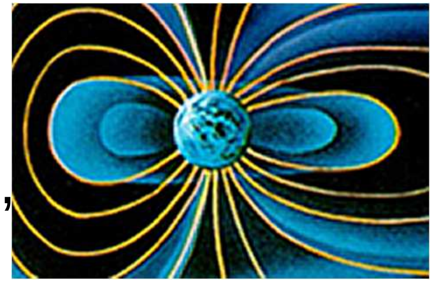
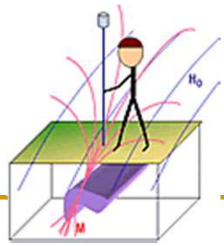
Magnetic surveying

After today, you will be able to

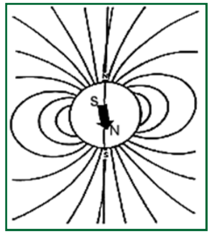


- Sketch anomalies over objects at any location, and explain how you derived the pattern.
- Explain the relation between dipoles and real targets.
- Outline the needs of a field survey.

- Outline necessary & some optional processing.



Basics of Magnetics Surveying



1. Earth's magnetic field is the source:

2. Materials in the earth become magnetized

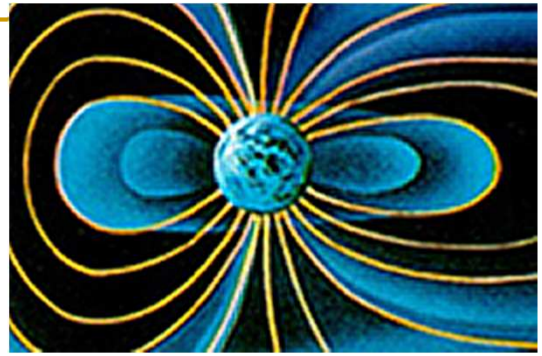
   ($M = \kappa H$ where $H = B/\mu_0$) (dipole moment per unit volume)

3. Magnetized material creates anomalous field (applet)
   magnetic moment $m = M \times$ (volume)

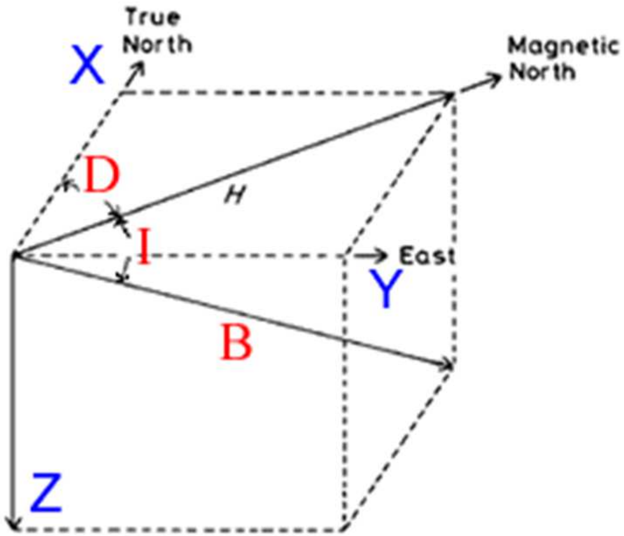
4. Magnetometer measures the total field

5. Anomalous field obtained by subtracting off the earth's field

Magnetics – Earth's field

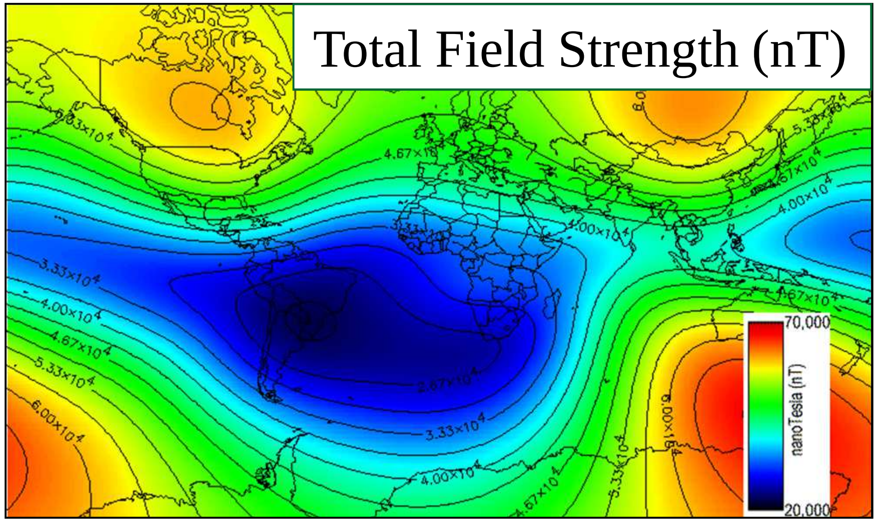


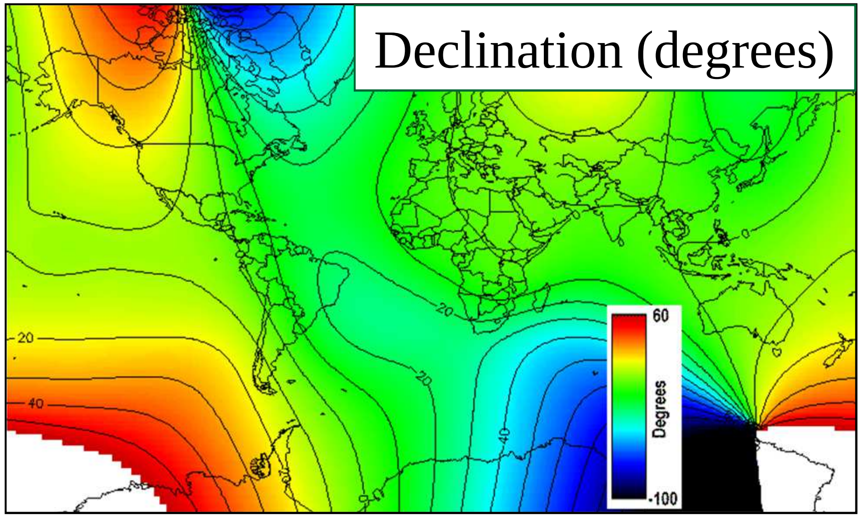
- Web Notes, GPG Ch.3.d.7.
- How is the field described anywhere?
  - X, Y, Z
  - Inclination, Declination, Magnitude

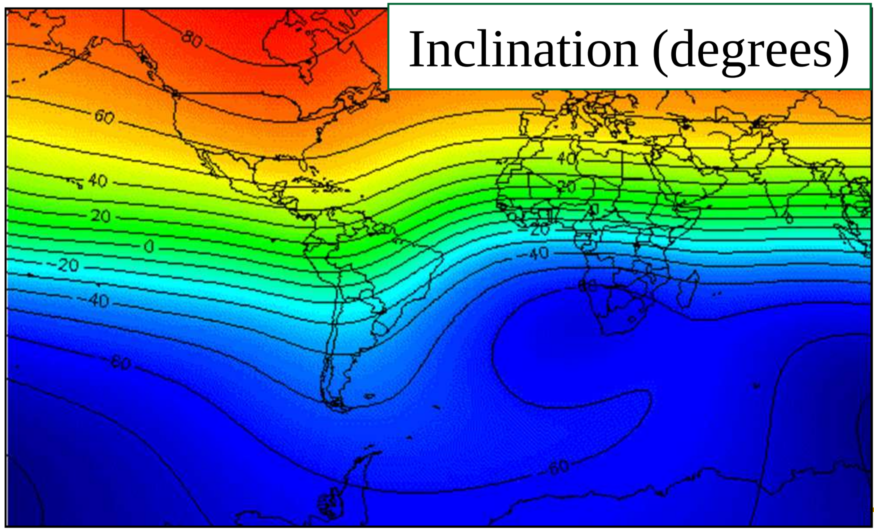


- Compass? Inclination?
- Declination?
- Earth's field strength vs anomalies.

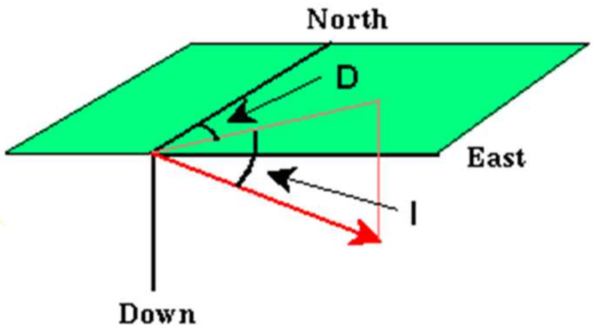
Earth's magnetic field: Strength |B| Inclination I Declination D

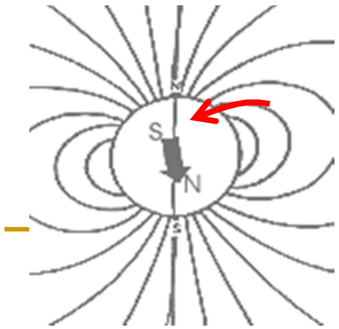






B$_{max}$ = 70,000 nT **H**$_{max}$ = 55.7A/m
B$_{min}$ = 20,000 nT **H**$_{min}$ = 15.9A/m



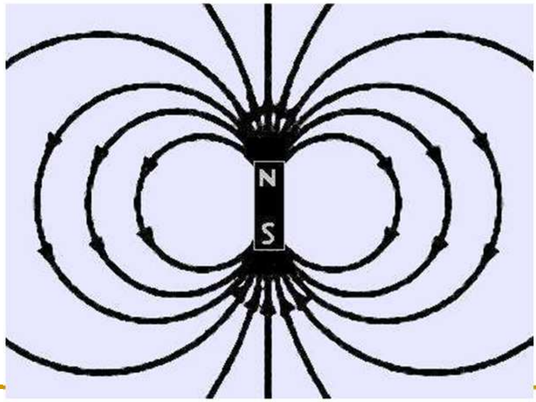


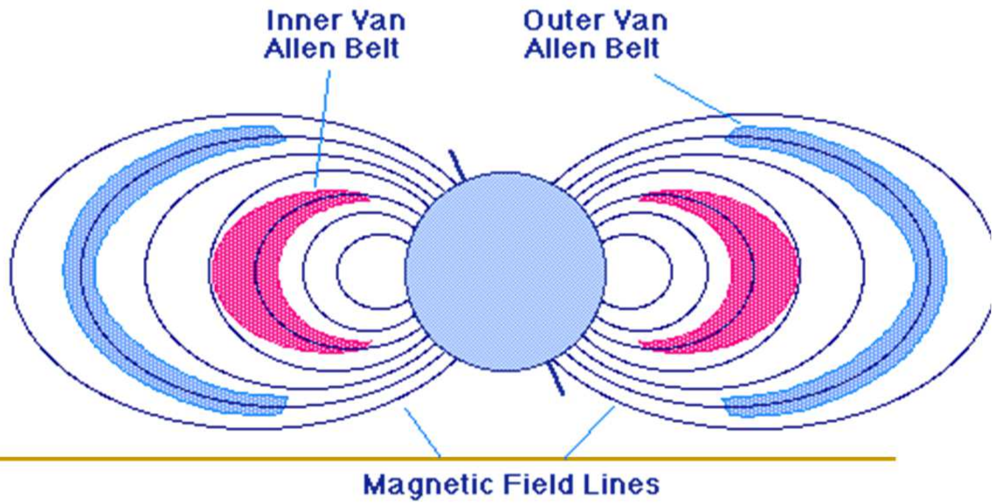
http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/igrfpg.pl

Magnetic field due to a dipole

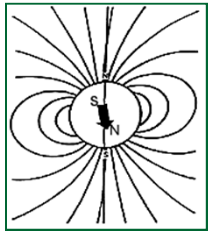
- A "dipole" is the basic quantity in magnetostatics

$$\mathbf{B} = \frac{\mu_0}{4\pi}\frac{\mathbf{m}}{r^3}\left(3\left(\hat{\mathbf{m}}\cdot\hat{\mathbf{r}}\right)\hat{\mathbf{r}} - \hat{\mathbf{m}}\right)$$





Basics of Magnetics Surveying



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2. Materials in the earth become magnetized

(**M = κH** called **Magnetization** (dipole moment per unit volume)

. where H = B/μ0)

3. Magnetized material creates anomalous field (applet)

magnetic moment m = M x (volume)

Drawing the field due to burried dipoles

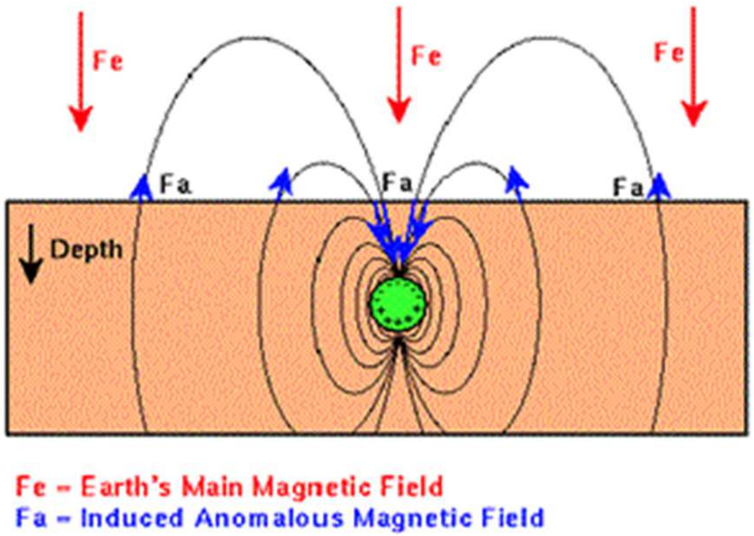
- Use the java applet on the website:
- Via GPG 8.c “Start the applet alone here”

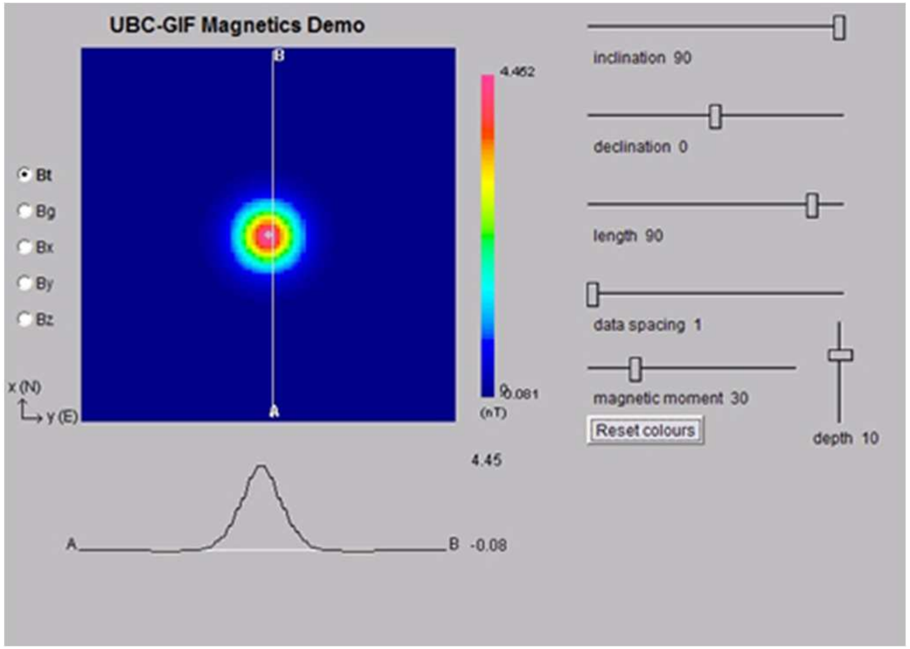
- Or via:

- http://www.eos.ubc.ca/courses/eosc350/content/exercises/meth_3a/dipoleapp.html

- (there will be a link on the main EOSC 350 page)

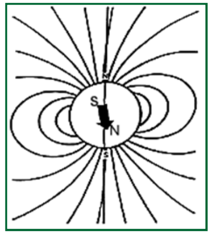
Examples





Note: To plot data we need a sign convention. Here we say that if a field points in the same direction as the source field, it is plotted as a positive value.

Basics of Magnetics Surveying



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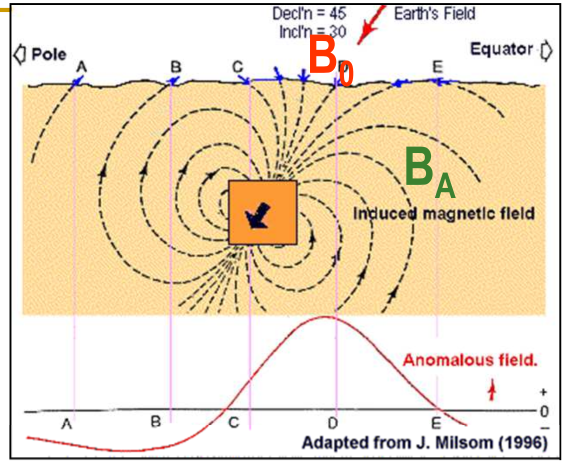
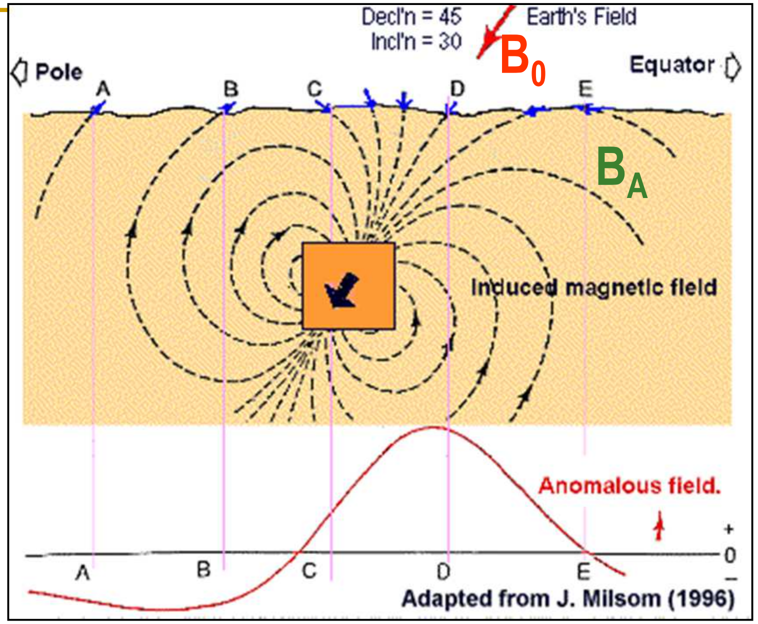
The composite field

Composite field B $= B_0 + B_A$



- The field components are
- $B = \{\mathbf{B_X}\ \ \mathbf{B_Y}\ \mathbf{B_Z}\ \}$

The Anomalous field



Measured field B = B_0 + B_A

- Therefore components are:

  $B_{AX} = B_X - B_{0X}$,

  $B_{AY} = B_Y - B_{0Y}$,

  $B_{AZ} = B_Z - B_{0Z}$

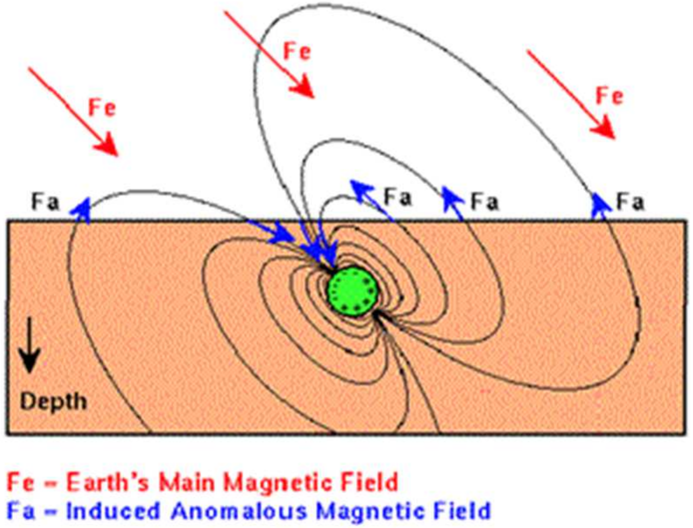
- The *total* field *anomaly*: $\Delta B = |B| - |B_0|$

- If $|B_A| \ll |B_0|$ then

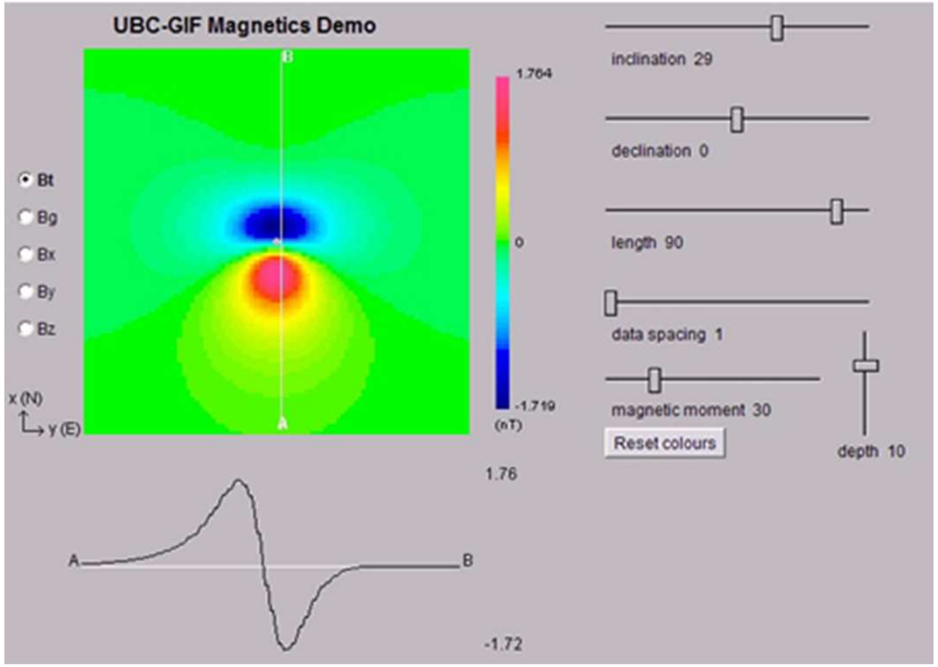
$$\Delta B \cong (B_A \cdot \hat{B}_0)$$

- That is, total field anomaly ΔB is the projection of the anomalous field onto the *direction* of the inducing field.

Examples



Fe
Fe
Fe
Fa
Fa
Fa
Fa
Depth
Fe – Earth's Main Magnetic Field
Fa – Induced Anomalous Magnetic Field



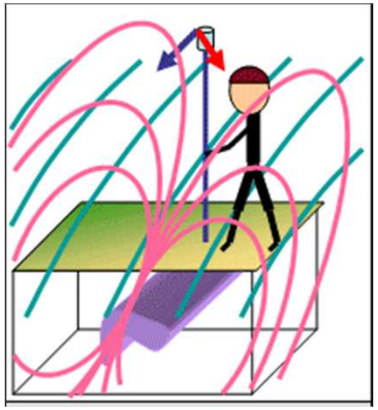
UBC-GIF Magnetics Demo
inclination 29
declination 0
length 90
data spacing 1
magnetic moment 30
depth 10
Reset colours
Bt
Bg
Bx
By
Bz
1.764
0
-1.719
(nT)
x (N)
y (E)
1.76
A
B
-1.72

Details on Anomalous Field

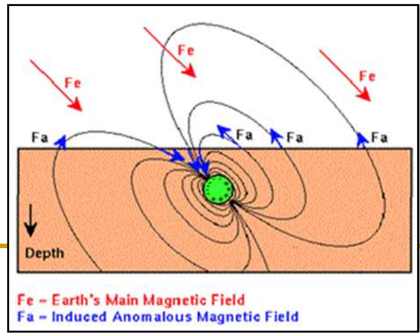
- See GPG d.8 Principles (anomalous fields)
- Also read: Magnetics GPG 3.d.0 – 3.d.13

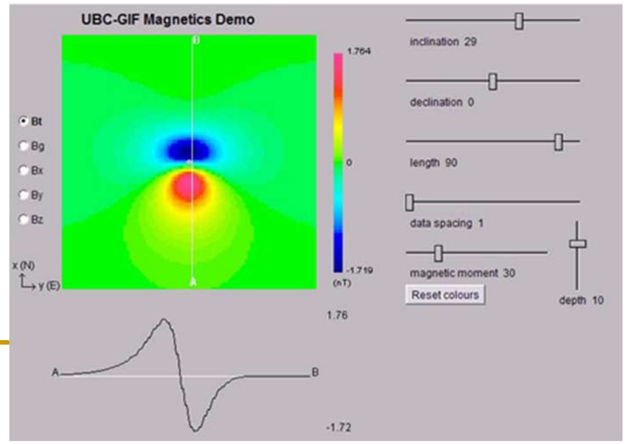
Magnetics – Data

- What exactly is measured?
  - GPG Ch.3.d.1.
  - The "**total field magnetic anomaly".**



- Consequently, what pattern of response can be expected for buried targets? (sketch on BB)
  - Start simple – buried dipole. GPG Ch.3.d.2.
  - Response to shallow or deep dipole targets.
  - Response near <u>magnetic</u> poles …
    … near <u>magnetic</u> equator.

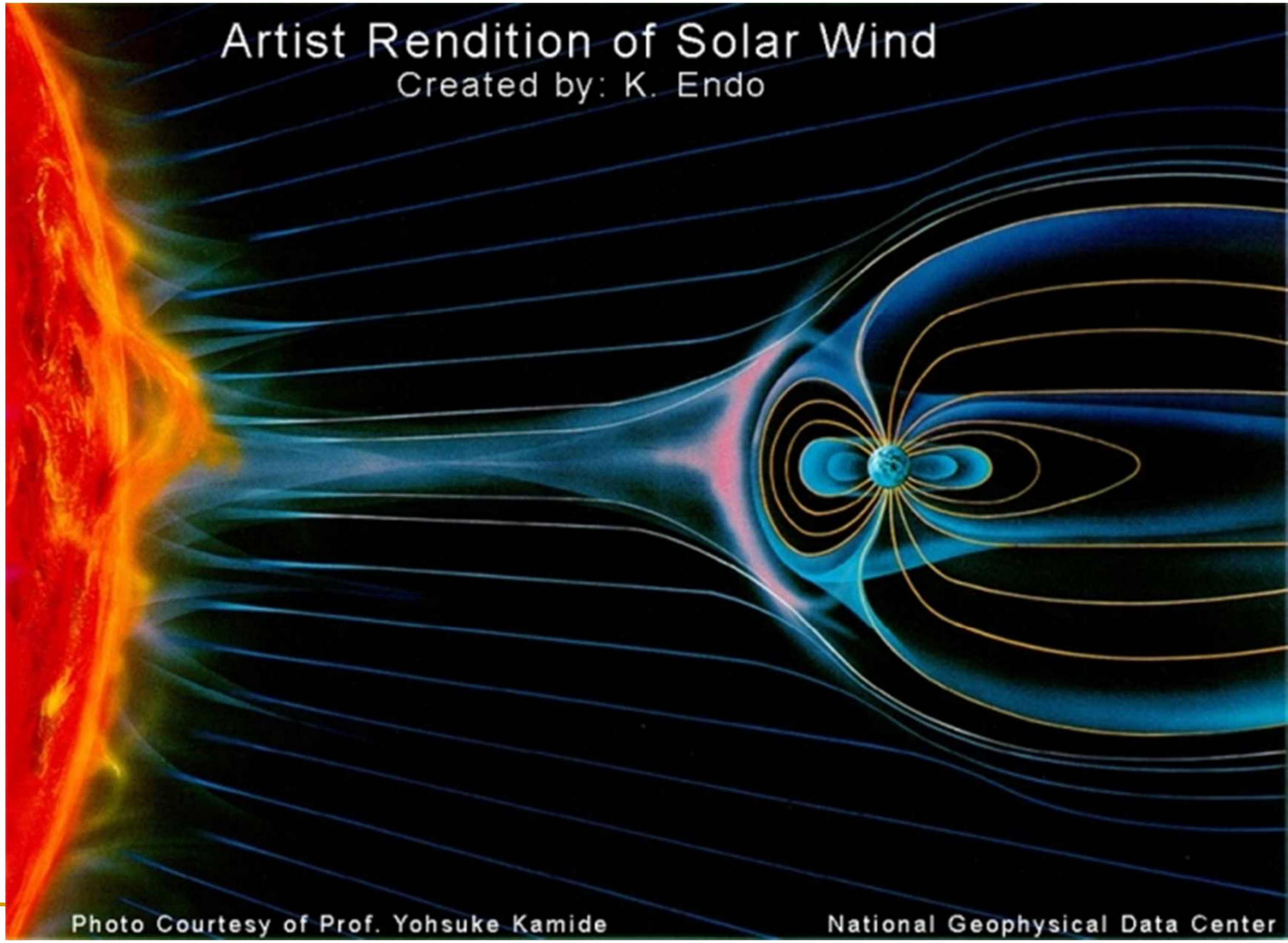




Processing Magnetic Field data

- Account for time variations (need a base station)
- Remove regional

Magnetics – Earth's field

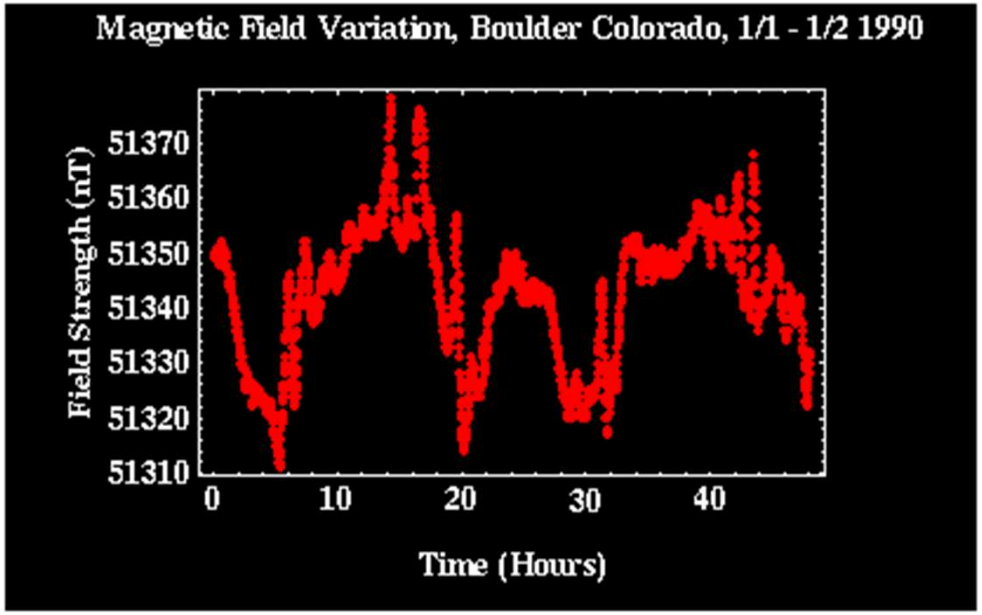


Time Variations of the Earth's Field

- External sources
  - Solar wind (micro-seconds, minutes, hours)
  - Solar storms (hours, days, months)
- Man made sources
  - Power lines (50/60 Hz plus harmonics) DC
  - Motors, generators
  - All electronic equipment
- Internal sources
  - Fluctuations in core (days – millions of years)

Field procedures

- Earth's magnetic field varies as a function of time
- Necessary to record the magnetic field at a fixed location to determine the Earth's field

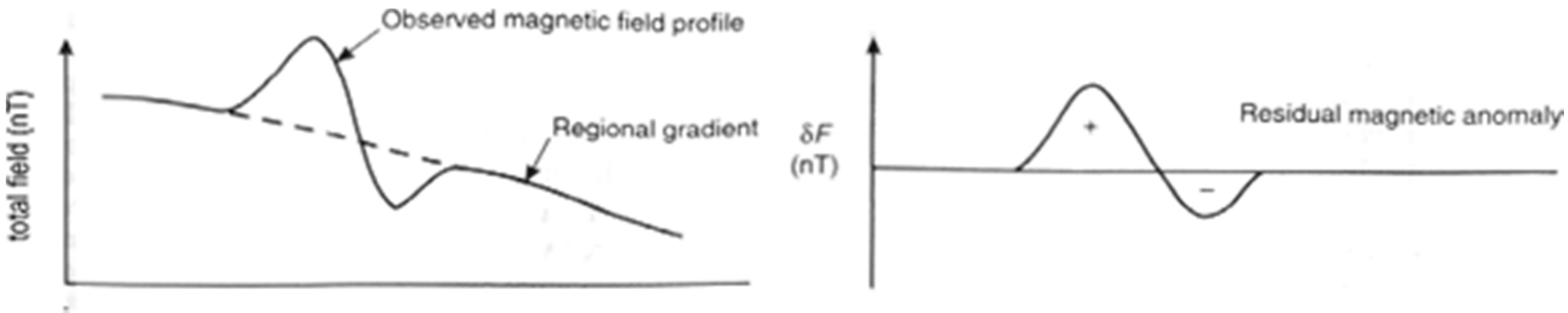


Base station correction

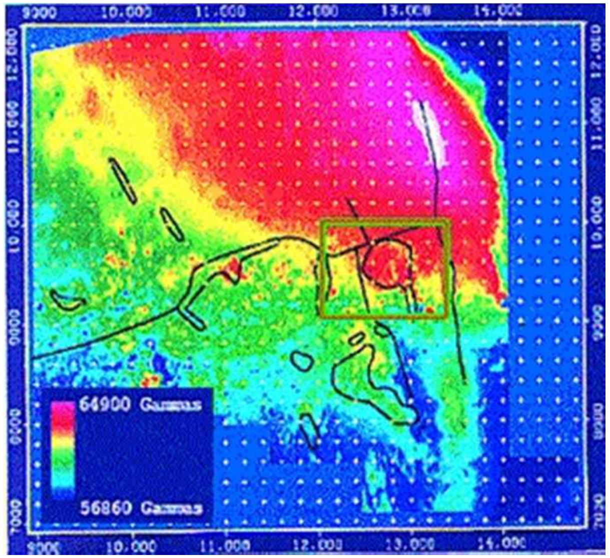
- Set out another magnetometer (base station)
- Assume time variations at the base stations are the same as at the observation location
- Synchronize the times
- Perform a correction by subtraction

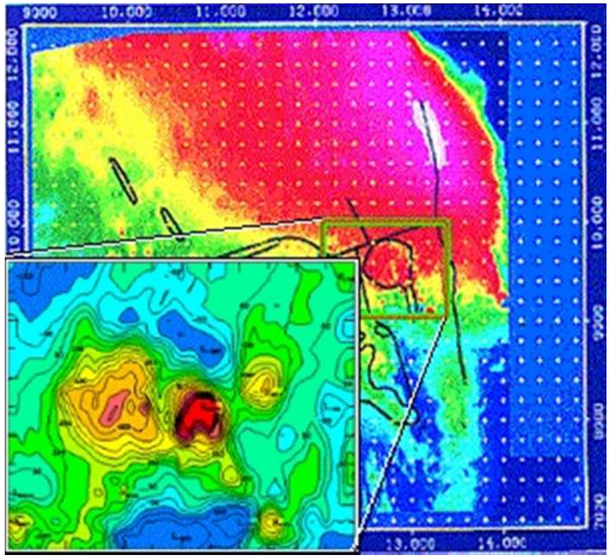
Anomalous field

- We measure the field at the Earth's surface but we are interested in the "anomalous" features
- Regional removal



Example of regional field removal





Airborne magnetic data gathered over a 25 square km area around a mineral deposit in central British Columbia. Some geological structural information is shown as black lines. The monzonite stock in the centre of the boxed region is a magnetic body, but this is not very clear in the data before removing the regional trend.

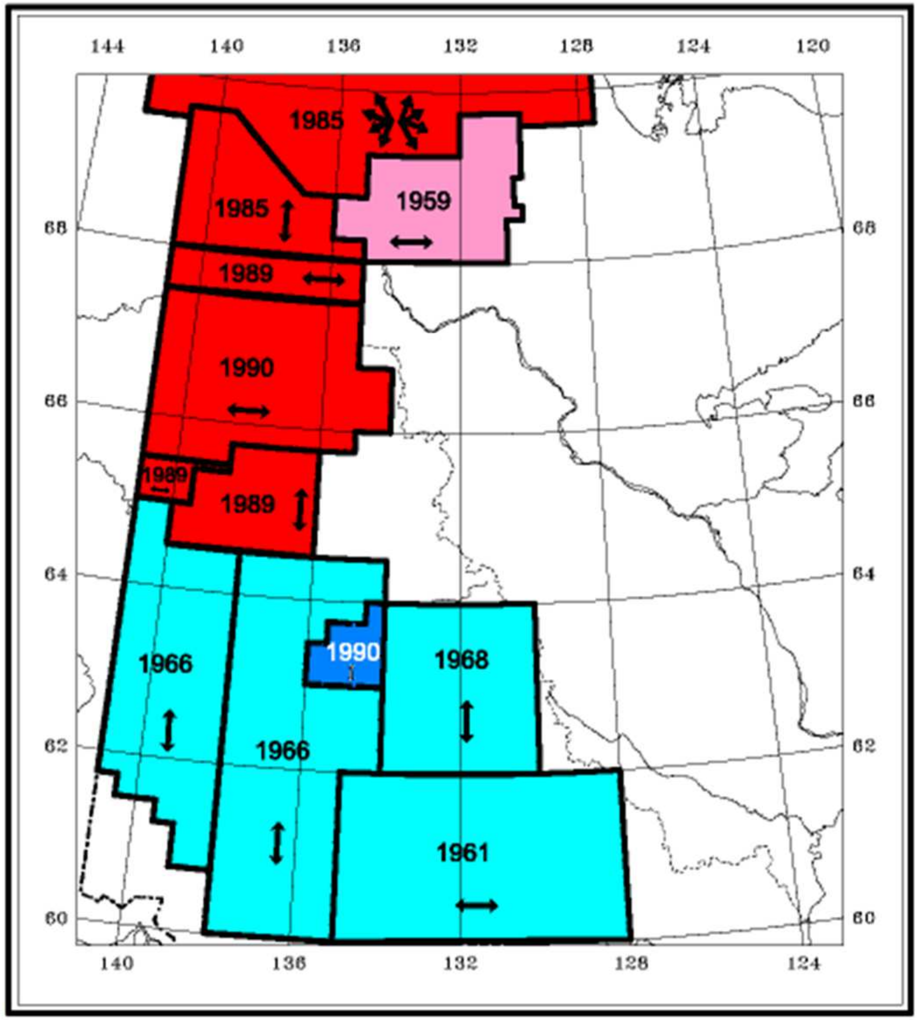
Summary: Data Collection

- Now we know what is measured.
- How – to make measurements?
- Requirements:
  - Base station.
  - Positioning & time tied to each measurement.
  - Measurement while moving.
  - Identify potential noise sources.

Possible routes to extracting information

- Plot the data in various map displays
- Interpret with a dipole
- Interpret with simple bodies of uniform magnetization
- Interpret as complex bodies (inversion)

Aeromagnetic map construction



Legend/Légende

Constant altitude analogue acquisition
Acquisition de données analogiques à altitude constante

Constant altitude digitial acquisition
Acquisition de données numériques à altitude constante

Mean terrain clearance analogue acquisition
Acquisition de données analogiques à hauteur de sol constante

Mean terrain clearance digital acquisition
Acquisition de données numériques à hauteur de sol constante

Flight line orientation
Orientation des lignes de vol

1985 Year of survey
Année du levé

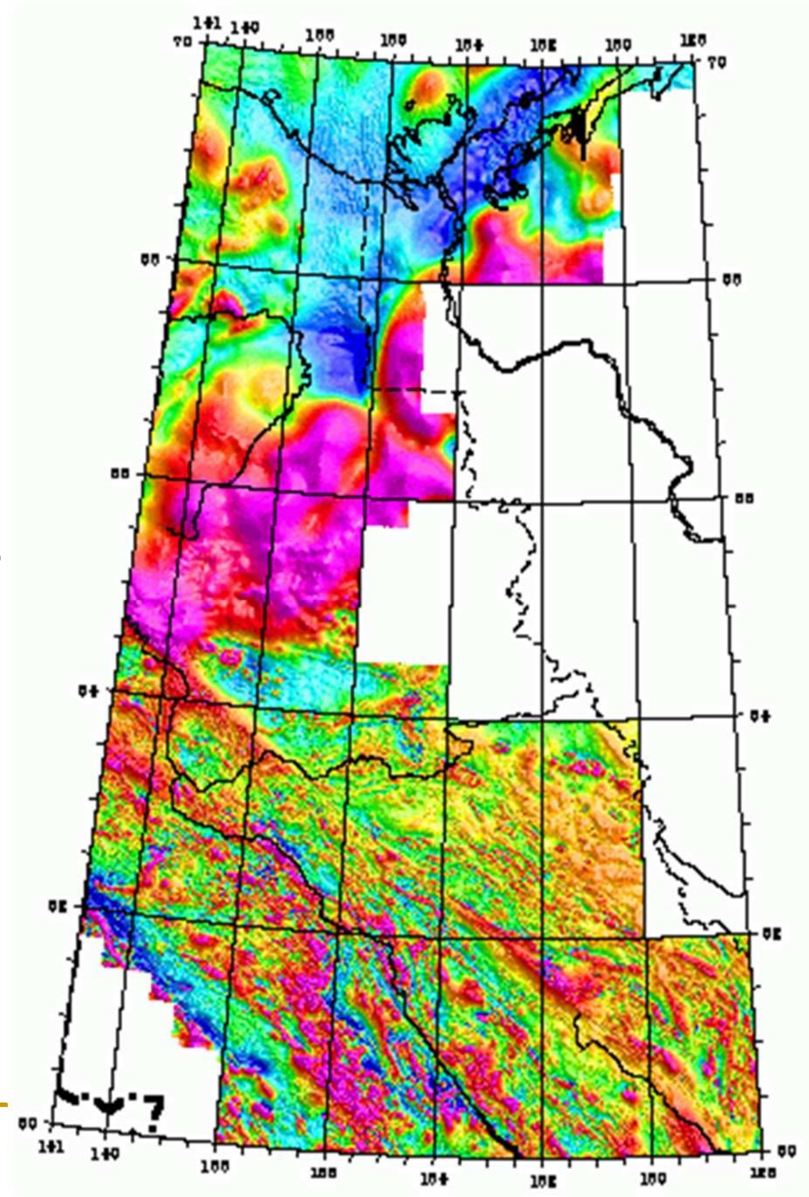
Essential airborne data preparation (processing)

“Levelling” data maps

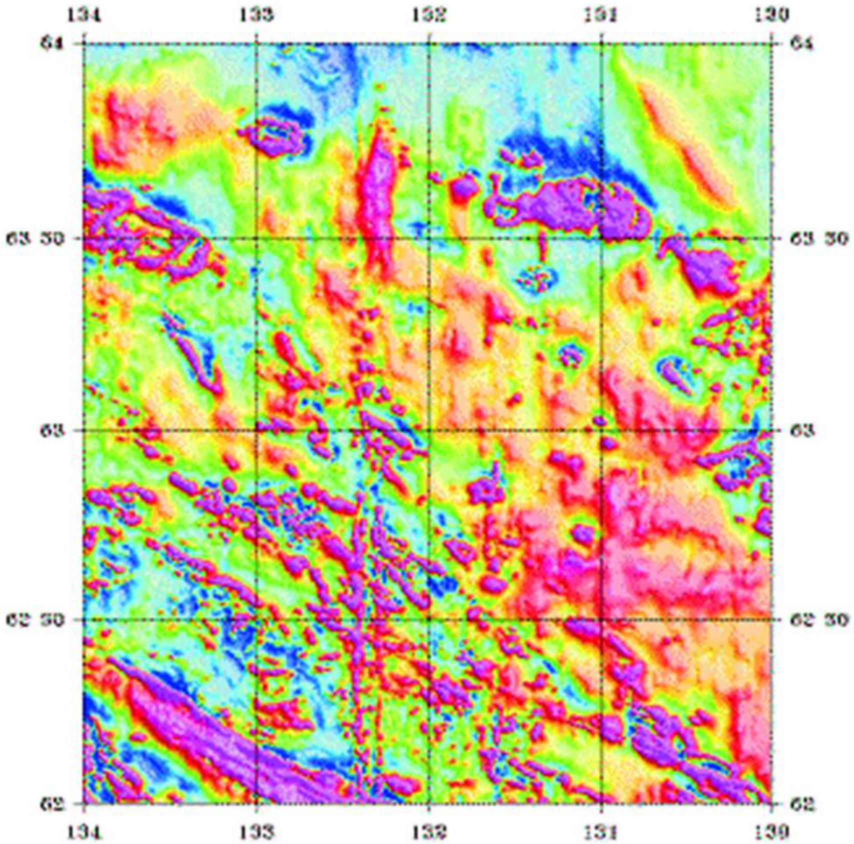
- Adjusting line locations
- drapping

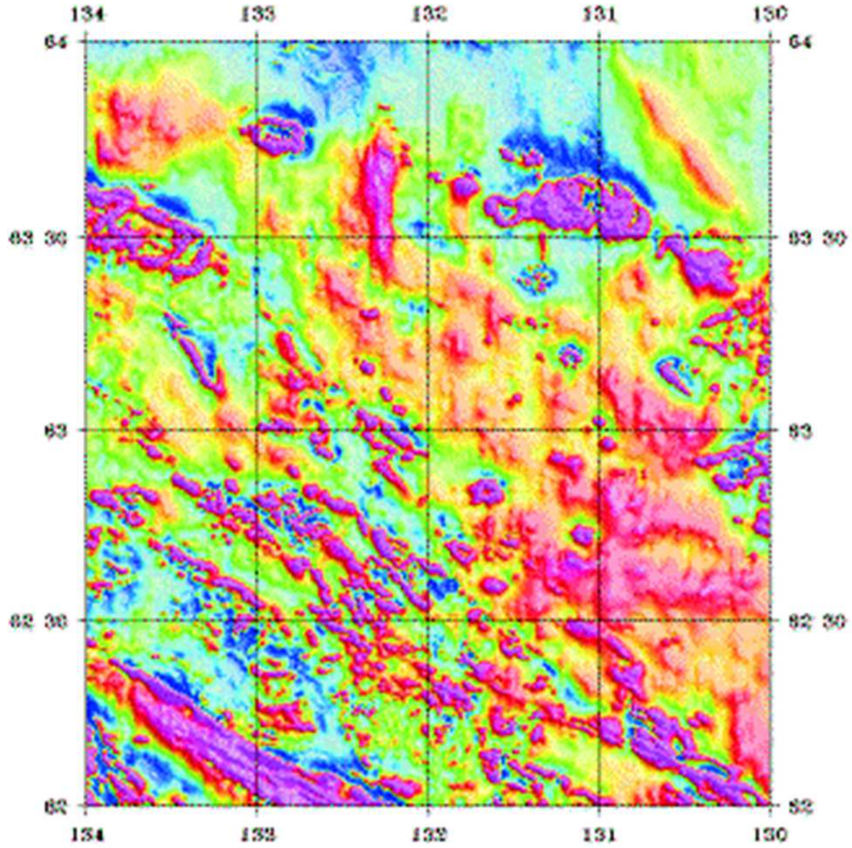
What can be learned directly?

- Trends
- Contacts
- Geologic settings



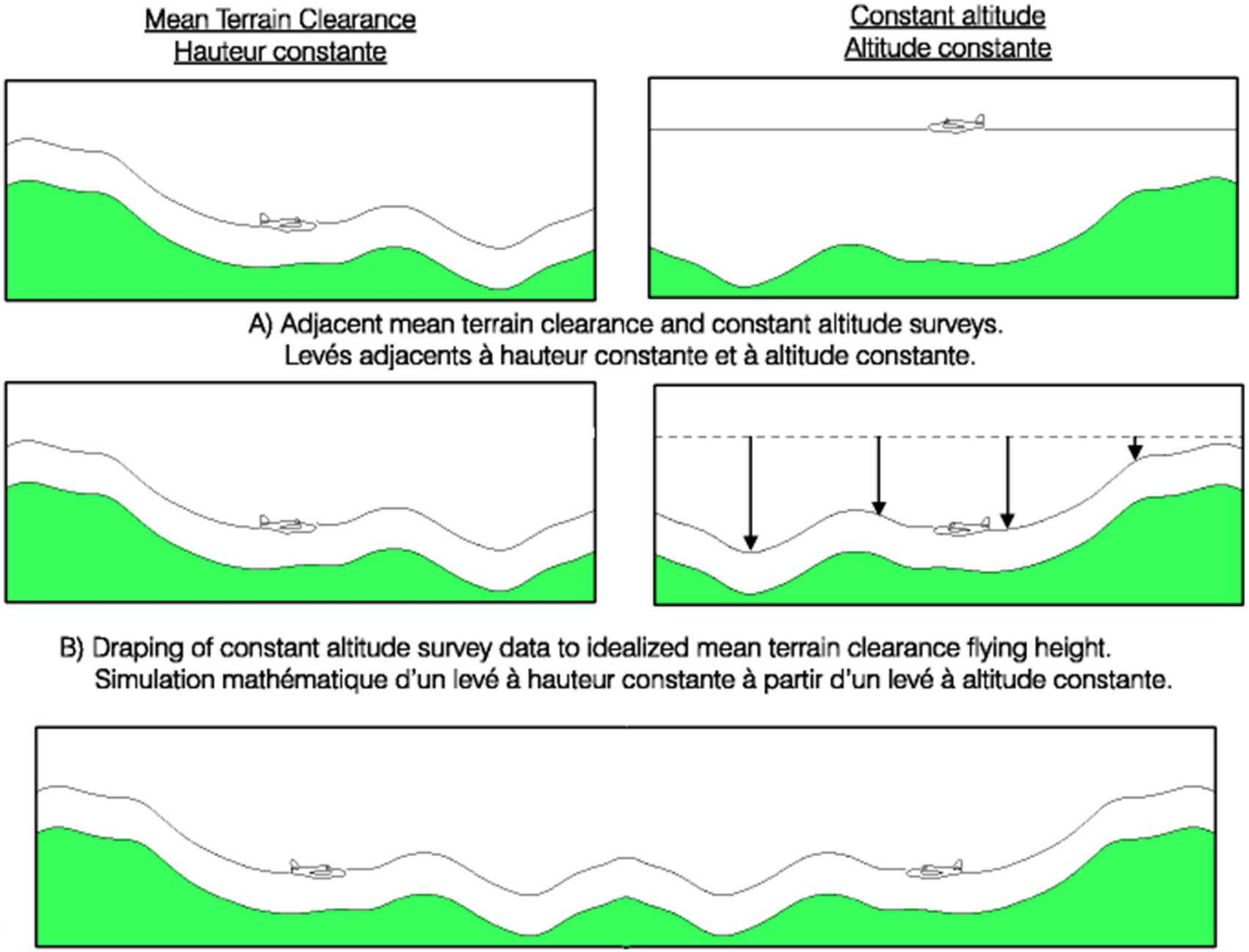
Positioning errors of flight lines (old data)





Essential airborne data preparation (processing)

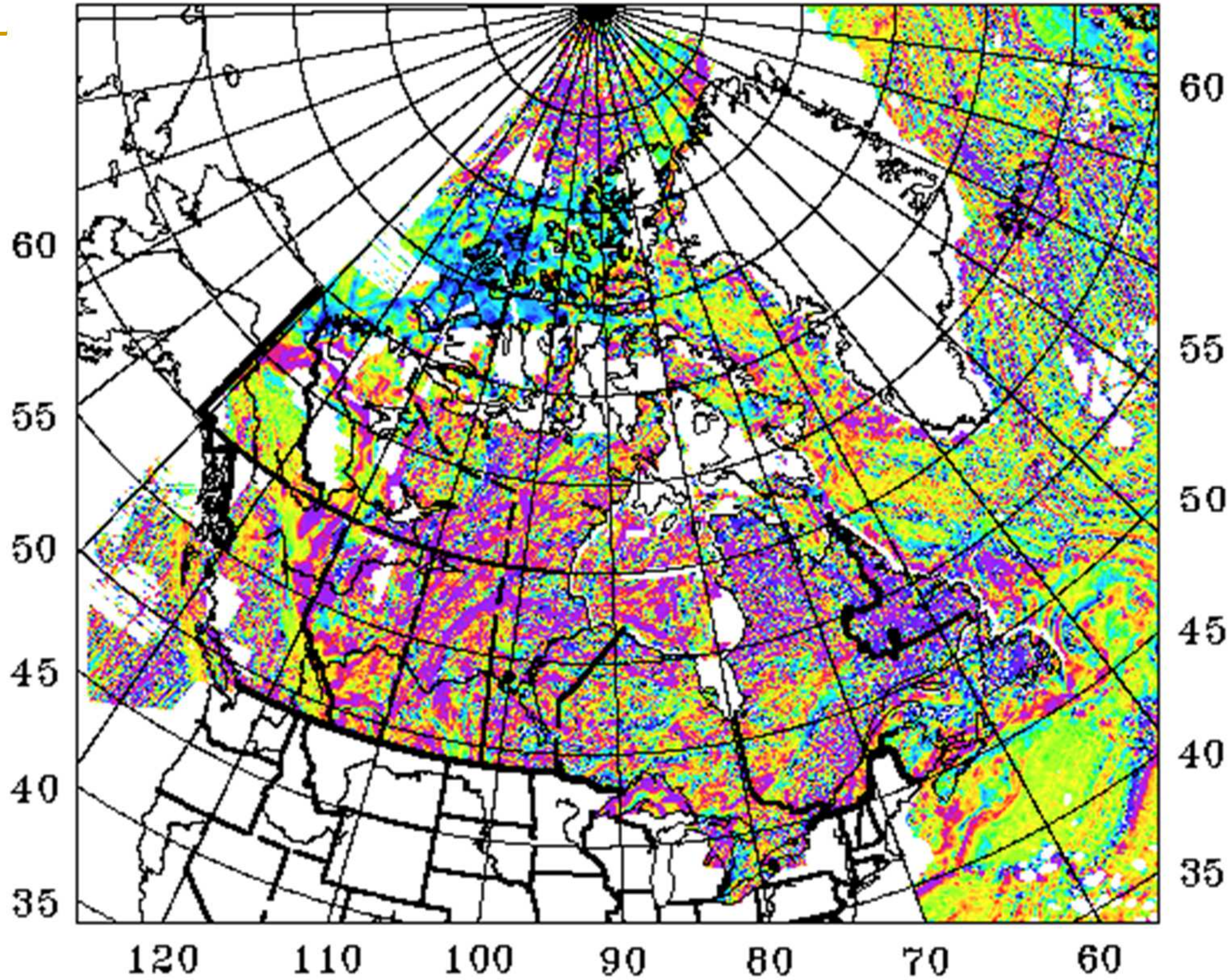
- Plotting
- Editing
- Drapping



A) Adjacent mean terrain clearance and constant altitude surveys.
Levés adjacents à hauteur constante et à altitude constante.

B) Draping of constant altitude survey data to idealized mean terrain clearance flying height.
Simulation mathématique d'un levé à hauteur constante à partir d'un levé à altitude constante.

C) Draping the constant altitude survey improves levelling between surveys.
Ce calcul facilite l'ajustement de levés adjacents.



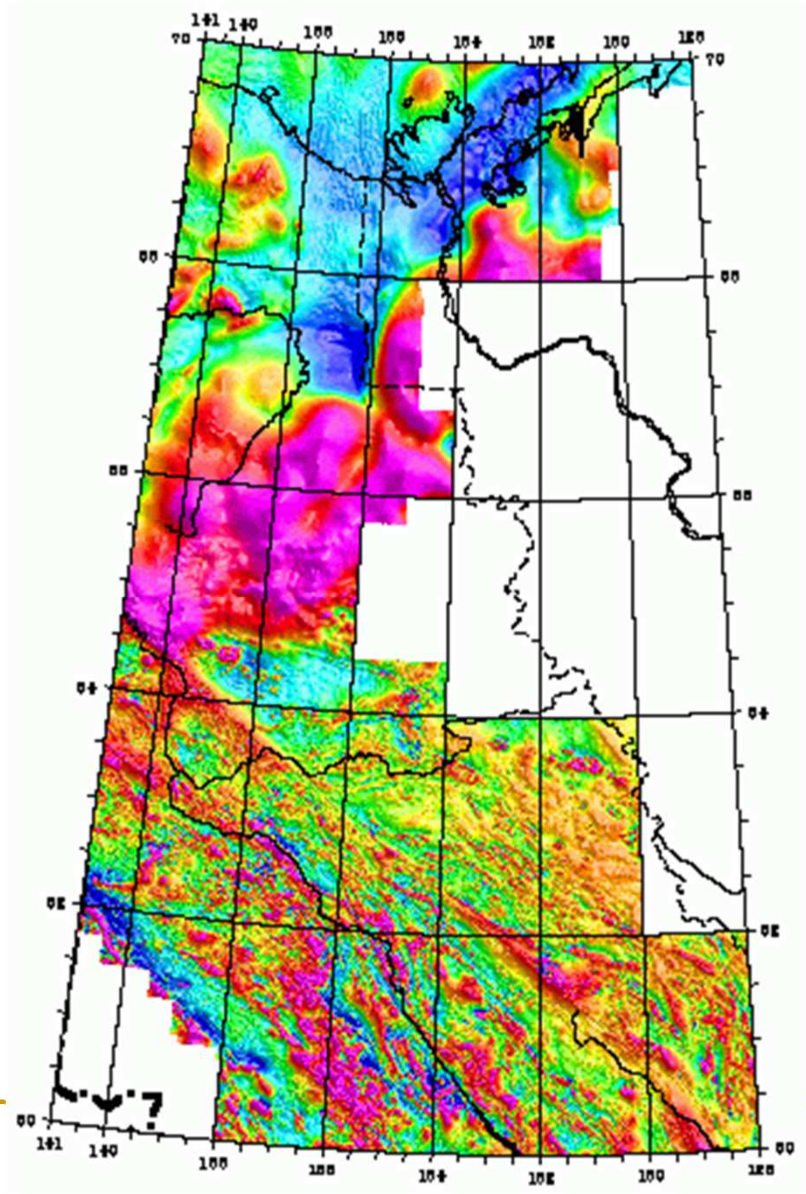
The entire data set is available as a 200 m grid which is updated annually to reflect recent data acquisition. $45 from the Canadian government

Essential airborne data preparation (processing)

“Residual total magnetic field”

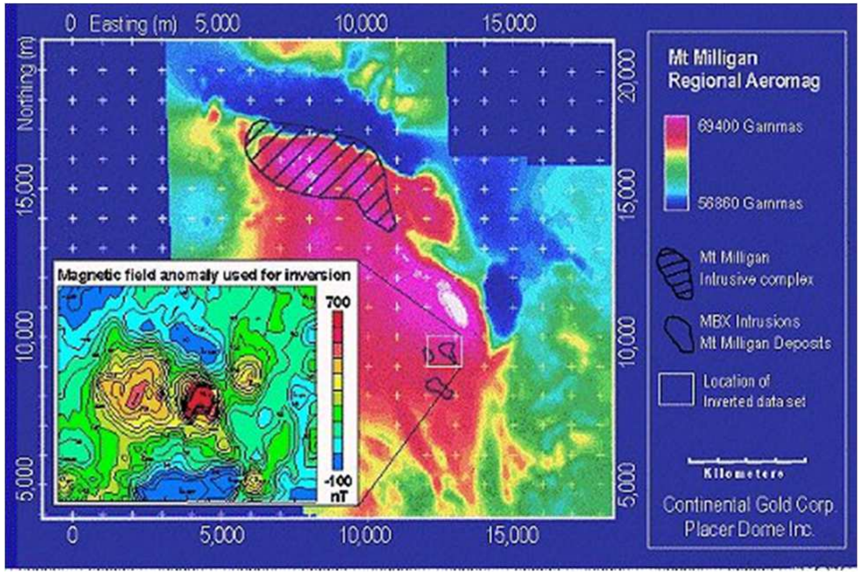
“Reduced to pole”

- What can be learned directly?
  - Trends
  - Contacts
  - Geologic settings

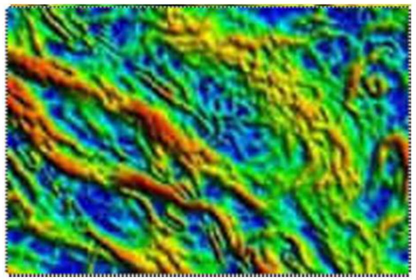


Processing needed before interpreting

- Required
  - Temporal correction
  - Remove regional if present.
  - Noise suppression
- Optional
  - Filtering to emphasize edges, other features.
  - GPG Ch.3.d.6.



Mt Milligan, BC. GPG Ch.6.d.1

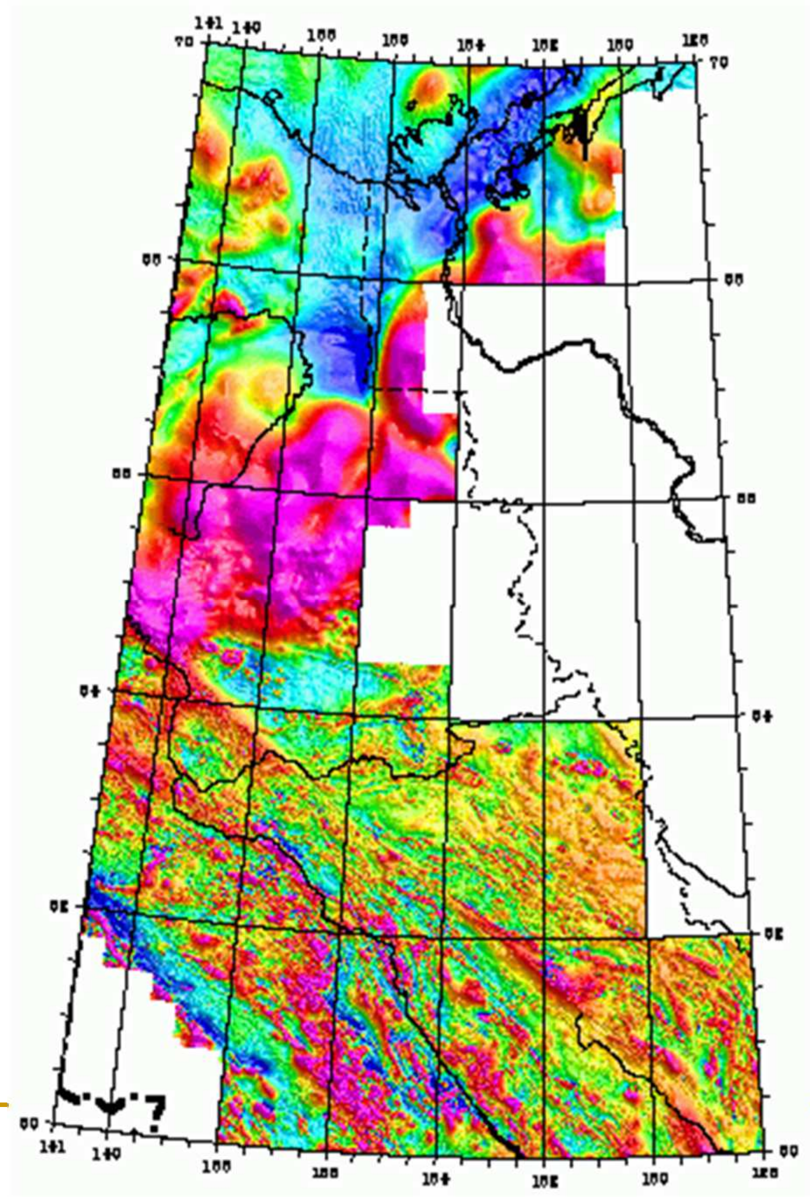


Essential airborne data preparation (processing)

“Residual total magnetic field”

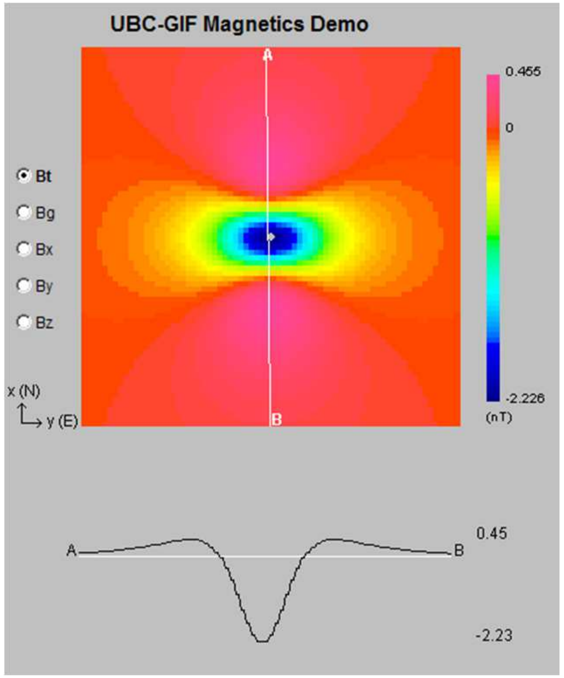
“Reduced to pole”

- What can be learned directly?
  - Trends
  - Contacts
  - Geologic settings

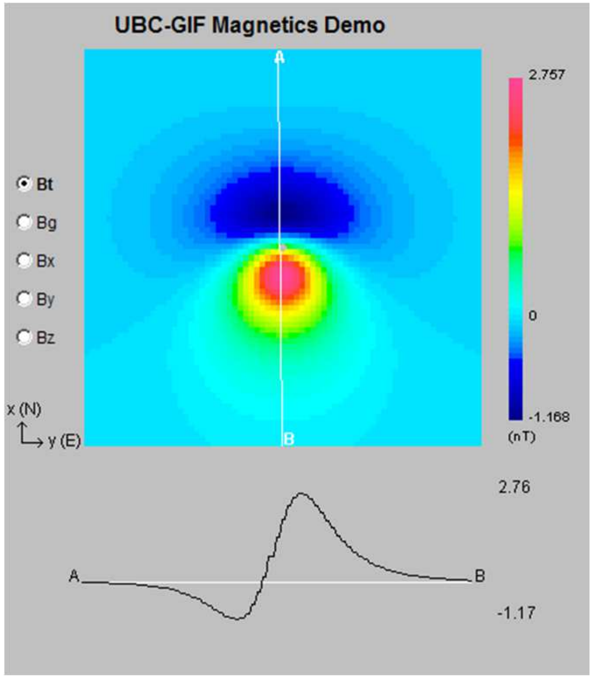


Reduction to Pole

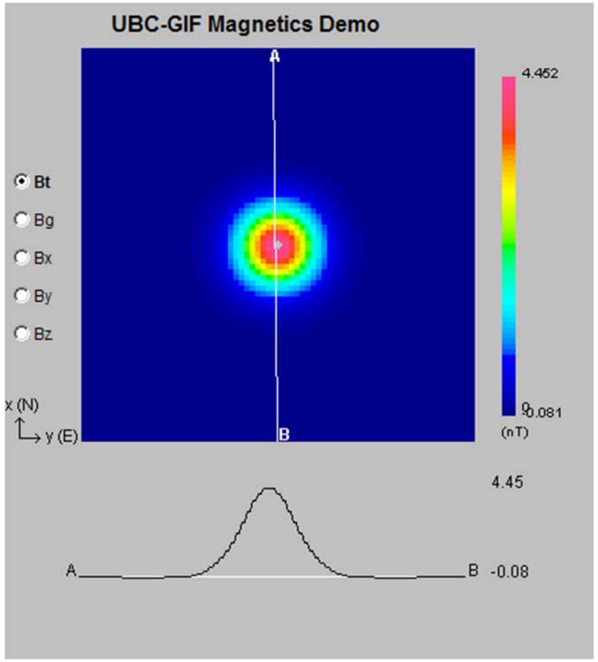
Same object buried at different locations on the earth yields different total field anomalies.



Inclination=0



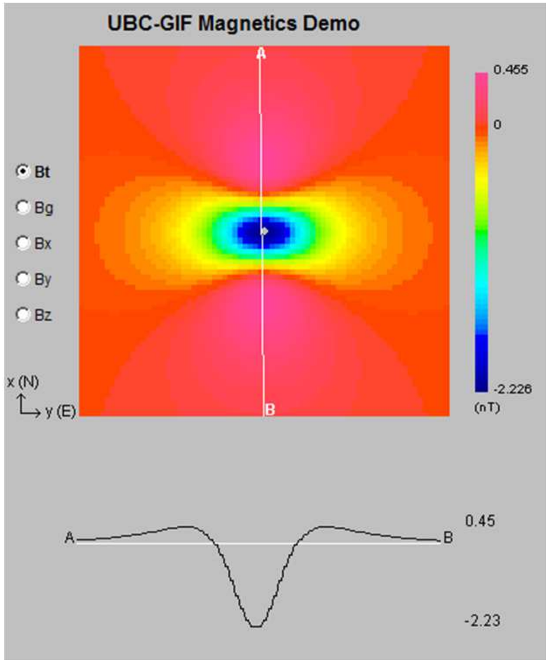
Inclination=45



Inclination=90

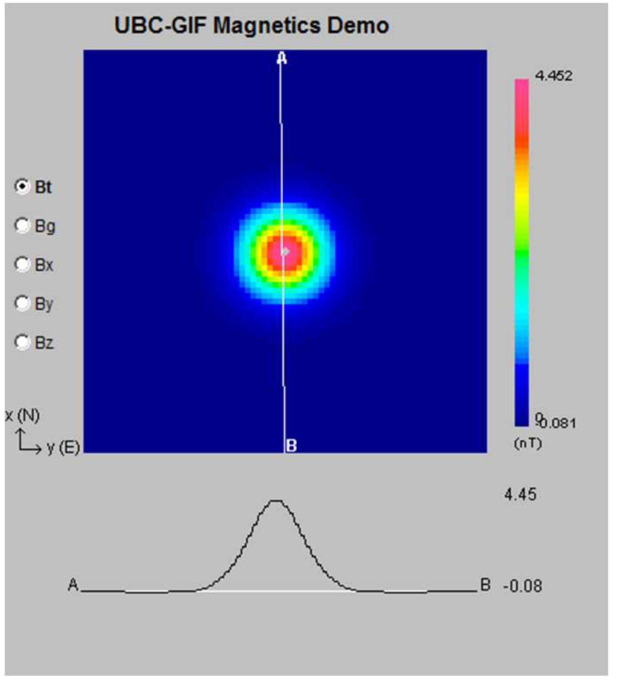
Reduction to Pole

Filter the data to emulate the response as if the survey was taken at the pole. (Earth's field is vertical; measure vertical component of the anomalous field)



2D Fourier Filter

→



This simplifies interpretation. Causative body lies beneath the peak.

Magnetics for Geologic Mapping

When rock outcrops are sparse we must rely on other available techniques to denote changes in geologic units and/or structures.

Magnetic surveys

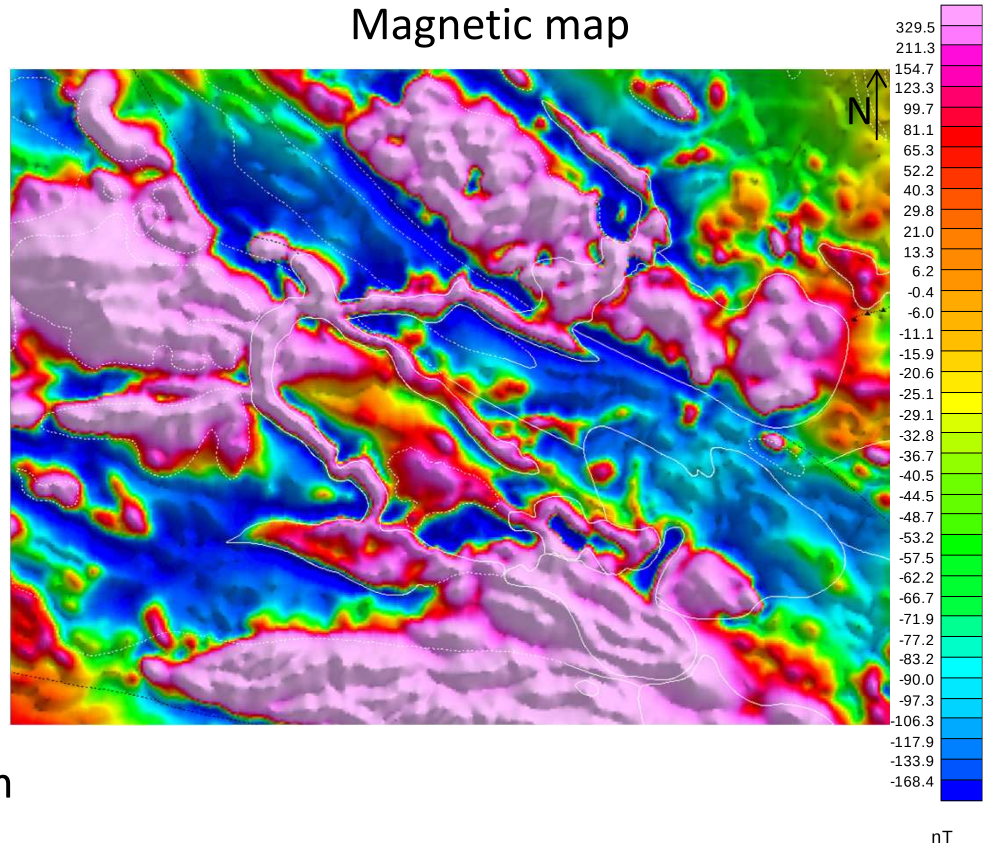
- Very common mineral exploration tool to aid with geologic mapping.
- One of the **cheapest** geophysical surveys to execute on land or with an aircraft.
- Used on regional and deposit scale to identify geologic boundaries and structures (such as faults or folds).
- Many mineral deposits are found on geology boundaries or faults so magnetic maps are useful for target prospective areas.

Geologic boundaries

Geology map

30 km

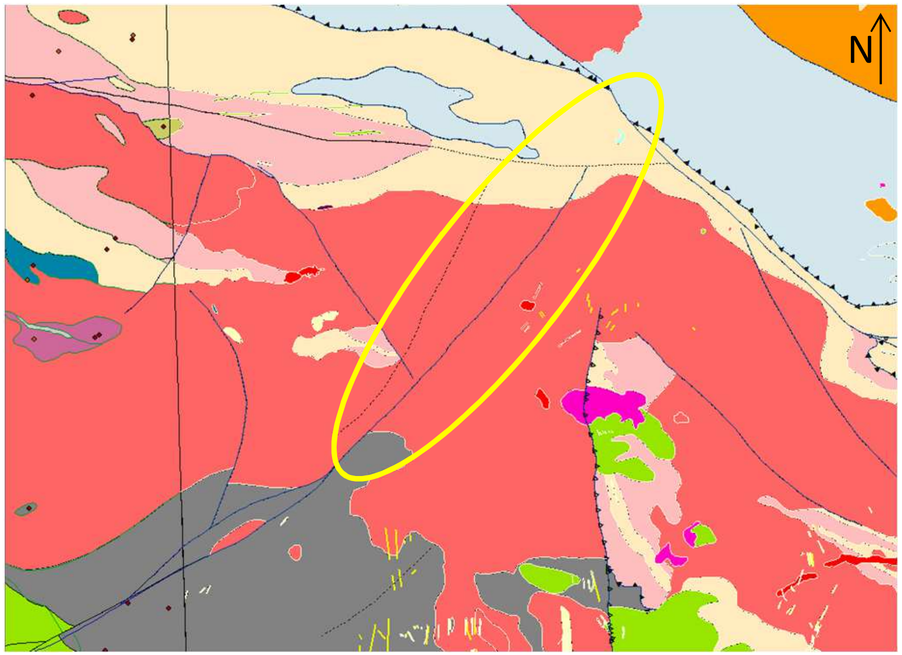
Magnetic map



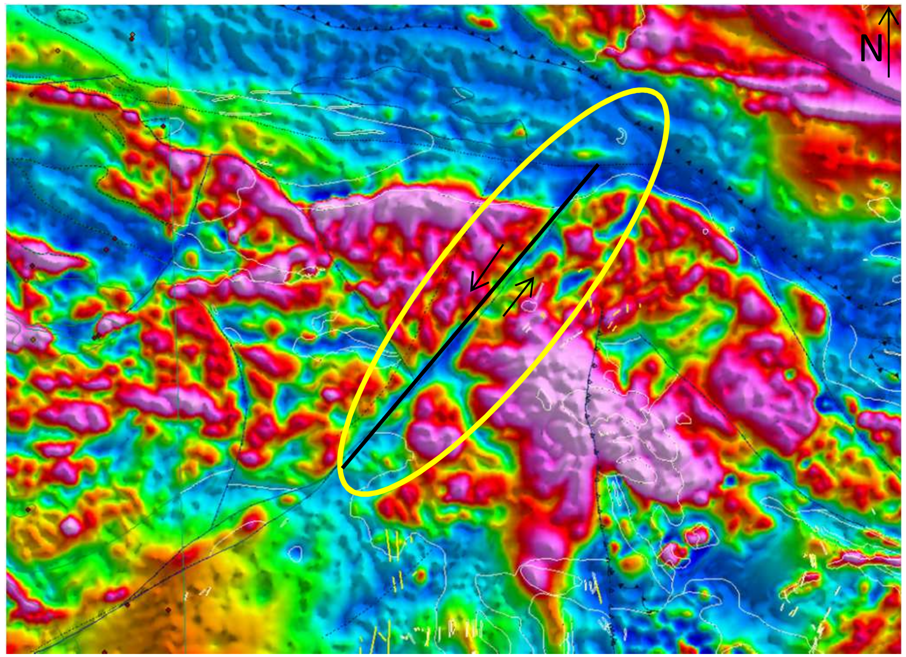
Geology contacts can be inferred from mag maps.

Identifying regional scale faults

Geology map



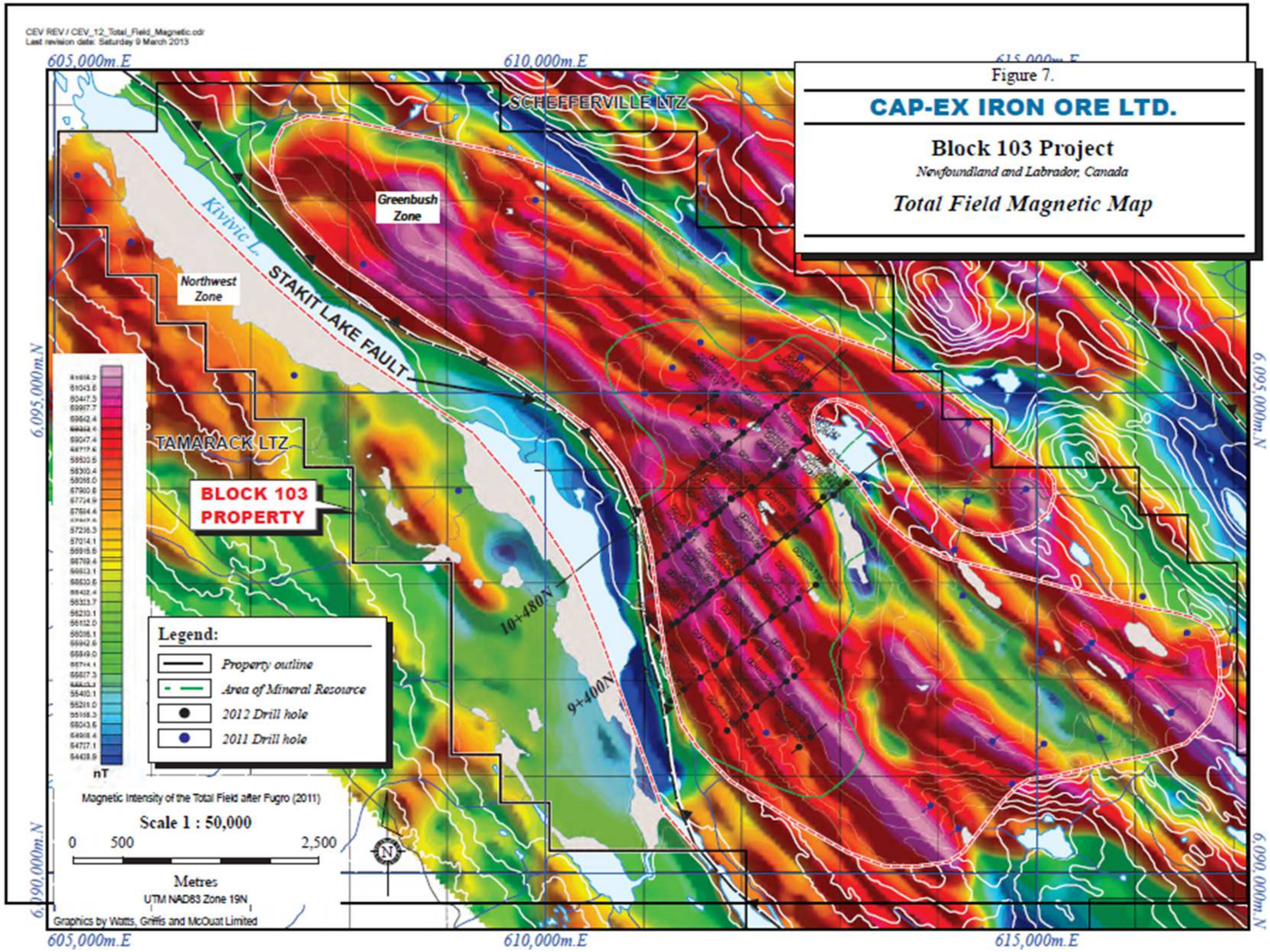
Magnetic map



55 km

Mag map highlights faults within known gold bearing plutonic body (red) in west-central Yukon.

Example - Iron ore deposit



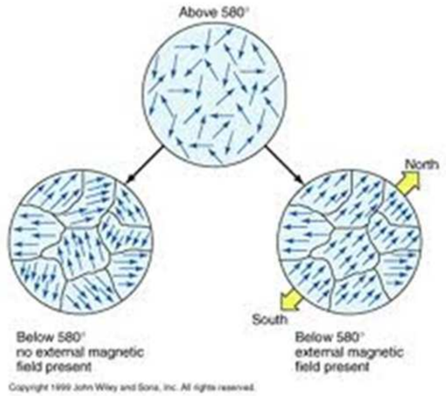
Magnetite rich rock shows as mag high anomaly

Possible routes to extracting information

- Plot the data in various map displays
- Interpret with a dipole
- Interpret with simple bodies of uniform magnetization
- Interpret as complex bodies (inversion)

Remanent Magnetization

- Magnetic material cooling through Curie temperature (~550 C) acquires a magnetic field in the direction of the earth's field.

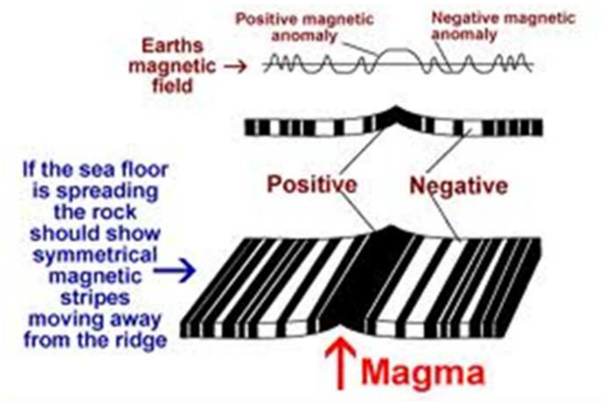


- Final magnetization sum of induced and remanent magnetization: $\vec{m} = \vec{m}_I + \vec{m}_R$

Remanent Magnetism at different scales

- Small scale: UXO, rebar, drums

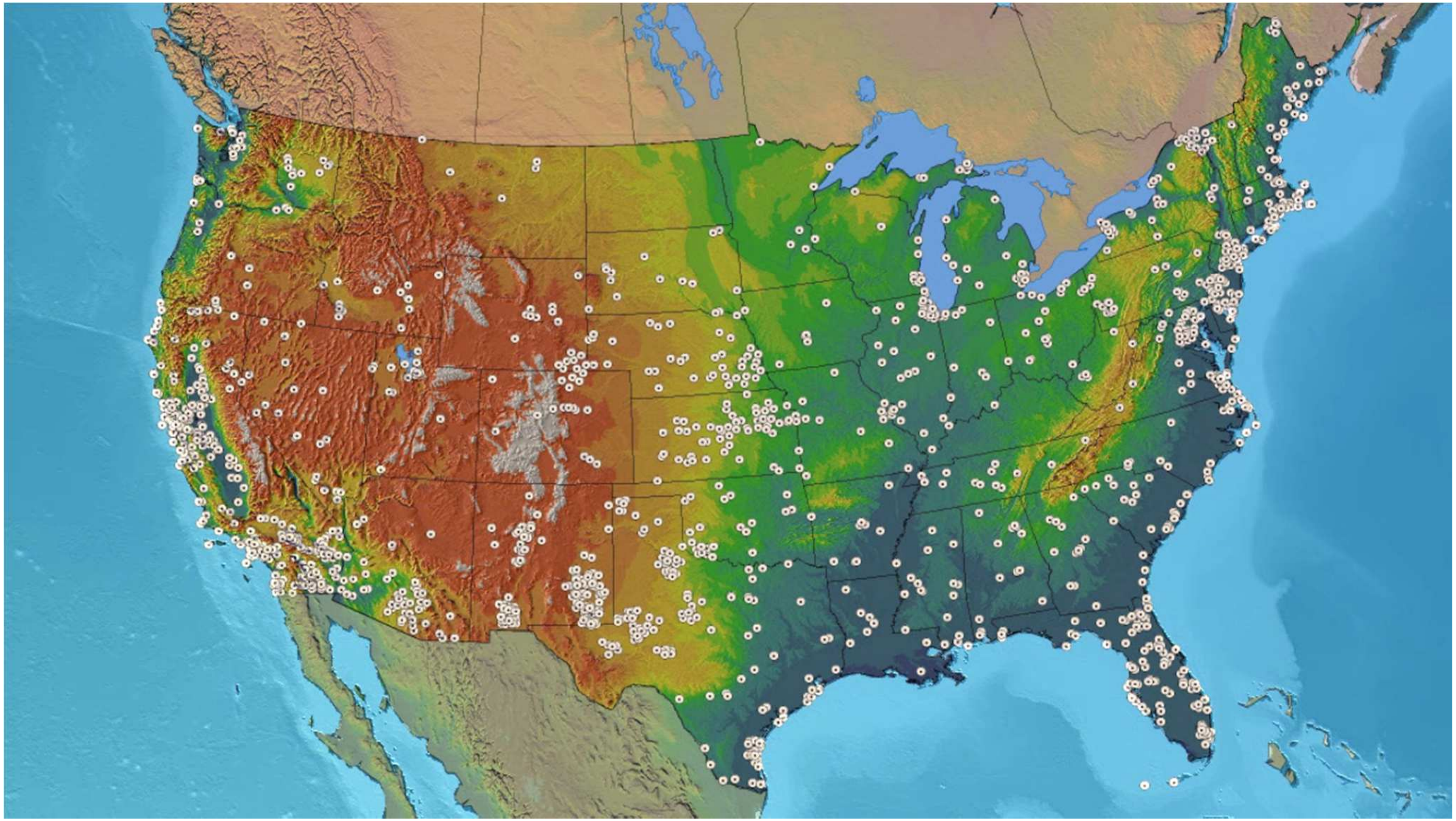
- Large scale: geologic units. Sea floor spreading



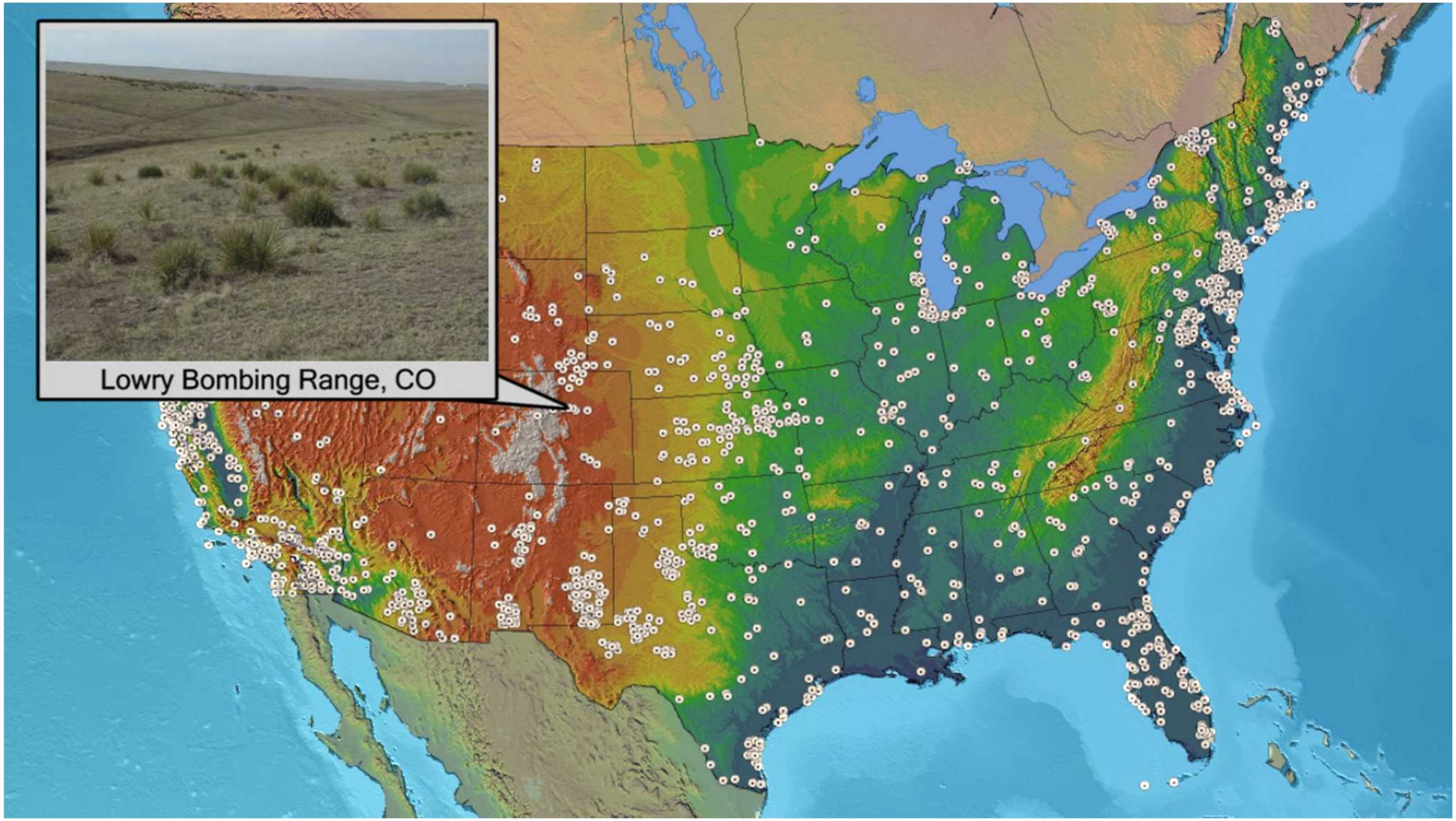
The Munitions Problem

- There are over 3,000 sites suspected of contamination with military munitions
- They comprise 10s of millions of acres
- The current annual cleanup effort is on the order of 1% of the projected total cost
- To make real progress on this problem, we need a better approach

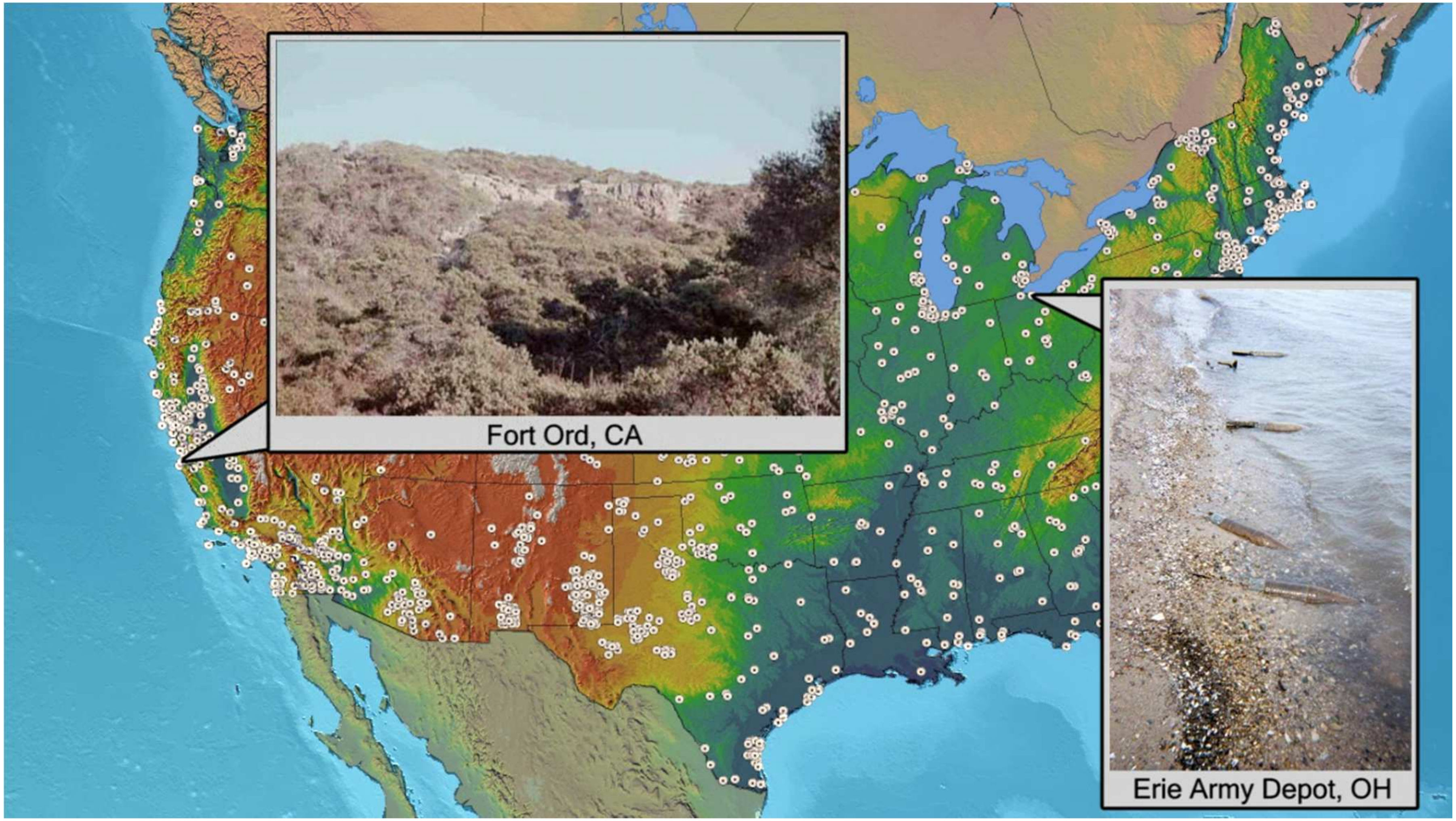
The Munitions Problem



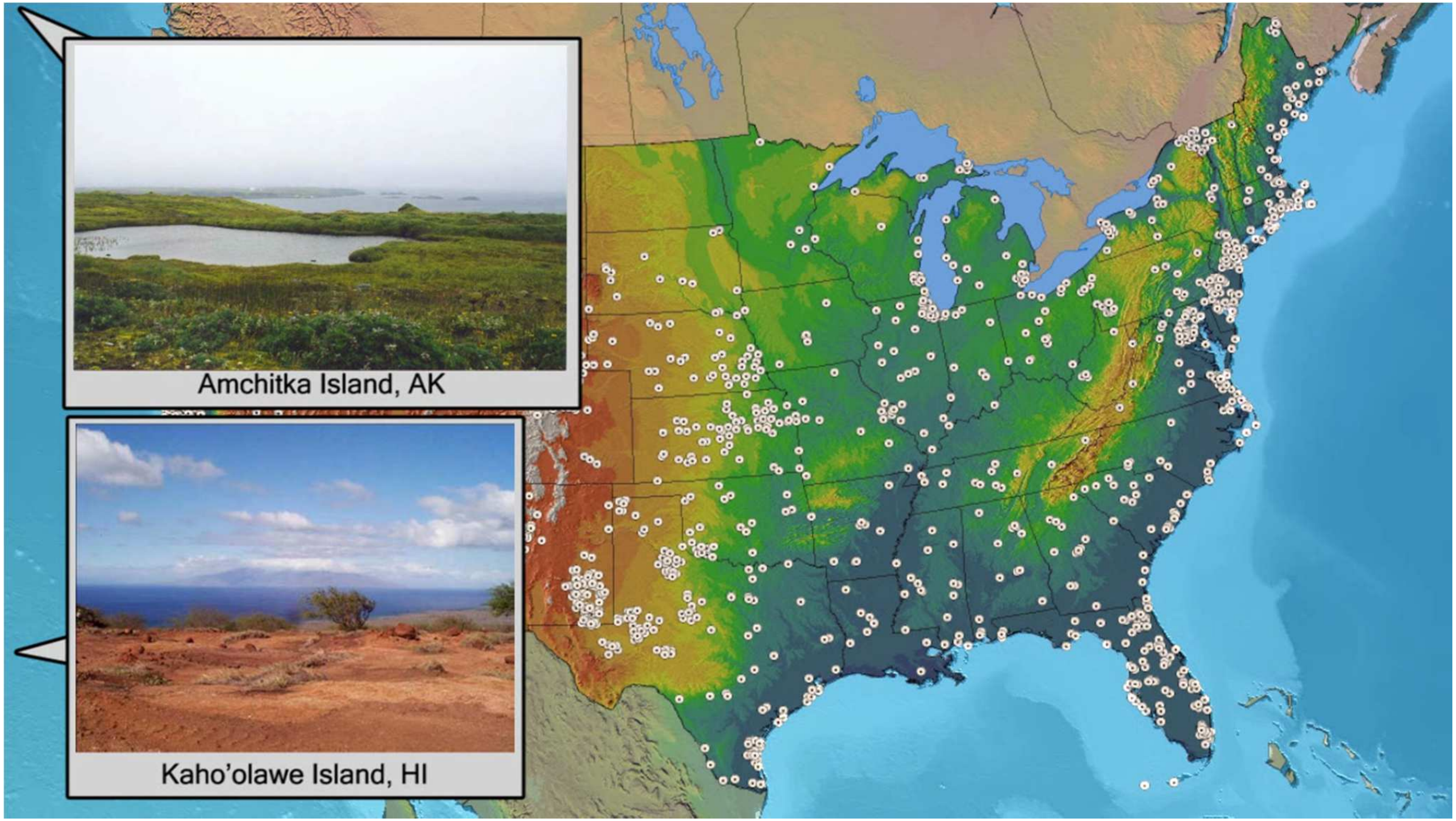
The Munitions Problem



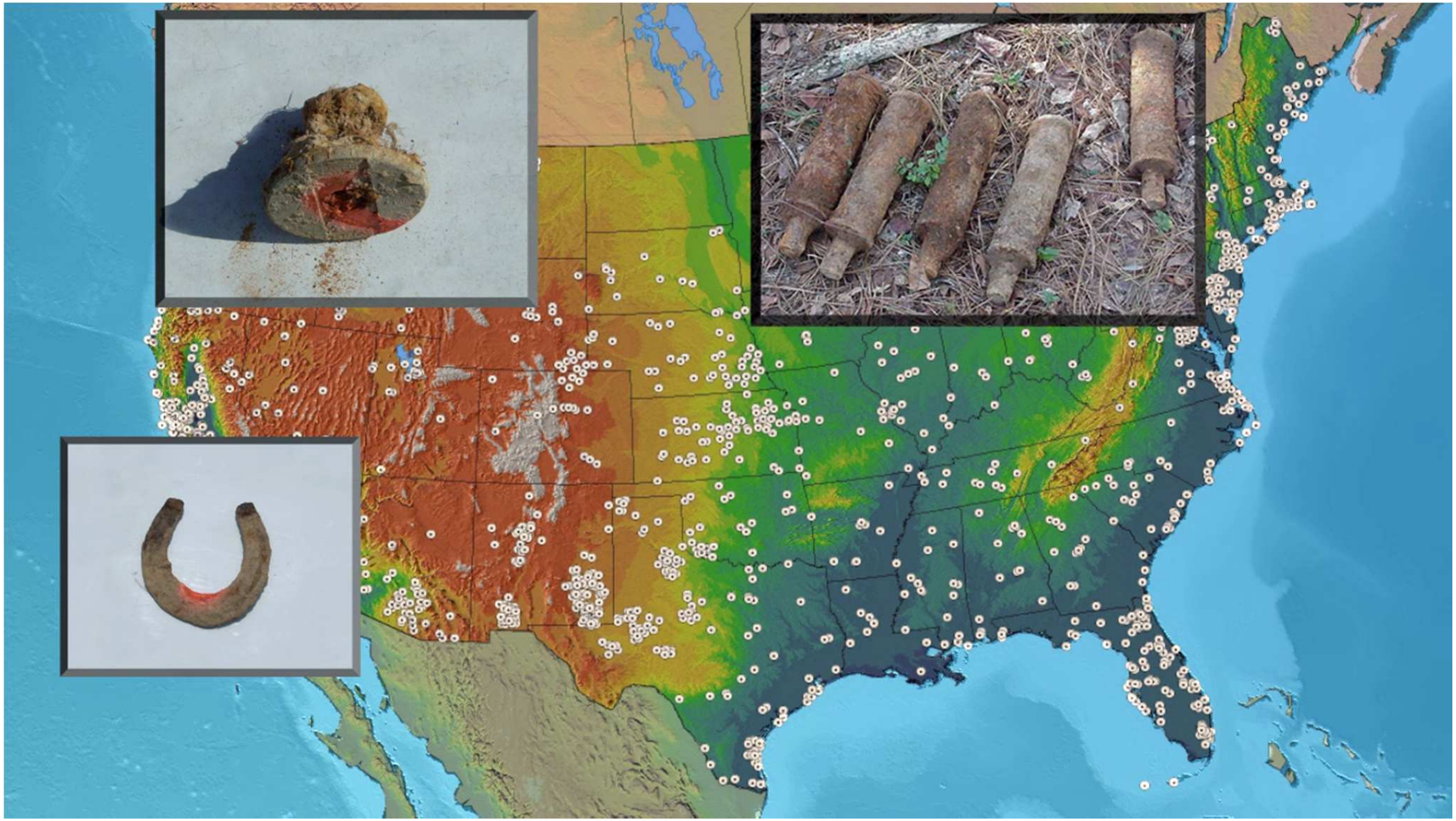
The Munitions Problem



The Munitions Problem



The Munitions Problem

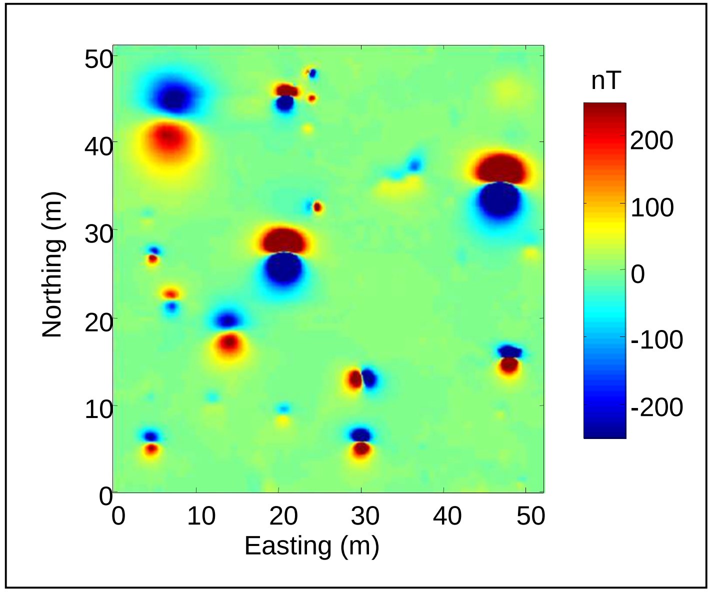


Environmental: How do we find UXO?

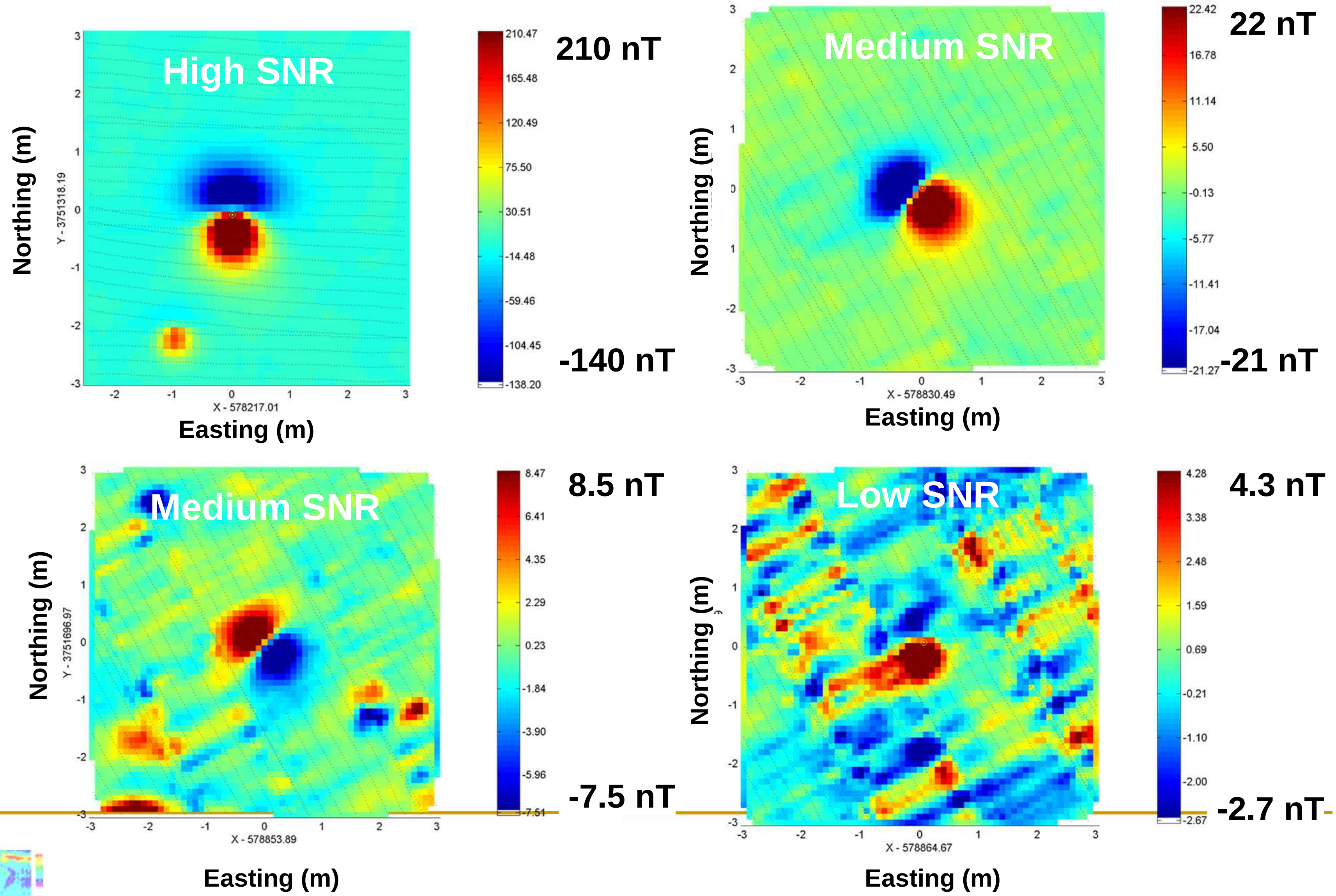
Environmental : Magnetic Survey

Ferrex

TM4

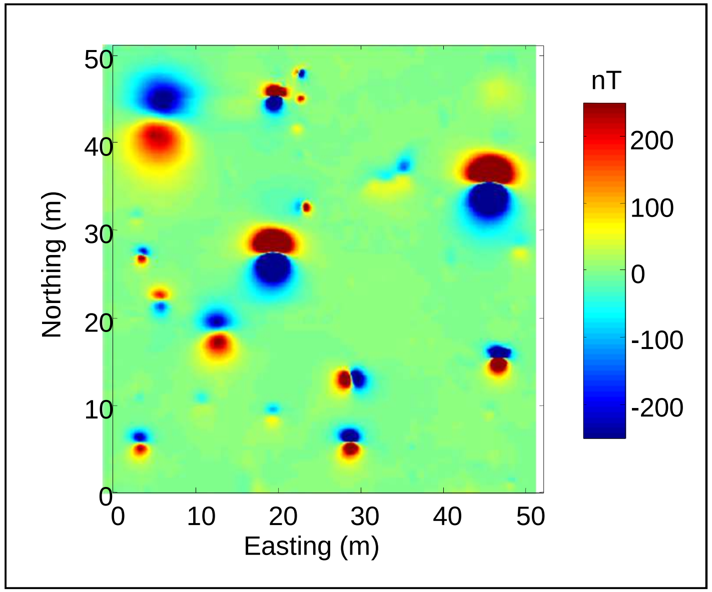


Examples of “good” data



What is the formula for a magnetic dipole

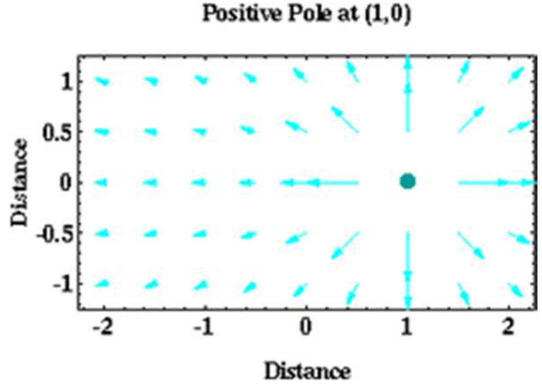
- These look like dipoles but how do we analyze the signal?

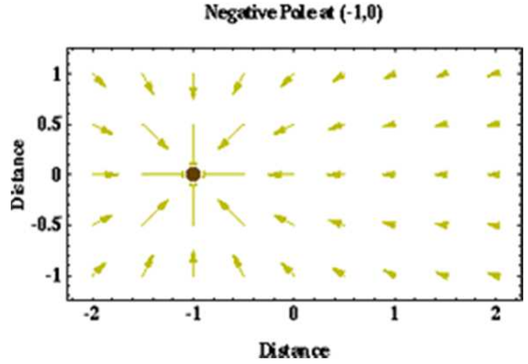


Magnetic Charges (or Poles) (GPG d3 & d8)

- A magnetic charge creates a magnetic field H

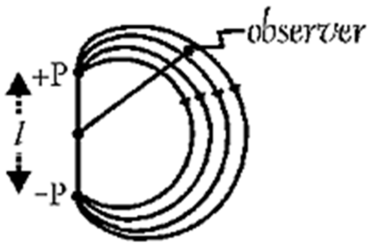
$$\vec{H} = \frac{\vec{F}}{Q_b} = \frac{Q_a}{4\pi\mu_o \mathbf{r}^2}\hat{\mathbf{r}}$$



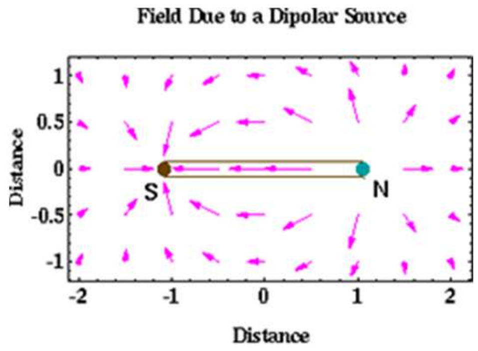


Magnetic Charges (or Poles)

In nature: magnetic poles always appear in pairs with a positive and negative pole yielding a dipole.



$$\vec{H} = \frac{P}{4\pi\mu_o}\left(\frac{\hat{r}_1}{\hat{r}_1^2} - \frac{\hat{r}_2}{\hat{r}_2^2}\right)$$



Magnetic moment $\mathbf{m} = \frac{Pl}{\mu_o}$

Magnetic field of dipole

$$\vec{H} = \frac{m}{4\pi r^3}\left(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}\right)$$

Magnetic field of dipole decays as 1/r^3.

Magnetics

Magnetics fundamentals

Sensor systems

Data examples and demo

↓

Parameter extraction

Concepts

Real-world examples

↓

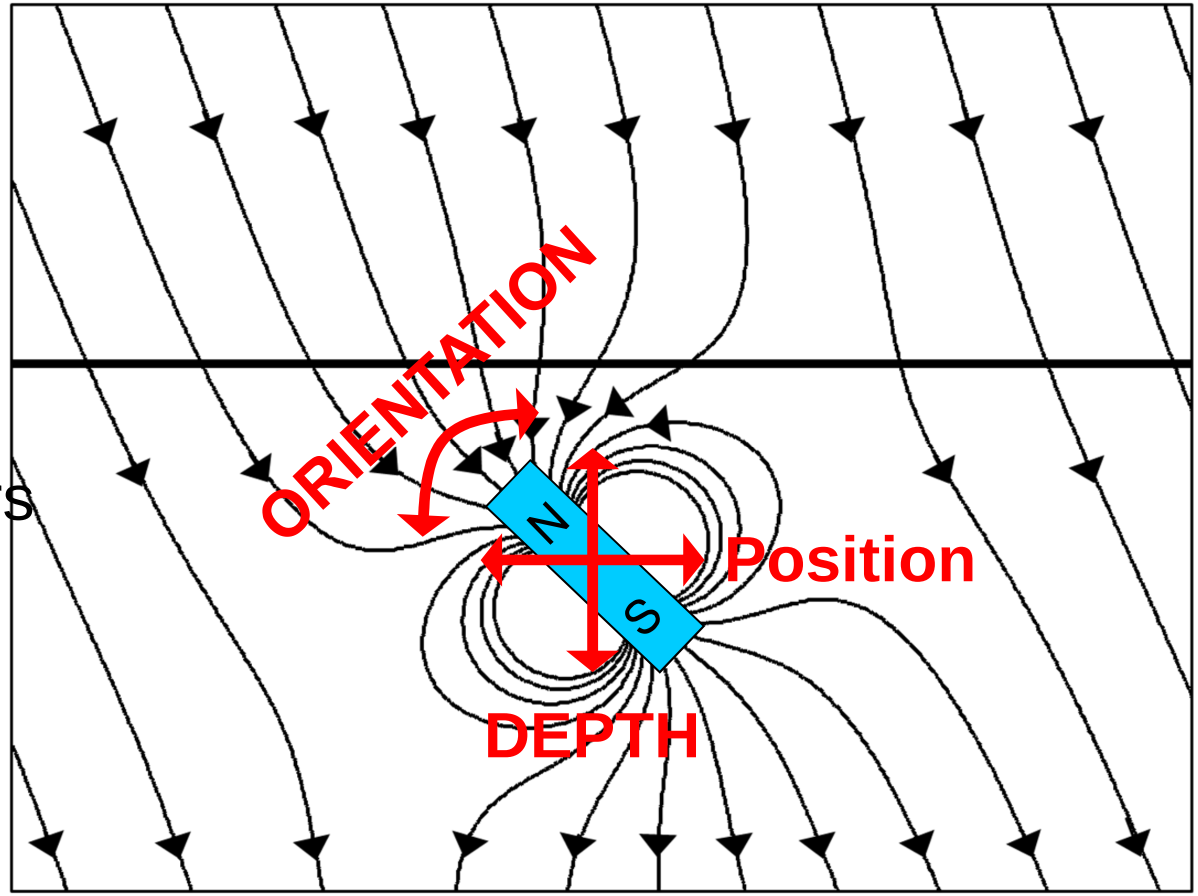
Classification

Using the parameters to make discrimination decisions

The model

- We model the response of buried items by a dipole (equivalent to a bar-magnet):
  - Position
  - Depth
  - Orientation
  - Size

  - 6 parameters



Parameter extraction

- Need six parameters (location, strength and orientation)

$$\vec{H} = \frac{m}{4\pi r^3}\left(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}\right)$$

- Inversion or “parameter extraction” is used to estimate the parameters of an underlying model that encapsulates some useful attributes of the buried object

Model Parameters: m

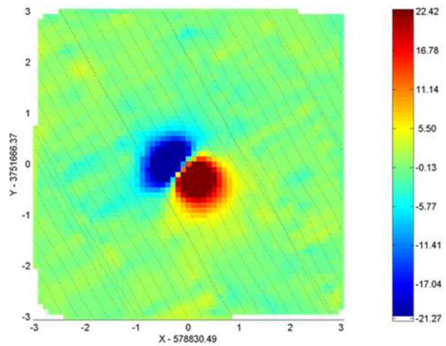
Forward Operator

$d = g\,[m]$

$m = g^{-1}\,[d\,]$

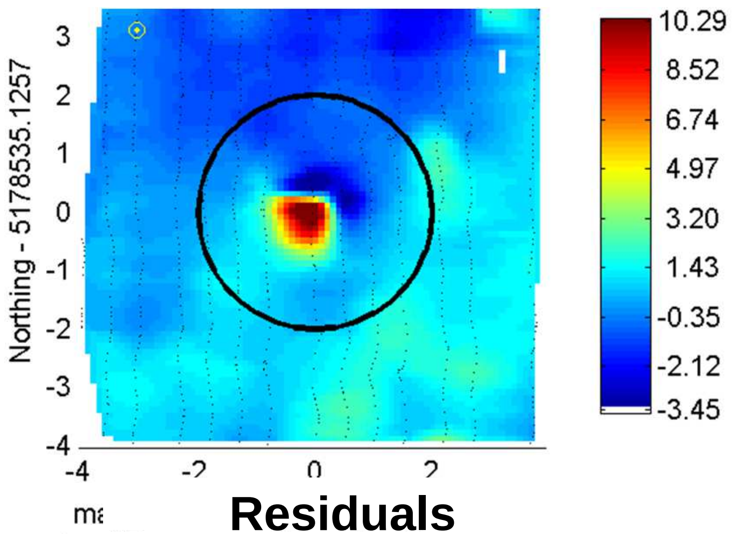
Inverse Operator

Sensor data: d

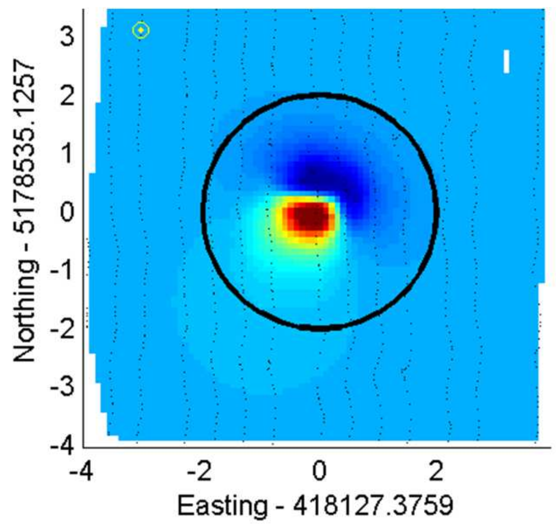


Parameter extraction

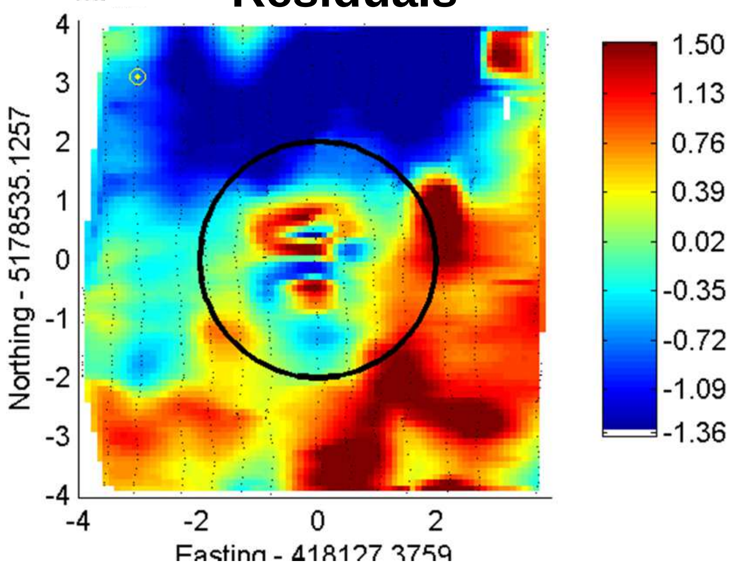
DATA



PREDICTED DATA



Residuals



Easting = -0.13 m

Northing = 0.16 m

Depth = 0.26 m

Moment = 0.0226 Am^2

Azimuth = 37^o

Dip = 28.8^o

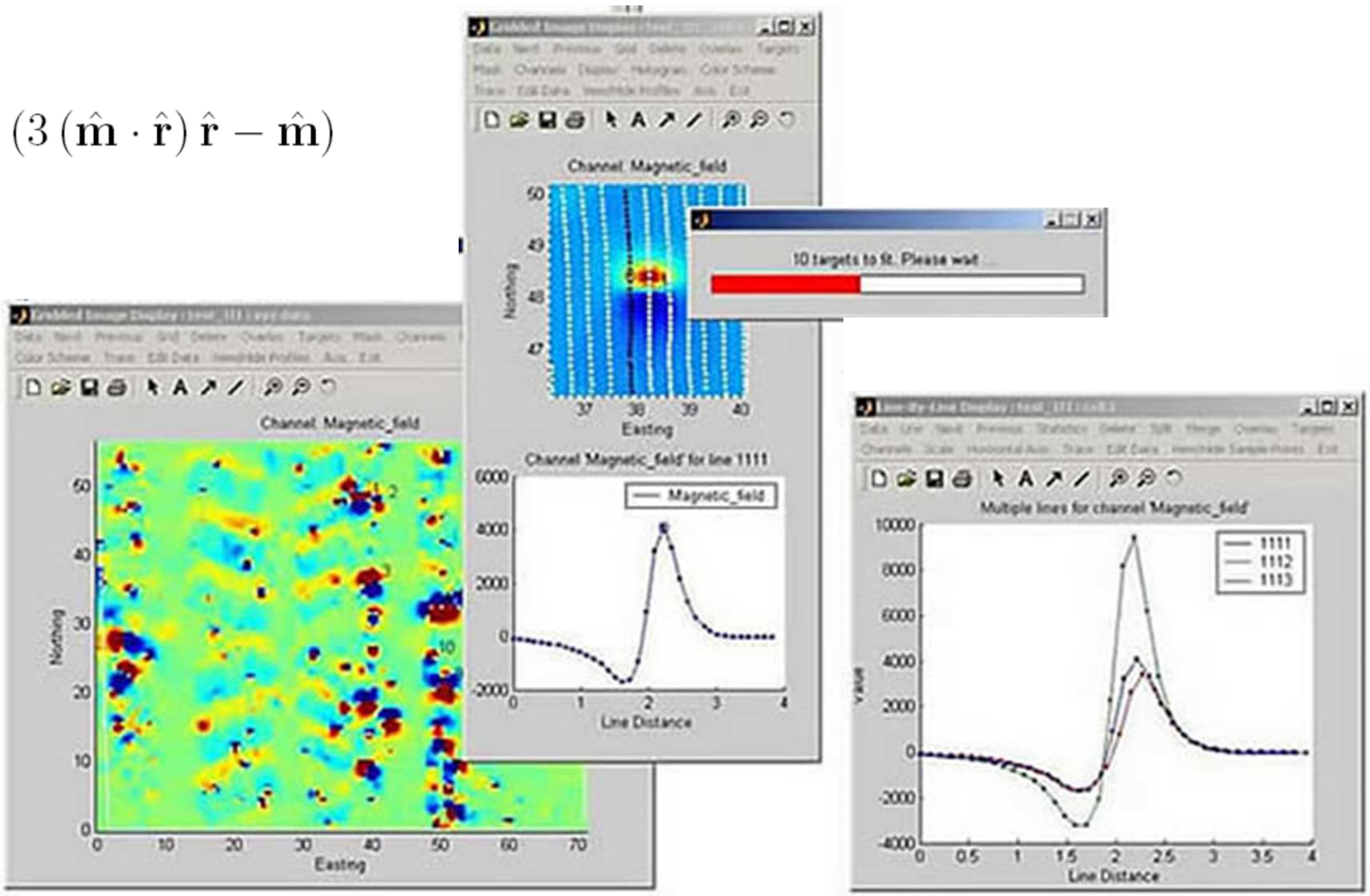
← Parameters of interest

Fit quality = 0.95

Eg of "dipoles" UXO data

UXO The Unexploded Ordnance and Landmine Research Group

$$\mathrm{B} = \frac{\mu_0}{4\pi}\frac{\mathbf{m}}{r^3}\left(3\left(\hat{\mathbf{m}}\cdot\hat{\mathbf{r}}\right)\hat{\mathbf{r}} - \hat{\mathbf{m}}\right)$$



http://www.eos.ubc.ca/research/ubcgif/uxo/software.html

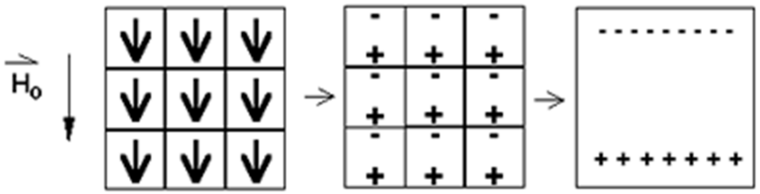
Possible routes to extracting information

- Plot the data in various map displays
- Interpret with a dipole
- Interpret with simple bodies of uniform magnetization
- Interpret as complex bodies (inversion)

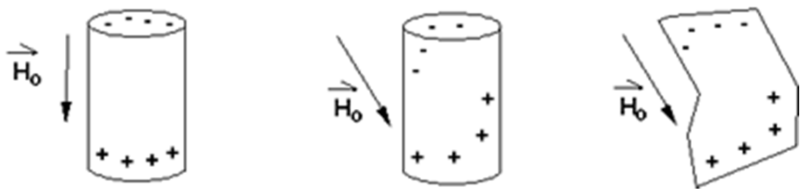
Beyond dipoles – real targets

- When is a buried feature like a simple dipole?
  - When it's diameter is much less than depth to it's centre.
  - GPG Ch.3.d.3. Ch.3.d.4 . Ch.3.d.5.

- Fields from some buried bodies, (cylinders, dykes) can be estimated by using charge concepts.

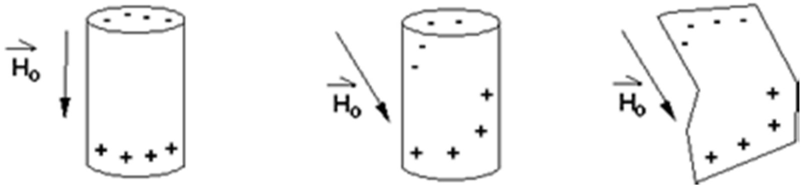


Charge strength = $\vec{M} \bullet \hat{n}$

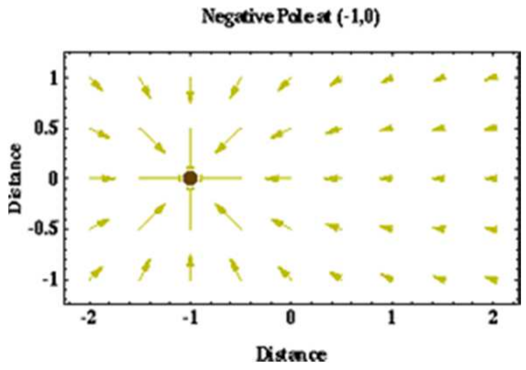


A simple model for a vertical pipe

- Fields from some buried bodies, (cylinders, dykes) can be estimated by using charge concepts.

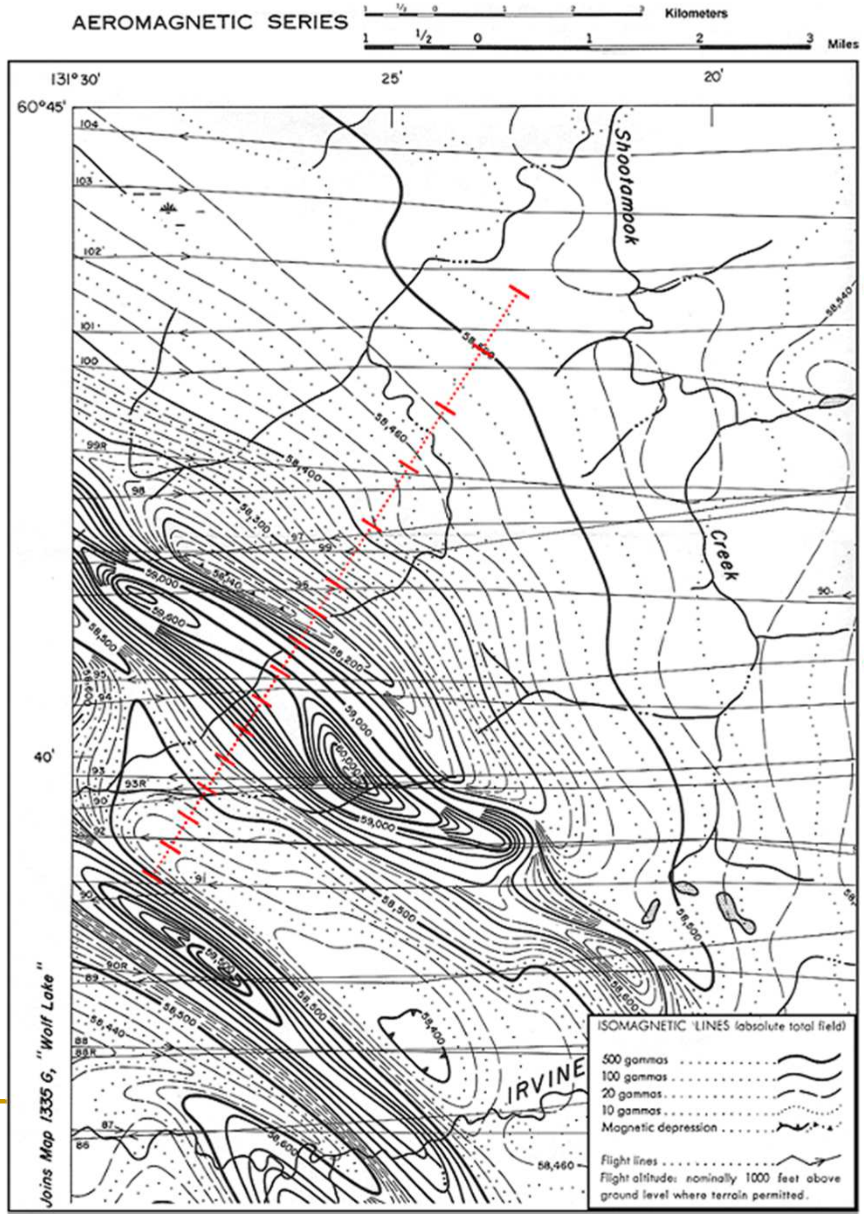


- A vertical pipe has anomaly like a single pole.(TBL 2)



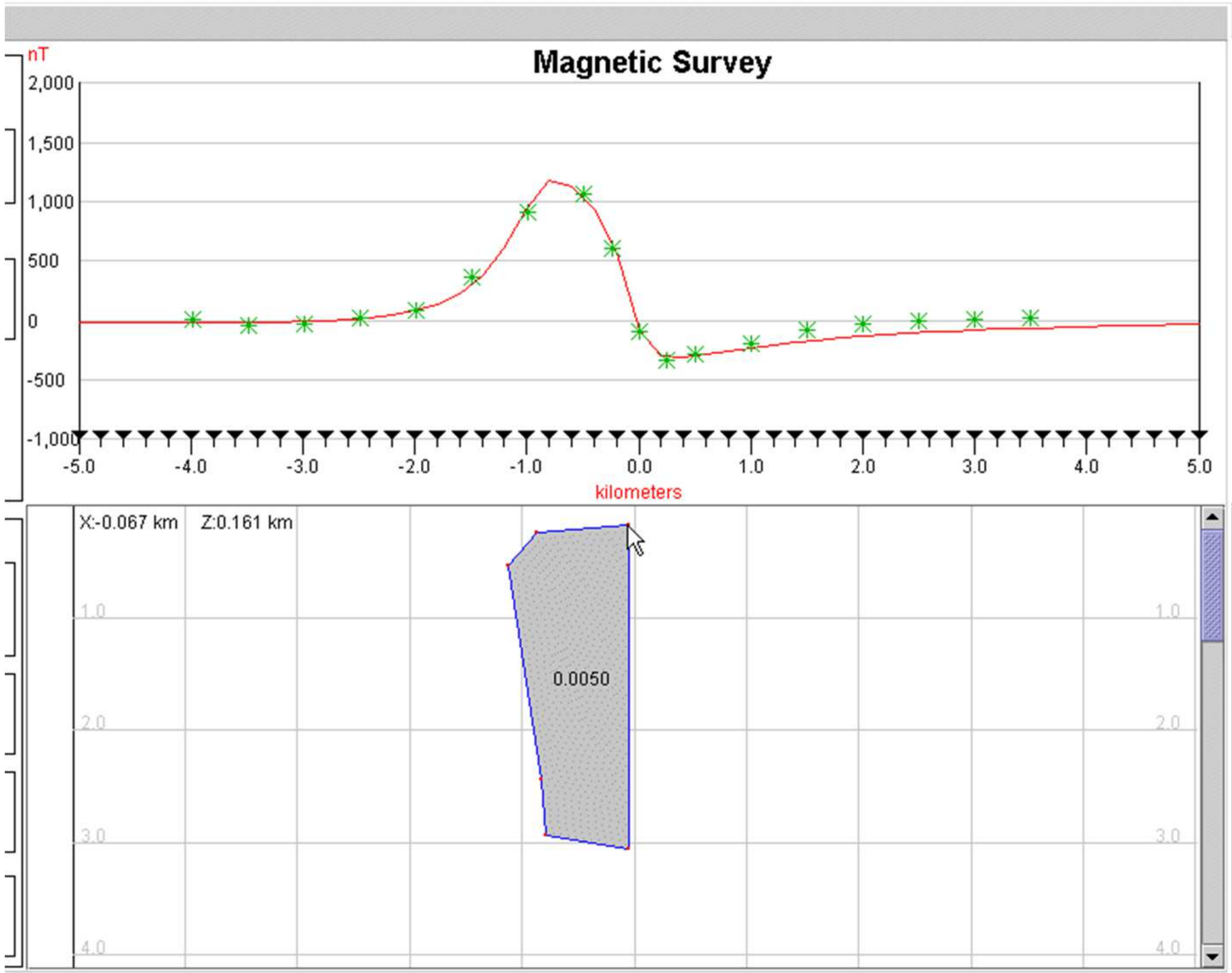
Magnetics Interpretation – 2D modelling

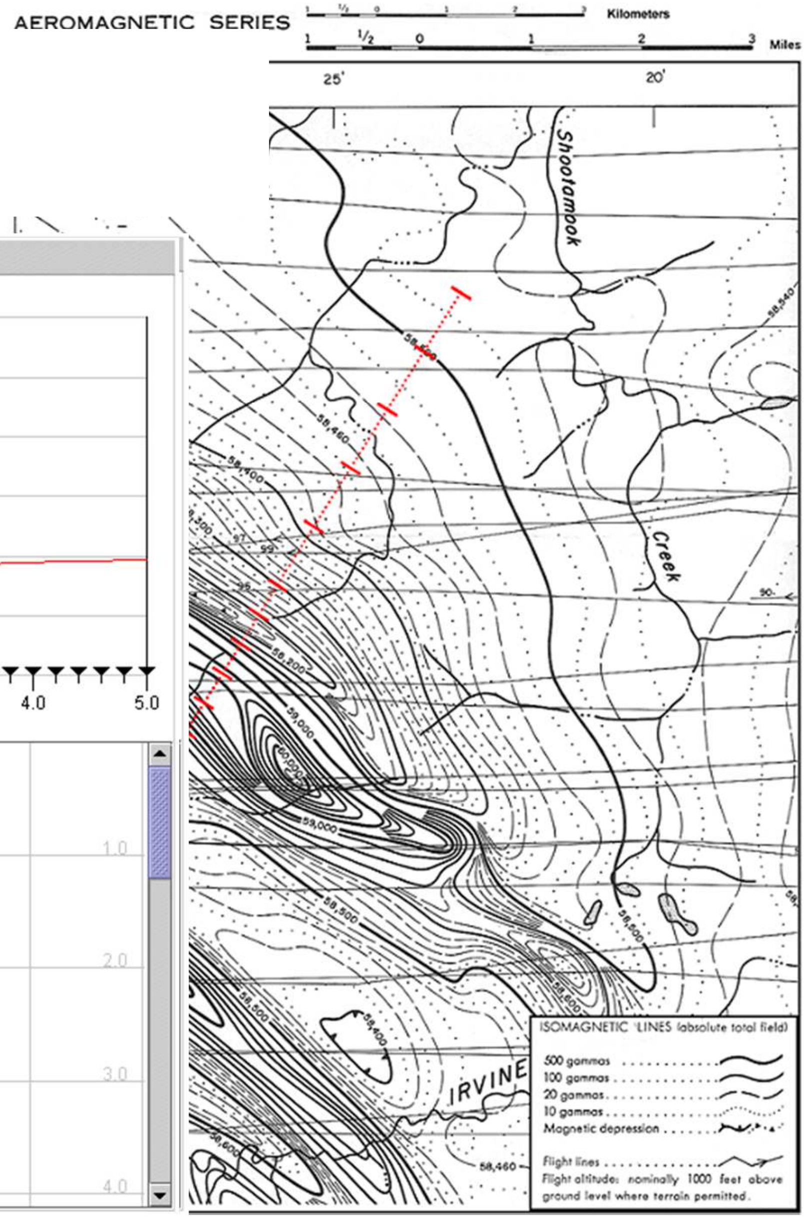
- Forward modelling
  - Line profiles might indicate 2D structure
    - First identify the feature of interest
    - Analyse data perpendicular to the structure
    - Forward model in 2D



Interpetation using Forward modelling:

- Response depends on *κ* and size / shape.
- Solution is non-unique



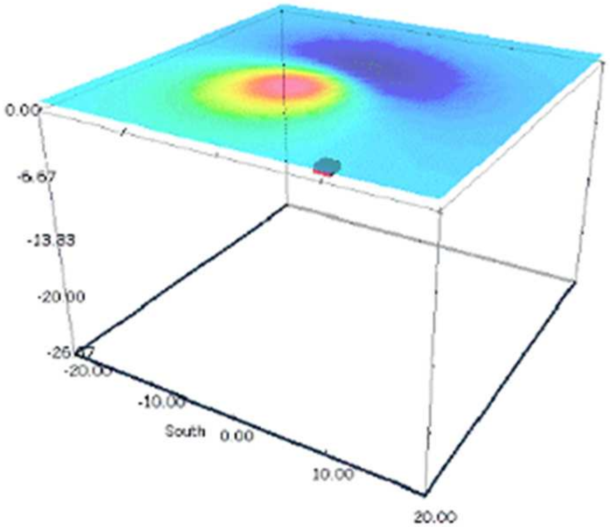


Possible routes to extracting information

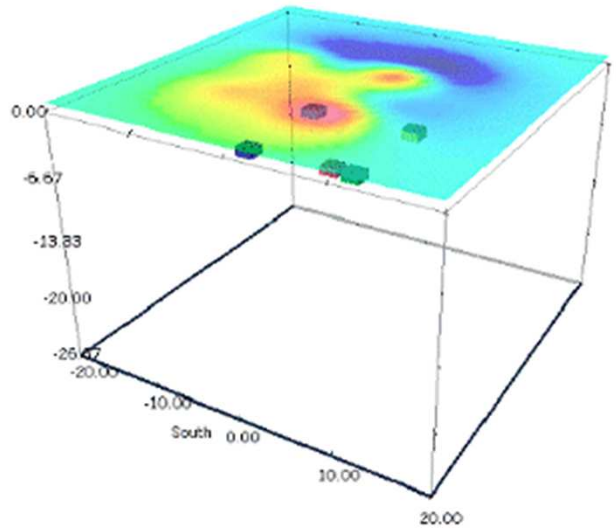
- Plot the data in various map displays
- Interpret with a dipole
- Interpret with simple bodies of uniform magnetization
- Interpret as complex bodies (inversion)

Superposition for Magnetics Data (GPG d5)

Magnetic field for one prism

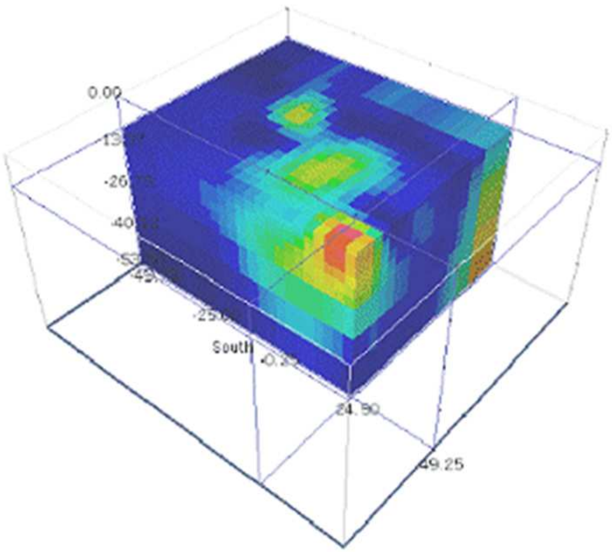


Magnetic field for 5 prisms

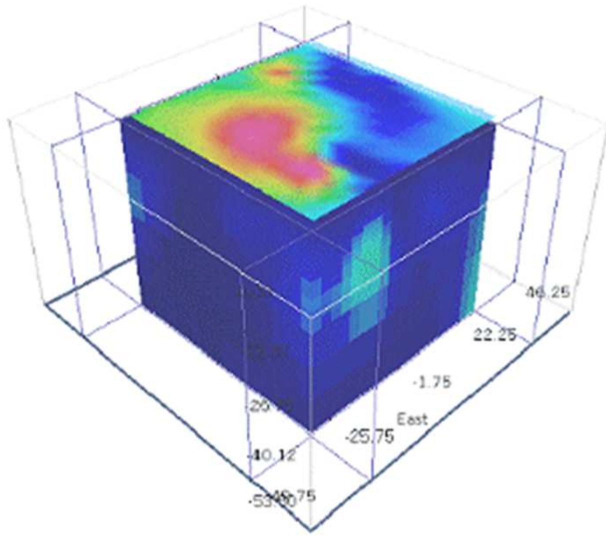


Earth can be complicated

A complicated earth model

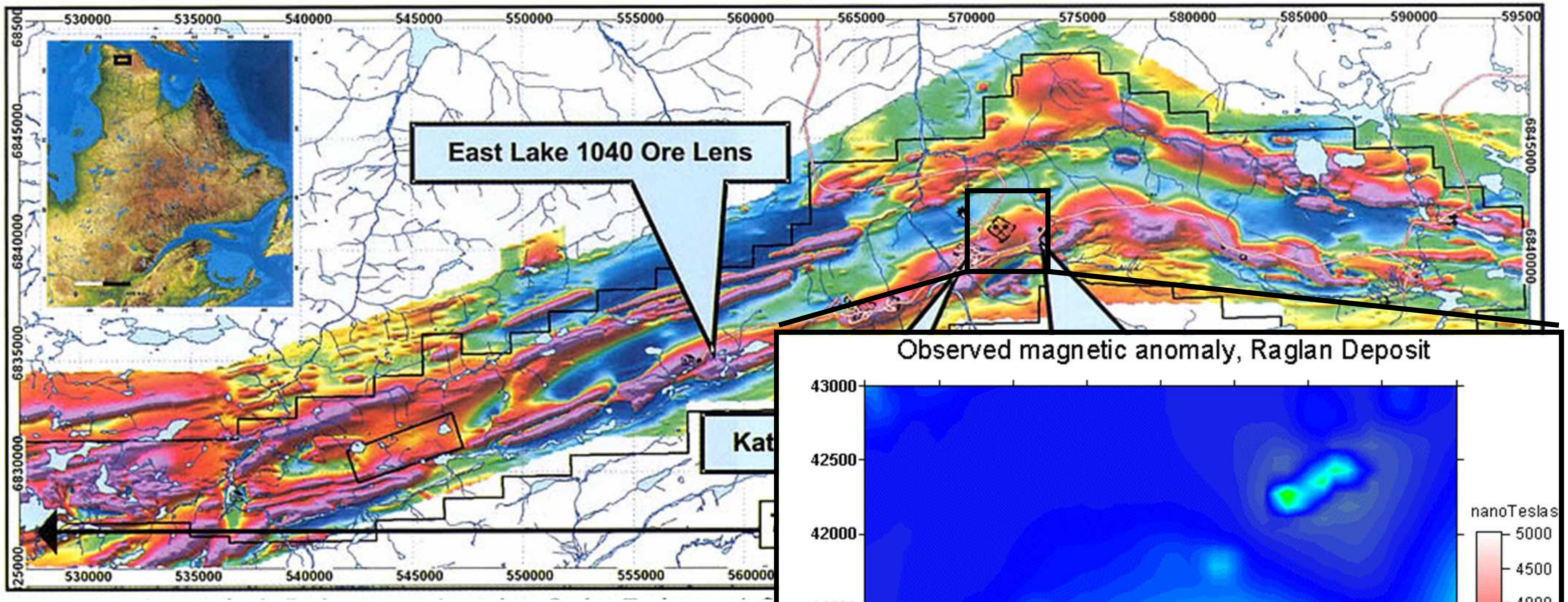


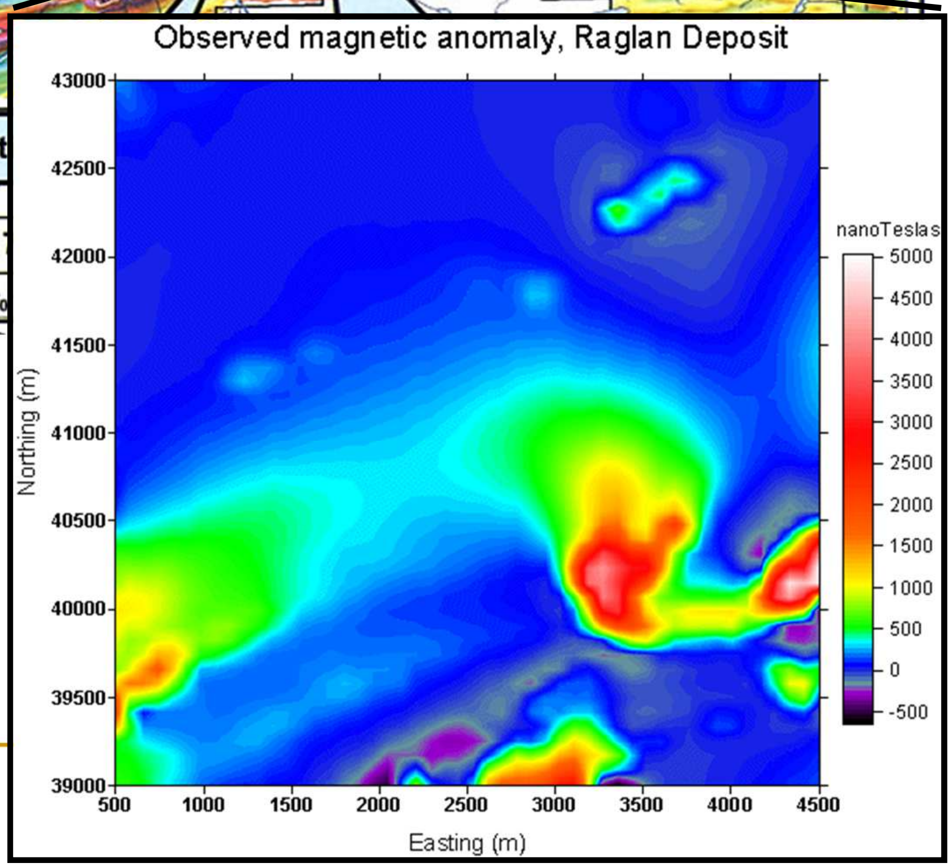
Magnetic data for a complicated earth model.



To interpret field data from a complicated earth we need to have formal inversion procedures that recognize non-uniqueness.

Example: Raglan aeromagnetic data





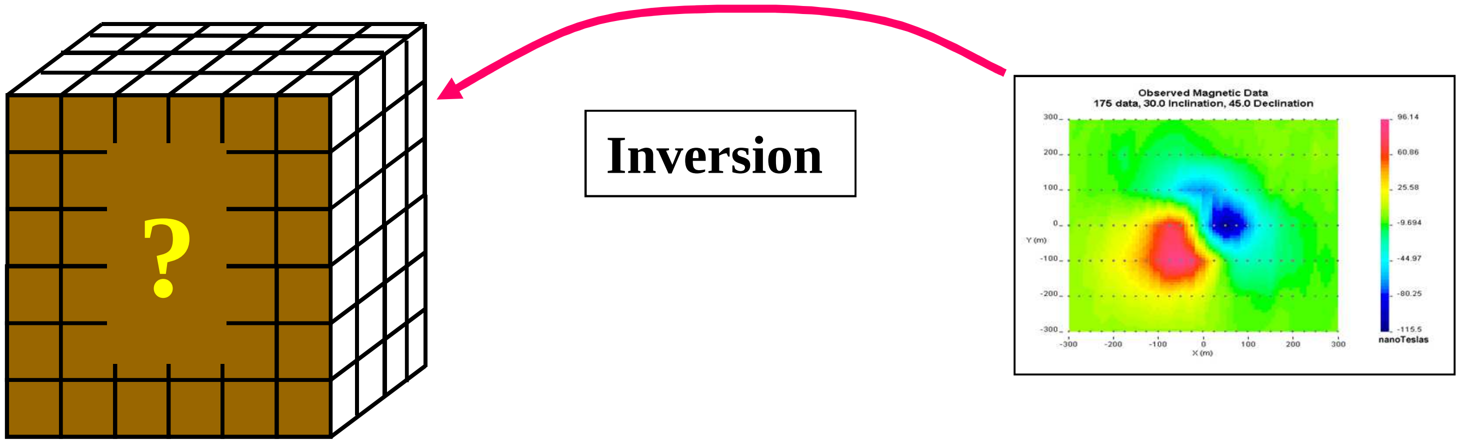
Select a region of interest.

Keep data set size within reason.

Digitized the Earth – up to 10^6 cells.

Inversion:

Finding an earth model that generated the data

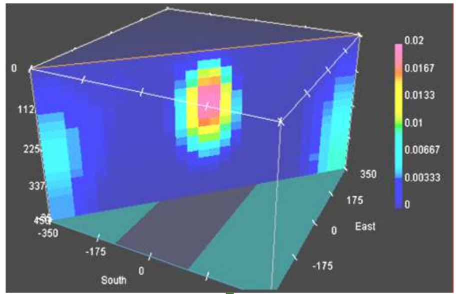


Divide the earth into many cells of constant but unknown susceptibility

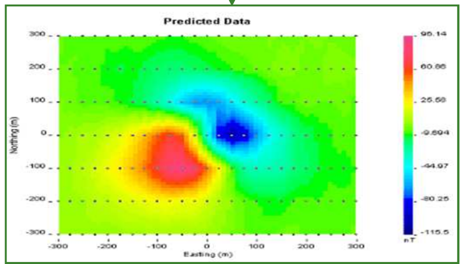
Solve the large inverse problem to estimate the value of each cell

Misfit: comparing predictions to measurements

Once a model is estimated …



- Calculate data caused by that model.



- Compare predictions to these measurements.

- Is comparison within errors?

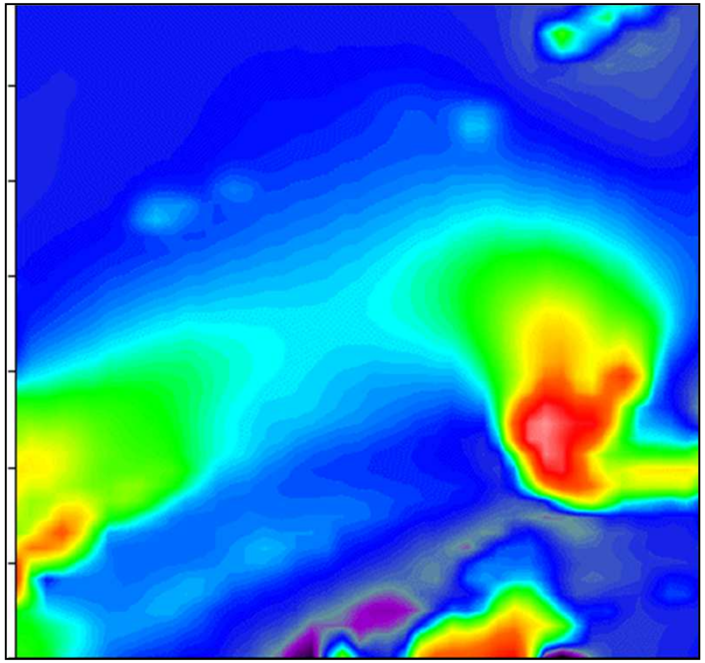
Compare

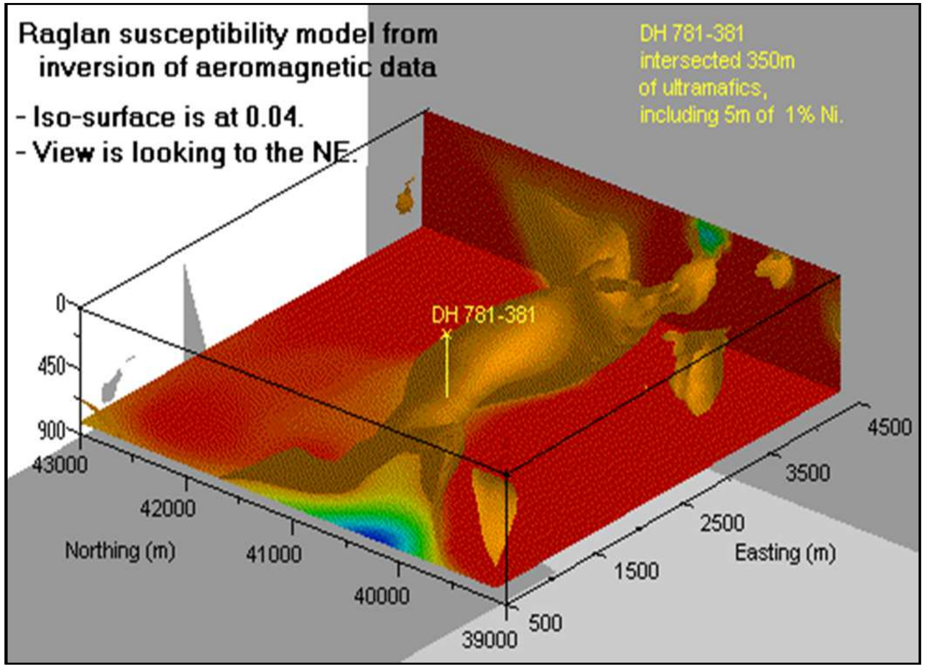
YES → Proceed to check for acceptibility

NO → Modify model and try again

Raglan aeromagnetic data

- Estimate a model for the distribution of subsurface magnetic material.
- Model will be "smooth", and close to pre-defined reference.
- Display result as cross sections and as isosurfaces.





- Are "sills" connected at depth? Inversion result supports this idea.
- It helped justify a 1050m drill hole.
- 330m of peridotite intersected at 650m 10m were ore grade.
- Image shows all material which has k > 0.04 SI.

Summary: Magnetics – interpretation

1. Qualitative:
   - Correlate magnetic patterns to geology

2. Quantitative interpretation
   - Determine shapes, volumes, contacts, materials

3. Direct interpretation of patterns

4. Forward modelling
   1. “Guess” geology
   2. Calculate result - Compare to data
   3. Iterate.

5. **Inversion:** Given data, estimate possible configurations of susceptible material that could cause those data.