnetic properties due to creation or destruction of ferromagnetic minerals.

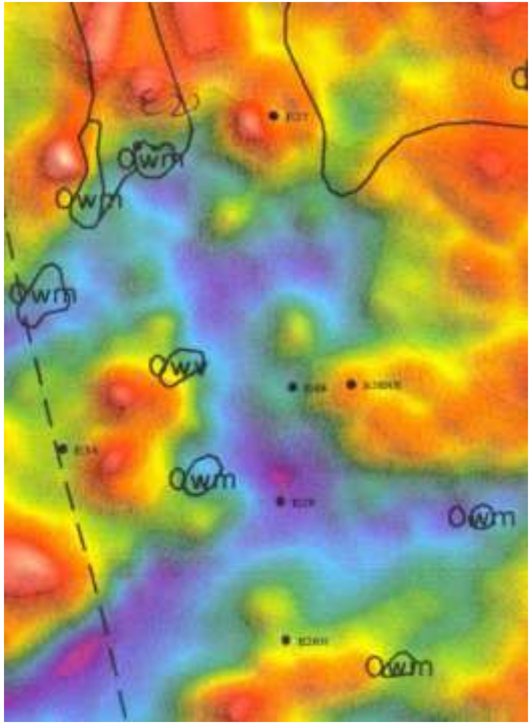
Example –
Goonumbla Volcanic Complex: Ordovician Shoshonitic Volcanics and Comagmatic Intrusions


GOONUMBLA
Schematic Intrusives - Alteration - Mineralisation
G Morrison & P Blevin 3/96
Ap
MZp
MMZm
MMZp
MZD
MMZp
MMZc
MMZa
MMZp
DI
MZD
MMZc
GRp
GRp
ALTERATION
Sericitic
K Feldspar destructive
>1% CU
K Feldspar-quartz
Kf network + biotite spots

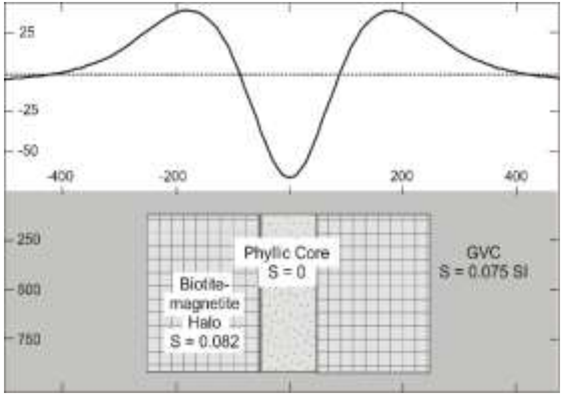


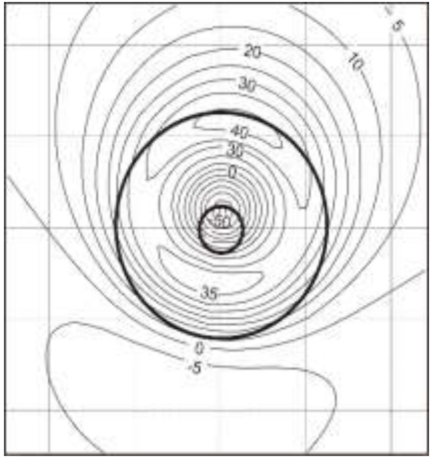
Goonumbla Detailed Aeromagnetics

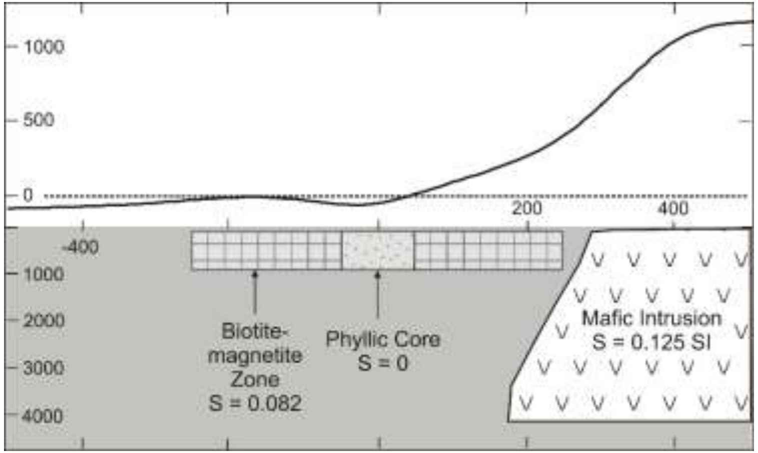
Large anomalies and strong gradients arise from intrusive stocks and variably magnetised volcanics, obscuring the signatures of the narrow mineralised spines and associated alteration zones



Type Magnetic Model for eastern GVC Deposits, associated with Endeavour Linear

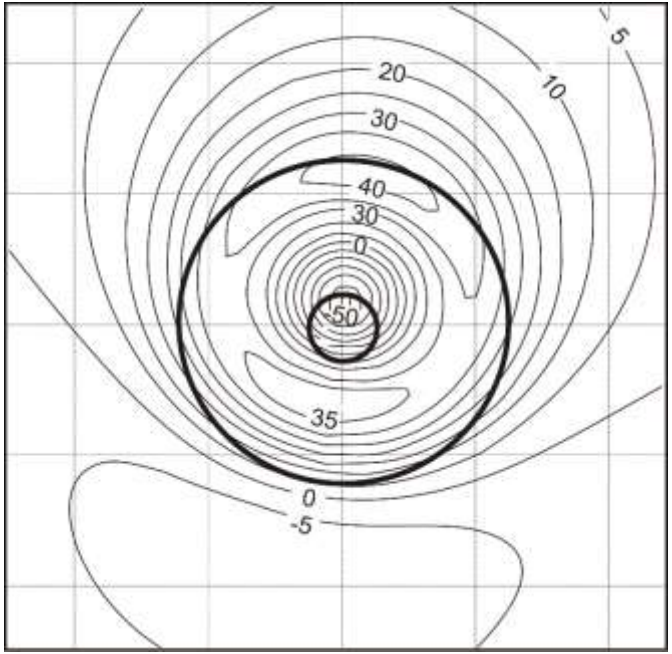




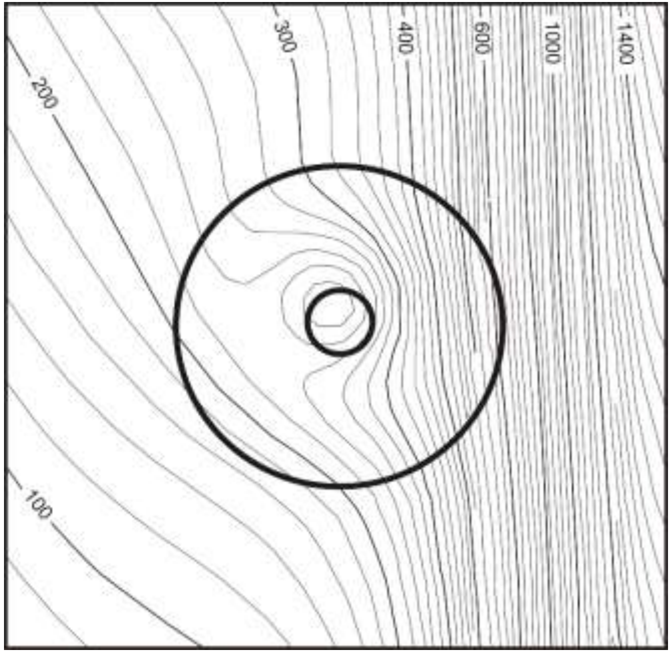


Distortion of Deposit Signatures by Strong Gradients

Isolated anomaly



Regional gradient

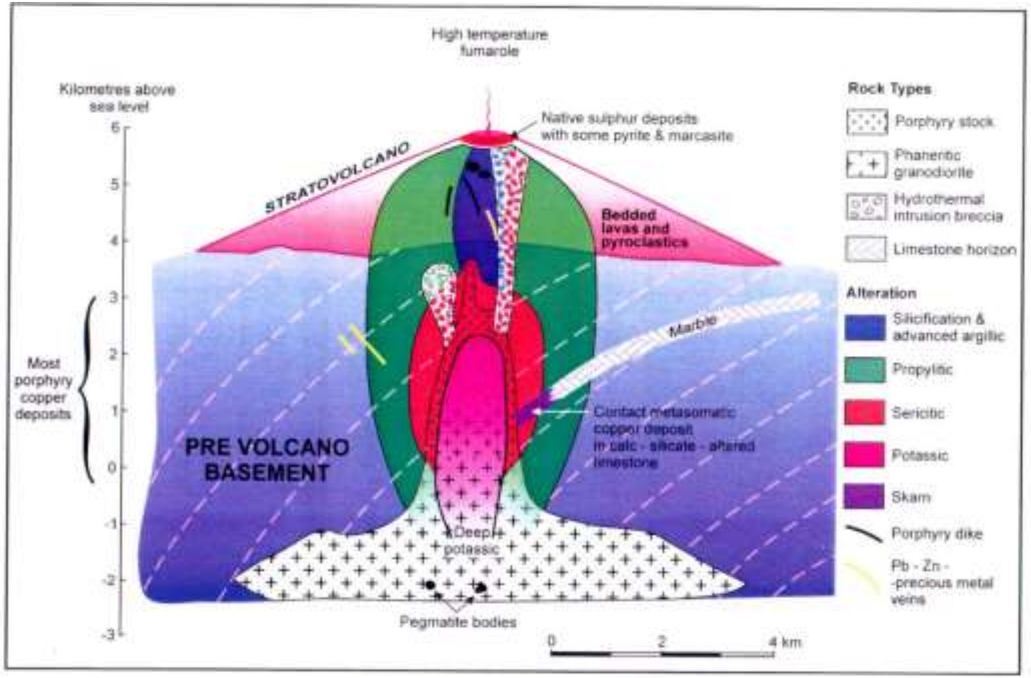


Predictive geophysical exploration models

e.g. Porphyry copper and IOCG deposits

Idealised cross-section of porphyry copper system

After Sillitoe



Idealised cross-section of porphyry copper system

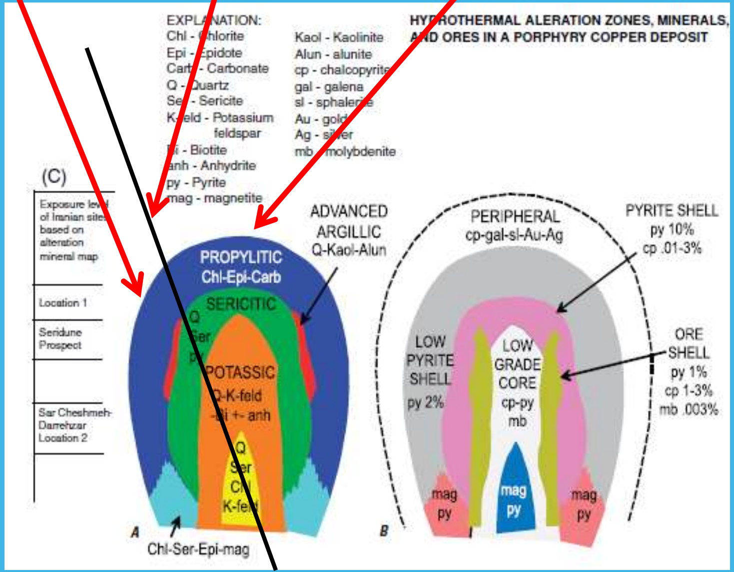
Laramide porphyry Cu deposits
Lowell – Guilbert QM model (1970)

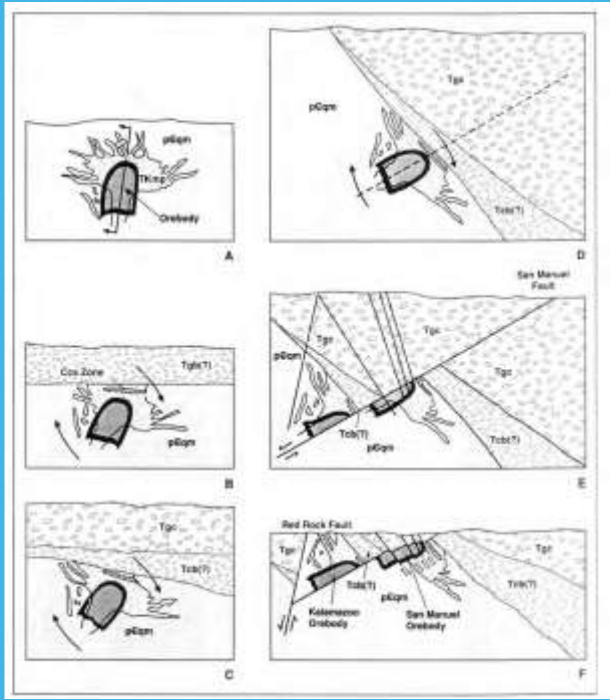
Structural evolution of the type example
(Wilkins & Heidrick, 1995)

Kalamazoo segment

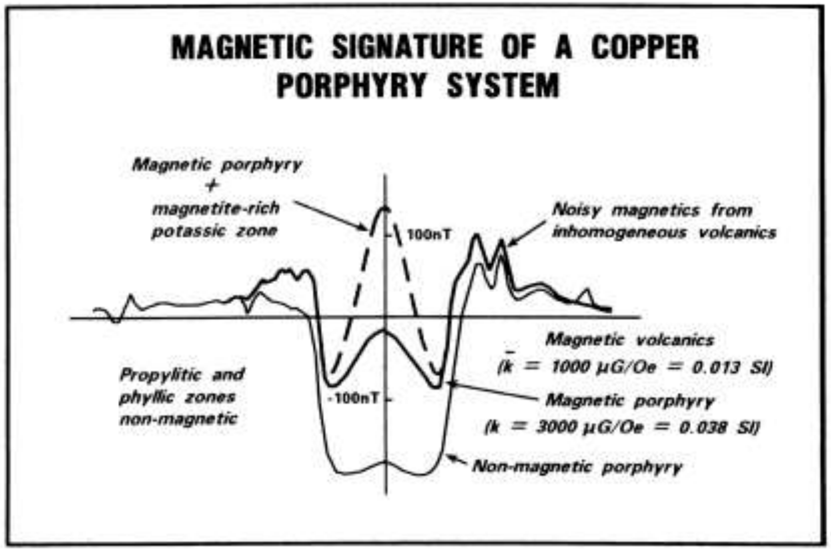
San Manuel Fault

San Manuel segment

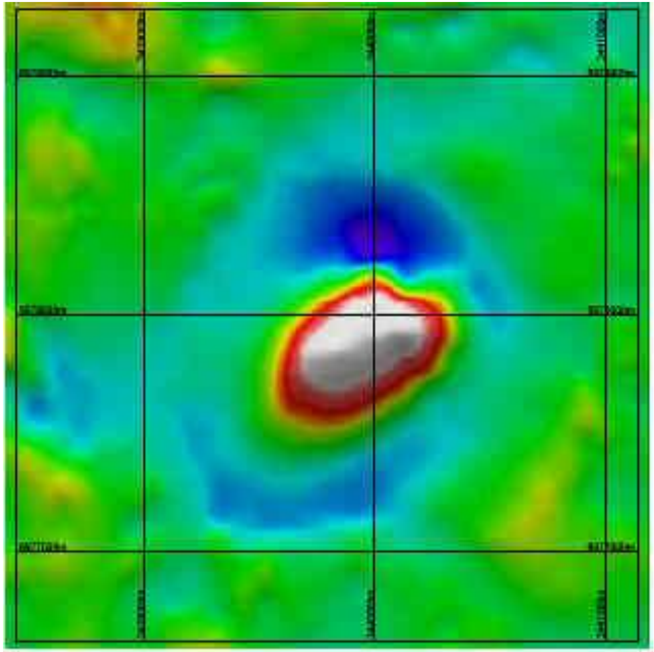




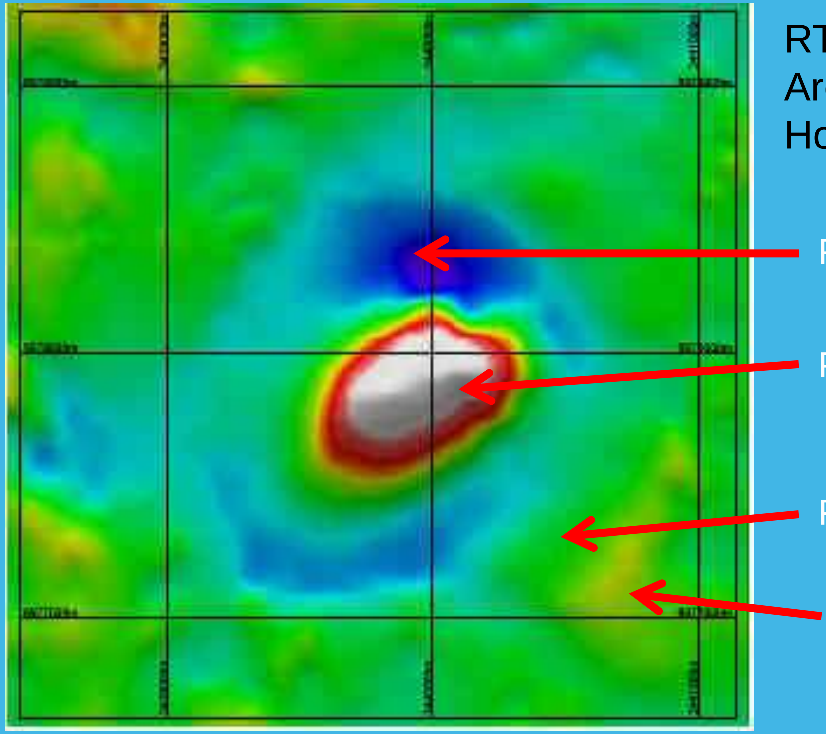
RTP TMI signature of an Au-rich porphyry Cu deposit that conforms to the idealised pattern



Idealised magnetic anomaly associated with a porphyry copper system, showing the noisy background associated with magnetic volcanics, the 'alteration low' associated with the propylitic and phyllic alteration zones, the high arising from the magnetic porphyry plus, in the case of gold-rich copper mineralisation, the magnetite-bearing potassic alteration zone.



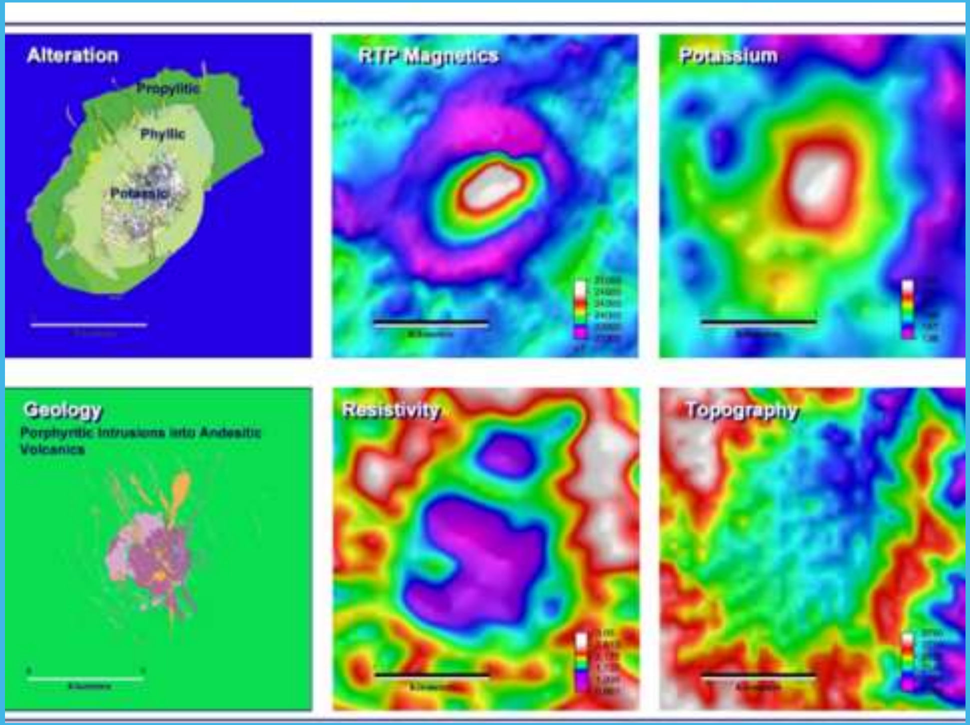
Type example of a gold-rich porphyry copper deposit with a classic zoned magnetic signature



RTP TMI of Bajo de la Alumbrera, Argentina (image by Terry Hoschke)

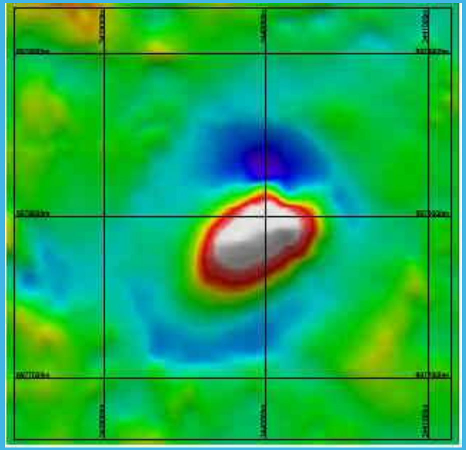
Bajo de la Alumbrera, Argentina

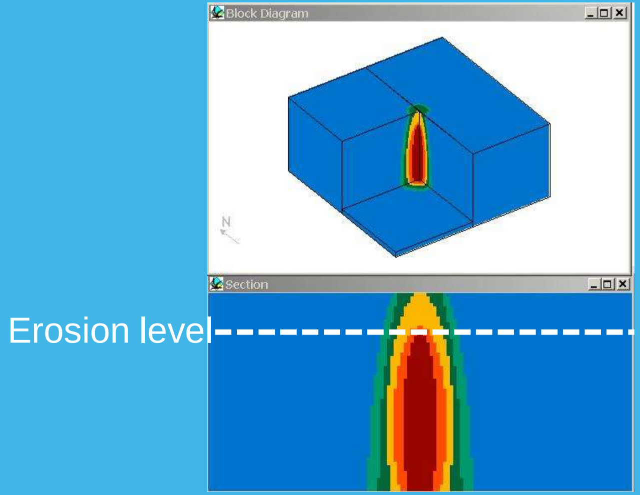
T. Hoschke, Geophysical signatures of copper-gold prophyry and epithermal gold deposits: implications for exploration. M.Sc. Thesis , Centre for Ore Deposit Studies, University of Tasmania



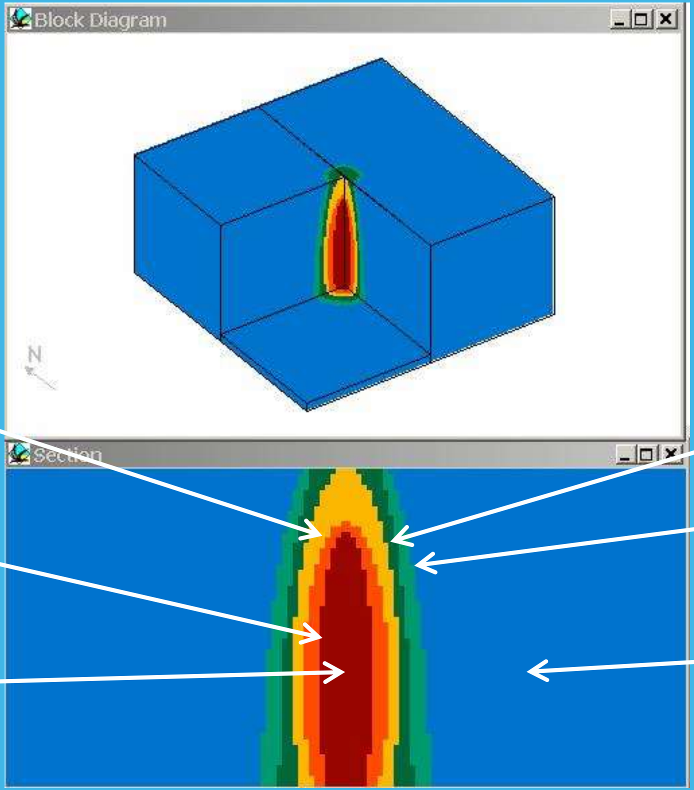
Why does the “archery-target” RTP signature of Bajo de la Alumbrera conform so well to the idealized model?

1. Emplaced into “homogeneous” volcanics
2. Untilted since emplacement
3. Erosion level means core of system subcrops (upper portion of phyllic/argillic shell removed)





Alumbrera type example ⇒ predictive model for Au-rich porphyry Cu emplaced into mafic host rocks



Phyllic (qtz-ser-py)
→ shallow argillic
k = 0.003 SI

Outer potassic
(bio-Kfsp-qtz-mt)
k = 0.173 SI

Oxidized intrusion + potassic
(qtz-mt-Kfsp veins) k = 0.351 SI

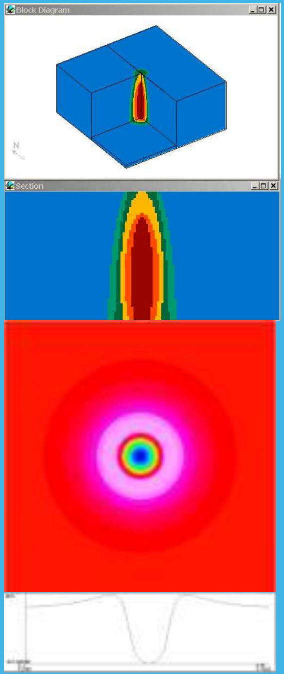
Strong propylitic
k = 0.007 SI

Weak propylitic
k = 0.027 SI

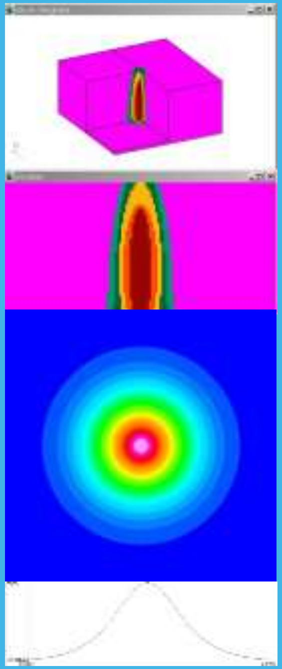
Mafic igneous/
mafic granulite
k = 0.043 SI

Effect of host rock composition: uneroded Au-rich porphyry Cu deposit in homogeneous host rock

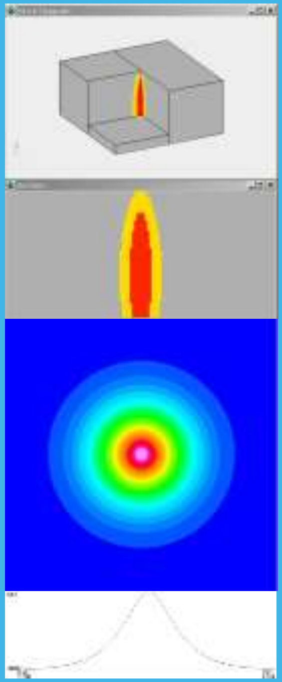
Mafic host – alteration low



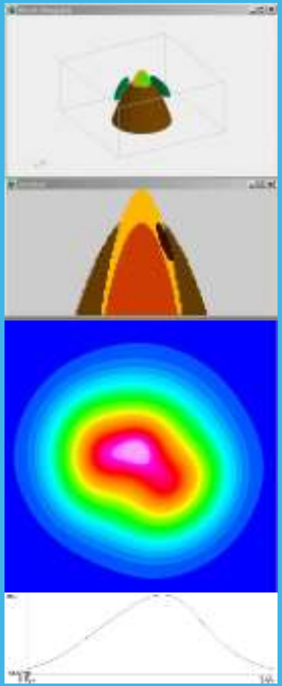
Felsic host – intrusion+alt. high



Quartzite host – intrusion high



Carbonate host – Int+alt+skn highs



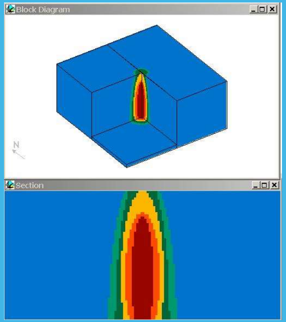
Effects of erosion level

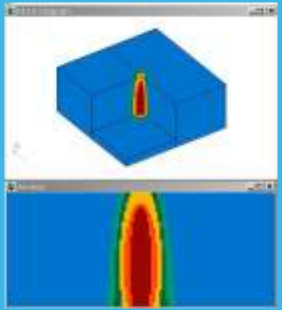
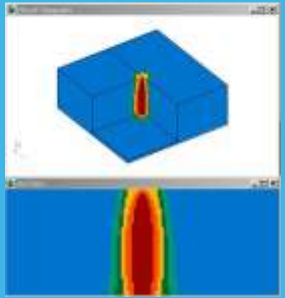
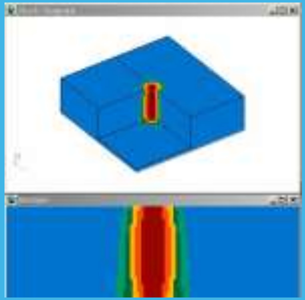
Uneroded

Eroded 250m

Eroded 500m

Eroded 1 km



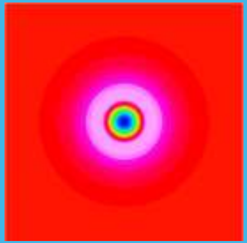
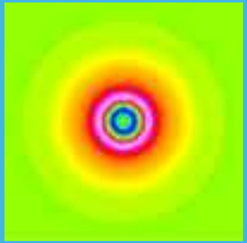
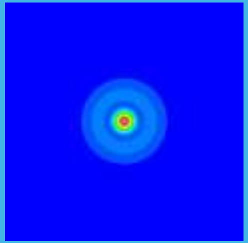
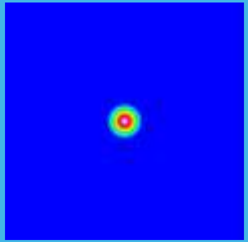




Alteration low

Archery target

Archery target

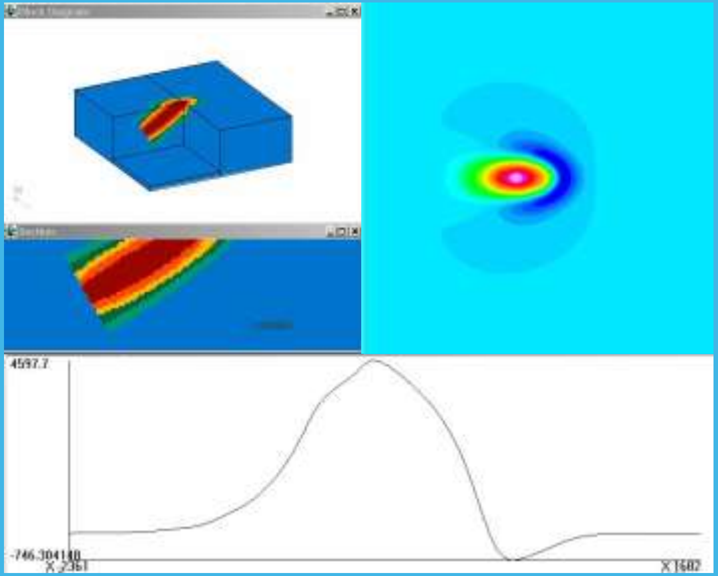
Alteration high

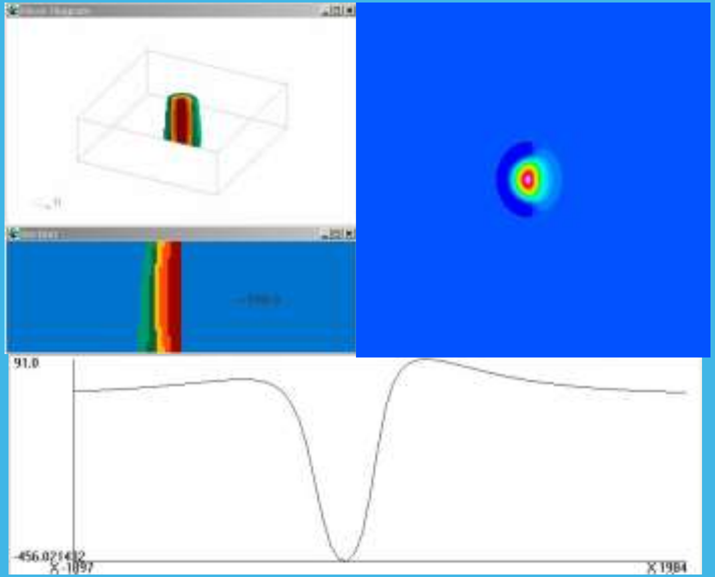


Effects of tilting and faulting

Tilted 60° and eroded 1 km

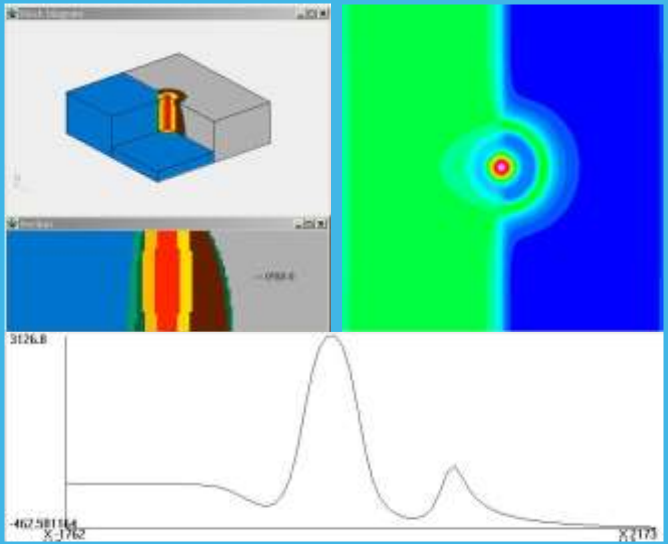


East half faulted out and eroded 1 km

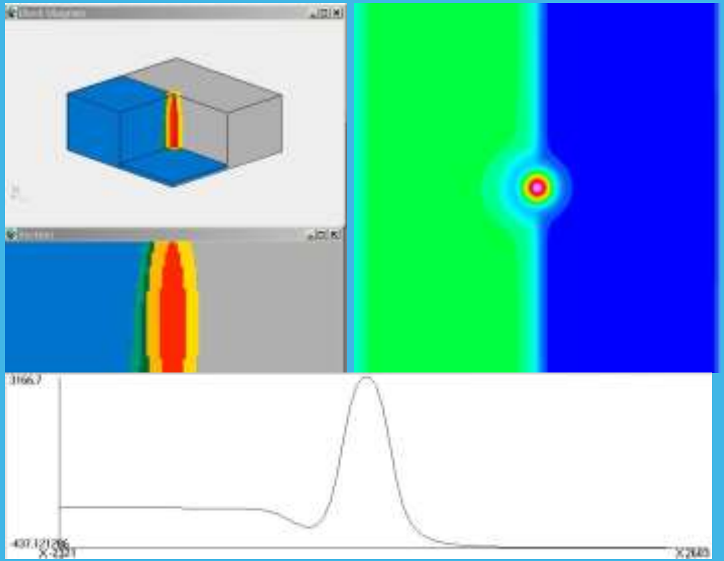


Emplacement along a geological contact

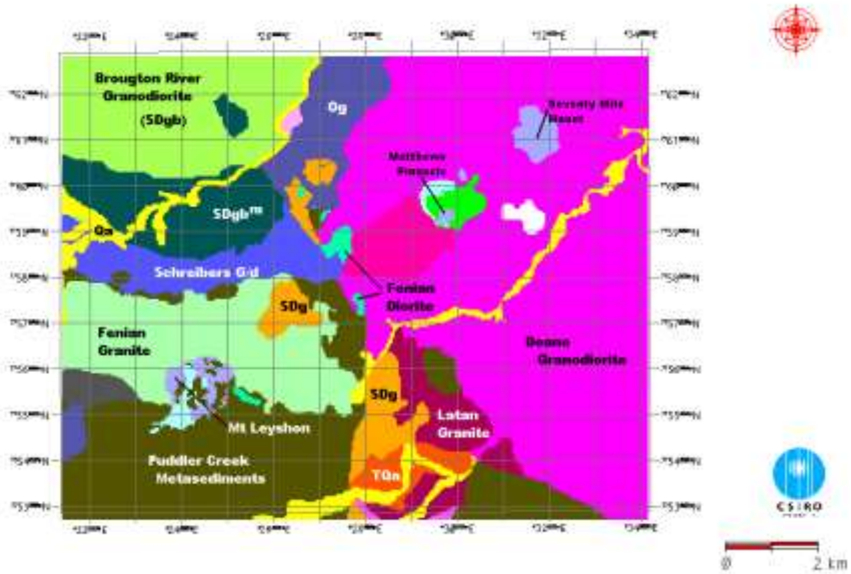
Andesite/carbonate

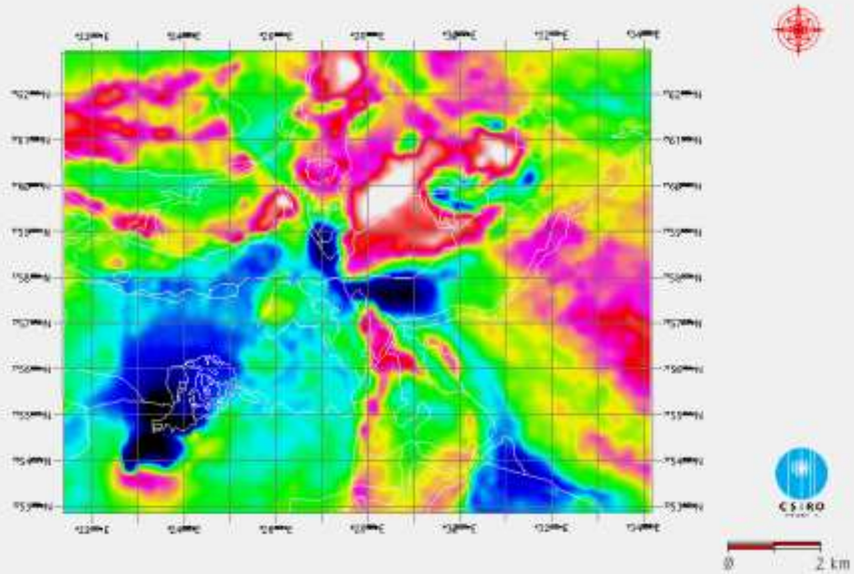


Andesite/quartzite



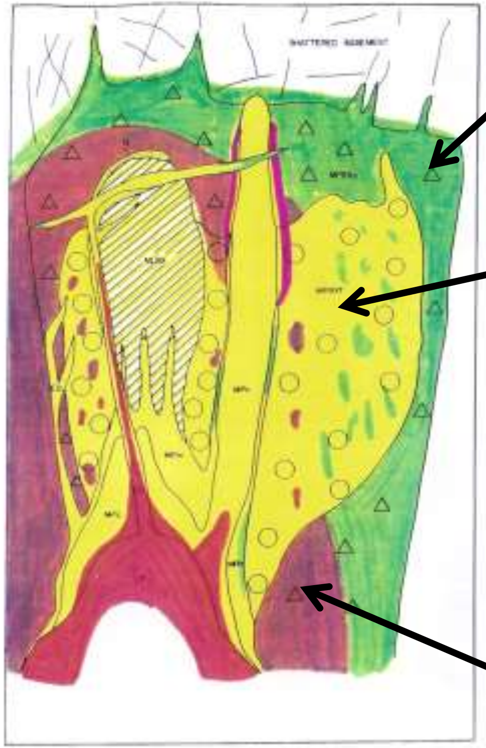
Mount Leyshon Intrusive Complex geology and TMI





Mount Leyshon alteration zoning

Blevin & Morrison, AMIRA P425

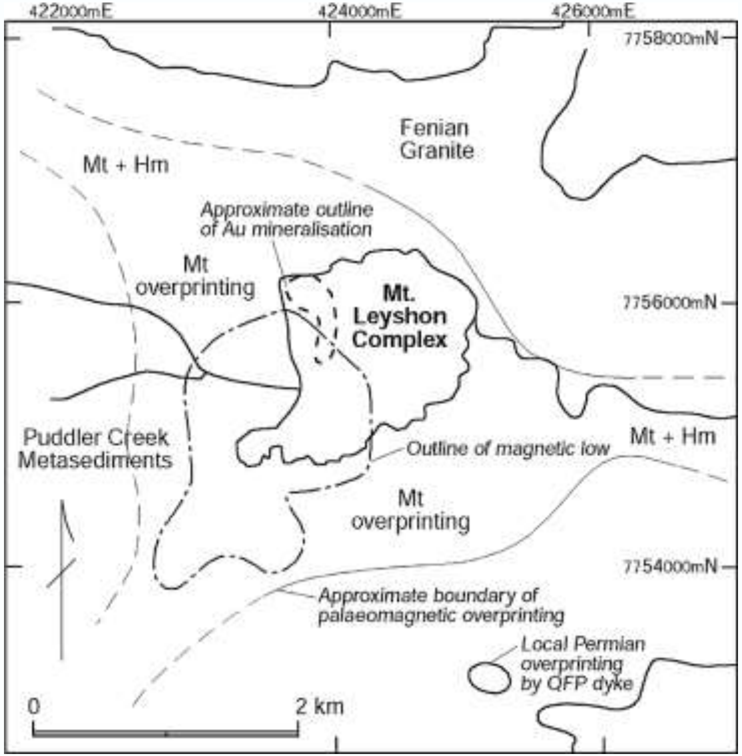


Propylitic: mt stable
→ hem stable (distal)

Phyllic overprint
(mt destructive)

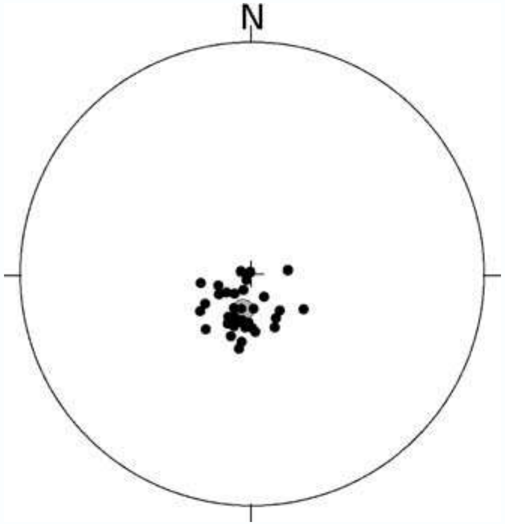
Potassic (biotite-mt
+ mt-qtz veins)

Clark & Lackie, GJI, 2003



Magnetic properties of MLIC

Early Permian (285 Ma)
remanence direction
(Clark & Lackie, 2003)



Dec = 196°, Inc = +77°

AMIRA P700 Database: Clark & Geuna (2004)

Fenian Diorite: k = 0.14, NRM = 4.2 A/m, Q = 2
(Permian direction)
Ord. Granite: k = 0.001, NRM = 0.06 A/m, Q = 1.2
(Silurian direction)

Phyllic alteration zone

Felsic porphyries & intrusive breccias of MLIC:
k < 0.001 SI

Potassic alteration zone

Dolerite: k = 0.06, NRM = 7.5 A/m, Q = 3.1
Puddler Ck: k = 0.048, NRM = 4.2 A/m, Q = 2.2

Unaltered (lower susceptibility; weak NRM)
Dolerite: k = 0.008; Puddler Ck: k = 0.00025

Conclusions and some exploration criteria

Hydrothermal alteration has a profound effect on magnetic properties of rocks and on magnetic signatures of mineralized systems

For certain well-studied deposit types, alteration zoning patterns are predictable and have predictable effects on magnetic properties

Magnetic signatures are highly variable, depending on local geological setting, *but in reasonably predictable ways*

Predictive magnetic exploration models guide explorationists towards magnetic signatures that are appropriate for the specific geological setting in each prospect, *not "look-alikes" of known deposits*

Conclusions and some exploration criteria

Indicators of favourable structures

Structural controls at a range of scales, from province to prospect scale, may be evident in detailed magnetic data. Intersections of such lineaments appear to be favourable for porphyry and/or epithermal mineralization.

Indicators of fractional crystallization

Zoned plutons

Multiple/nested intrusions

Geophysical indications of an underlying magma chamber

Well-developed contact aureoles

Strong remanent magnetization of contact aureoles

Predictive magnetic exploration models

Magnetic signatures should be appropriate for specific geological setting

Predictive models can also be used to assess the detectability of particular types of deposit in the local geological setting.

Conclusions and some exploration criteria

Understanding effects of primary composition and alteration on magnetic properties

- Understanding the effects of protolith composition and alteration type on magnetic properties is crucial for evaluating magnetic signatures of hydrothermal systems.
- Cu-Au is associated with more magnetic magmatic-hydrothermal systems than Cu-Mo; W-Mo-Bi and Au in tin provinces is much less magnetic.
- In oxidized Au-bearing systems, Au mineralization is often associated with the felsic end of magmatic evolution and is then associated locally with a weaker magnetic character and higher radioelement contents.
- Strong alteration zoning of magnetic character is favourable: early potassic alteration, particularly of mafic protoliths, is often magnetite-rich, contrasting strongly with phyllic overprinting, which is magnetite-destructive. Large zones of contrasting intense alteration suggest development and preservation of a mature hydrothermal system.

Thank you

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