Mineral Exploration Using Natural Source EM

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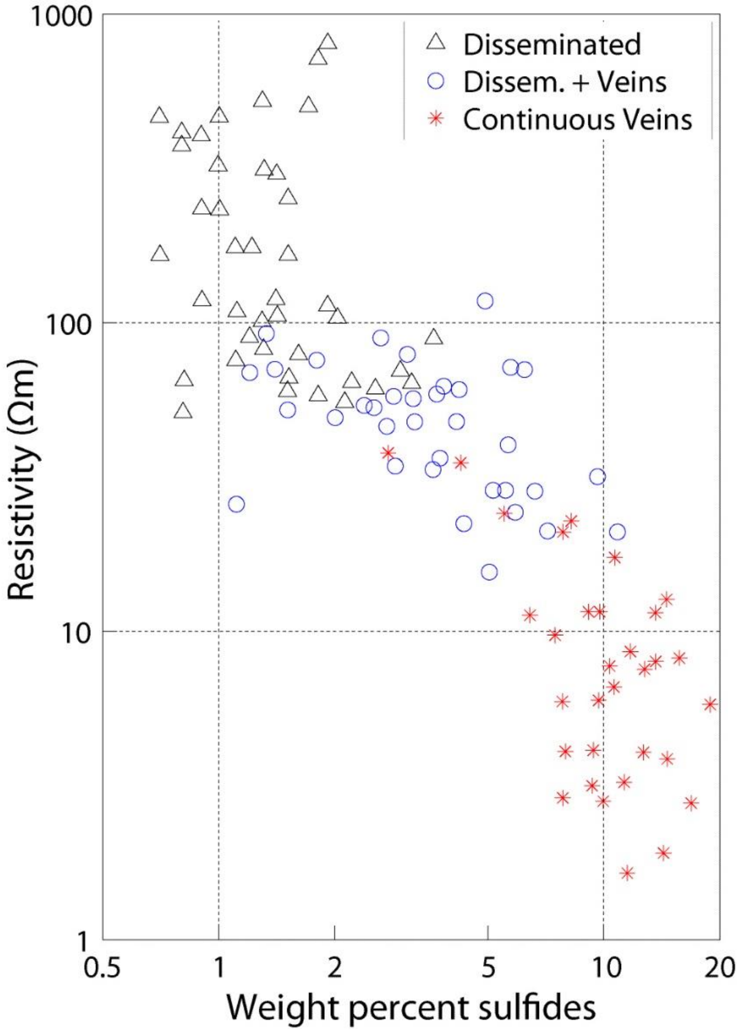
Real Mining. Real People. Real Difference.

OUTLINE

- Last ~~10~~ 13 years
- Mineral System Context
- Magnetotellurics
- ZTEM
- Four examples
- Topics at Exploration’27
- Acknowledgements



After Nelson and Van Voorhis (1983) as modified by Lee (2015)

THE LAST 10 YEARS

Integrating the Geosciences: The Challenge of Discovery

1. Technology, and the increasing uptake of Natural Source EM methods:

- MT, ZTEM, and inversion codes
- Frank Morrison said the same thing 20 years ago

(Morrison, H.F. and E. Nichols, 1997, Mineral Exploration with Natural Electromagnetic Fields, in Proceedings of Exploration 1997.)

2. A maturing perspective on Physical Properties:

3. The Mineral System Concept:

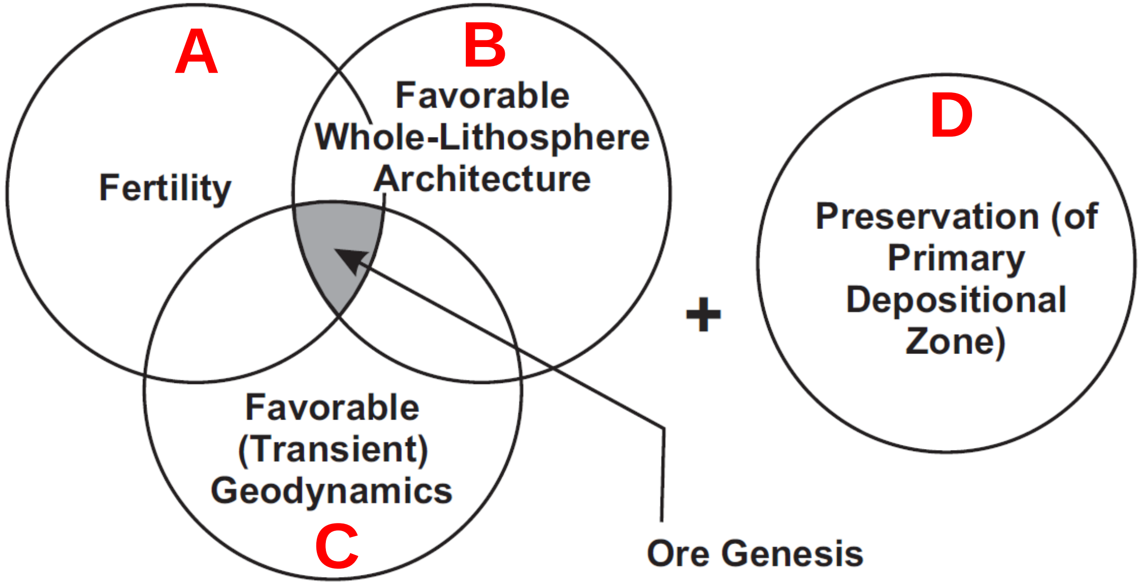
"[that] focuses mineral exploration strategies on incorporating primary datasets that can map the critical elements of minerals systems at a variety of scales, and particularly the regional to camp scales needed to make exploration decisions"

(McCuaig, T.C. and J.M.A. Hronsky, 2014, The mineral system concept: The key to exploration targeting: Society of Economic Geologists, Special Paper 18, 153-175.)

THE MINERAL SYSTEM CONCEPT: THE KEY TO EXPLORATION TARGETING

1. Four critical elements of a mineral system:

- Ore genesis occurs as a conjunction of whole lithosphere architecture, favorable transient geodynamics, and fertility.
- Post-mineralization preservation of the primary depositional zone is a critical element for ore deposit discovery.



McCuaig and Hronsky (2014)

THE MINERAL SYSTEM CONCEPT: THE KEY TO EXPLORATION TARGETING

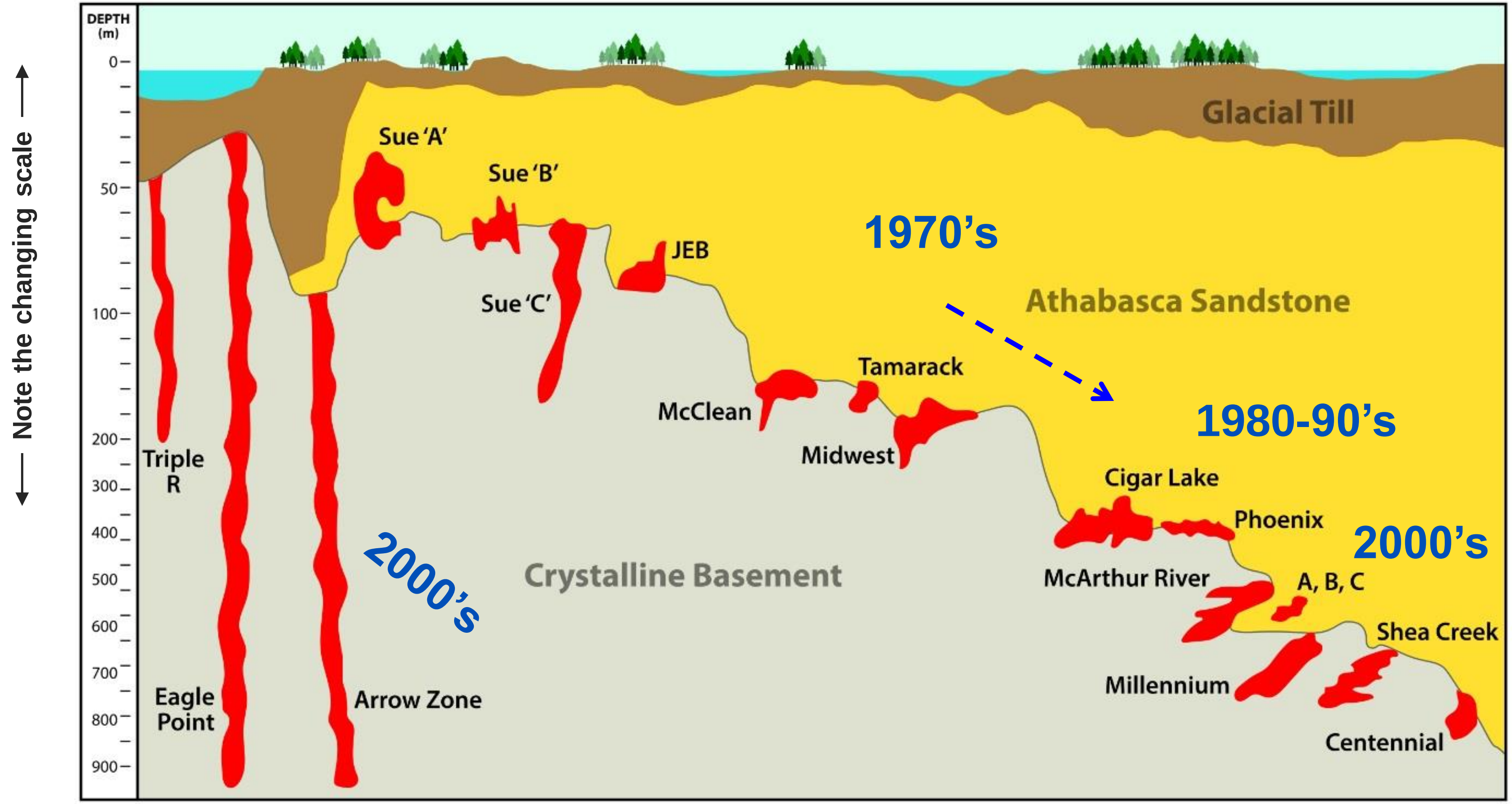
2. Scale dependency:

- These critical elements require translation into features that can be mapped directly in existing or obtainable geoscience datasets at the appropriate scale to generate targets
- Through an understanding of physical properties in the context of the mineral system and the appropriate use of inversion, Natural Field EM is applicable to exploration targeting from Deposit through to Continental scales

	Fertility	Favorable Geodynamics	Favorable architecture	Primary Depositional Zone
Ore-shoot				
Deposit			Audio MT	
Camp			AMT / ZTEM	
Province			Broadband MT / ZTEM	
Continental			Long Period MT	

EXPLORATION SEARCH SPACE IS INCREASING → DEEPENING

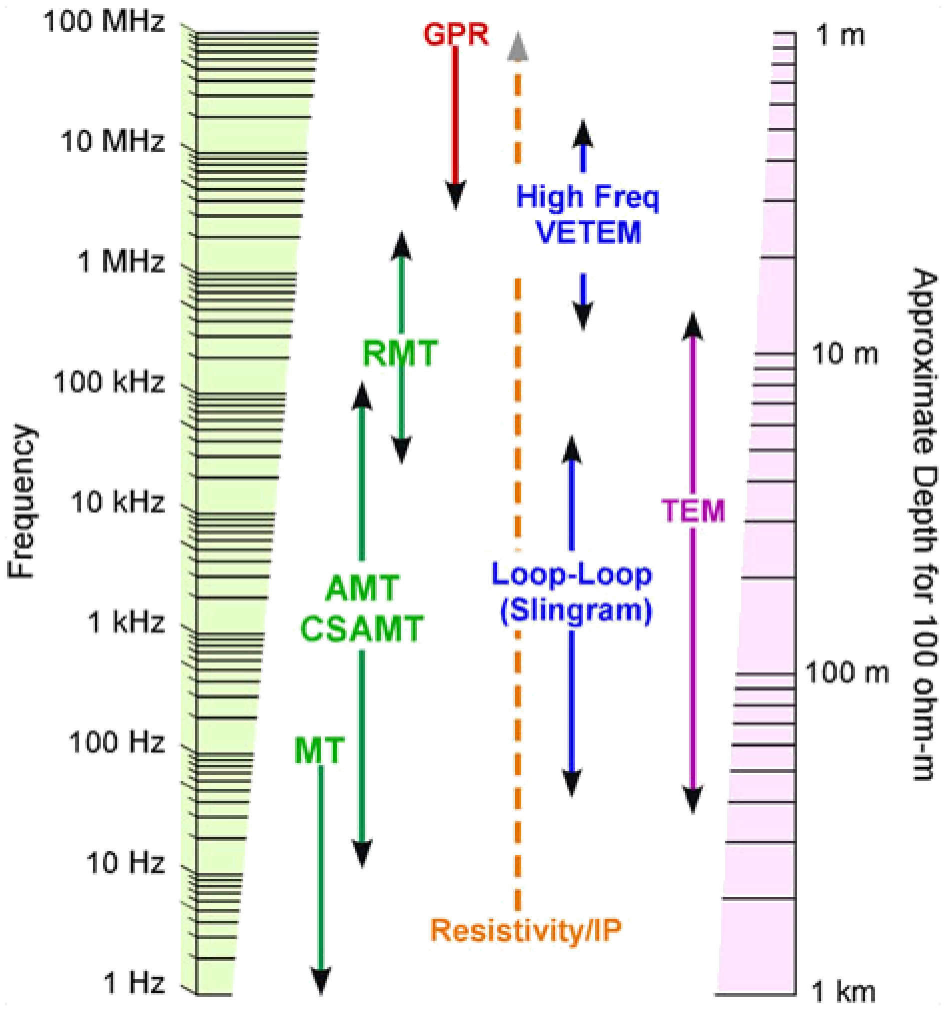
The Athabasca Basin (Unconformity-Associated Uranium)



Modified from Thomas (2015)

MAGNETOTELLURICS

- *Resistivity* is proportional to the $\frac{telluric}{magneto}$ ratio
- … analogous to $Resistance = \frac{voltage}{current}$
- Measurement of the E-field is thus a requirement to infer the geo-electric structure in an absolute sense
- Incremental advances in the past 10 years:
  - ✓ Multi-parameter surveys / distributed arrays
  - ✓ 24-bit electronics
  - ✓ Broadband coils
  - ✓ Capacitive line-antennas
  - ✓ Remote referencing
  - ✓ Inversion: 3D, meshing, joint MT+NFEM
  - ✓ Related fields: CSEM



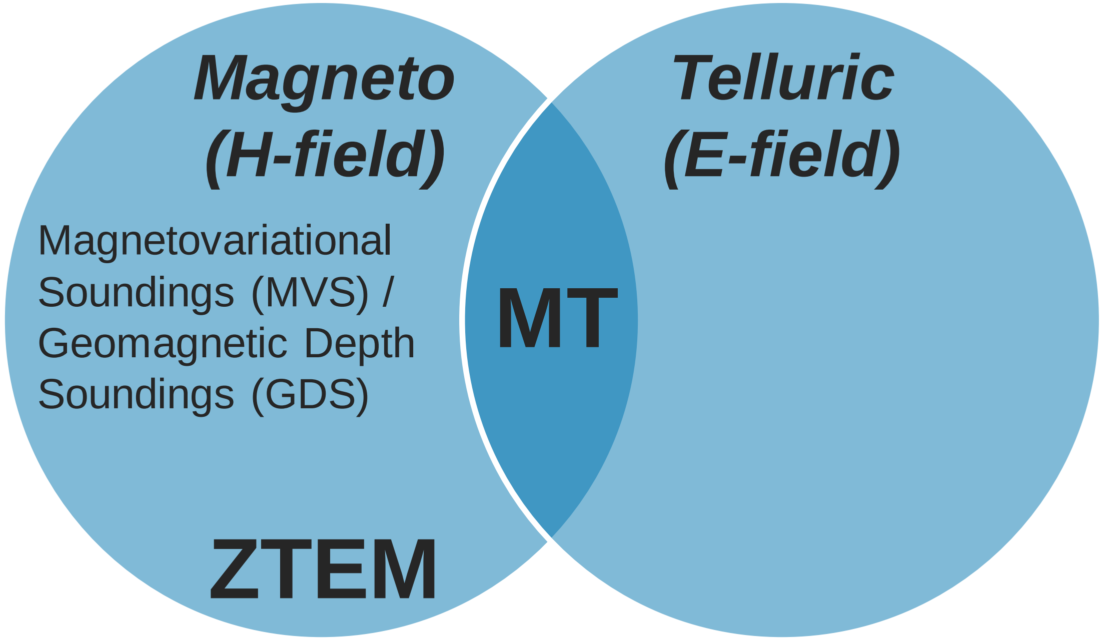
http://emgeo.sdsu.edu/foreward.html

ZTEM: Z-AXIS TIPPER ELECTOMAGNETICS

- A Natural Field EM system…but it's *not* "airborne MT"
- Tipper measurements ($\frac{Hz}{Hx}$ or $\frac{Hz}{Hy}$) are dimensionless
- These *magnetovariational* soundings therefore say nothing about absolute resistivity.

∆ Lack of intrinsic resistivity, can't resolve layered geology, limited bandwidth

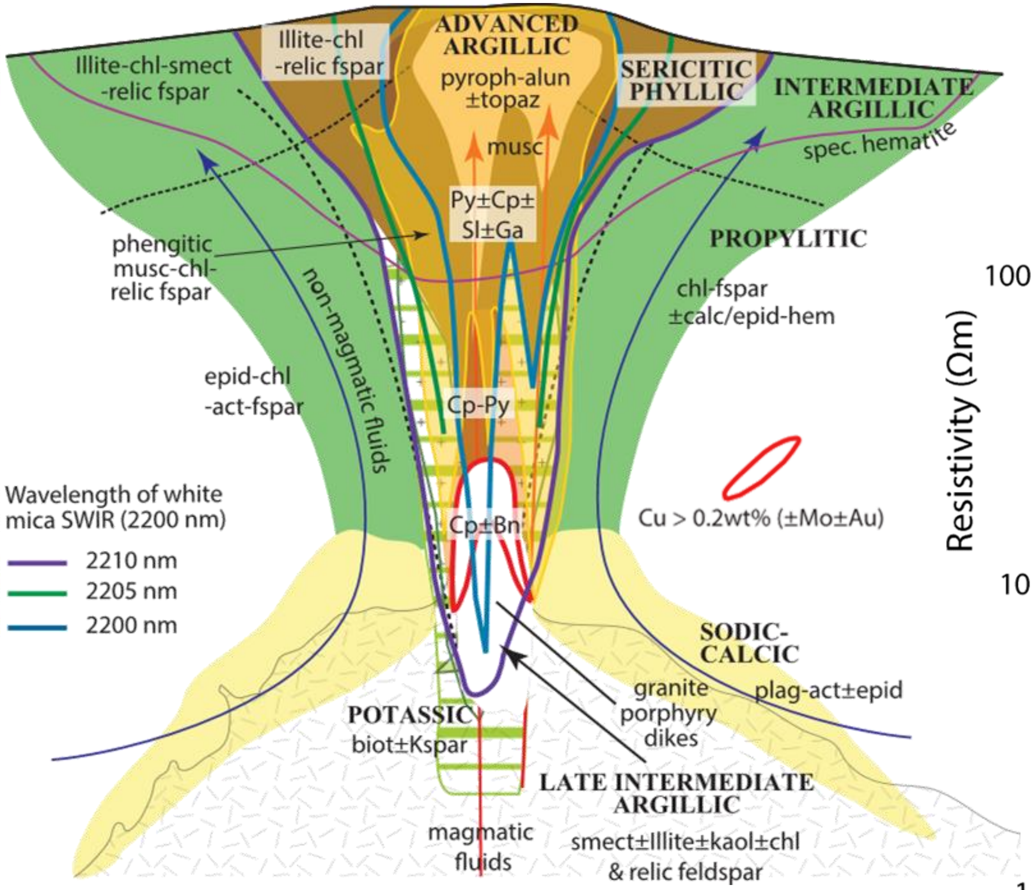
+ Can collect large swaths of data in rugged and remote areas at low cost, deepest penetration of any airborne system, less affected by ground clearance variations



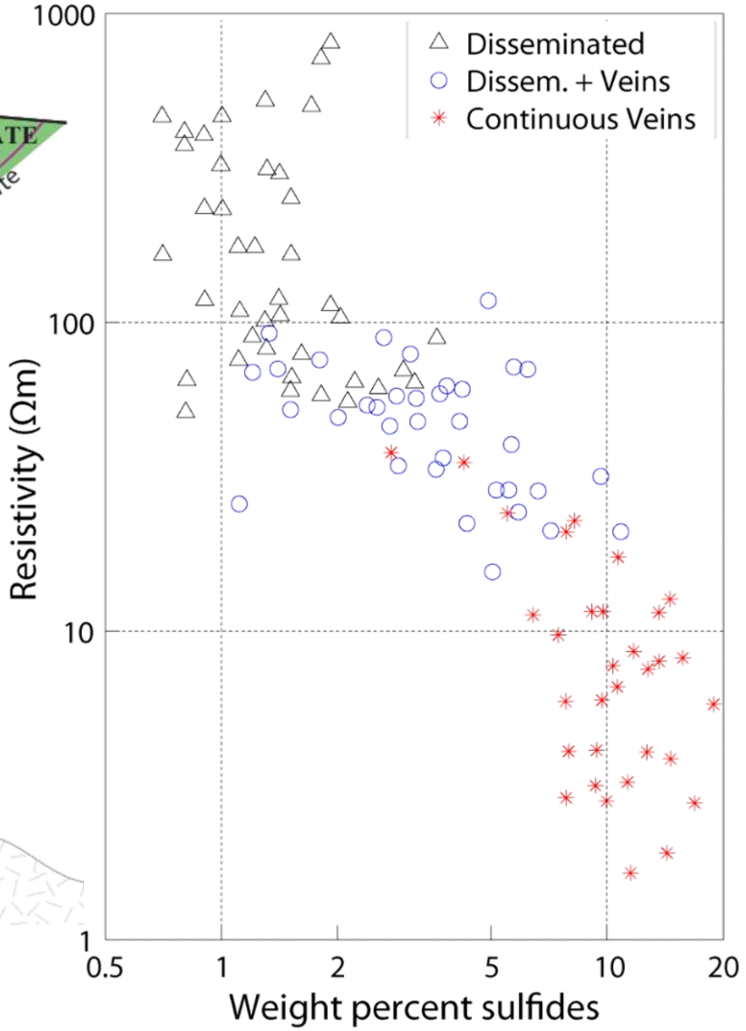
- Advances in the past 10 years
  ✓ Inversion → no longer interpreting 24 grids

FACTORS THAT INFLUENCE RESISTIVITY WITHIN A PCD

- Porosity, permeability, fluid saturation, pore fluid salinity (TDS)
- Amount and composition of clay minerals (alteration intensity)
- Sulphides (wt% abundance and electrical connectivity)
- Porosity and alteration are often intimately associated with sulphide abundance, so an empirical correlation remains despite not quantifying all the factors

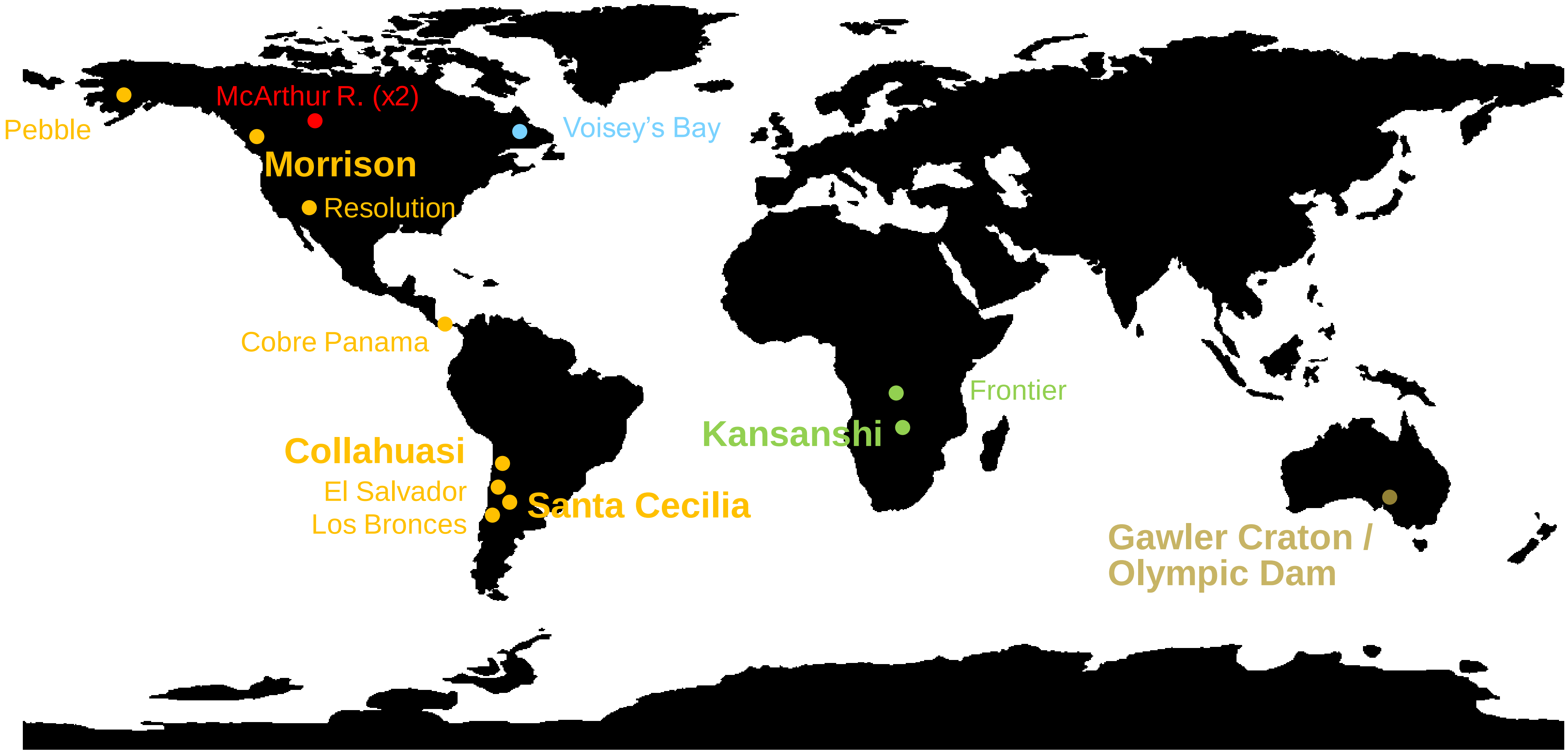


After Halley et al. (2015)



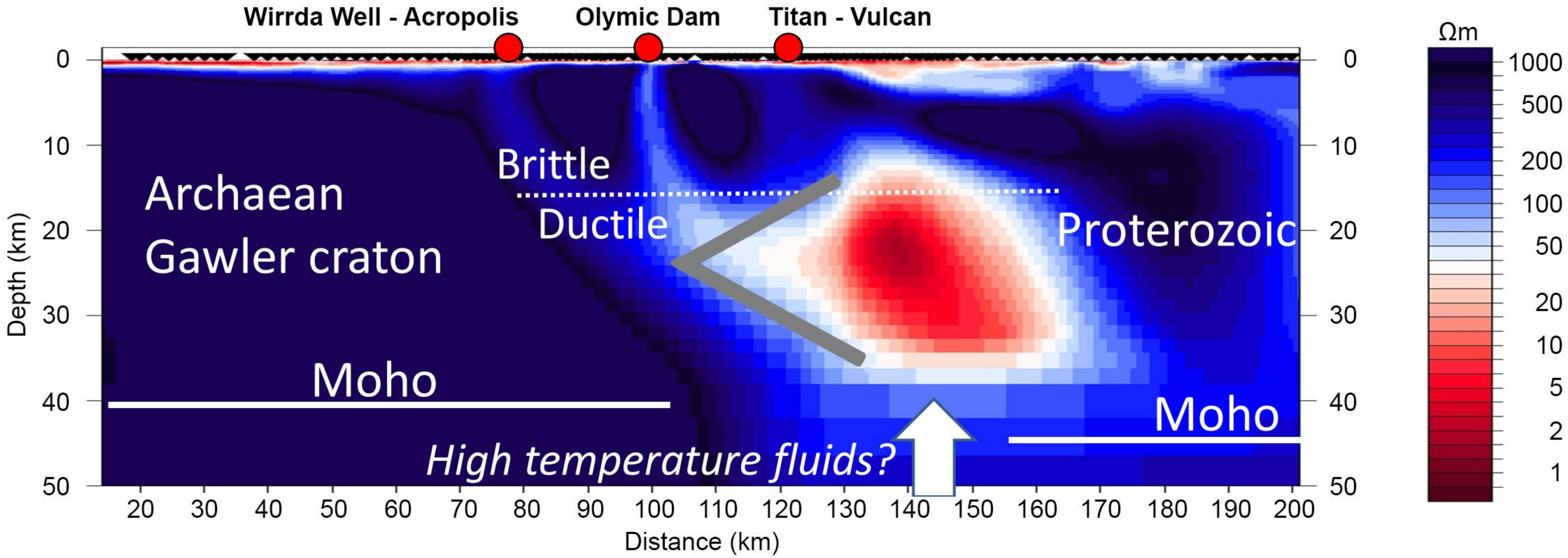
After Nelson and Van Voorhis (1983), modified by Lee (2015)

EXAMPLES DISCUSSED IN THE PAPER



GAWLER CRATON, SOUTH AUSTRALIA

Regional MT transect 2D inversion over Olympic Dam



Modified from Heinson et al. (2016)

GAWLER CRATON, SOUTH AUSTRALIA

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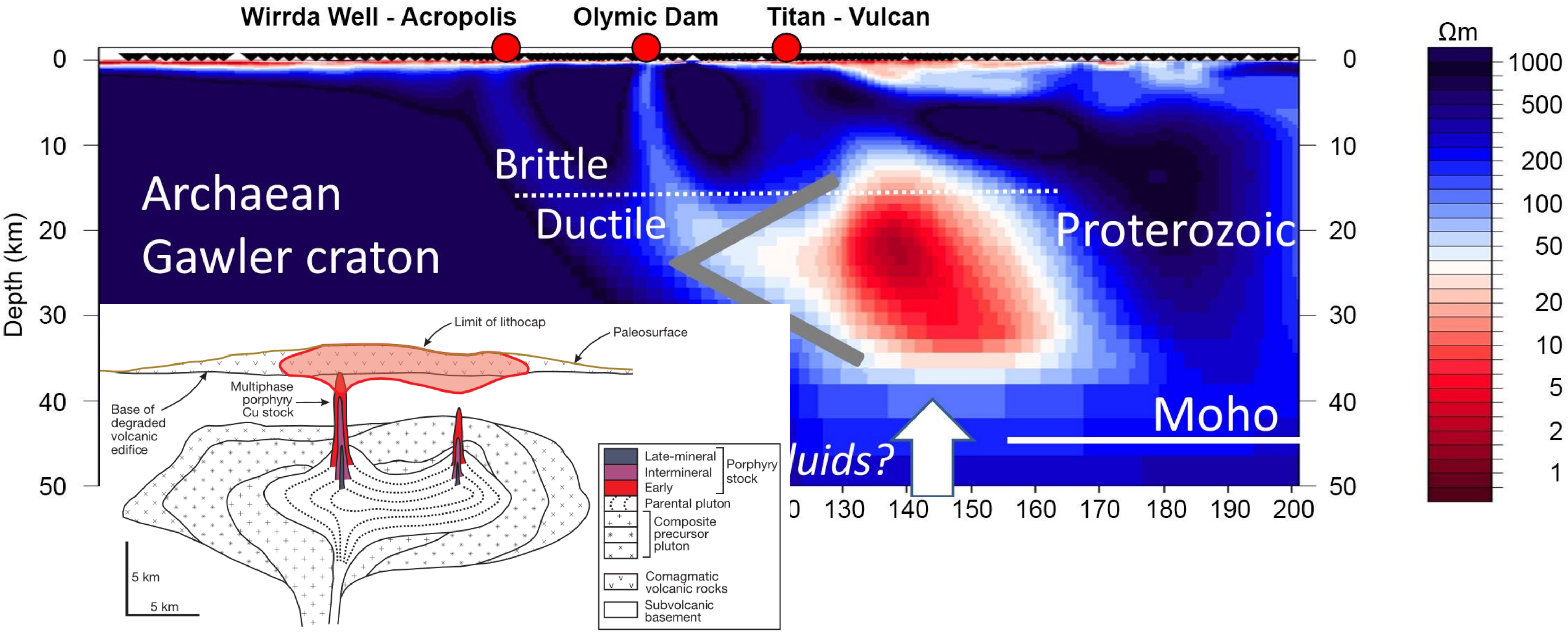
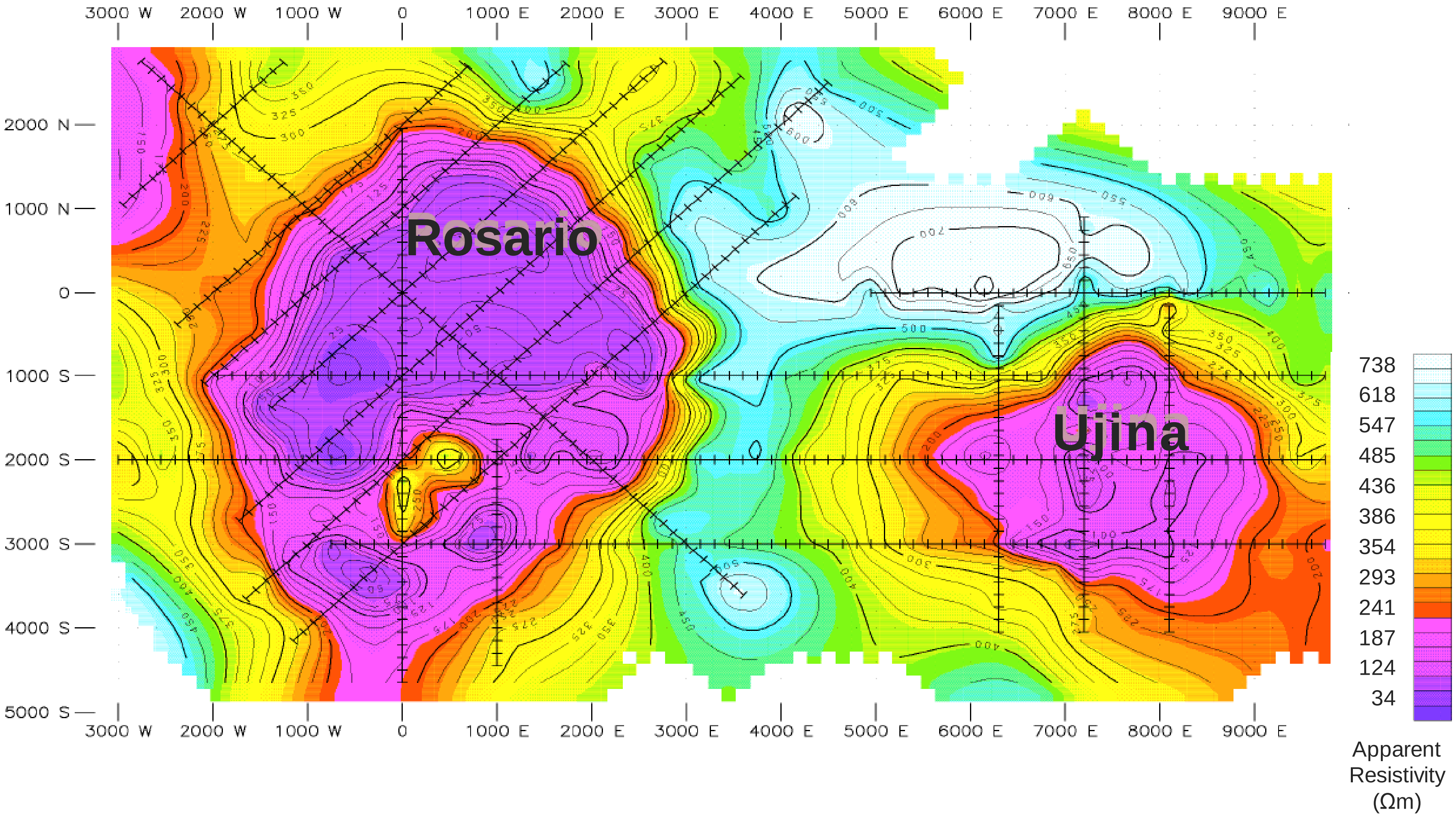


Modified from Heinson et al. (2016) and Sillitoe (2010).

COLLAHUASI, CHILE

Dipole-dipole resistivity data

- One of the earliest PCD's discovered by directly targeting a geophysical conductor
- Rosario's high-grade vein system was known, but Ujina's supergene enrichment blanket covered by 170m of ignimbrite wasn't
- Ironically, the first drill holes targeted the large, yet offset, barren-pyrite IP anomaly (not shown).



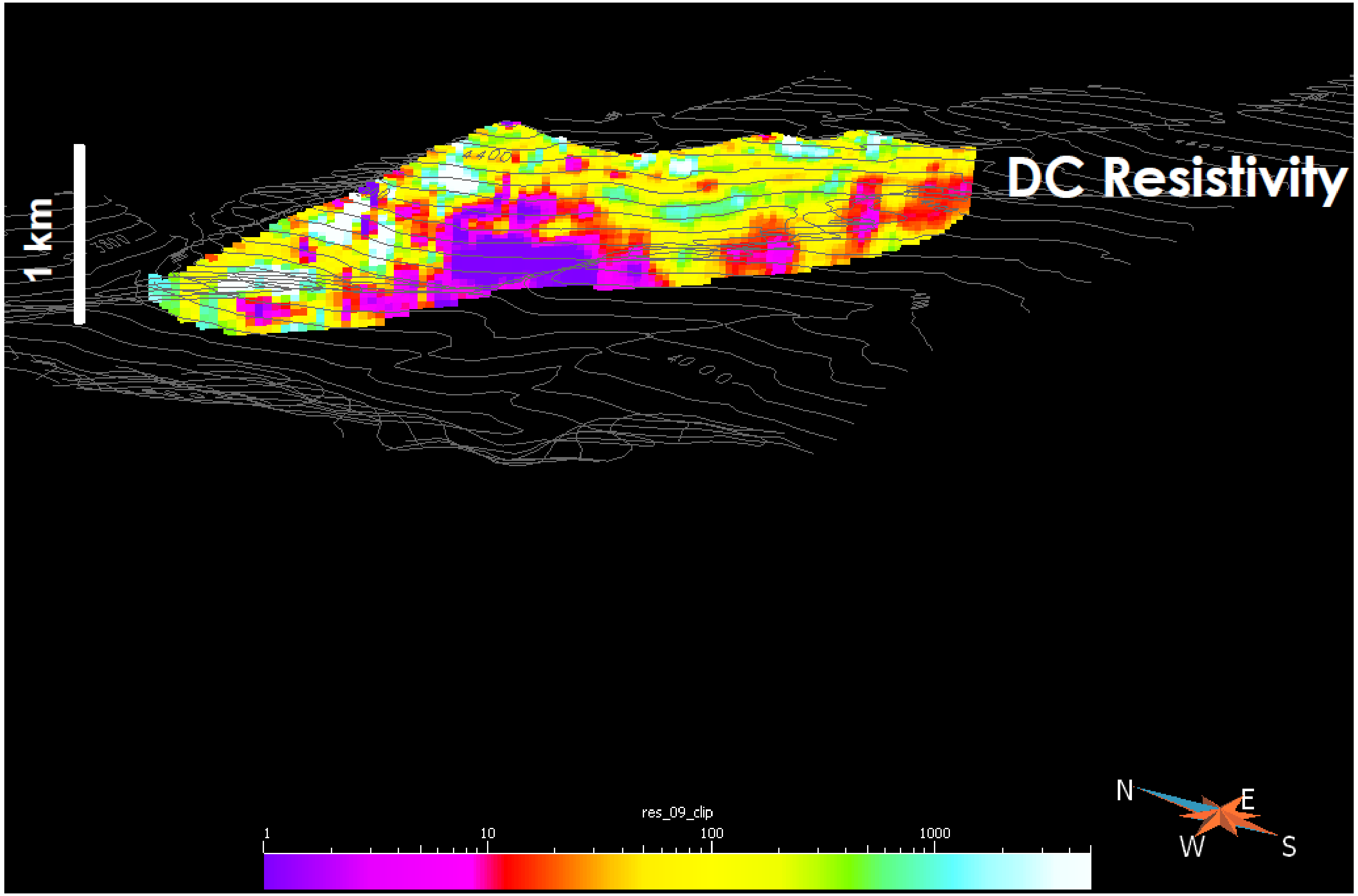
Modified from Hoschke (2001)

SANTA CECILIA, CHILE

Gold-rich porphyry in the Maricunga belt

- Vertically elongated system, with multiphase quartz-diorite stocks intruding volcanic host rocks

- 2010: shallow CSAMT survey identified a conductive drill target that returned >1000m at 0.25% Cu, 0.2 g/t Au, and 80 ppm Mo.

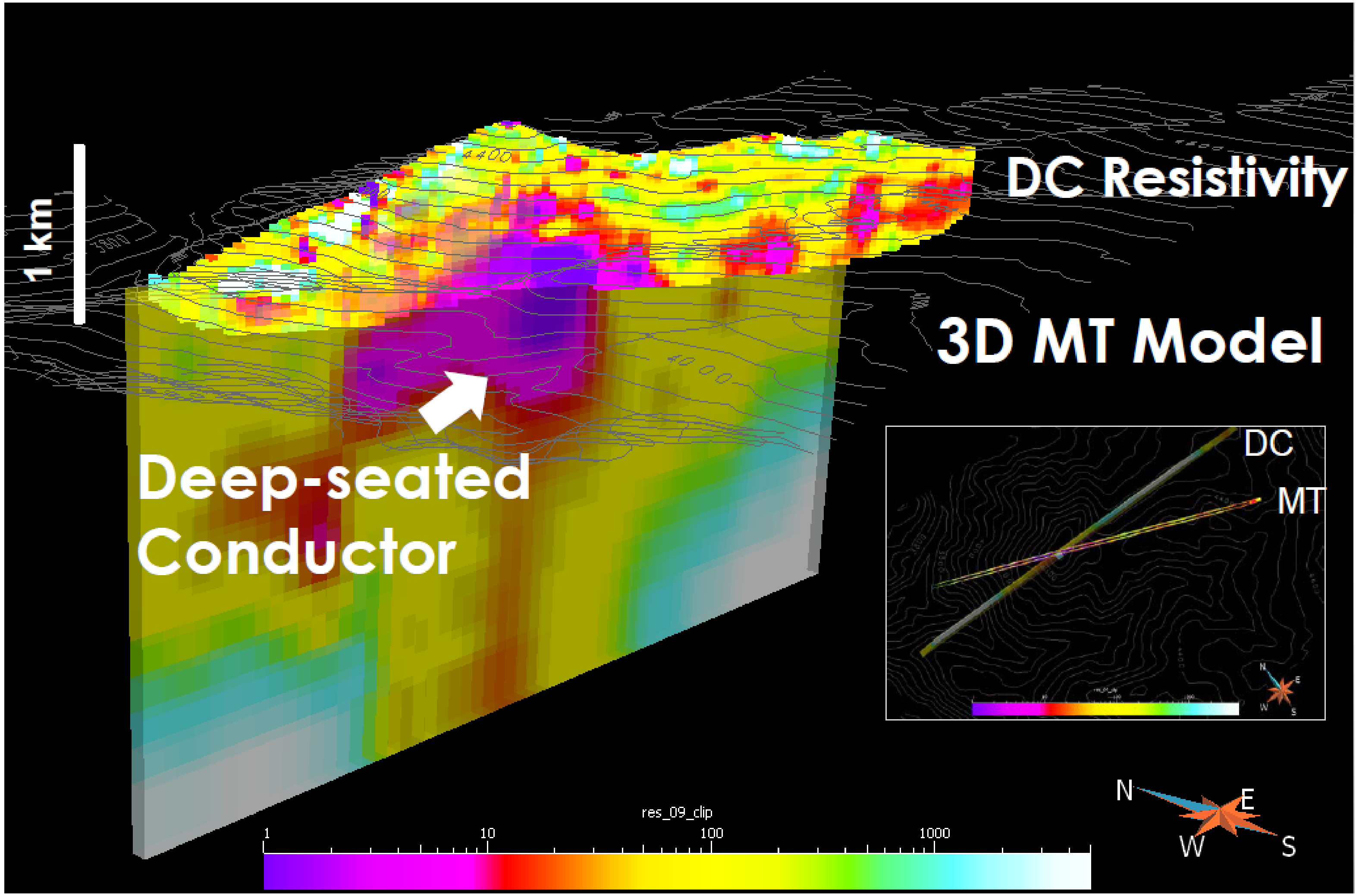


After Bournas and Thomson (2013)

SANTA CECILIA, CHILE

Gold-rich porphyry in the Maricunga belt

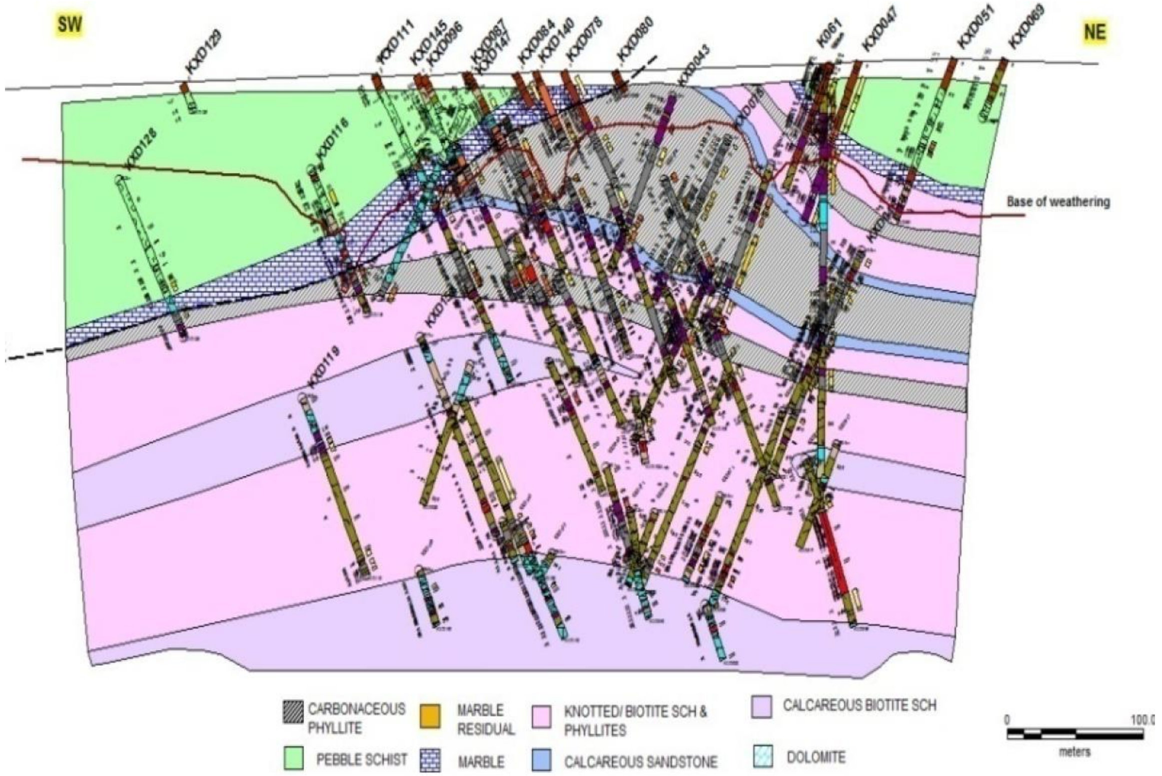
- 2012: larger DCIP/MT "*3D Orion*" survey with 50 portable Distributed Acquisition Units
  - 300 Rx units, 539 Tx sites provided >150,000 DC and IP data points
  - Advantage: "free" NFEM data during time when not transmitting
  - Excellent agreement between the DC and MT data, with near-surface resolution and an indication of the deep-seated resistivity structure, with an inferred relationship to the causative stock(s)

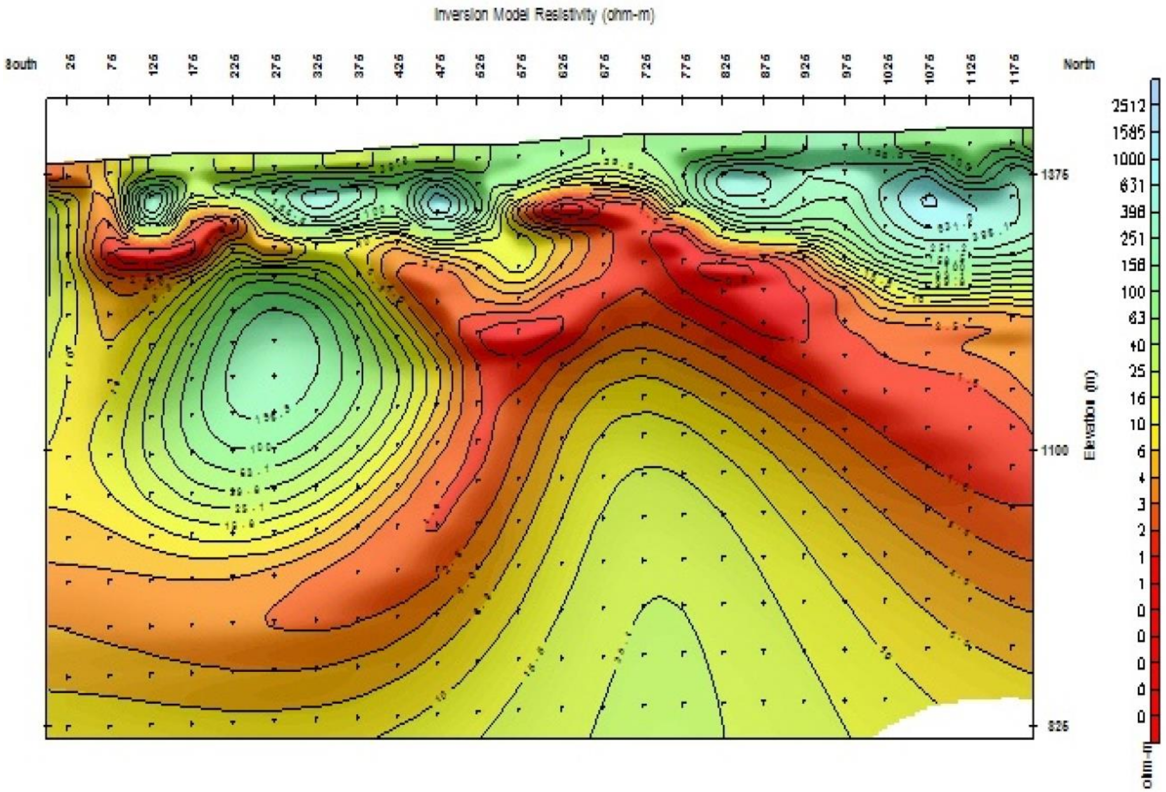


After Bournas and Thomson (2013)

KANSANSHI, ZAMBIA

AMT Mapping Geology





Wijns (2014)

MORRISON, BC

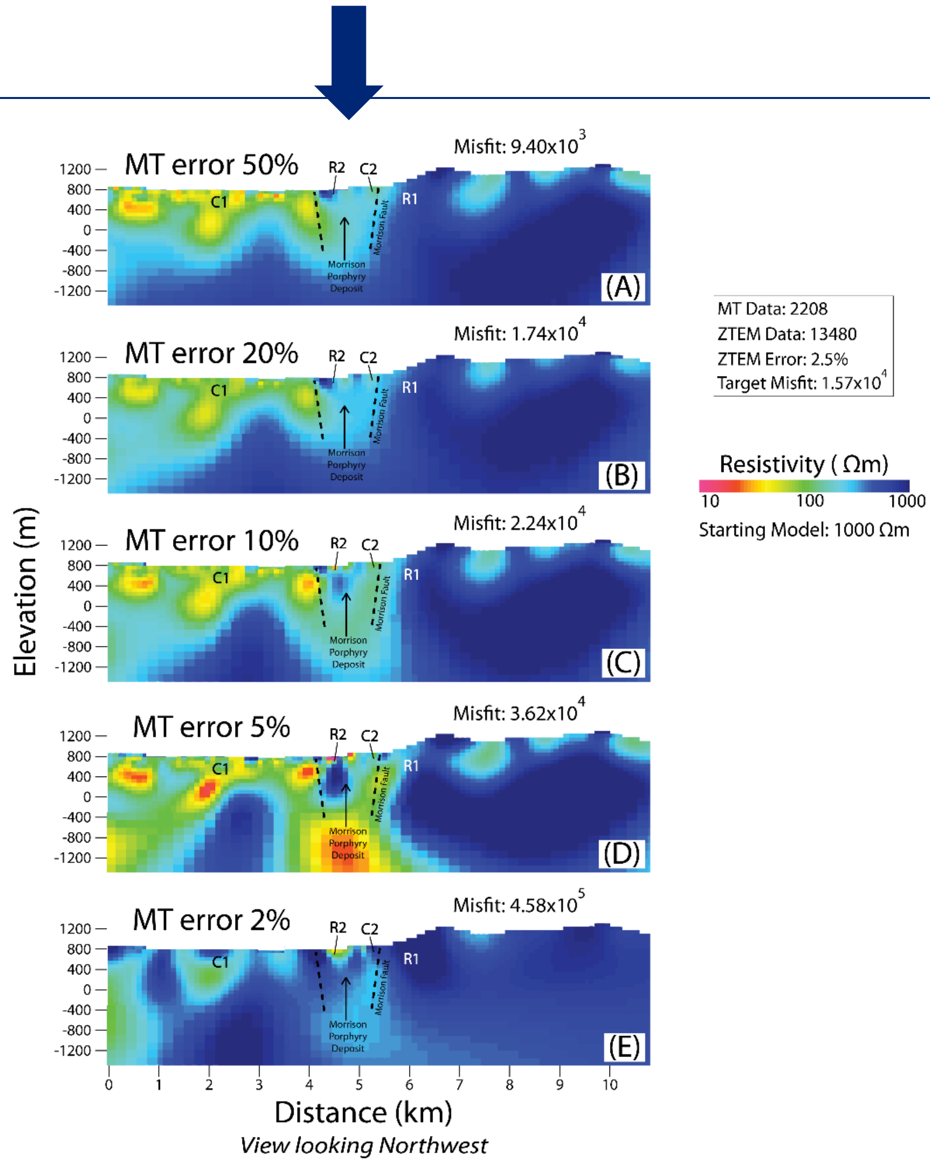
Joint MT – ZTEM inversion

- Recent advances in the joint inversion of ground and airborne data are making Natural Field EM methods an even more powerful tool for resolving complete mineral systems.

- Sasaki et al. (2014): "…inversion of sparse AMT data was shown to be effective in providing a good initial model for ZTEM inversion. Moreover, simultaneously inverting both data sets led to better results than the sequential approach by enabling [the identification of] structural features that were difficult to resolve from the individual data sets."

- Lee's work was recently published:

  Lee, B., M. Unsworth, J. Hübert, J. Richards, and J. Legault, 2017, 3-D Joint Z-axis Tipper Electromagnetic and Magnetotelluric Inversion: A case study from the Morrison porphyry Cu-Au-Mo deposit, British Columbia, Canada, Geophysical Prospecting.

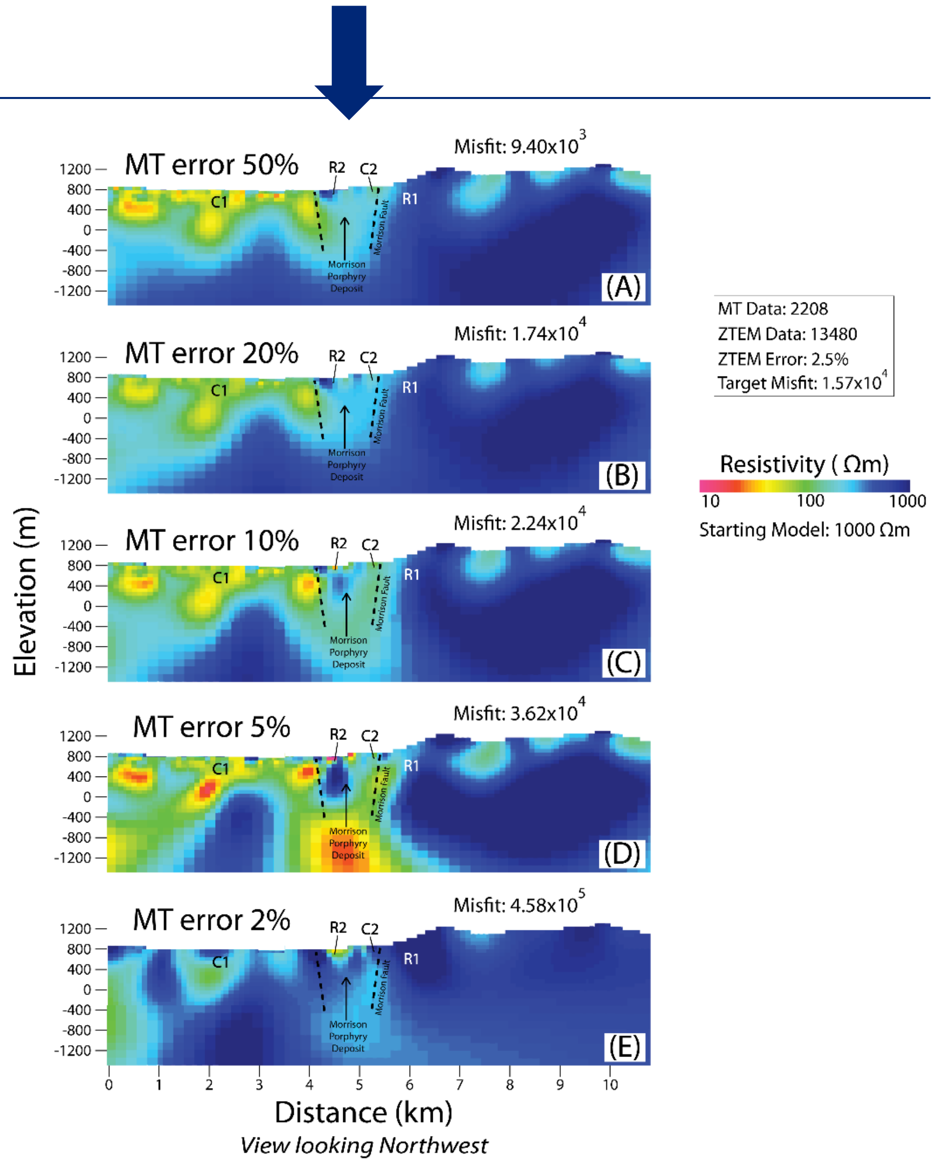


Lee (2015)

MORRISON, BC

Joint MT – ZTEM inversion

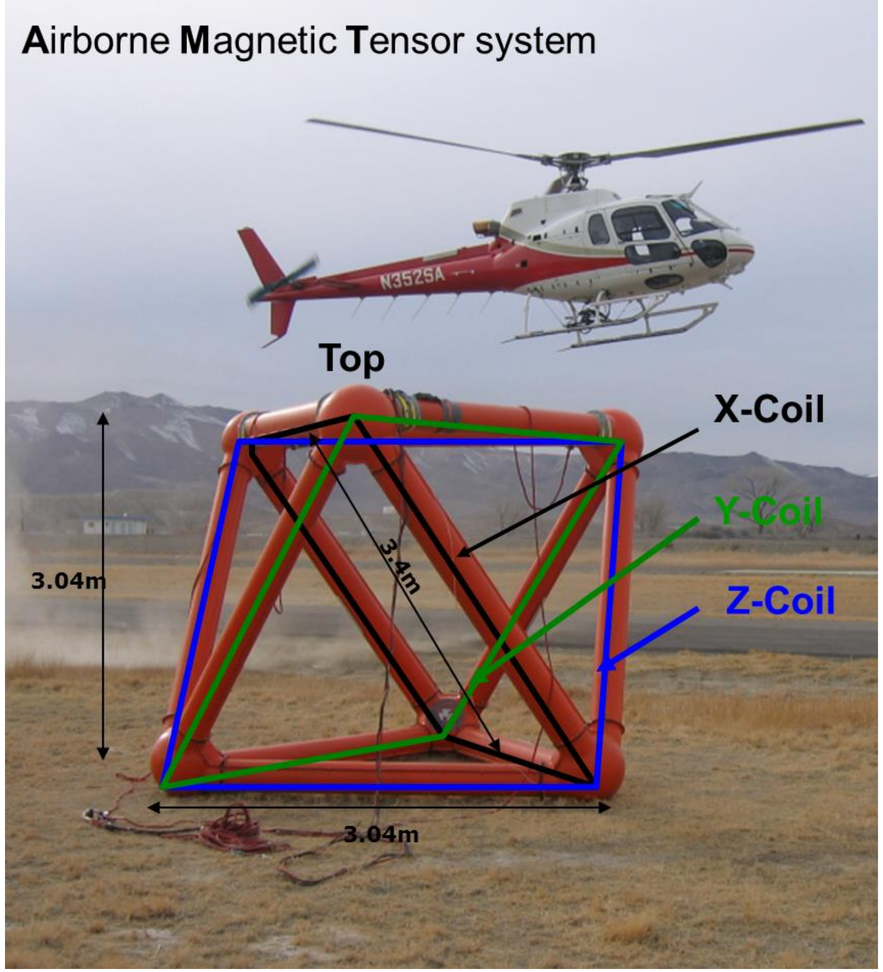
- But there are challenges:
  - Coordinate conventions: ENU vs NED vs XYU
  - Data density: 1000’s of ZTEM data vs 10’s of MT stations
  - Setting optimal error bars
  - Mesh generation
  - Galvanic distortion
  - MT/ZTEM model reconciliation



Lee (2015)

NEXT 10 YEARS…

- In airborne systems:
  - Total field systems (like AirMT)
  - 3-component systems (MobileMT)
  - Reductions in the low frequency limit
- In ground systems:
  - Combined acquisition methods of E only, H only, and E+H (± Tippers)
  - Improved capacitive antennas and broadband coils
  - Drones to position coils in magnetovariational surveys
  - More large-scale surveys: USArray, AusLAMP, EON-ROSE, probably including airborne magnetovariational data
  - Better incorporation of hard and soft constraints in inversions
  - Hopefully… better understanding of the geophysical expression of mineral systems so we can answer why the lower crust exhibits seawater conductivity?



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