Application of DHMMR at Broken Hill (and other things)

Kate Godber †

† Geoforce Pty Ltd, Brisbane
Current follows the 'least path of resistance' i.e. conductive mineralisation

This is called current channeling
DC Current flow near good and poor conductors

After Kunetz (1966)

Body more conductive than host – current channeling
Body more resistive than host – current diversion
Current injected into mineralisation 200m below surface.

Strong response obtained ~450m to the south.

Applied Potential survey at Potosi showed mineralisation had >450m strike extent.
Mineralisation is zinc-rich and only weakly conductive

Mineralisation is lead-rich and quite conductive

9m @ 0.9 Pb, 10.2% Zn

1m @ 2.0 Pb, 4.8% Zn

DHMMR interpretation intersected mineralisation

Potosi cross section

Hoares Gneiss (Unit 4.7)

Freres Metasediments (Unit 4.5)
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!
Ribbons of 5-10% sphalerite, minor to non-existent galena ± pyrrhotite

Target zone Zinc Lodes

Zinc Lodes

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

SMEDG Recent Advances Symposium September

North Electrode down NM6035 @ ~550mbc in s 10% intersection in Zinc Lodes mineralisation
The North Mine Zinc Lodes

Plan view

Surface Projection
Zinc Lodes

Surface Expression Main
Mine Minz (conductive)

Transmitter dipole can be any shape, any location (e.g. around infrastructure)
Response from:
1. Zinc Lodes above the hole
2. Zinc Lodes intersection
3. Zinc Lodes below the hole
4. Main Mine mineralisation
5. Railways!
Drill hole NM6035
Positive electrode
2300ftN
2000ftN
1500ftN
1200ftN
Negative electrode
2 Lens
3 Lens
DHMMR polygons
Dipole wire
Perspective view looking west
SMEDG Recent Advances Symposium September 2009
Zinc Lodes and Pb Lodes

Perspective view looking southeast of main lode and interpreted MMR polygons

Zinc Lodes

2 lens mined

3 lens mined

Open Cut

9550 L

10350 L

SMEDG Recent Advances Symposium September 2009
Example 3: Flying Doctor
MMR vs Helicopter EM(!)

DHMMR Transmitter Electrode

SkyTEM
Example 3: Flying Doctor MMR vs Helicopter TEM

Plan view

1-2 km

IP-Tx

transmitter dipole

500 m

C₁

C₂

Section surveyed with SkyTEM

Flying Doctor
Surface MMR 1VD
EQMMR results
(Cattach and Boggs, 2005)
2. Surface MMR survey on Section 25.25S

Example 3: Flying Doctor
MMR vs HelicopterEM

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 \sim 1/r^3
- Unambiguous location above or below the drillhole
- Selective targeting
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.

SMEDG Recent Advances Symposium September 2009
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.
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
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 (i.e., 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 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 $\mathbf{J}$ within the earth.

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

(after Grant and West, 1965)
Surface MMR - Geometry

Plan view

1-2 km

IP-Tx transmitter dipole

Survey direction

Approximate surface projection of target

Geological strike

Survey area

1-2 km

500 m

C1

C2

SMEDG Recent Advances Symposium September 2009
DH MMR – Response Polarities

B field

SMEDG Recent Advances Symposium September 2009
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.
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)