**Long section view of the Broken Hill orebody**


# Application of DHMMR at Broken Hill

## (and other things)

Kate Godber †

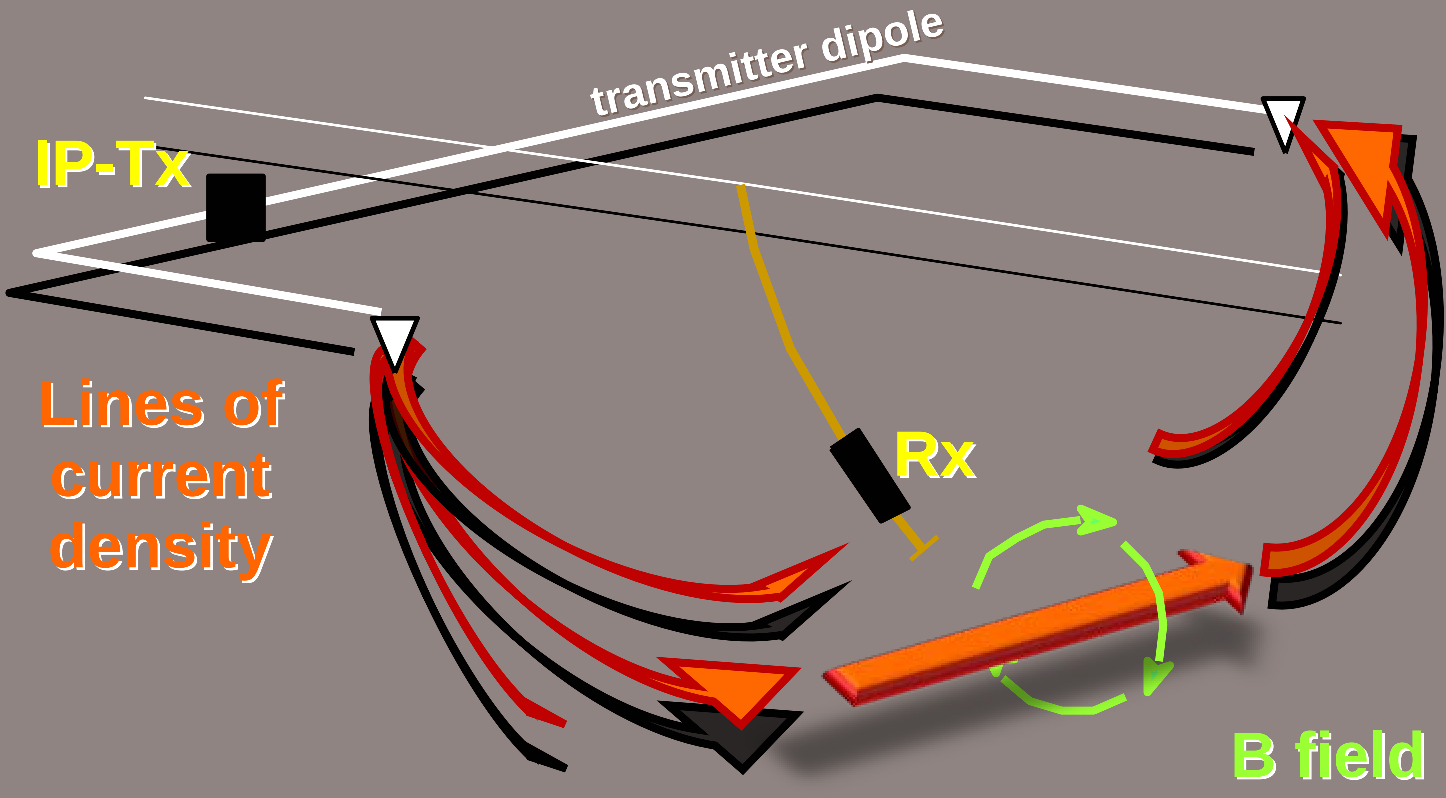
† Geoforce Pty Ltd, Brisbane

geoforce perilya

# Down hole MMR - Geometry

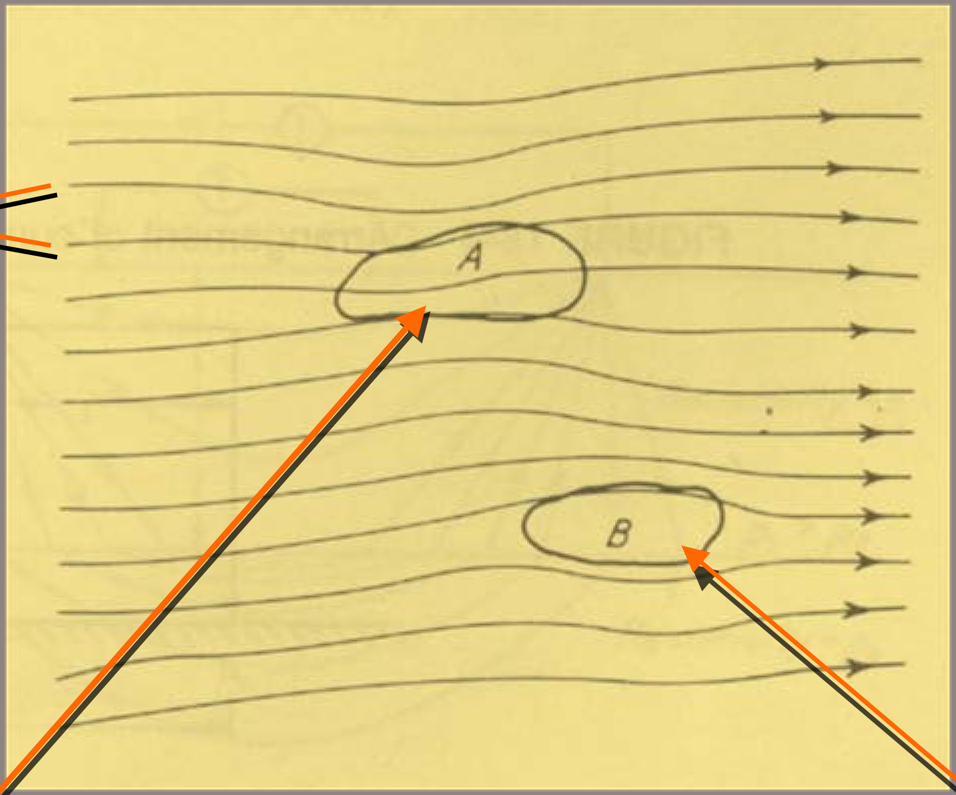
Current follows the 'least path of resistance'
i.e. conductive mineralisation

This is called current channeling



# DC Current flow near good and poor conductors

Current streamlines

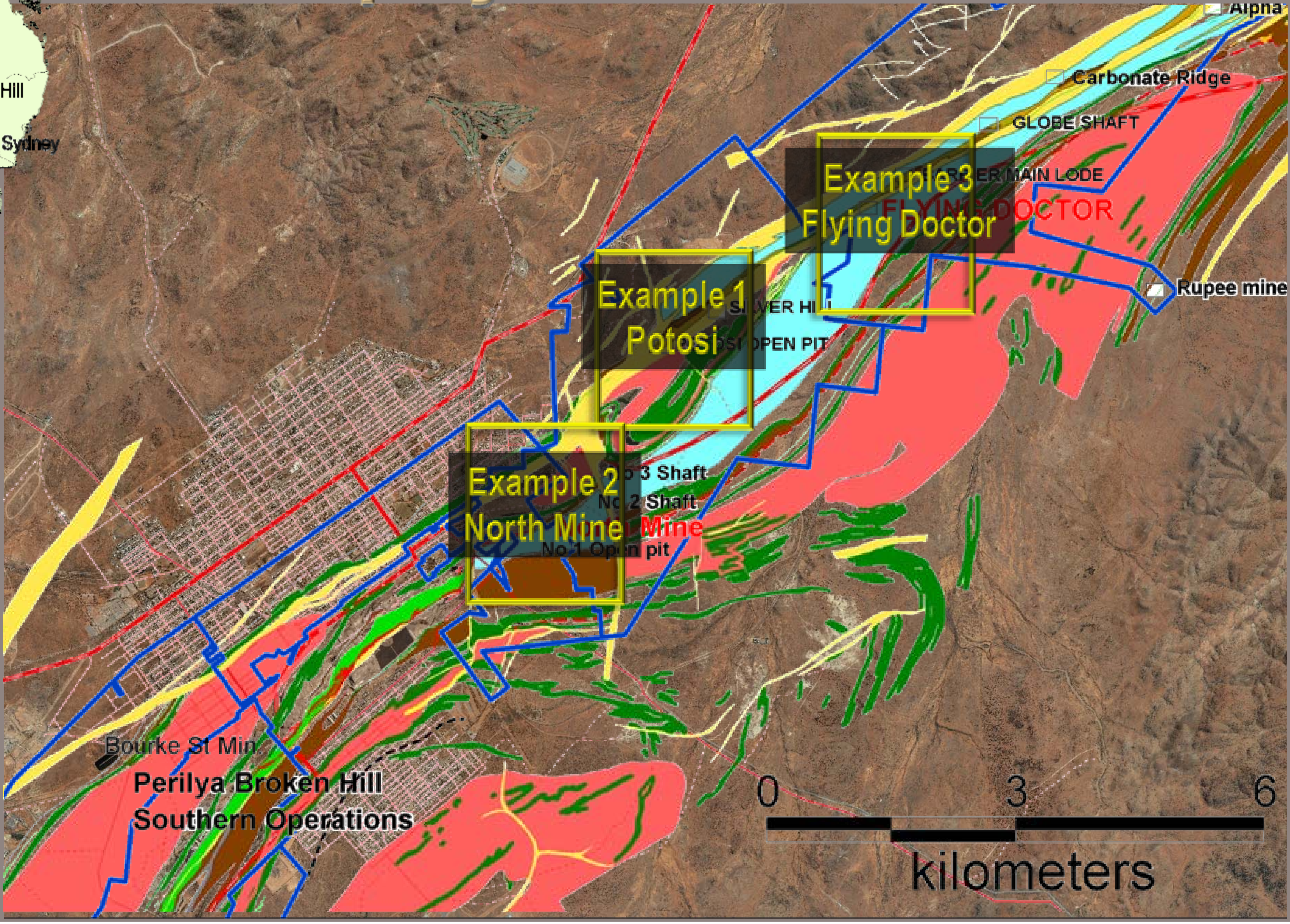



After Kunetz (1966)

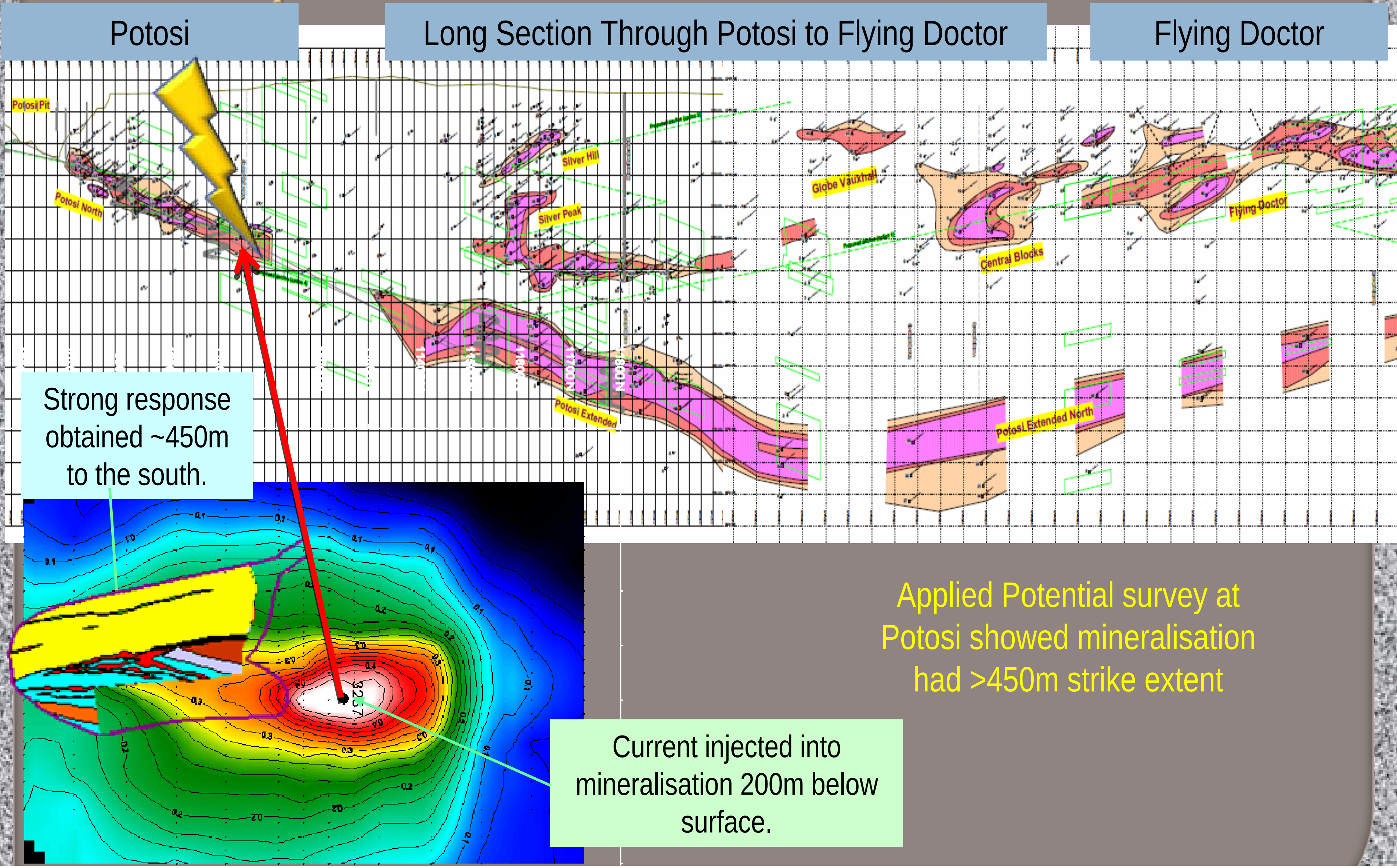
Body more conductive than host – current channeling

Body more resistive than host – current diversion

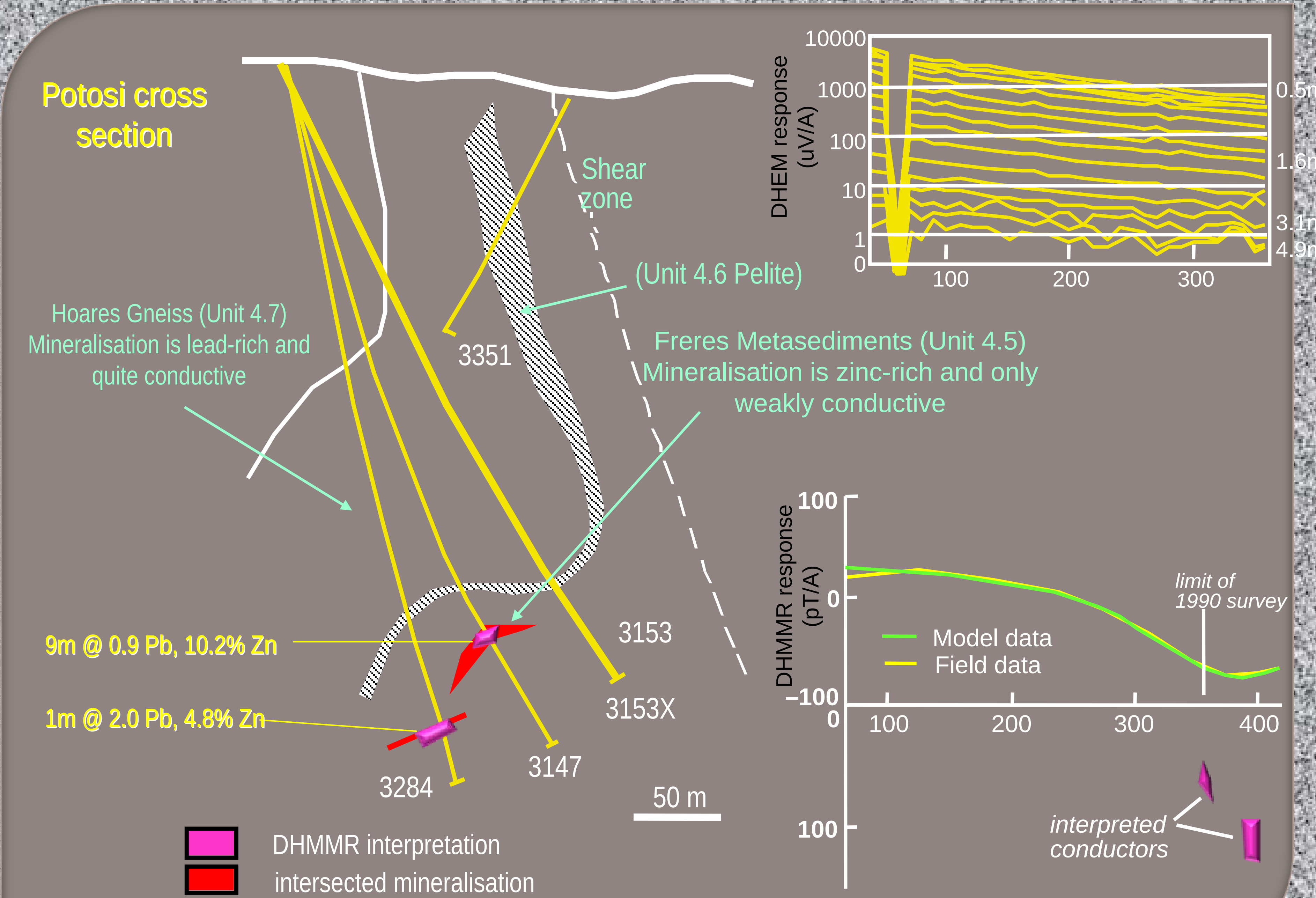
# DH Geophysics at Broken Hill

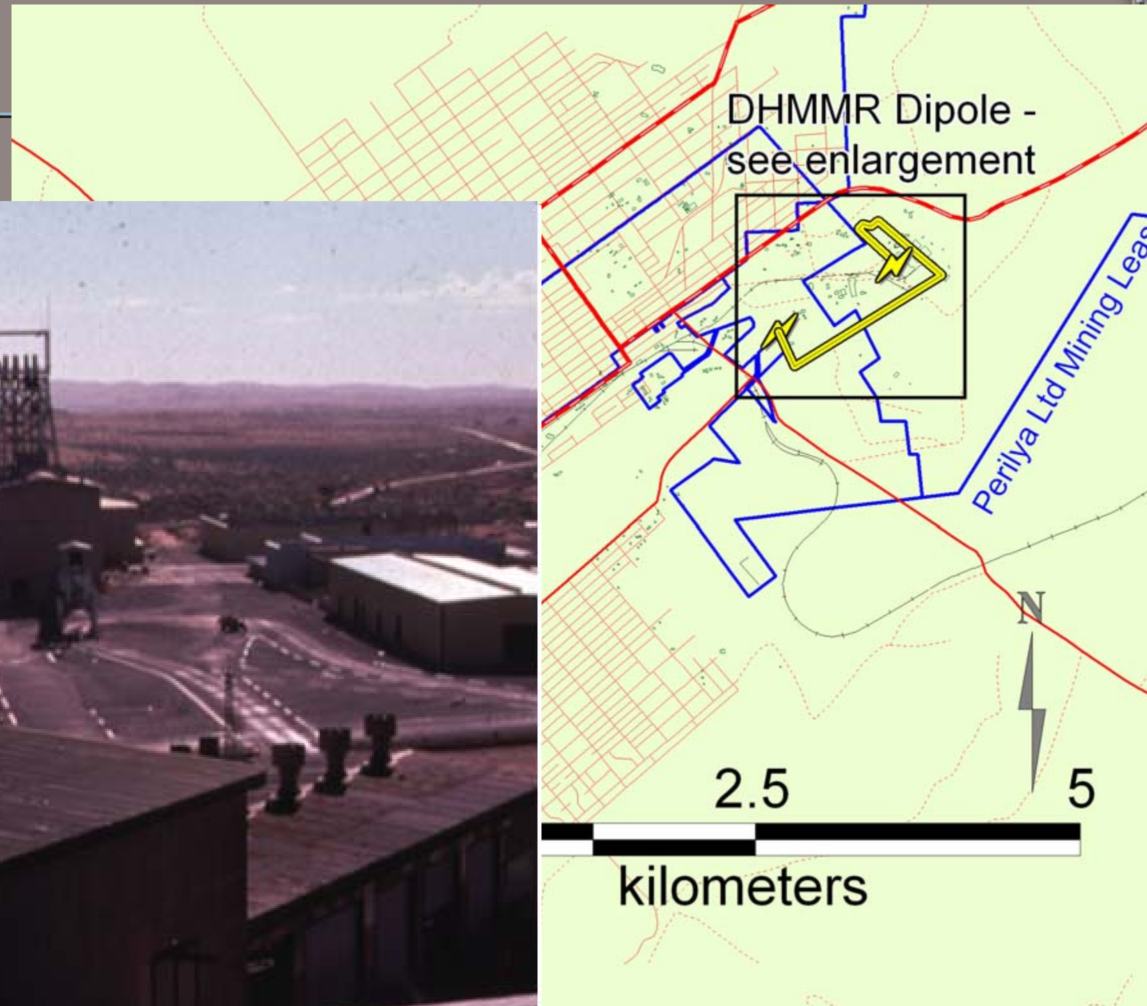
# Example 1: DHEM vs DHMMR at Potosi




Applied Potential survey at Potosi showed mineralisation had >450m strike extent


Potosi cross section
Shear zone
(Unit 4.6 Pelite)
Hoares Gneiss (Unit 4.7)
Mineralisation is lead-rich and quite conductive
Freres Metasediments (Unit 4.5)
Mineralisation is zinc-rich and only weakly conductive
3351
3153
3153X
3147
3284
9m @ 0.9 Pb, 10.2% Zn
1m @ 2.0 Pb, 4.8% Zn
50 m
DHMMR interpretation
intersected mineralisation
DHEM response (uV/A)
10000
1000
100
10
1
0
100
200
300
DHMMR response (pT/A)
100
0
−100
Model data
Field data
limit of 1990 survey
interpreted conductors

# Example 2: North Mine DHMMR



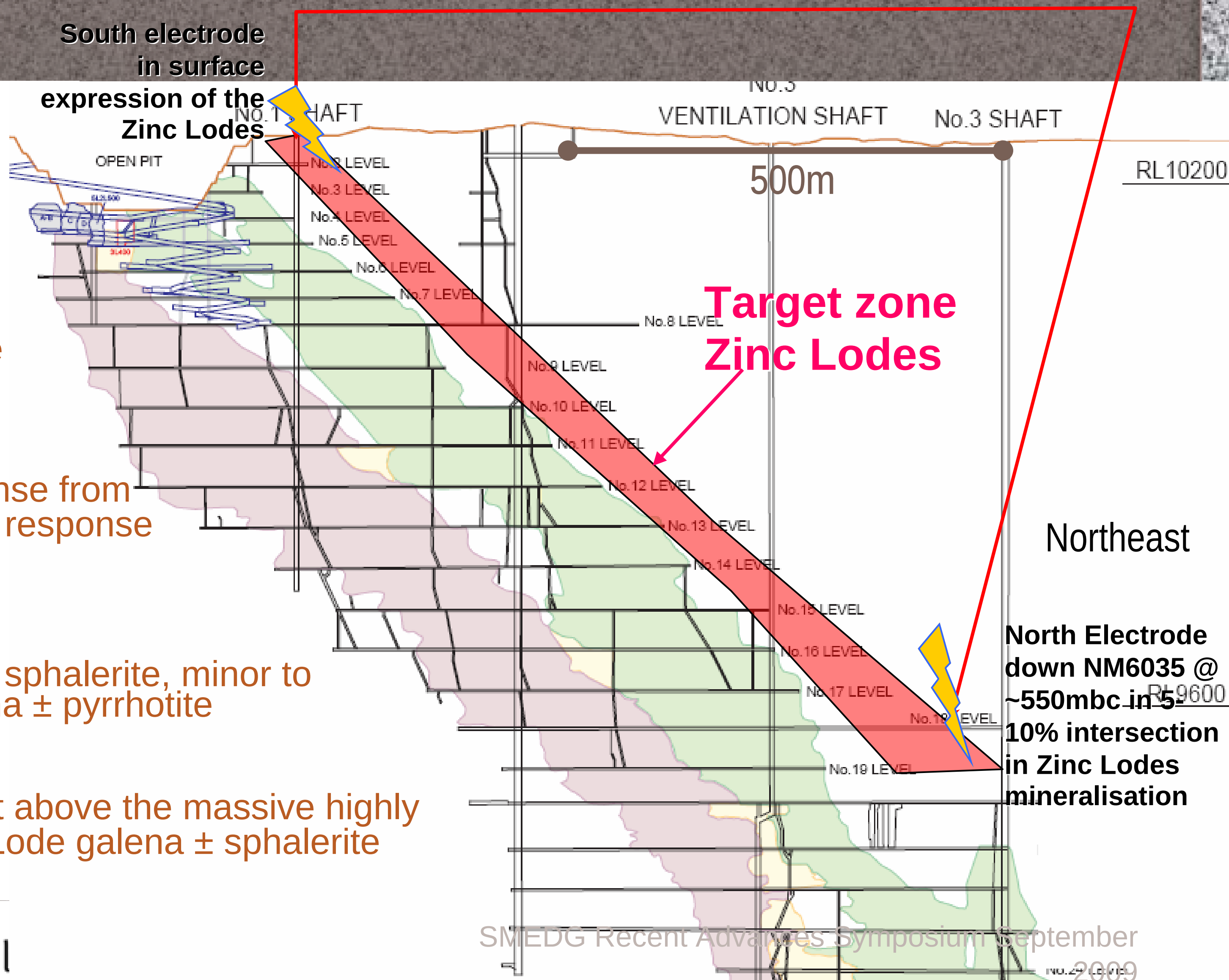

North Mine looking North East

- Lots of infrastructure!
- DHEM very useful on 'Main Mine Minz (e.g. 2K deposit) BUT
- DHEM *not* effective for Zinc Lodes

- Challenging environment and VERY challenging target!

# The North Mine Zinc Lodes

Long Section

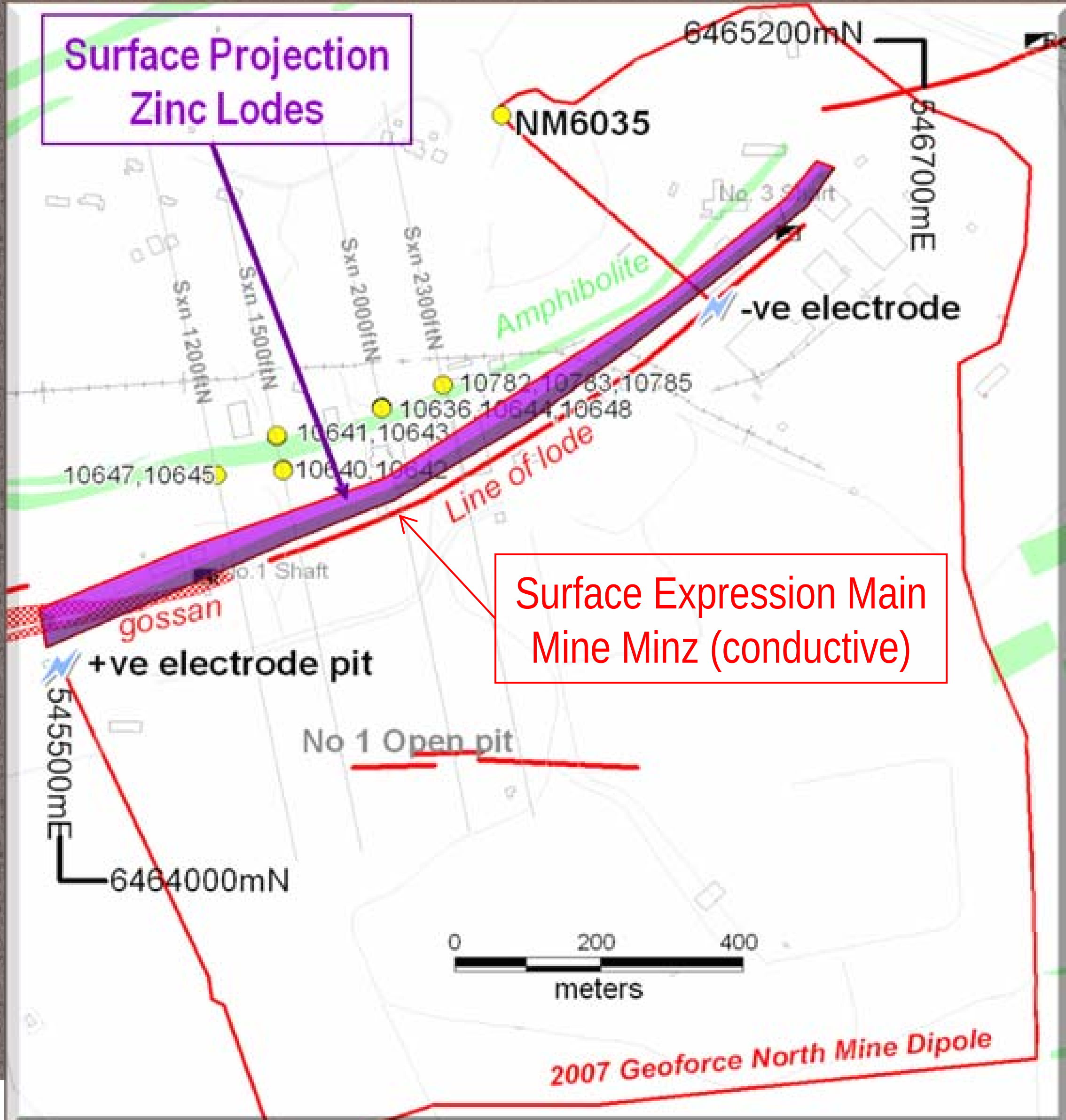


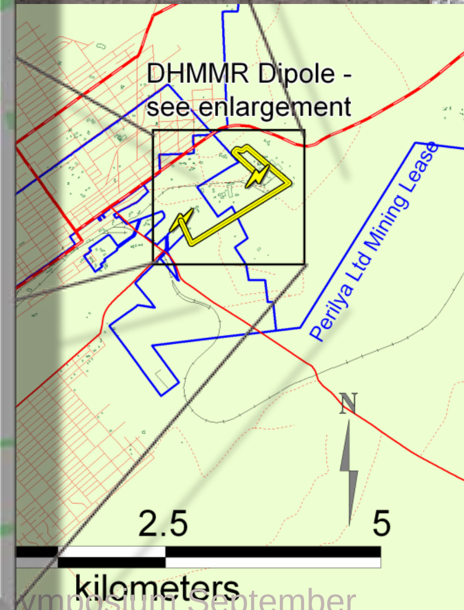

- Poorly conductive
- DHEM: No response from Zinc Lodes, good response from Main Lode
- Ribbons of 5-10% sphalerite, minor to non-existent galena ± pyrrhotite
- 20-50m northwest above the massive highly conductive Main Lode galena ± sphalerite mineralisation

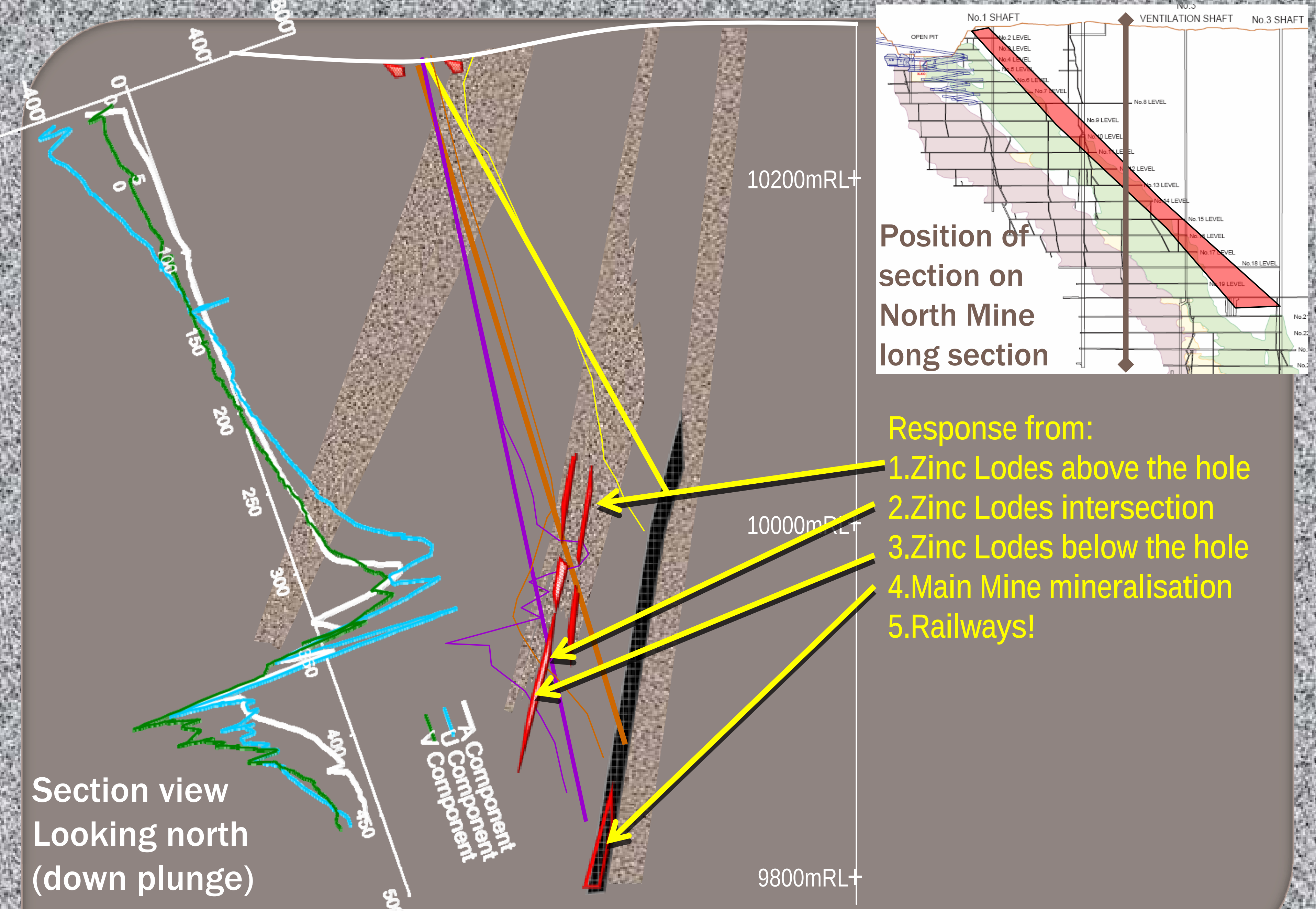
# The North Mine Zinc Lodes

Plan view

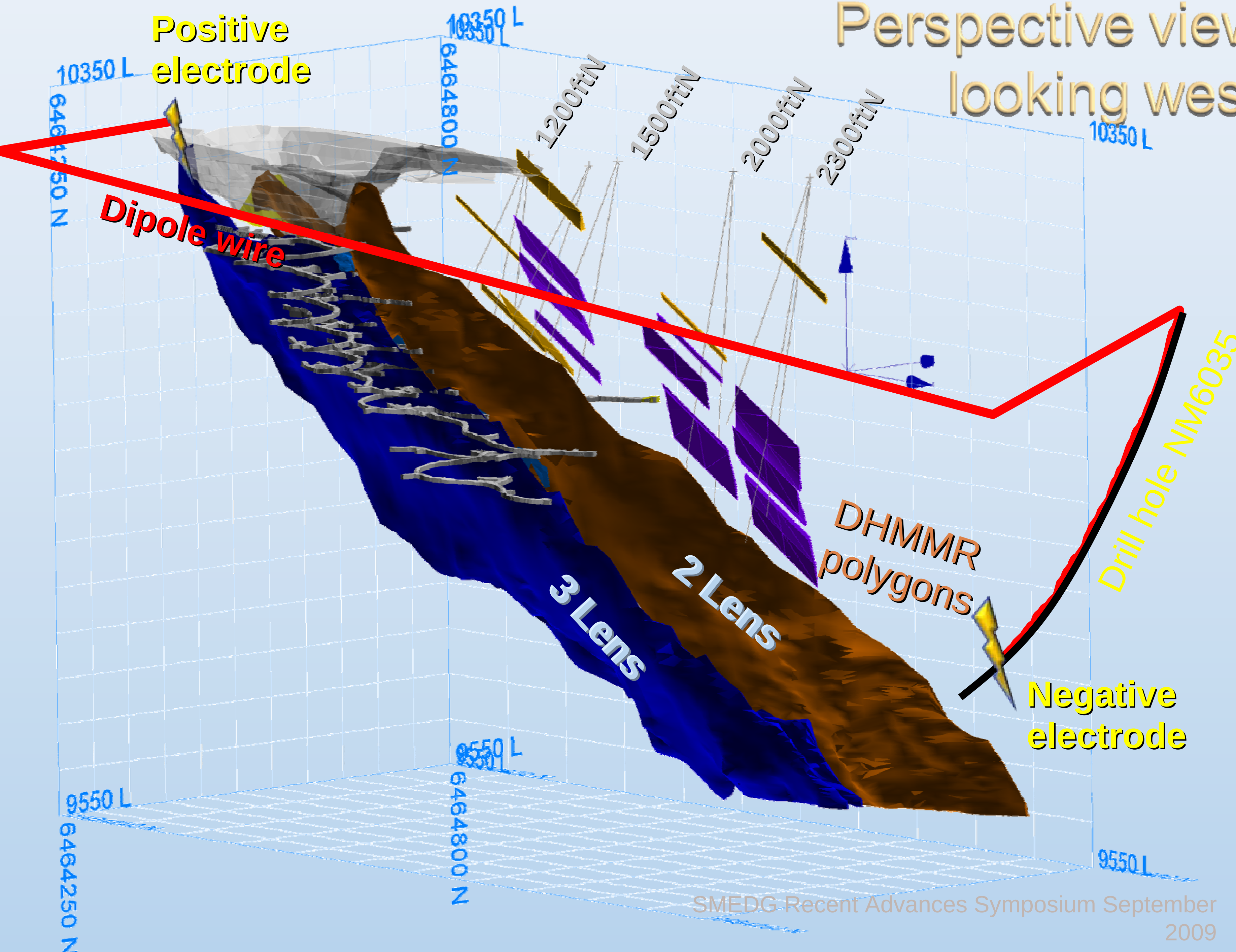
Transmitter dipole can be any shape, any location (e.g. around infrastructure)



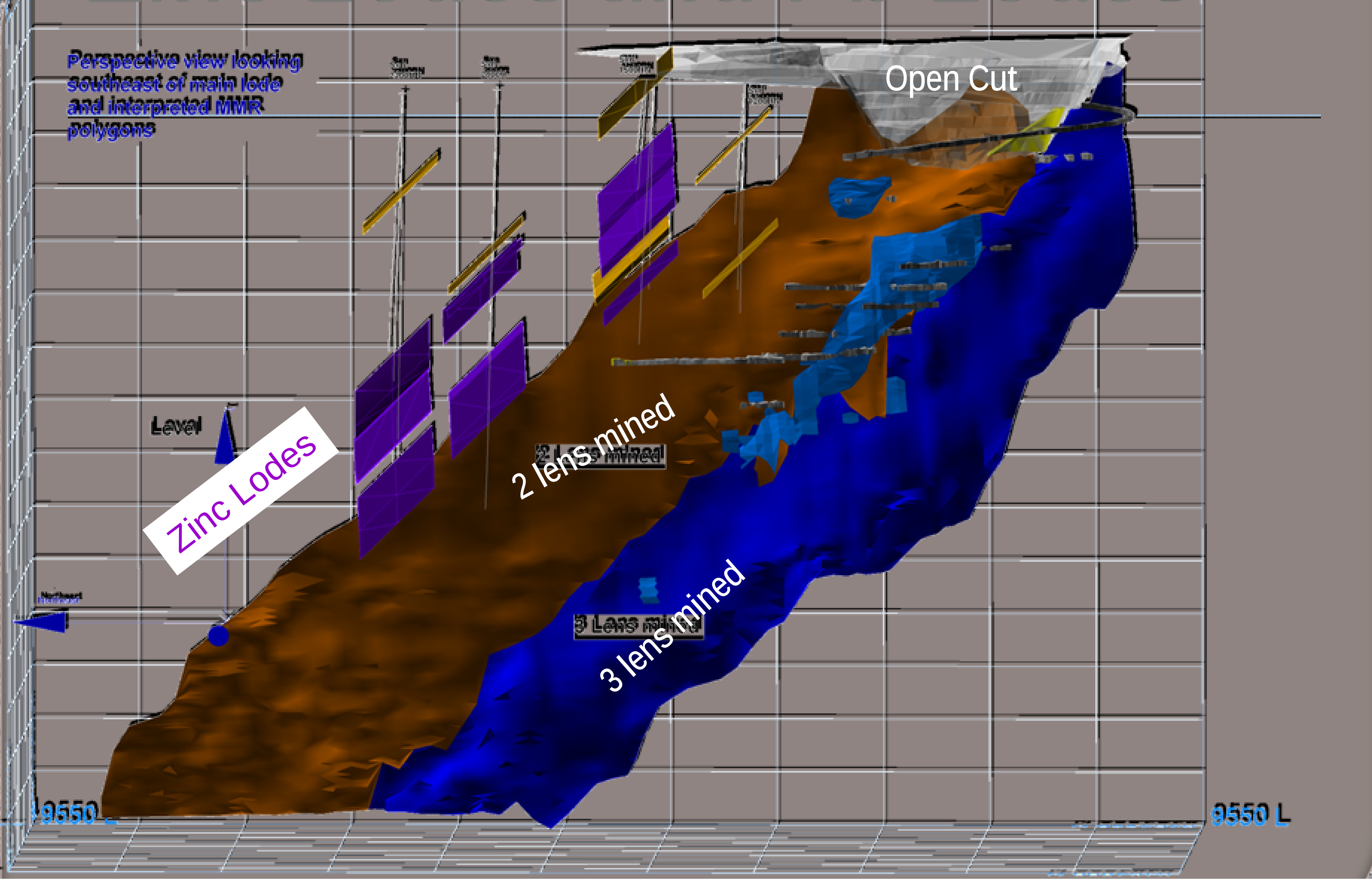




No.1 SHAFT
VENTILATION SHAFT
No.3 SHAFT
OPEN PIT
Position of section on North Mine long section
10200mRL
10000mRL
9800mRL
Response from:
1.Zinc Lodes above the hole
2.Zinc Lodes intersection
3.Zinc Lodes below the hole
4.Main Mine mineralisation
5.Railways!
A Component
U Component
V Component
Section view
Looking north
(down plunge)

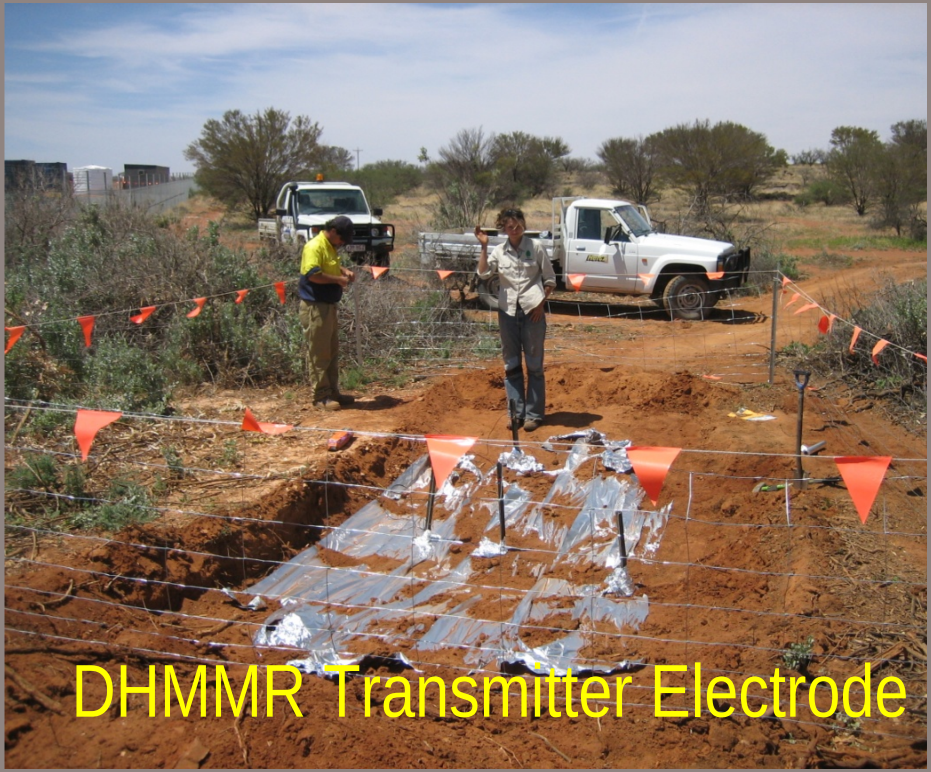
# Perspective view looking west



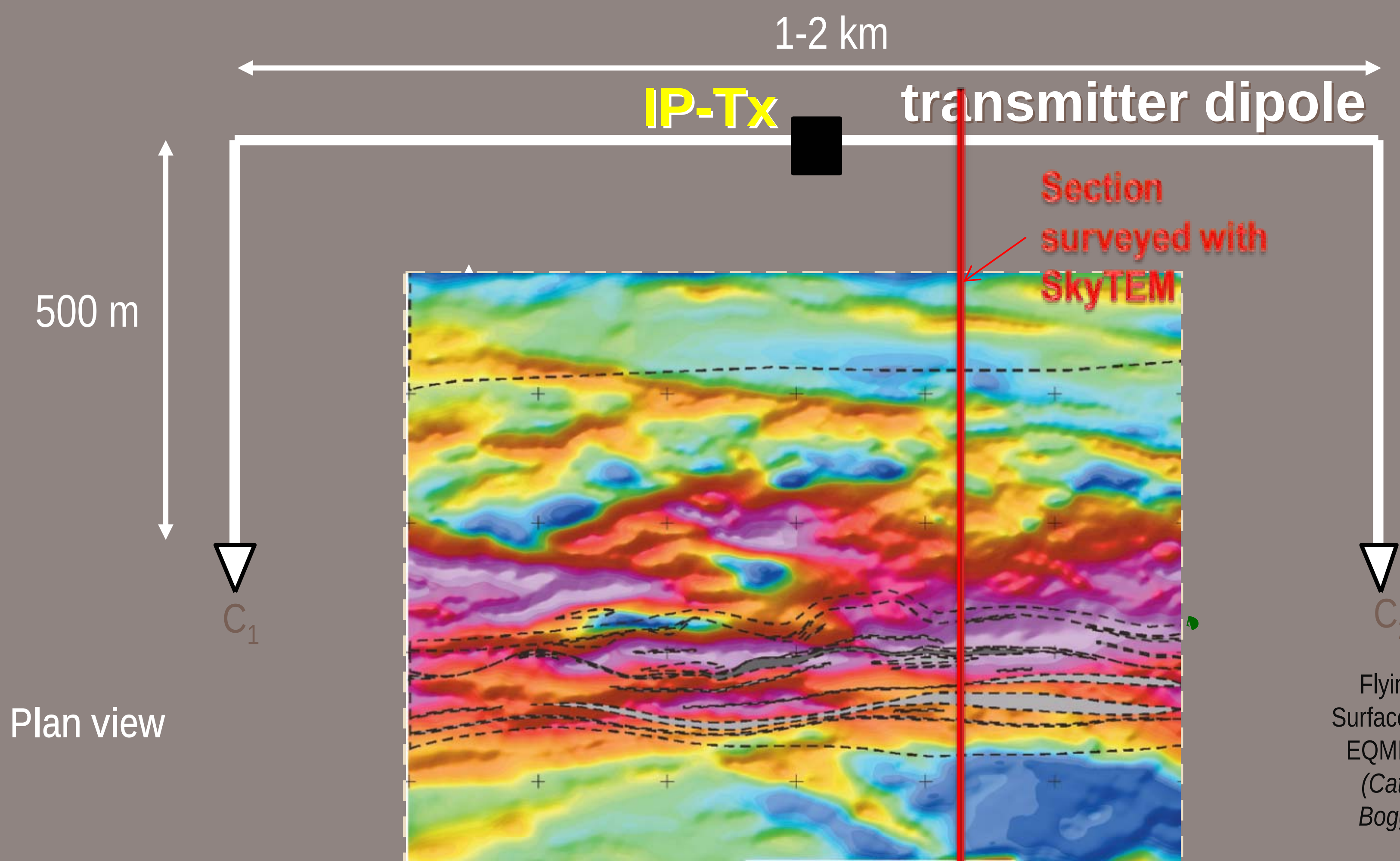
# Zinc Lodes and Pb Lodes



# Example 3: Flying Doctor MMR vs Helicopter EM(!)

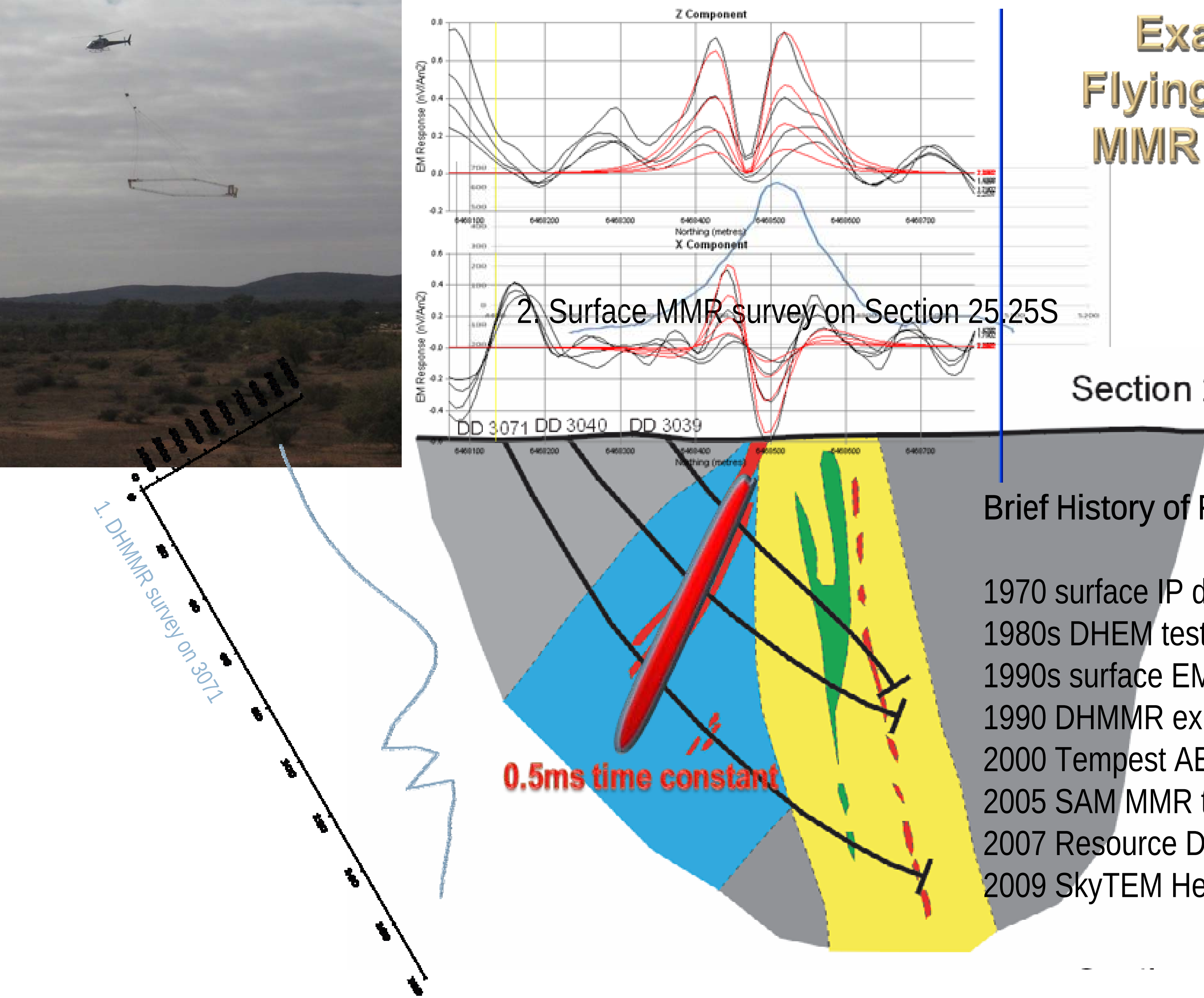



# Example 3: Flying Doctor MMR vs Helicopter TEM




Flying Doctor Surface MMR 1VD EQMMR results *(Cattach and Boggs, 2005)*

# Example 3: Flying Doctor MMR vs Heli-TEM




Brief History of Flying Doctor

1970 surface IP discovery
1980s DHEM testing
1990s surface EM testing
1990 DHMMR exploration
2000 Tempest AEM test
2005 SAM MMR test
2007 Resource Delineation
2009 SkyTEM HelicopterEM test

# Advantages 1

- Requires only a relatively less-resistive target
  - 3 x background conductivity is sufficient
  - Not an absolute good conductor, as in EM
- Good responses from strike-extensive conductors which may give a weak or no EM response
- Greater detection distance than EM
  - Signal decays as 1/r vs ~~1/$r^3$
- Unambiguous location above or below the drillhole
- Selective targeting

geoforce perilya

# Advantages 2

- The galvanic saturation effect means that MMR anomalies of weak conductors are as strong as those due to very conductive targets
- MMR is more sensitive to weak conductors than EM methods
  - Often, when a massive sulfide target is surrounded by a halo of disseminated mineralisation, the MMR method will respond to both the massive core AND the halo. EM will respond only to the massive mineralisation
  - Sensitivity to weak conductors an advantage in exploration for poorly conducting (ZnS-rich or disseminated) ores

# Advantages 3

- MMR is relatively unaffected by conductive overburden, provided there is sufficient primary current density in the vicinity of the target
  - This has important implications for exploration in deeply weathered terrains, where conventional resistivity/IP methods may be ineffective
  - Current electrodes can be emplaced in boreholes below conductive overburden, or directly in the mineralisation, in order to enhance the MMR response.

geoforce perilya

# Disadvantages

- Does not work everywhere!
- Poorer resolution of target dip/distance from hole
- Requires strike-extensive electrical connectivity
  (possibly use surface/xhole MALM to establish this)
- Lack of commercially available modeling/inversion software (in house)

# Recent advances in DHMMR

- Use of a 3-component probe (A-U-V)
- Fluxgate Probe
- 2.5 D current density modeling
- 3D Current filament modeling

# Acknowledgments

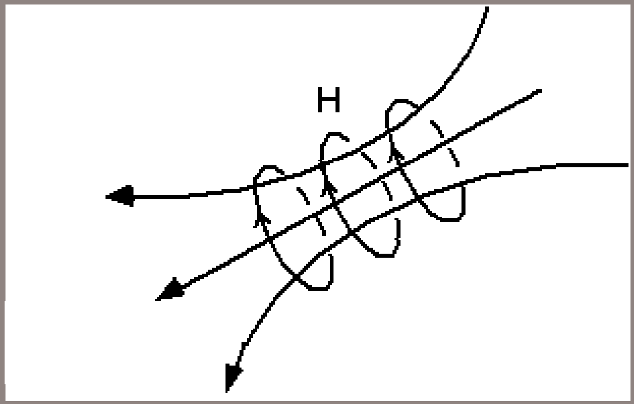

- *John Bishop, Mitre Geophysics*
- *Justin Anning, Geoforce*
- *Andrew Duncan, EMIT*
- *James Reid, Geoforce*
- *SkyTEM*


# Summary

- Subsurface targets which are more conductive than their host rocks concentrate or “channel” DC current
- This anomalous local current density produces an anomalous magnetic field, which can be measured on the surface of the earth or downhole using a sensitive magnetometer
- A weak conductor (ie a target with a small conductivity contrast with the host) can produce the same anomaly magnitude as a very good conductor
- The main advantages of the MMR method are its sensitivity to weak conductors, and  insensitivity to the presence of a conductive overburden layer
- DHMMR measurements can be can be made using a standard IP transmitter, and downhole electromagnetic receiver

# The MMR method

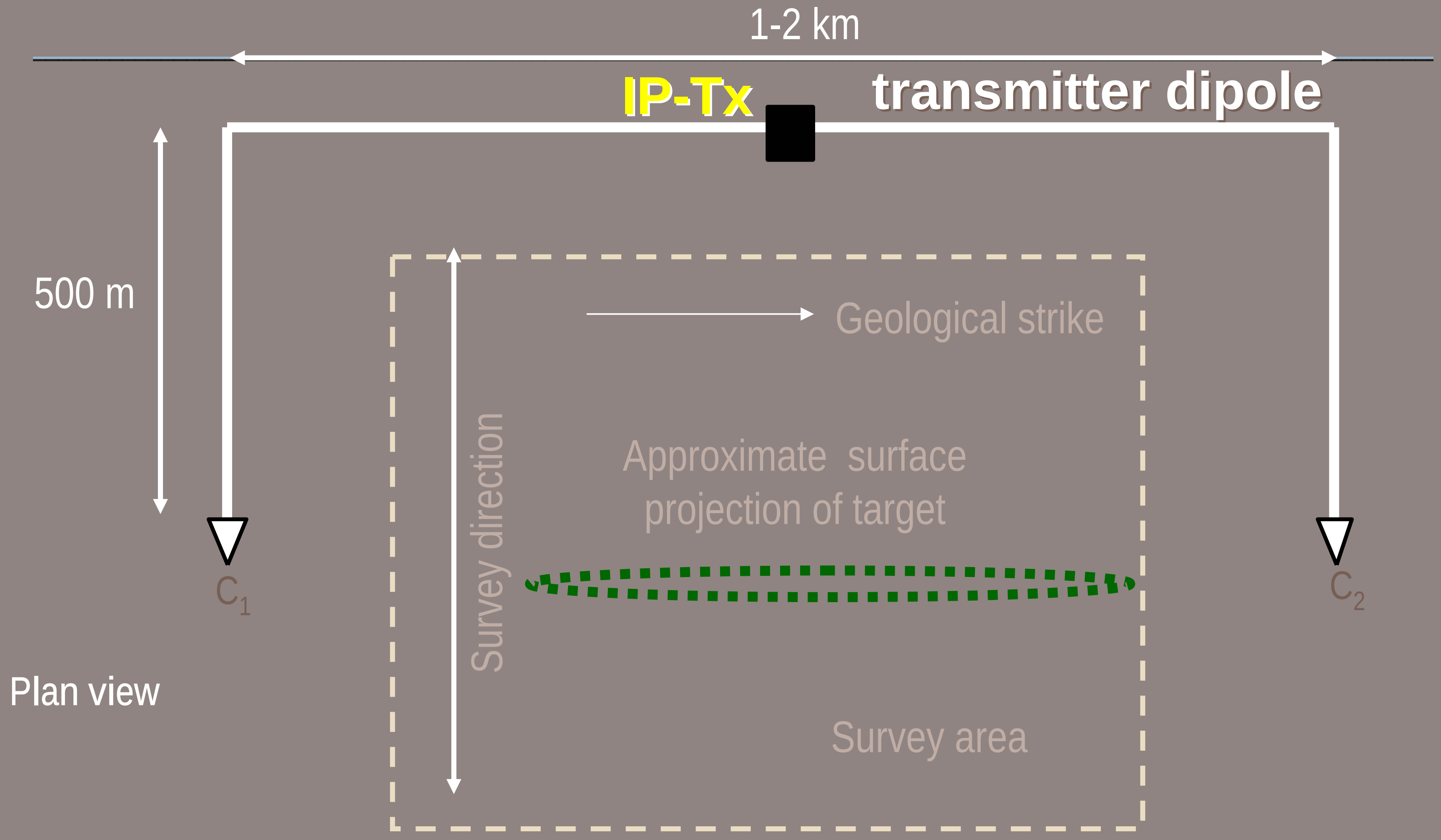
- MMR is somewhat similar to the DC resistivity technique, except that rather than measuring the potential (gradient of electric field) we instead measure the magnetic field due to DC current flow in the ground
- By Ampère's Law, a magnetic field "circulates" around the current density **J** within the earth



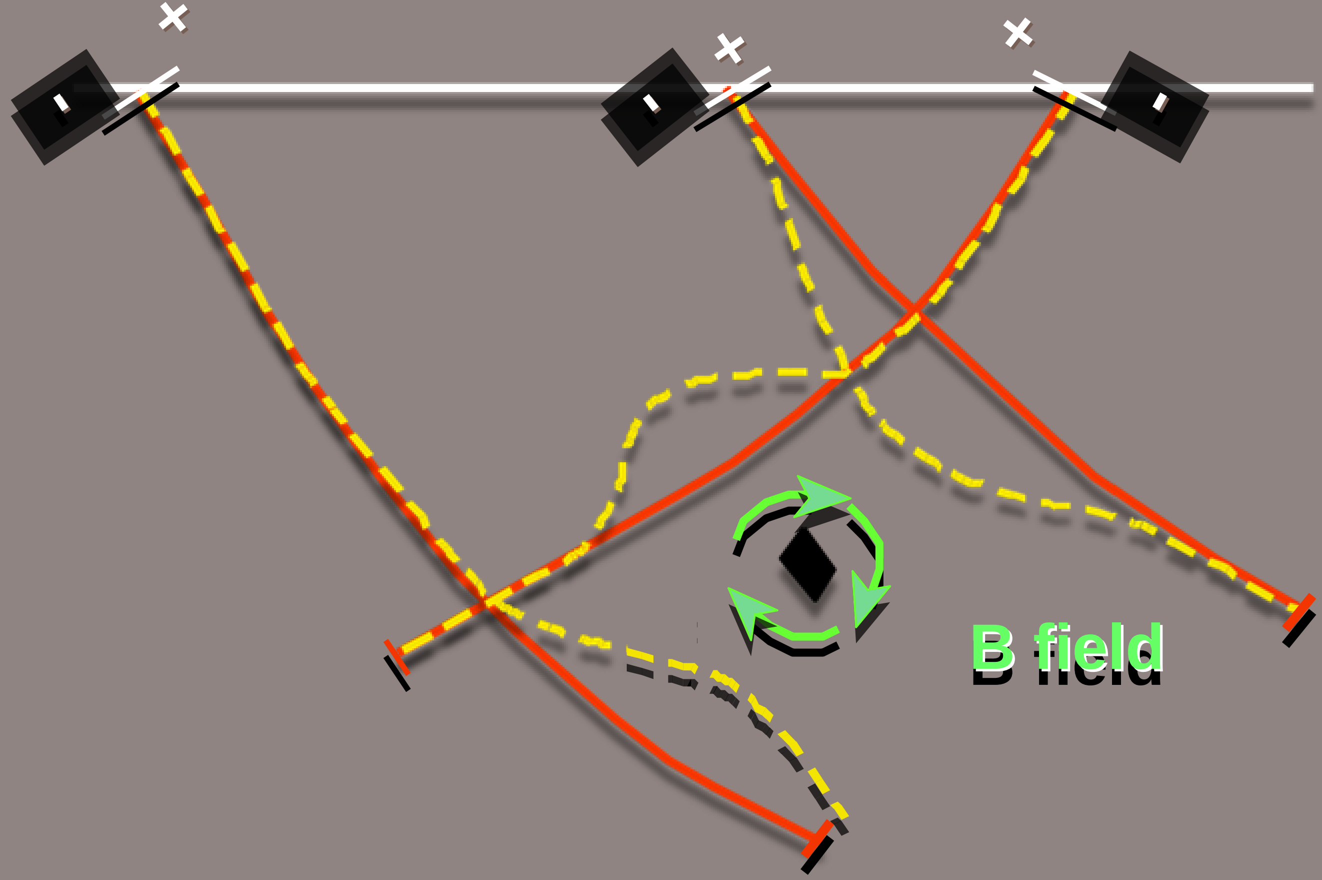

(after Grant and West, 1965)

- Note that the current does ***not*** have to be time-varying to give rise to a magnetic field!

# Surface MMR - Geometry



# DH MMR – Response Polarities



# Advantages of MMR 1

- The galvanic saturation effect means that MMR anomalies of weak conductors are as strong as those due to very conductive targets
- MMR is more sensitive to weak conductors than EM methods
  - Often, when a massive sulfide target is surrounded by a halo of disseminated mineralisation, the MMR method will respond to both the massive core AND the halo. EM will respond only to the massive mineralisation
  - Sensitivity to weak conductors an advantage in exploration for poorly conducting (ZnS-rich or disseminated) ores

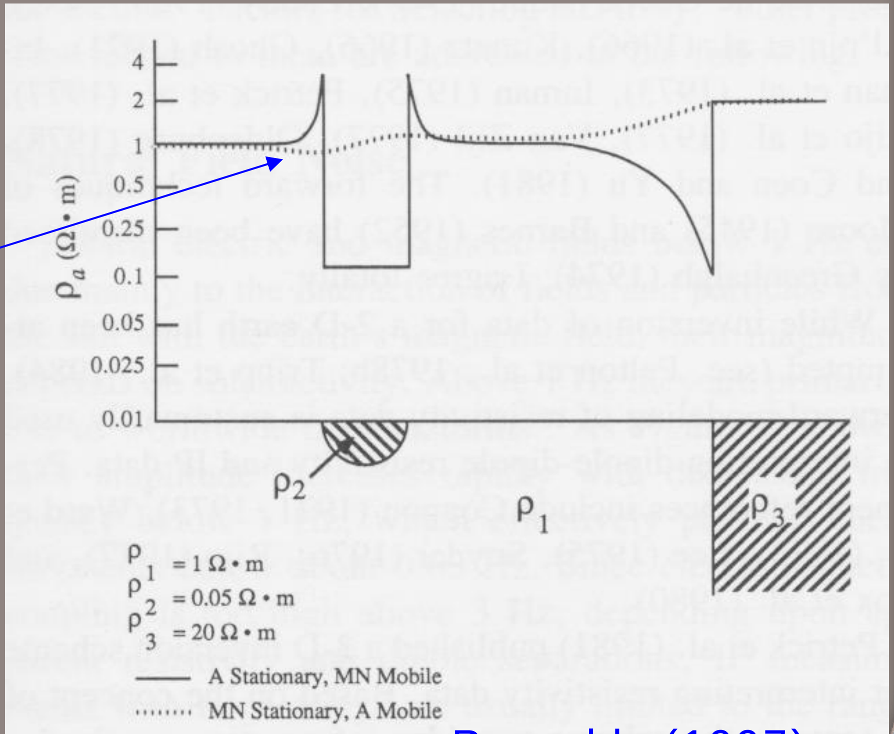
# Advantages of MMR 2

- MMR is relatively unaffected by conductive overburden, provided there is sufficient primary current density in the vicinity of the target
  - This has important implications for exploration in deeply weathered terrains, where conventional resistivity/IP methods may be ineffective
  - Current electrodes can be emplaced in boreholes below conductive overburden, or directly in the mineralisation, in order to enhance the MMR response.

# Advantages of MMR 3

- The MMR method is much less affected by local conductivity variations close to the Rx than are conventional DC resistivity/IP methods
- The magnetic field is produced by the entire volume of currents flowing in the earth

In conventional DC resistivity, measured voltages (and hence $\rho_a$) are strongly affected by near-surface conductive inhomogeneities e.g., when Rx dipole (MN) straddles a conductivity boundary




Reynolds (1997)