Low frequency AEM and AIP with B and dB/dt sensors

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Towards a measured B and dB/dt field
AEM system

• Why airborne IP?
• Why measure B?
• Early experiments, reported and unreported
• AMIRA P1036
• The technical challenges of low-frequency airborne B
• Rotation corrections
• BIPTM
• Lewis Ponds

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THOMSON AVIATION
Airborne Geophysical Survey
IP remotely detects electrochemical and charge storage reactions in the ground.

This example is a successful case of hydrocarbon identification.

Resistivity-chargeability cross plot of reservoir

Advanced progress of TFEM method for hydrocarbon mapping
Zhanxiang He*, Gang Yu, Zhigang Wang, Xuejun Liu, and Zhi Zhao, BGP Inc., Zhuozhou, Hebei Province, 072751, P. R. China

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Airborne Geophysical Survey
Why consider AIP?

- **Porphyry Deposits**
  - Ground IP is the most important geophysical method in porphyry sulphide exploration
  - Limited by ground contact problems in desert areas
  - Constrained by high voltage restrictions in many jurisdictions

- **IP effects from surficial conductors** are frequently seen in ground and airborne EM surveys using dB/dt detectors.

- Can the IP effect be better characterised with changes to AEM systems?
Why measure B?

- **AEM:**
  Much more sensitive to good conductors than dB/dt

  - Modelled ground responses for SQUID and coil

  - Chwala et al., 2017

- **AIP:**
  Much more sensitive to IP effects than dB/dt

  - Measured ground IP responses with SQUID and coil

  - Du et al., 2017

  - dB/dt measurement often do not have enough bits to numerically integrate to calculate B correctly

  - Macnae and Kratzer, 2013
AEM with B field sensors: a partial history

- **SQUIDs**
  - BHP flew CSIRO high temperature SQUIDs in the 1990’s
  - Spectrem Air flew IPHT low temperature SQUIDs in the 2000’s
  - Results encouraging but no commercial operations; many undisclosed issues
    
    Lee et al., 2001; LeRoux et al., 2009

- **Total Field (Cs)**
  - HeliSAM Flying with large loop source on ground. Limited to measuring the one component in the direction of the Earth’s magnetic field
    
    Parker et al, 2014

- **Fluxgates**
  - Used extensively in boreholes and for compensation in airborne magnetics, and have been analysed for AEM response as being marginal
    
    Joseph, 2006
AMIRA P1036 and P1036a

• 2010 to 2013
• With sponsors BHPBilliton, Teck-Cominco, Anglo-American, Abitibi Geophysics, Outer Rim Exploration the RMIT project developed and successfully test flew combined E, B and dB/dt sensors over a synthetic target near a ground transmitter

• The P1036a test flight was conducted by Outer Rim with assistance from Monex GeoScope and Thomson Aviation.
• Outer Rim ceased operations, and after a hiatus, Monex GeoScope and Thomson Aviation have resumed developments
Low frequency vector AEM

• Problems:
  1. Rotation Noise takes off at low frequency
  2. Less stacking means noisier early- to mid-delay time data (almost inevitably)
     • Until recently, 25 Hz was the lower limit for useful base frequency
  3. dB/dt sensors have decreasing sensitivity to long time-constant decays

• Solutions
  1. Better suspension?
     • Everyone works on this” some systems collecting 7.5 and 15 Hz data, BIPTEM
  2. More transmitter current?
     • Lightweight loop structures patented. Increases cost as bigger helicopters or planes required; BIPTEM > 1 MAm²
  3. Use B field sensor
     • AMIRA P1036, BHP, Spectrem, BIPTEM

1. ¼. Correct rotation noise?
     • AMIRA P1036, BIPTEM
Effect of Rotation

- Earth’s field $B_E$ has components
  - $B_z = B_E \cos(\phi)$
  - $B_x = B_E \sin(\phi) \cos(\theta)$
  - $B_y = B_E \sin(\phi) \sin(\theta)$

- $B_z$ field sensor (e.g. fluxgate) “sees” effects of rotations in $x$ and $y$ directions, but insensitive to rotations around $z$ axis.

- ARMIT $A_z$ sensor detects changes in $B_z$ above corner at 7 Hz and changes in $dB_z/dt$ below the corner.
Correction of sensor responses

The ARMIT corner frequency is set at 0.1 Hz for ground sensors, set at 7 Hz for airborne sensors to reduce sensitivity to rotation noise by > factor of 10 at frequencies below 1 Hz.

Ground ARMIT sensor sensitivity

Airborne ARMIT sensor sensitivity

Rotation filtered by ARMIT sensitivity

Rotation rate sensor response
3 component BIPTEM Rotation prediction

Raw rotation rates

Angles $\psi$ are deviations measured w.r.t. rotation sensor axes

Integrated: Rotations $\psi$

Cosine coupled ARMIT responses

Sine coupled ARMIT responses
Correction (shaker table data)

Bx, By, Bz data in black with predicted rotation noise (red) superimposed

Rotation predictions at maximum coupling to $B_E$. The rotation data under each B component does not contribute to its fit (prediction).
Correction with Tx operating (shaker table)

Bx, By, Bz data with predicted rotation noise (dashed)

Rotation predictions at maximum coupling to $B_E$
Airborne BIPTEM data

Raw data over Tx loop

Strong VLF and sferics evident in dB/dt. Rotation noise still there

Mean fluxgate on bird subtracted to show variations

Note rotation rate has same general “frequency content” as ARMIT B
Airborne 12.5 Hz data, ~300 m from loop, 0.8 sec sec average

“Vertical”

“Horizontal”

Monex GeoScope
12.5 Hz airborne B field (not dB/dt) Line 5 data, u,v components at 45° to flight line

Monex
GeoScope
Upcoming BIPTEM™ system

• To date
  – Constructed new sensor housing for balanced sensor with resonant rotation frequency < 1Hz
  – Flown in several bird designs
  – Collected good AEM data over Lewis Ponds conductor using Tx loop on ground
  – Tested new 1 MAm² transmitter

• Imminent
  – Test flight of new transmitter loop design
  – Flight testing in central loop mode; optimum for AEM
  – Flight testing in separated loop mode; optimum for AIP.
Conclusions

• B field and low base-frequency are better for AEM and essential for AIP
• Suspensions have their limits in reducing rotation noise
• Rotation rate measurements can predict noise on vector B sensors in the 30 sec to 100 Hz bandwidth.
• Commercial flights with BIPTTEM are imminent
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