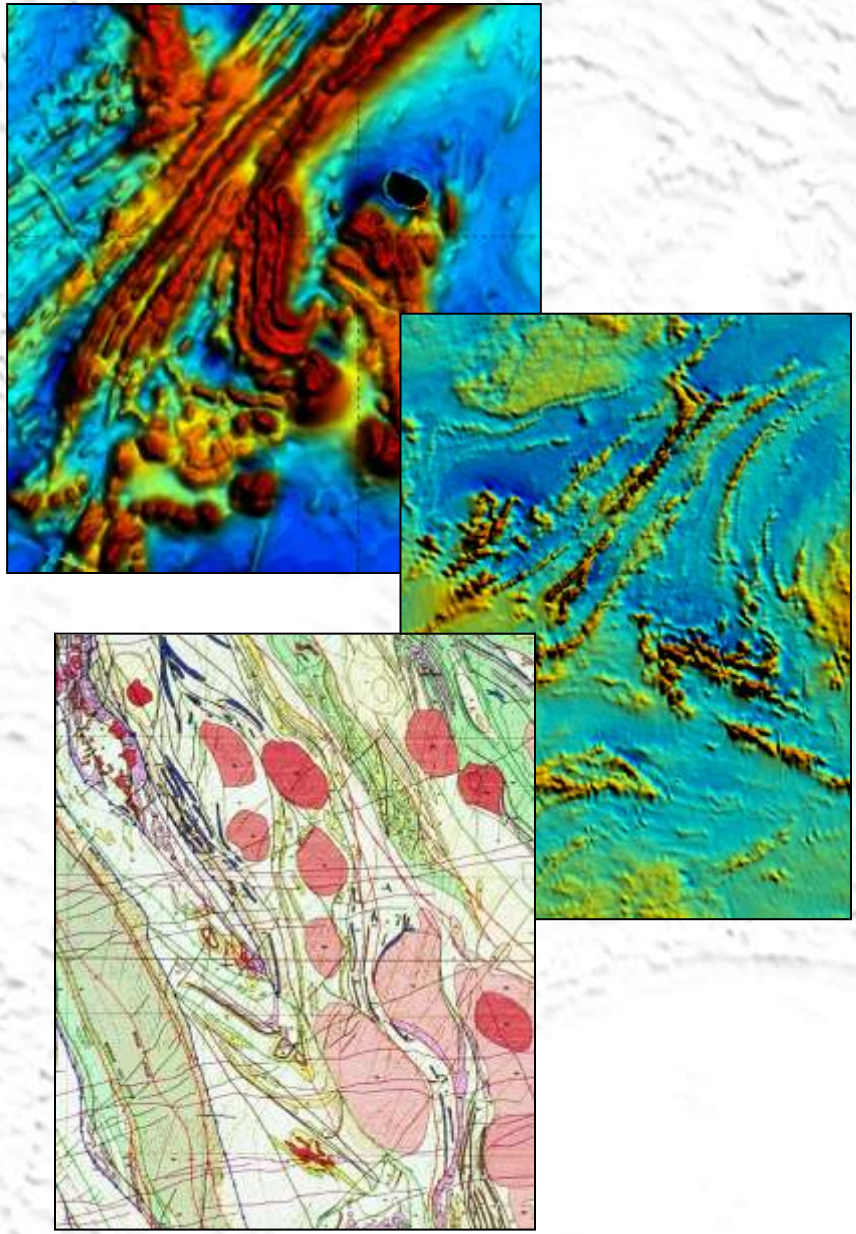
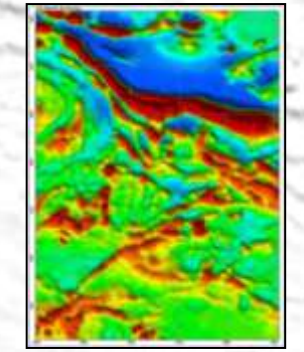


The geological interpretation of aeromagnetic data: A geologist's perspective.

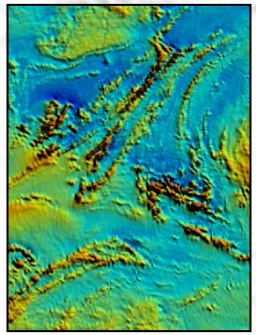
James P. Siddorn, P.Geo.
Principal Consultant
SRK Consulting (Canada) Inc.
Email: jsiddorn@srk.com

Uses of aeromagnetics

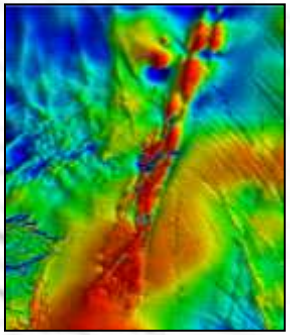
- **Mapping geology…..what attributes?**
  - Lithology;
  - Structure;
  - Alteration;
  - Metamorphism;
  - Mineralization.



- **Mapping geology…..why/how is it possible?**
  - Magnetic minerals are present in (almost) all ‘rock types’;
  - Magnetometers can measure tiny magnetic signals; and
  - Airborne surveys allow rapid and inexpensive coverage.

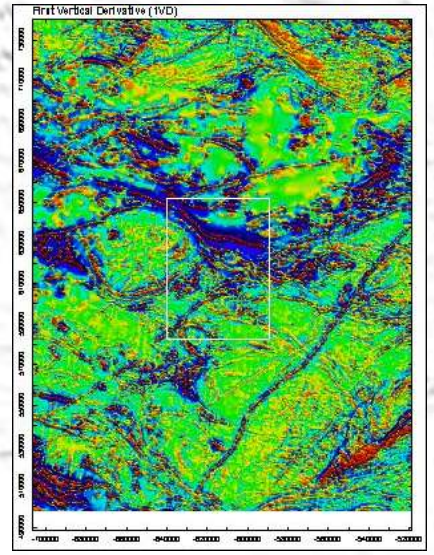


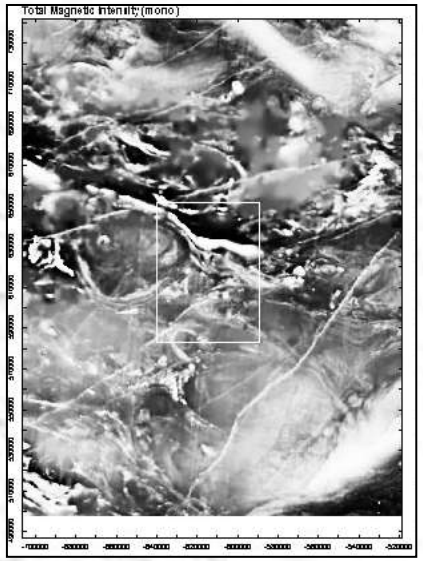
- **When do we need aeromagnetics?**
  - Poorly exposed areas…..help interpolate between outcrops;
  - Covered areas……provide some geological control; and
  - Well exposed areas……there’s always surprises.



Processing

- Field processing & supervision;
- Contractor line data processing supervision;
- Contractor line data gridding supervision;
- Enhancement processing and filtering: 1VD, RTP, 2VD etc;
- Interpretation processing specialist products:
  - AutoMag;
  - Euler 3D.
- Use specialists and supervise every stage of the process.





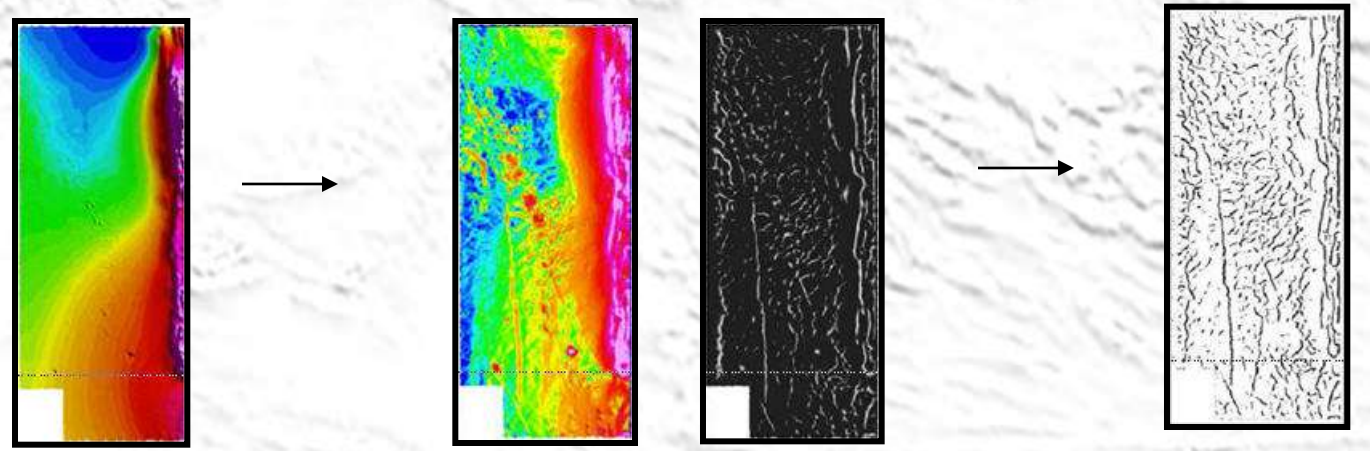
New Techniques: CET Grid Analysis

- A set of algorithms that enhances, locates and vectorises discontinuity structures within potential field data;
- Outcomes of image analysis research at CET;
- Commercial software – plug ins for Geosoft Oasis Montaj;
- Due to be released in Feb/March 2010 by Geosoft.
- Provided algorithms:
  - Texture Analysis Filters:
    - *Enhance* discontinuity regions by measuring local data variations;
  - Phase Analysis tools:
    - *Locate* laterally continuous structures;
  - Structure Detection Filters:
    - *Vectorise* structures detected from phase analysis.

THE UNIVERSITY OF WESTERN AUSTRALIA
Achieving International Excellence

Centre for EXPLORATION TARGETING

Two Trend Detection Methods

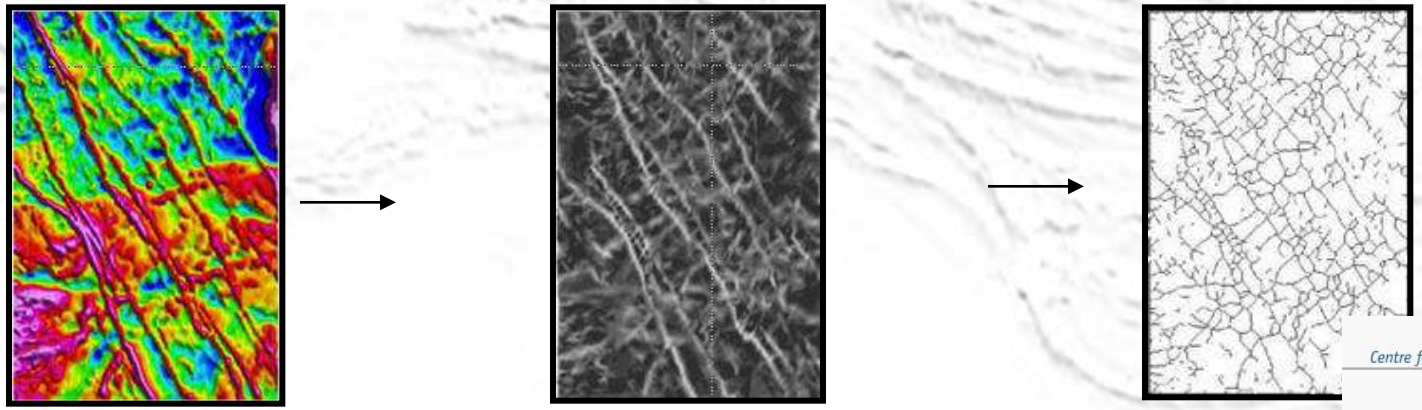


Input grid

Texturally complex line-like region detection

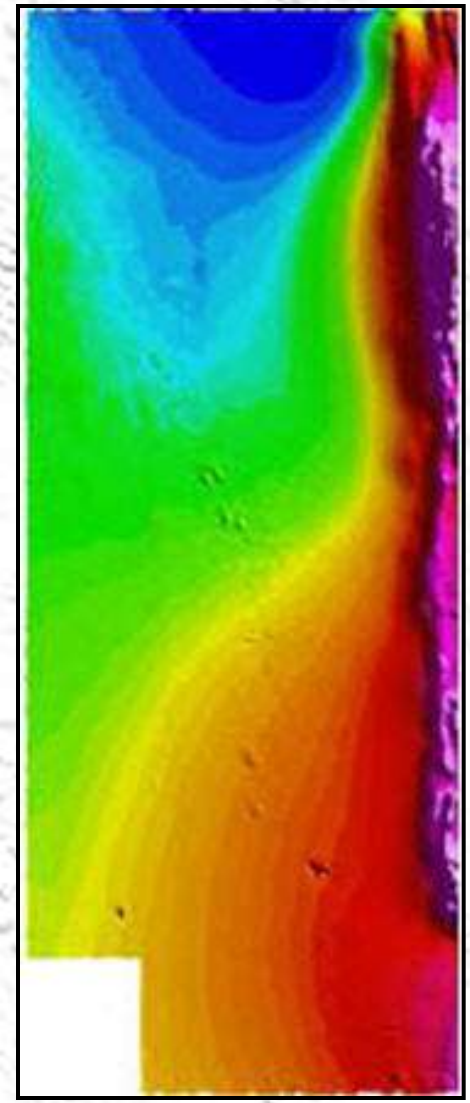
Edge detection

Structure detection

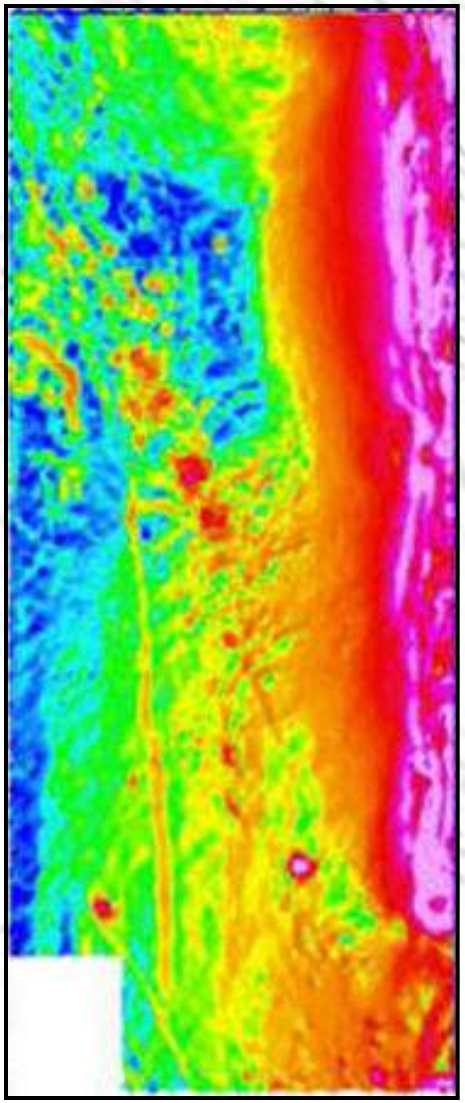


Example Output

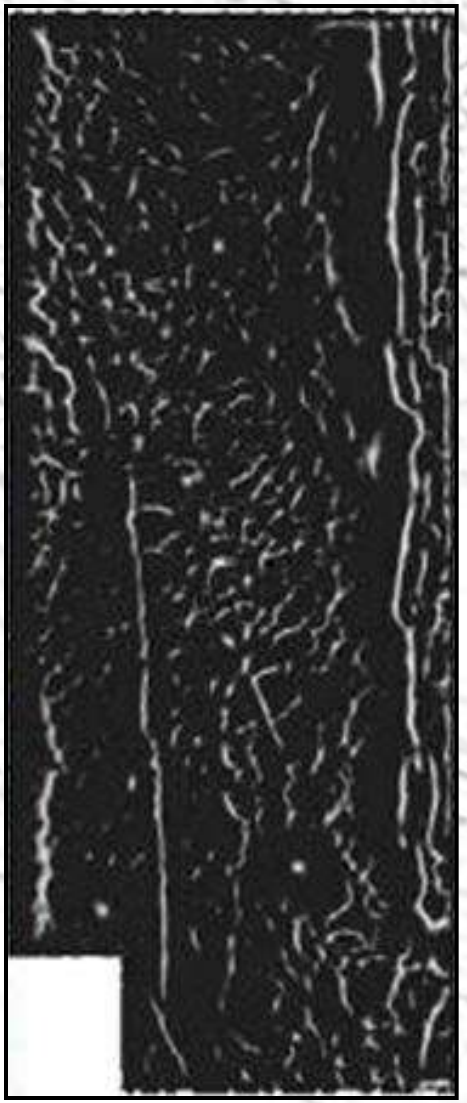
Centre for EXPLORATION TARGETING



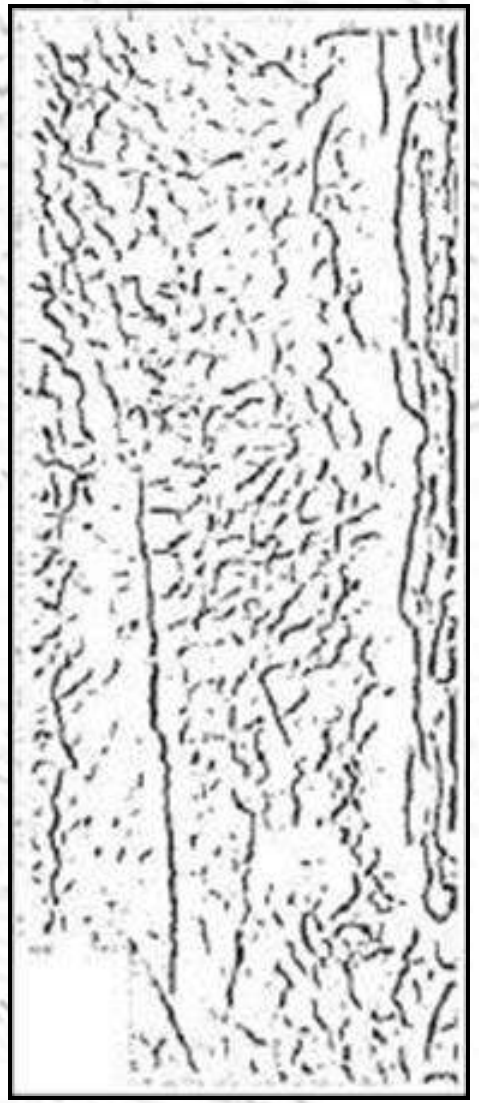
Input Data



Texture Enhancement

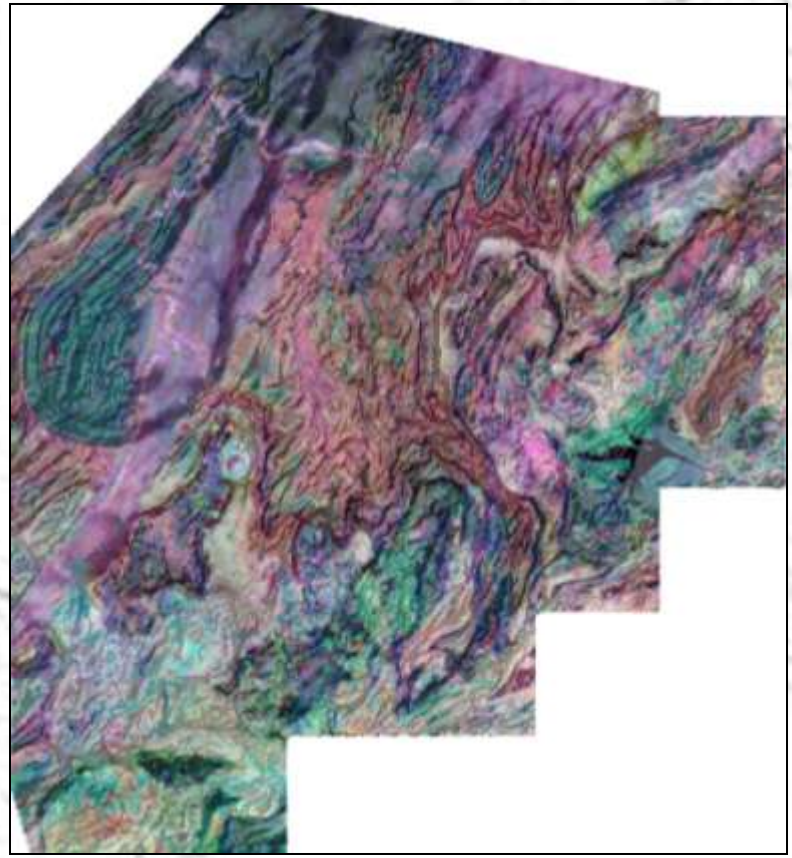


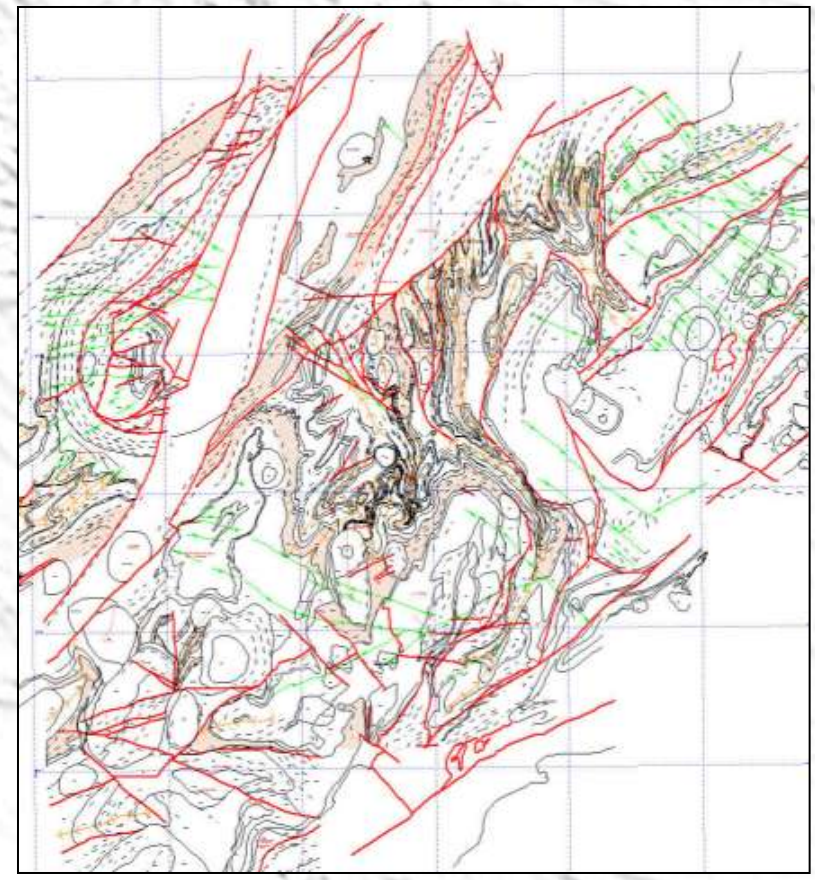
Locating lineaments



Vectorising lineaments

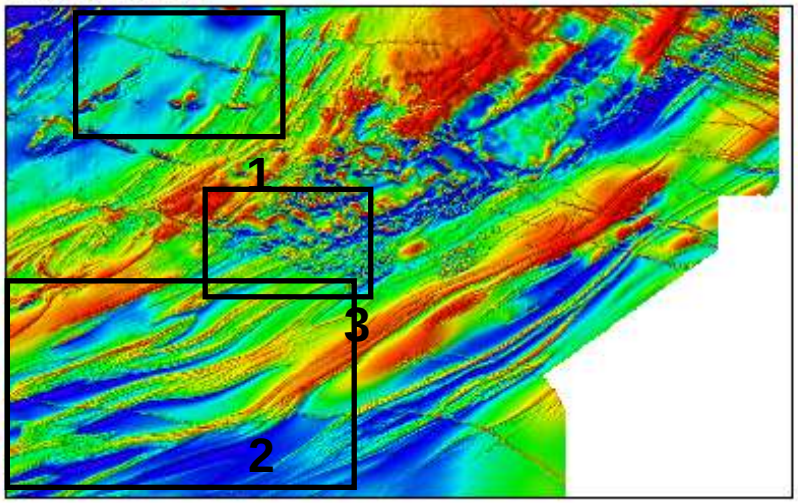
Magnetics as an effective mapping tool



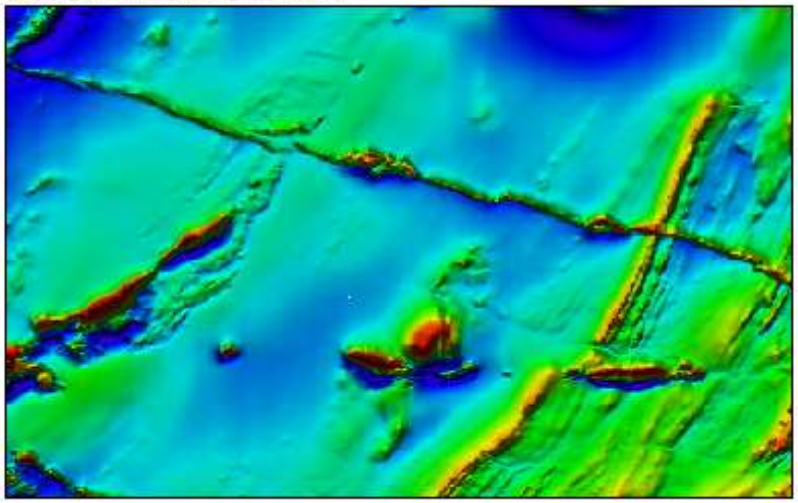


Aeromagnetic Expressions of Geological Features - 1

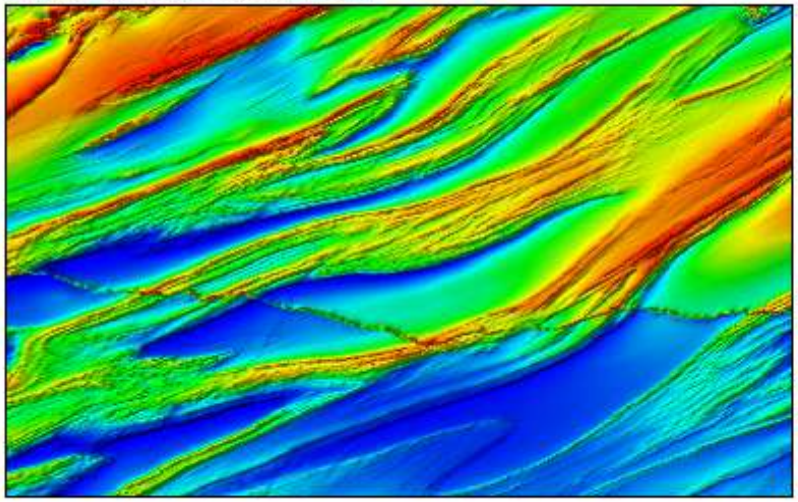
Regional TMI



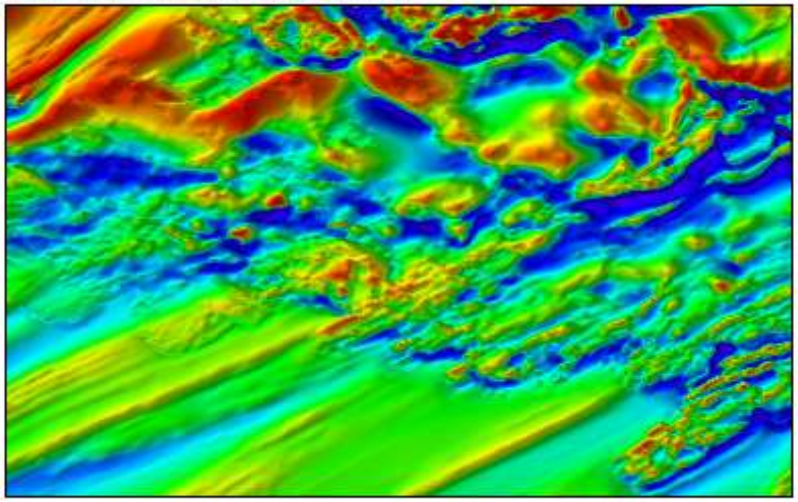
Intrusion & Graben (1)



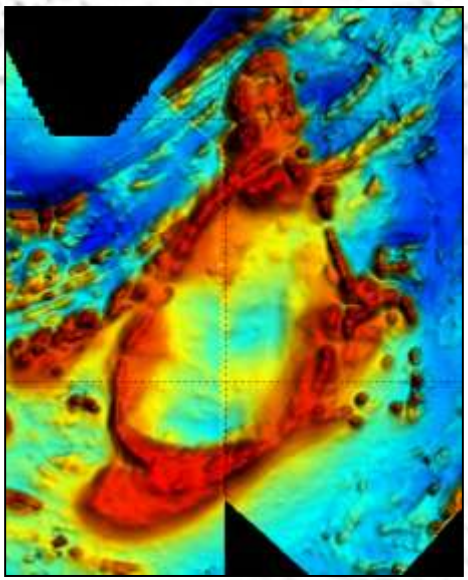
Bedding & structure (2)

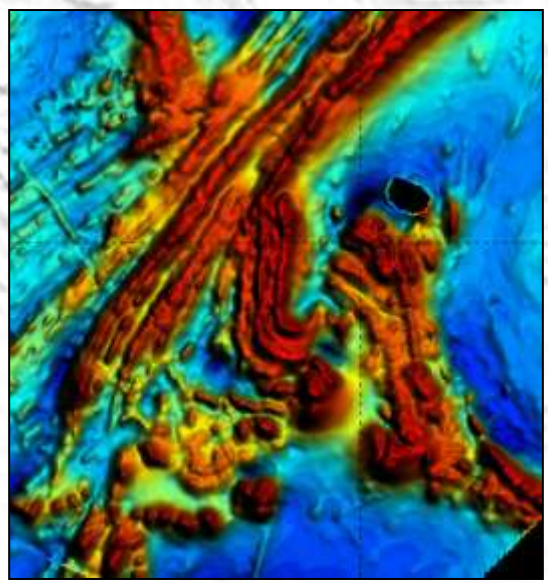


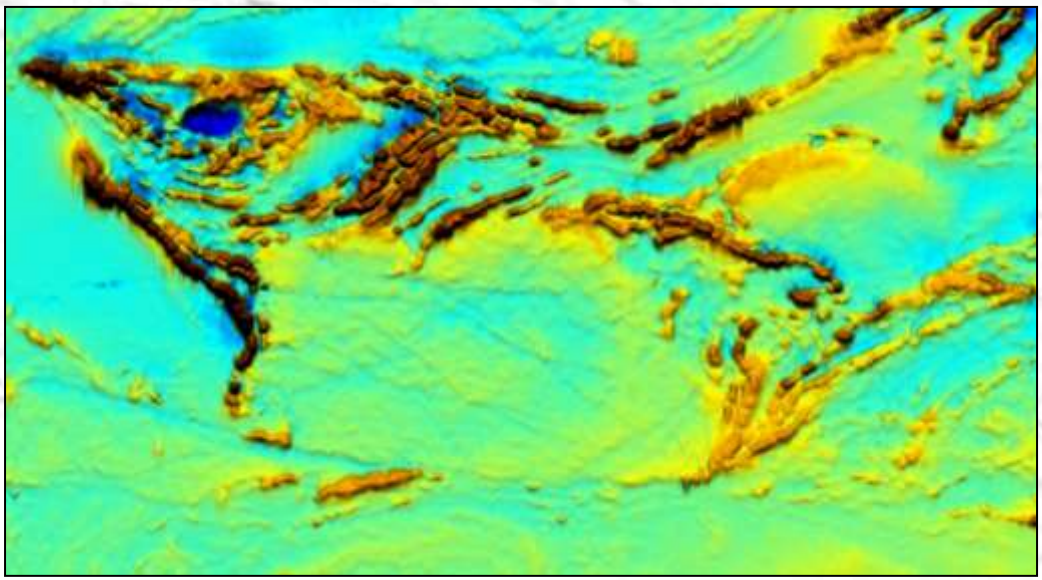
Extrusives & alteration (3)



Aeromagnetic Expressions of Geological Features - 2





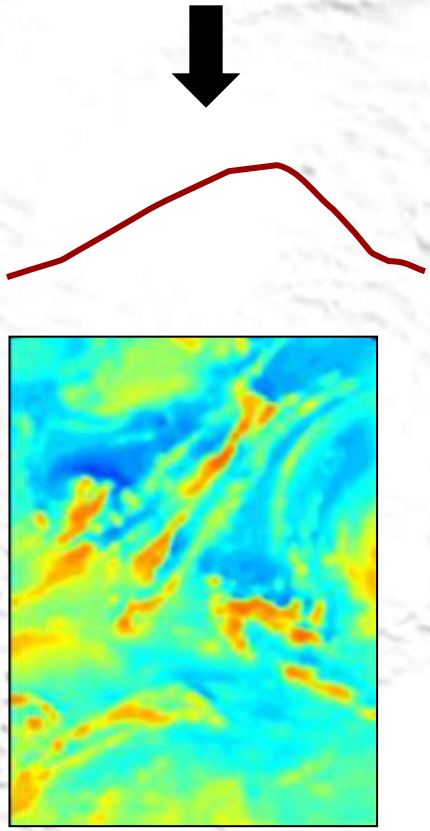


Digital Data Filters

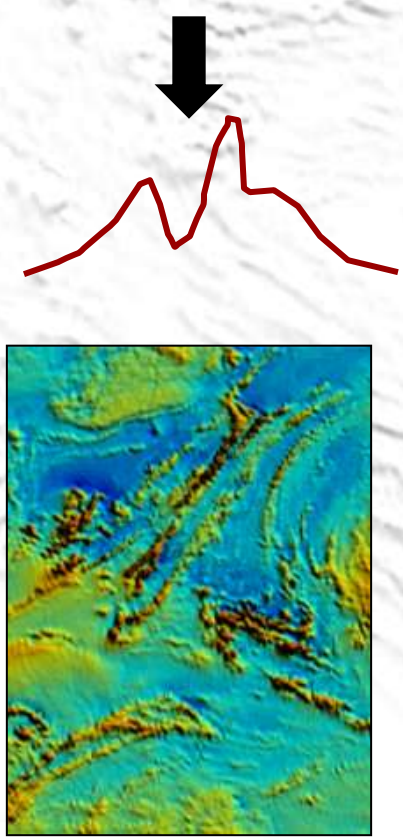
LOW PASS FILTERS

Retain long wavelength, low frequencies = **deep sources**.

E.g. Upward continuation.



MEASURED DATA

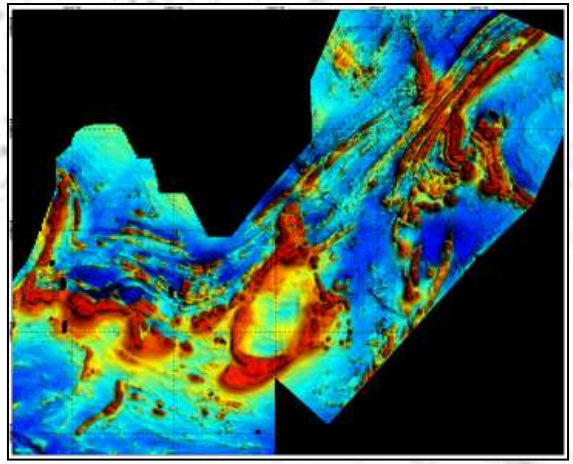


HIGH PASS FILTERS

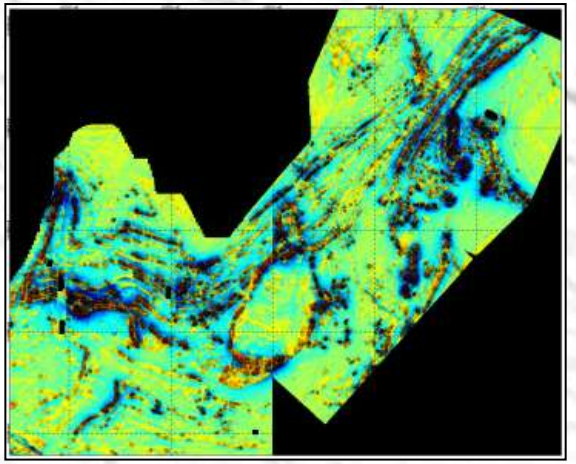
Retain short wavelength, high frequencies = **shallow sources.**

E.g. 1VD, 2VD, downward continuation.

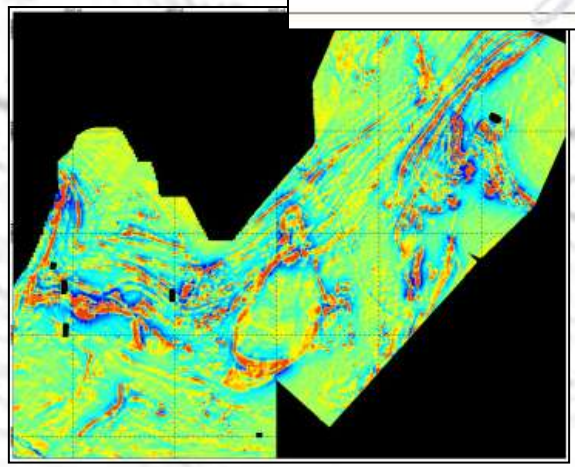
Typical Images Used



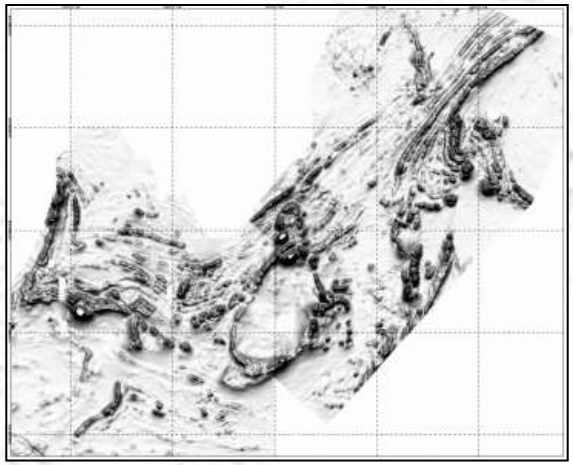
TMI – colordrape



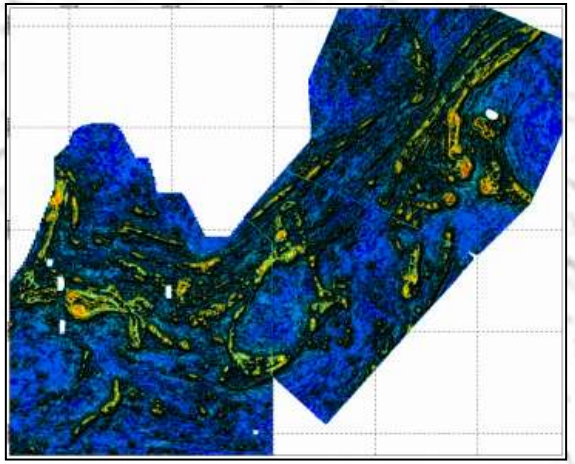
RTP1VD – colordrape



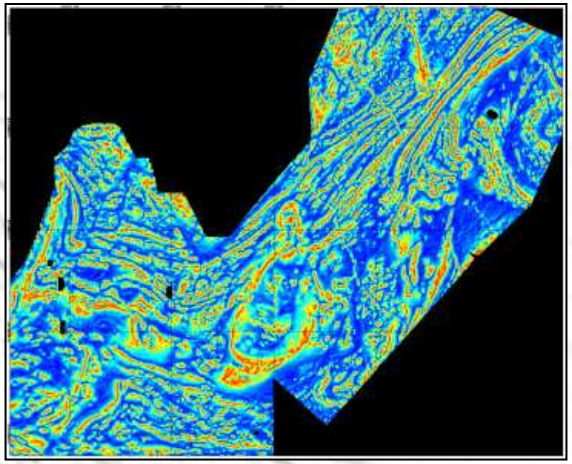
RTP1VD – density sliced



TMI – intensity



AS – colordrape



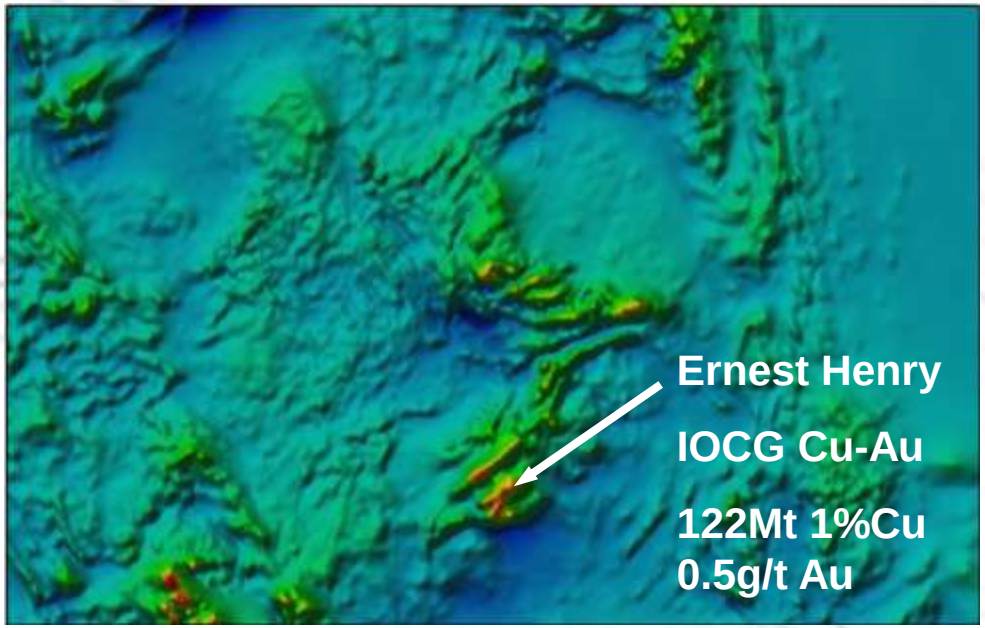
TILT – density sliced

Images Courtesy of Rainy River Resources Ltd.

Indirect verses Direct Targeting

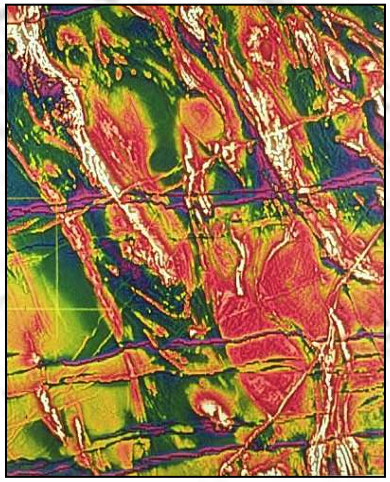
- **Indirect targeting (*most common*):**
  - Interpretation & structural analysis of magnetic data assists by
  - Highlighting suitable fluid conduits and traps;
  - Recognition / interpretation of favorable host (& source) lithologies.

- **Direct targeting (magnetic signature associated with deposit):**
  - Kimberlites;
  - BIF's;
  - Some porphyries & skarns;
  - Some IOCG's.



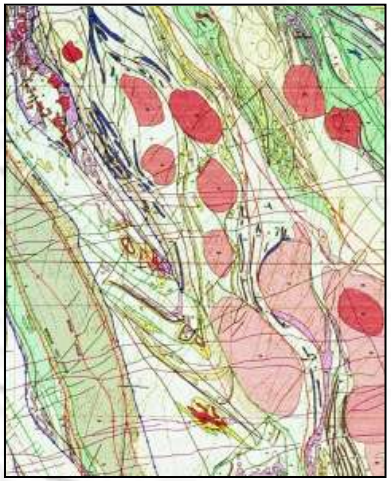
Interpretation - 1

- Aeromagnetic interpretation should be broken down into three stages:
  - **OBSERVATION**
  - **COMPILATION**
  - **INTERPRETATION**



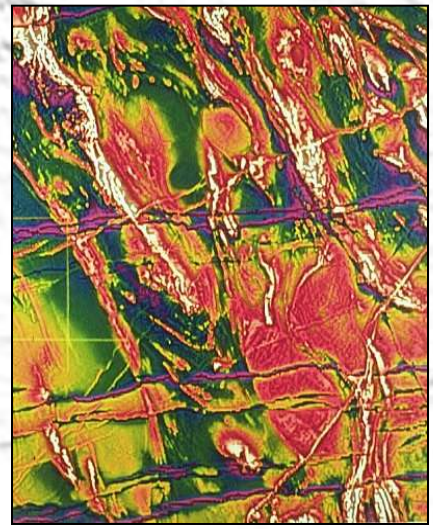
- **All** of the principles of geological mapping and interpretation apply **equally** to aeromagnetic data; and

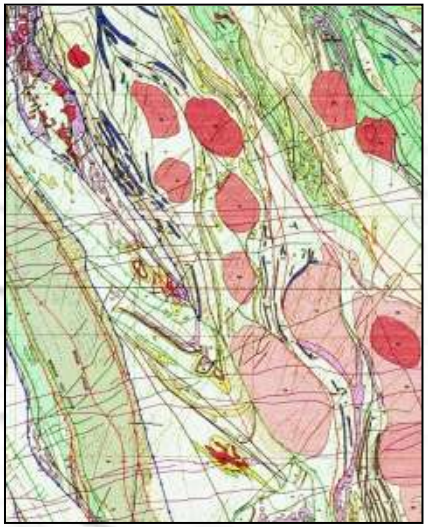
- Decide on the:
  - Scale;
  - Filters;
  - Resolution achievable and the resolution required; and
  - Time needed and time available.



Interpretation - 2

- **When relating lithology or stratigraphy to magnetics, think:**
  - Which rocks contain the magnetic minerals (field evidence, susceptibility measurements, petrology)?
  - Do these rocks always contain magnetic minerals in this area?
  - How and when did the magnetic minerals form?
- **Be wary of making the following generalizations:**
  - "The XYZ Formation is highly magnetic" - *Is it?? Always?? Everywhere?? Uniformly??*
  - "The igneous and metamorphic rocks will be more magnetic than the sedimentary rocks" - They are frequently not!!
  - "The mafic rocks will be more magnetic than the felsic rocks" - They are frequently not!!



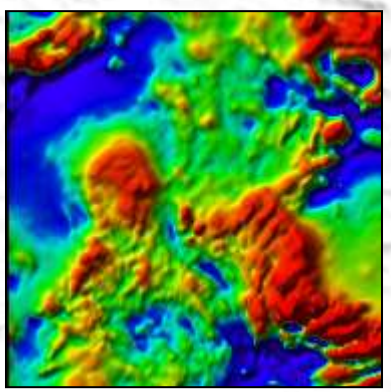


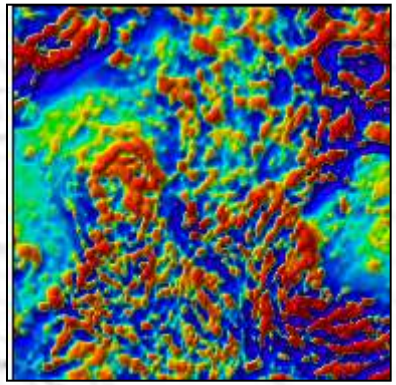
- **Think in terms of the magnetic rock body in the ground….not the magnetic field it causes.**
- **Formulation of structural history consistent with observations.**

Structural Analysis - 1

- **What can you use it for?**

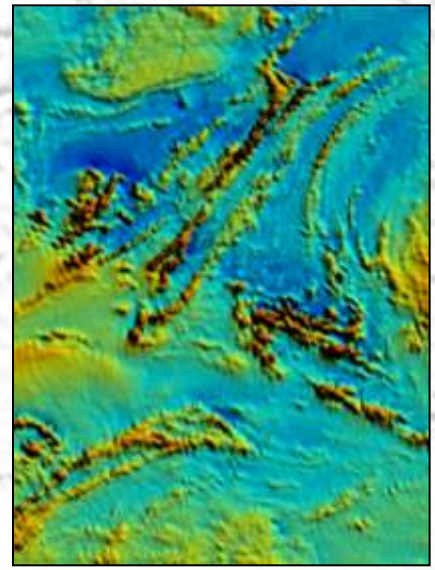
  - Provide regional framework for understanding of known mineralization & regions of unknown geology;
  - Develop tectonic / metallogenic models;
  - Predictive targeting (regional and prospect scale);
  - Problem solving (“where’d it go??”);
  - Attempt reconstruction of early tectonic settings;
  - Comprehensive metallogenic targeting; and
  - Engineering geology problems.

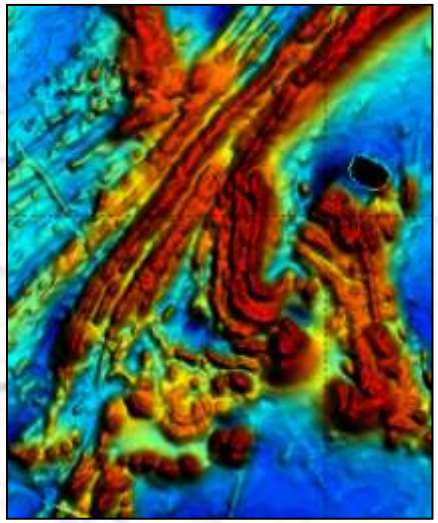




Structural Analysis – 2

- **What can we get out of the data?**
  - Distribution of structures (folds / faults etc), lithologies & alteration - form surface mapping - extend from 2D plan view to 3D (section / block view)
  - Kinematics?
  - Relative timing?
  - Development of tectonic models (local & regional);
  - Predictive targeting:
    - Direct anomaly;
    - Direct structural analogy; and
    - Indirect structural targeting (new models?)
  - Extension of models outside immediate area to different areas or terranes.

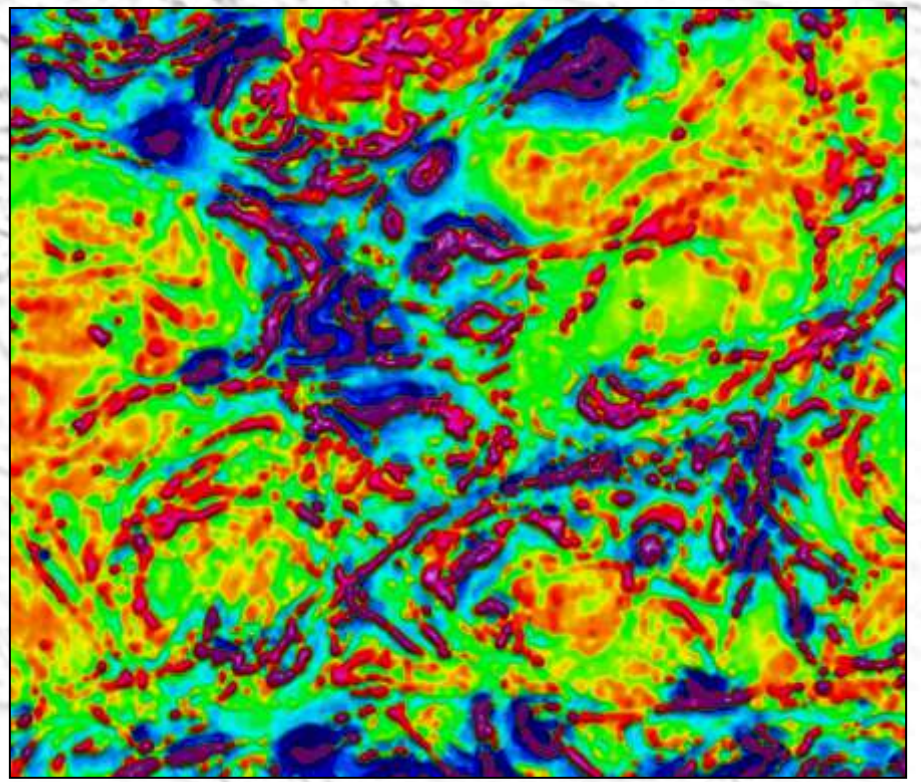




Structural Analysis – 3

Key Questions:

- What structures occur?
- What is their extent?
- Relative geometry?
- What strain was produced?
- What P/T conditions did they form at?
- What is the 3-D geometry?
- What was the tectonic driving force & history?
- What is the relationship of all this to mineralization?

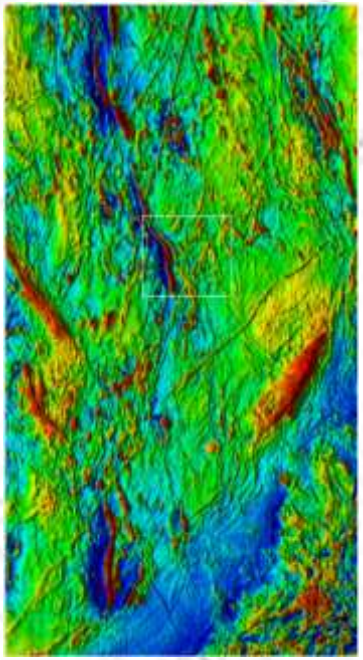


Ontario – Superior/Grenville Compilation, 400m line spacing, RTPIVD. Wabigoon subprovince.

Structural Analysis – 4

Important Observations To Make:

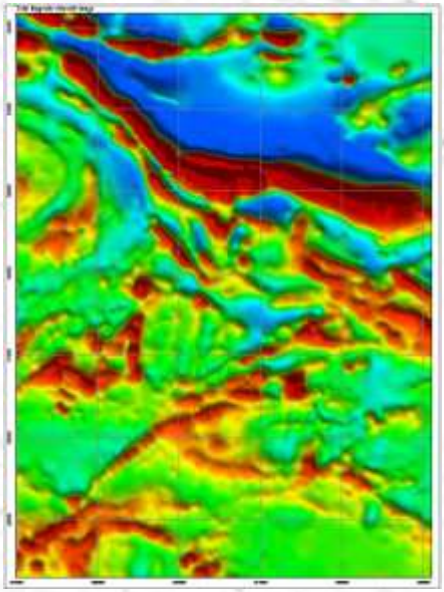
- Map structural traces (geophysics, field data, maps, remote sensing);
- 3-D - fault dips (field data, magnetic profiles);
- Fault displacement vectors:
  - relative displacements;
  - kinematic indicators;
  - associated structures (veins / R, R' faults & fractures);
- Timing relationships:
  - fault - fault relationships;
  - displacement of marker units;
  - absolute dates.
- Fault characteristics:
  - thin, straight (brittle, shallow, low T);
  - broad zone with discrete breaks (brittle-ductile zone - mod P & T);
  - broad zone, no breaks (ductile - deep, high T).



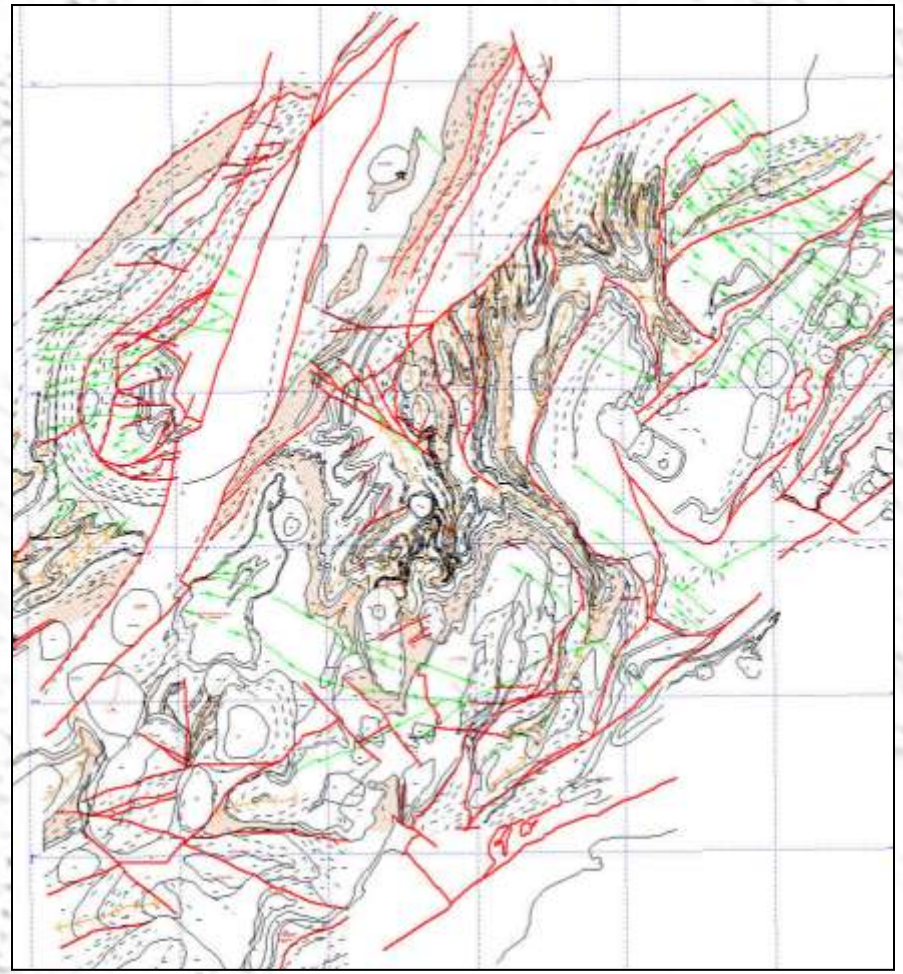
Structural Analysis – 5

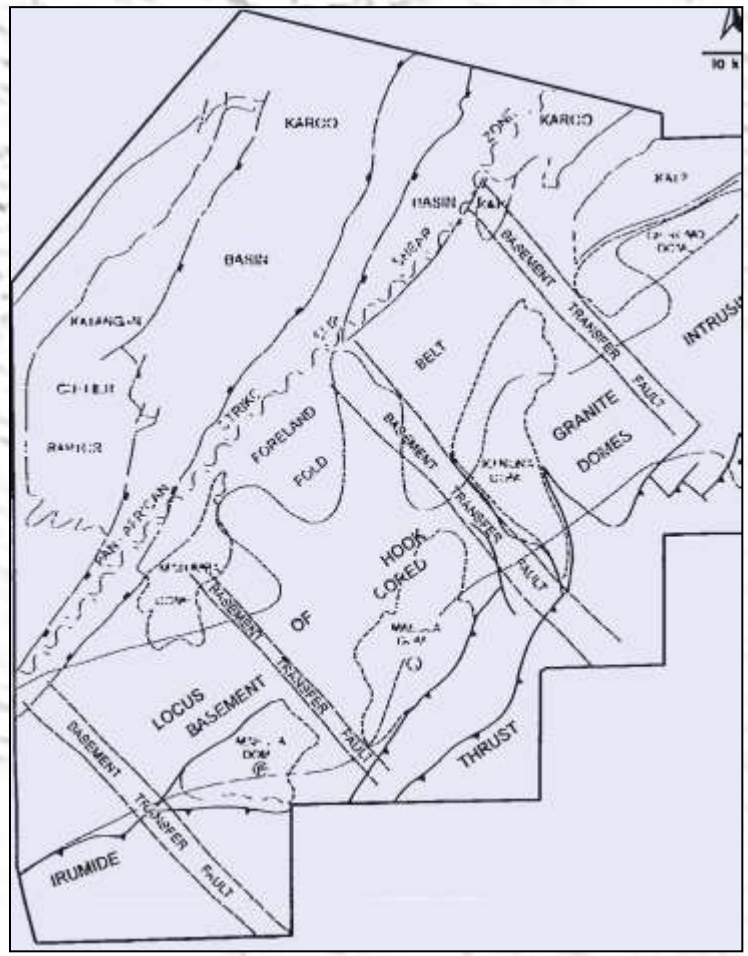
Important Observations To Make (cont….):

- Associated features:
  - folds (parallel / oblique);
  - 2nd order sediments / basins;
  - associate intrusives / extrusives;
  - veining / alteration; and
  - Recognition of fault hierarchy (1st order, 2nd order etc).
- Strain variations inferred from block geometries:
  - structures at block margins; and
  - strain within blocks (possible modified stress fields).
- Regional context:
  - relationship of area to regional structures;
  - setting (e.g. basin, mobile belt, arc etc.);
  - orogenic events elsewhere at inferred time of faulting?
  - pre-existing structures possibly reactivated?



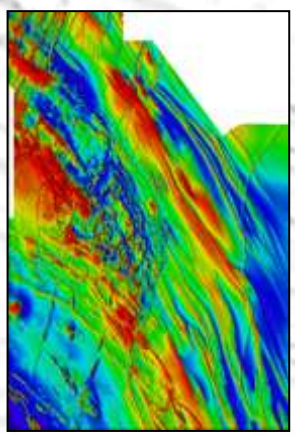
Apply structural models





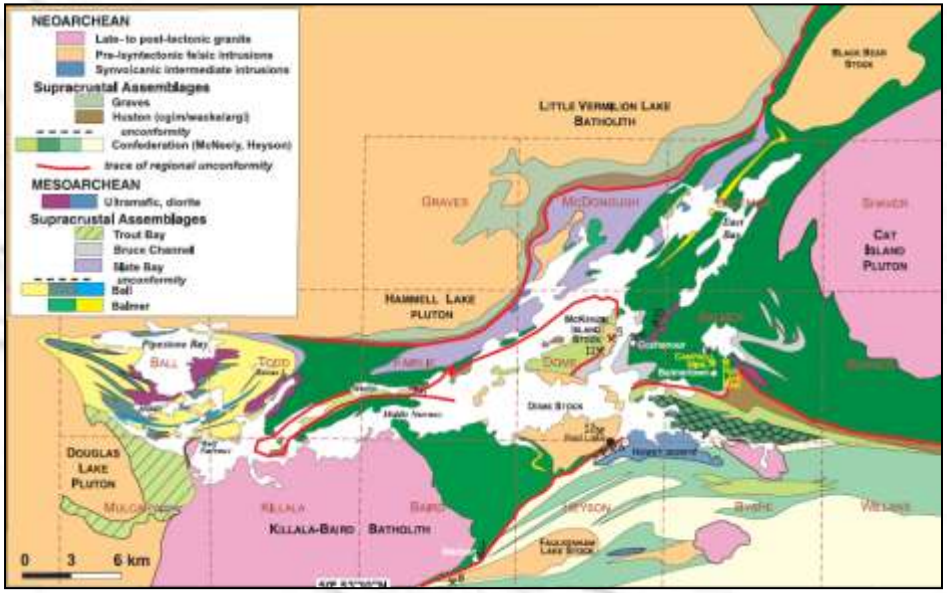
Geological models for mapping

- Geological models are a **primary** component of the interpretation process for producing maps;
- In order to present an **interpretation** of the geology of the region, there needs to be a coherent framework of stratigraphic and structural principles that form the basis of the interpretation;
- A coherent regional geological pattern can be followed through the series of maps;
- Individual structures can be interpreted in both a time and space context. We can interpret when and how faults moved;
- **The spatial distribution of mineral deposits in relation to structures becomes evident, and can be related to the geological evolution of the region, not just the geometry;**
- Areas and structures with potential for reactivation at later times become apparent; and
- Cross-sections can be developed which provide a realistic 3D form consistent with the geological models.



Reviewing the structural history.... e.g. Red Lake

- **Stratigraphy:**
  - **Balmer Mafic volcanism:** **3.0-2.98 Ga[1]**
  - **Confederation Mafic-Intermediate volcanism:** **2.75-2.73 Ga[1]**
  - **Granodiorite plutonism:** **2.720-2.704 Ga[1]**
  - **Granodiorite dykes (Madsen, post-gold):** **2.699 Ga[2]**
- **Deformation:**
  - **D_1** **Northwest trending, south plunging F_1 folds** **2.744 Ma-2.733 Ga[1]**
  - **D_2** **East to northeast trending F_2 folds** **~2.720 Ga (Coeval with Dome Stock)[1]**
  - **D_3** **Coplanar with D_2** **~2.690 Ga[1]**
- **Metamorphism: Peak ~2.720-2.715 Ga[1]**
- **Gold mineralization @ Madsen :**
  - **2.744-2.699 Ga[2]**
  - **Or 2.723-2.712 Ga[3]**
- **Gold mineralization @ Red Lake, Campbell, Cochenour:**
  - **2.712 and 2.702 Ga[3]**



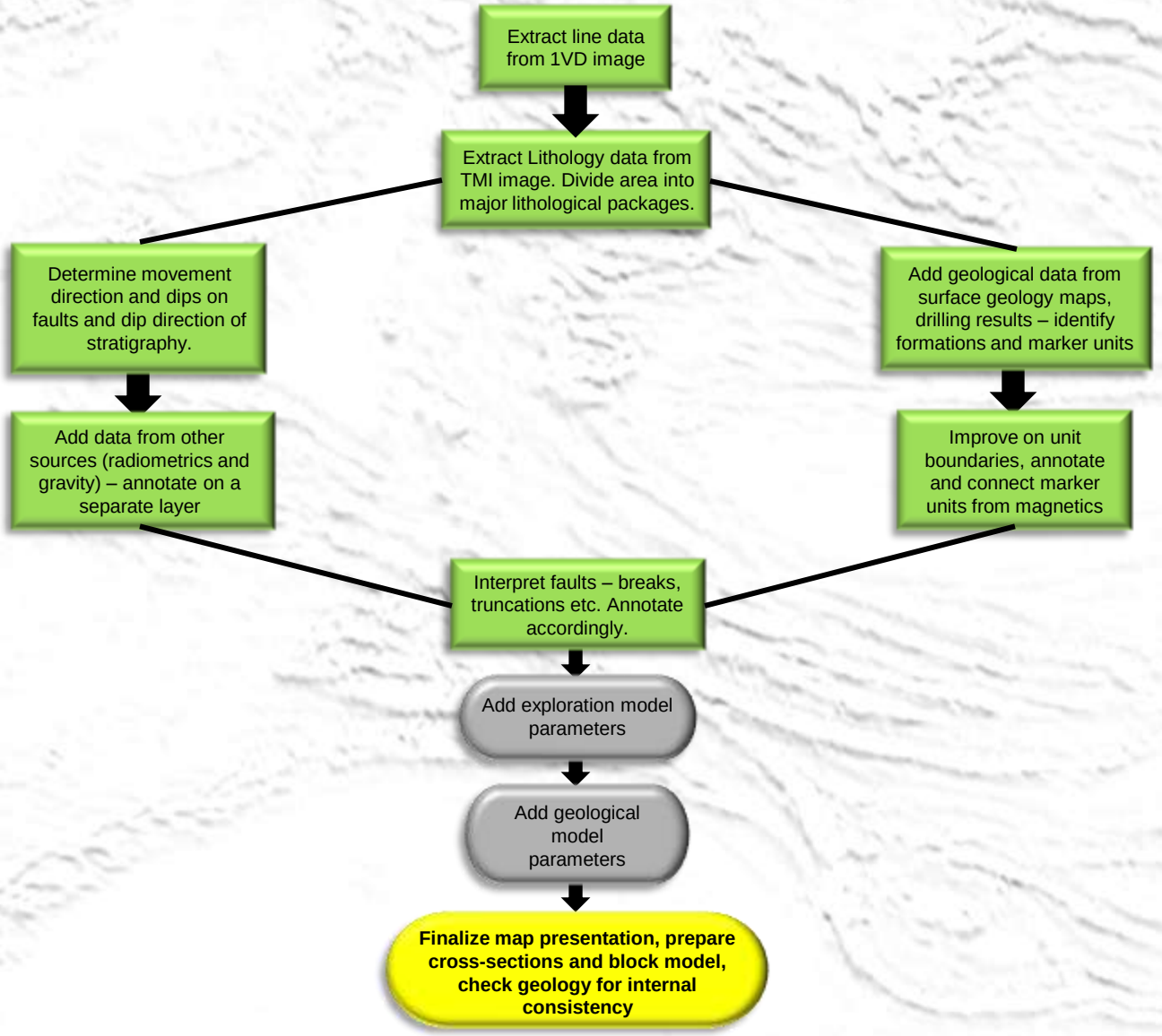
Red Lake Age Data Map, Figure 3, Sanborn-Barrie et al. 2004.

[1] Sanborn-Barrie et al. 2004. Geology, Red Lake greenstone belt, western Superior Province, Ontario. GSC Open File 4594.

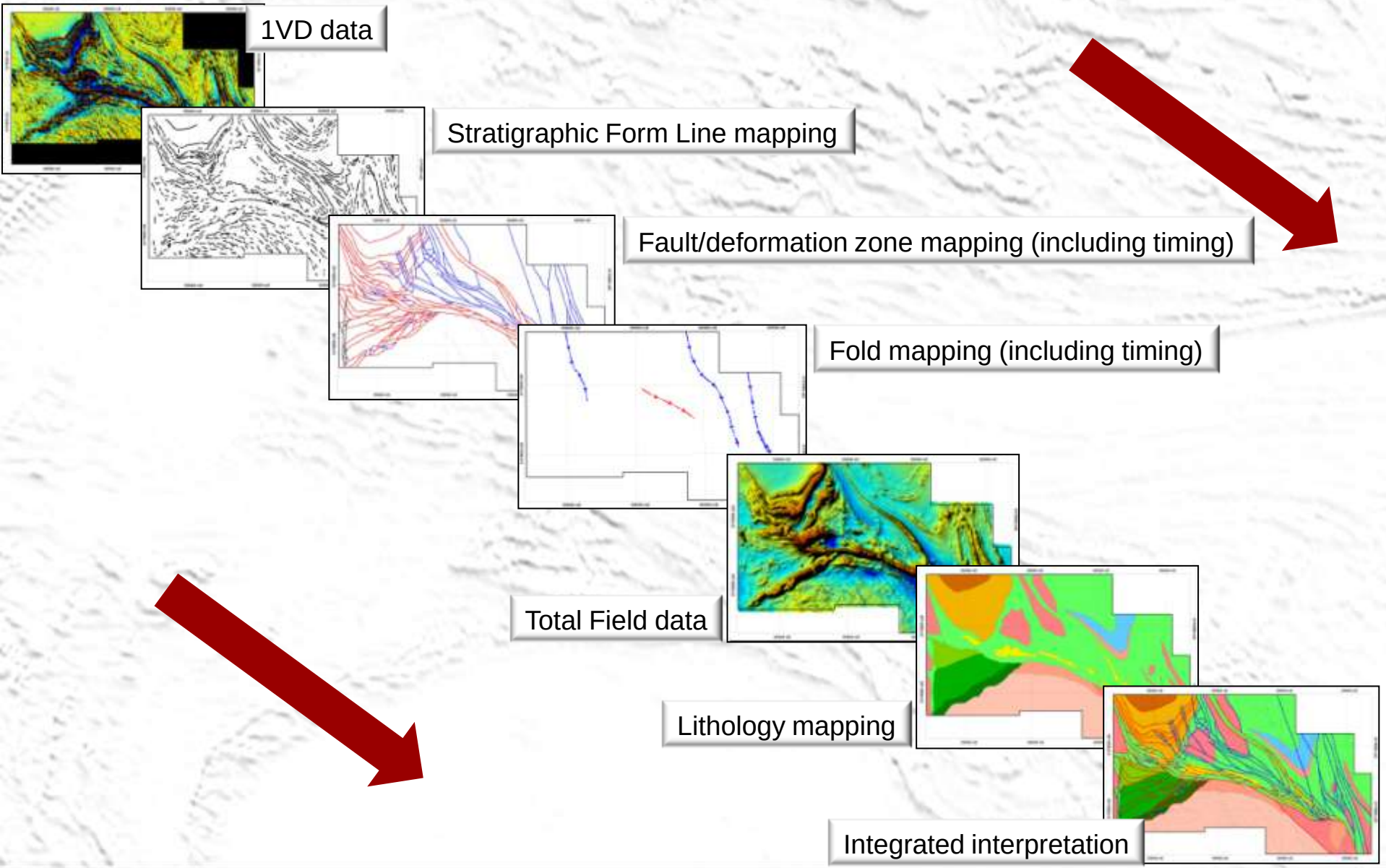
[2] Dube et al. 2000. A preliminary report on amphibolite facies, disseminated-replacement style mineralization at the Madsen gold mine, Red Lake, Ontario. GSC Current Research 2000-C17.

[3] Dube et al. 2004.Timing of gold mineralization at Red Lake, NW Ontario, Canada. New constraints from U-Pb geochronology at the Goldcorp High-Grade Zone, Red Lake Mine, and the Madsen mine. Economic Geology, V.99.

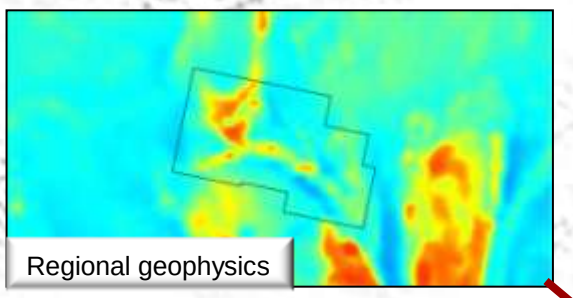
Interpretation Flowchart



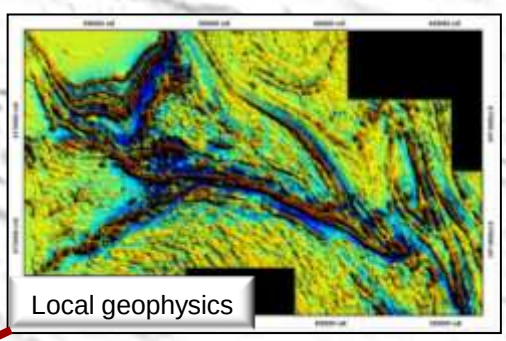
Method

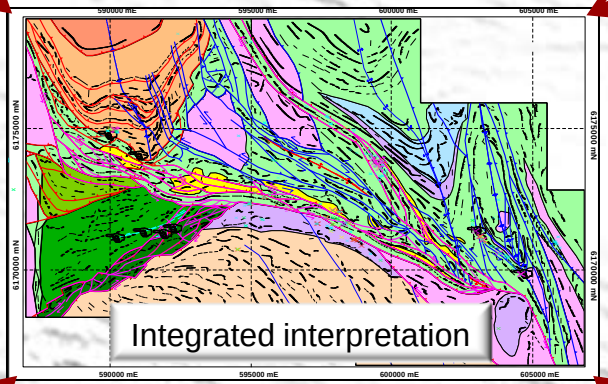

1VD data
Stratigraphic Form Line mapping
Fault/deformation zone mapping (including timing)
Fold mapping (including timing)
Total Field data
Lithology mapping
Integrated interpretation

Dataset Integration

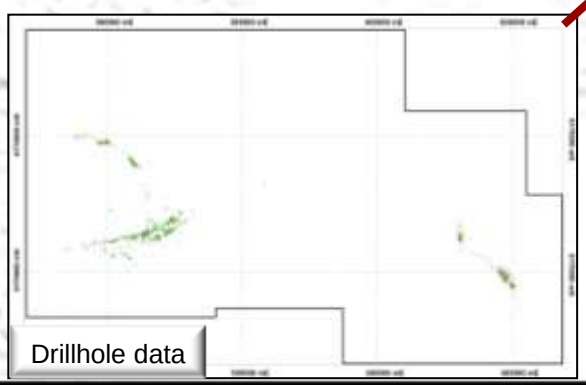

Regional geophysics

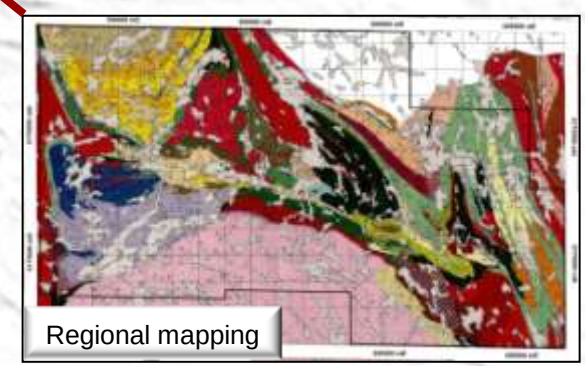

Published literature


Local geophysics

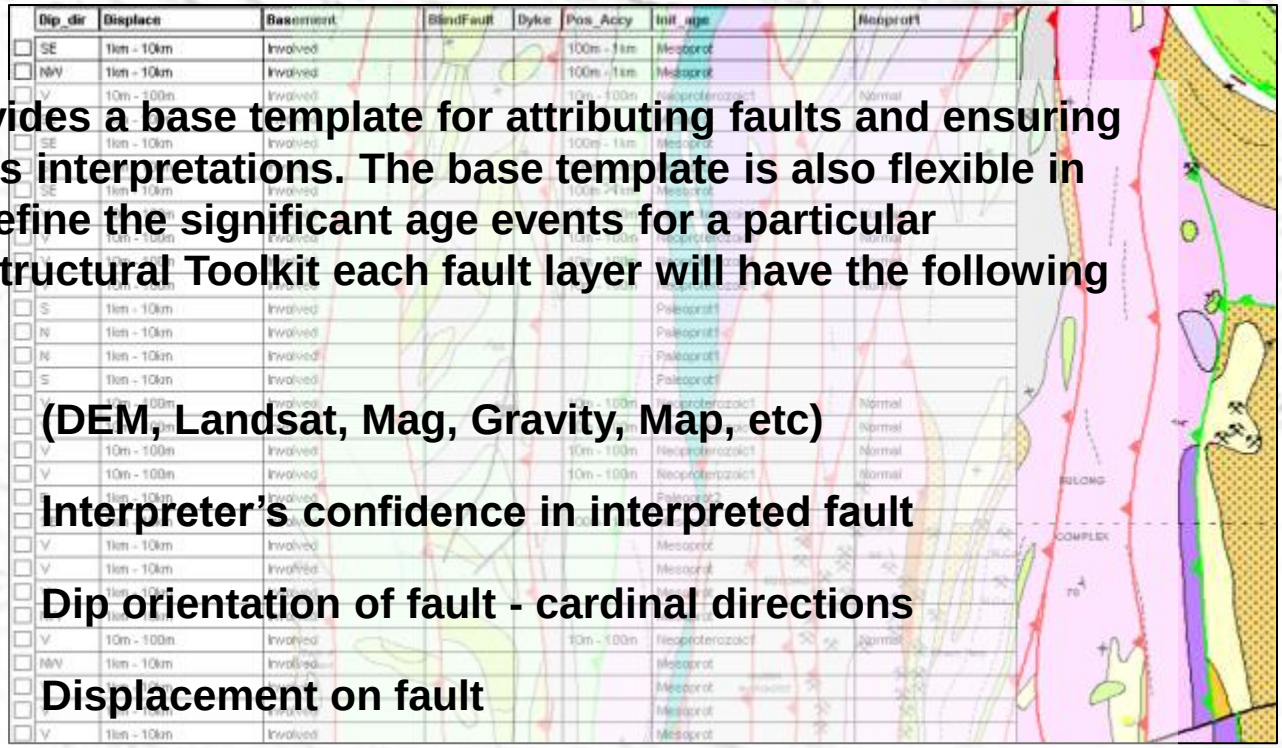


Integrated interpretation


Drillhole data


Regional mapping

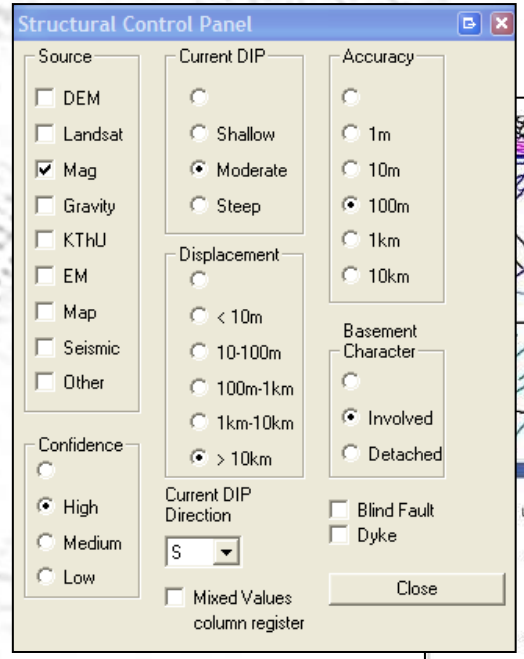
SRK's Structural Toolkit

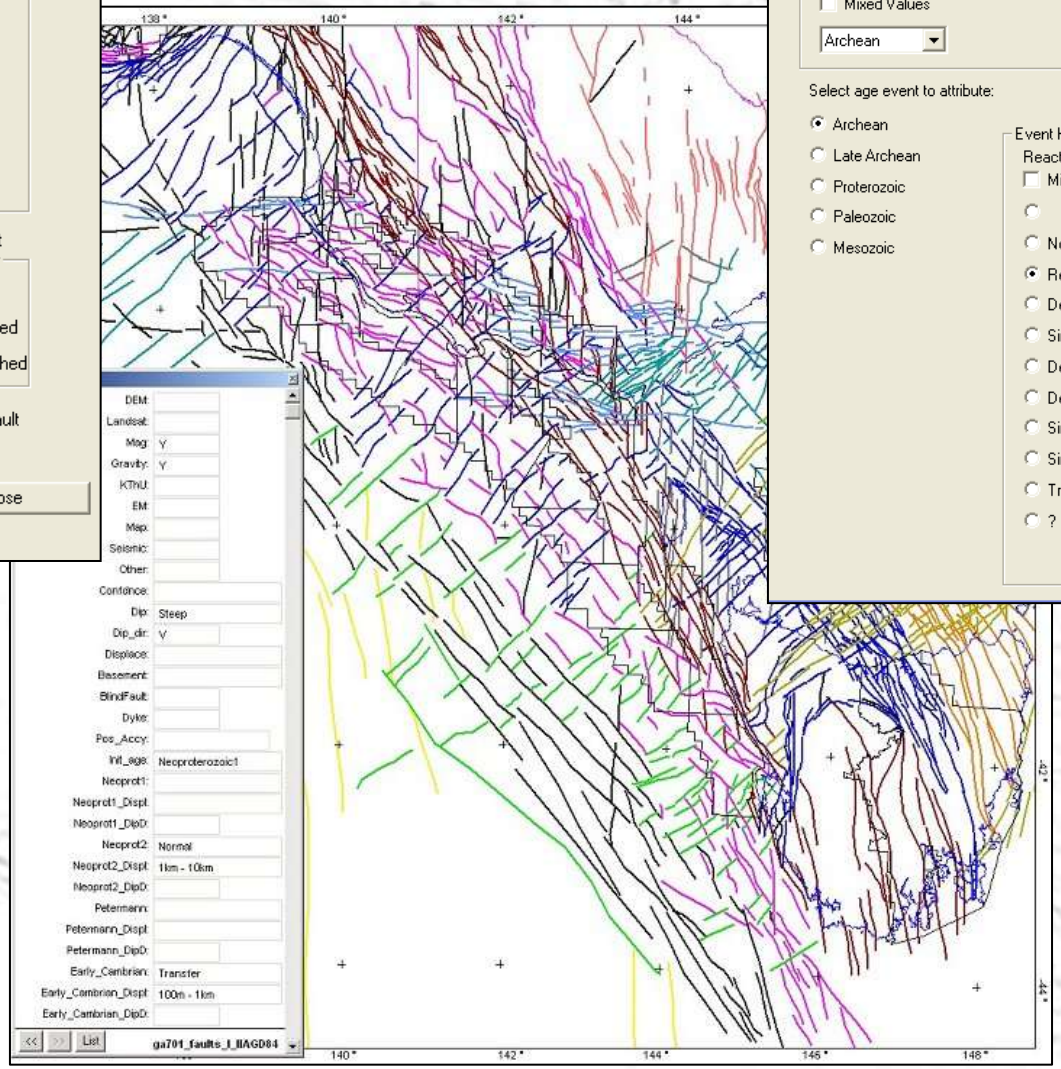


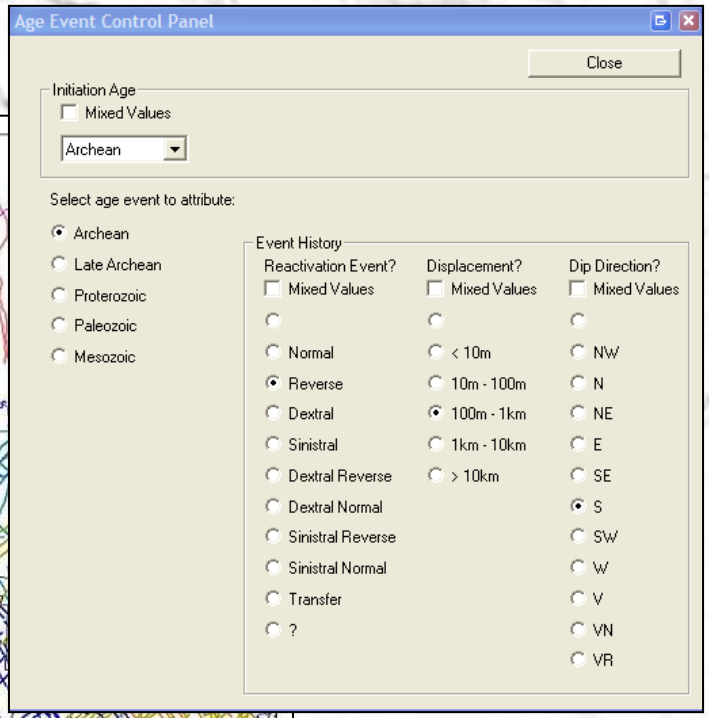
The Structural Toolkit provides a base template for attributing faults and ensuring consistency across various interpretations. The base template is also flexible in that it allows the user to define the significant age events for a particular interpretation. Using the Structural Toolkit each fault layer will have the following attribute columns:

Interpretation Source	**(DEM, Landsat, Mag, Gravity, Map, etc)**
Confidence	**Interpreter's confidence in interpreted fault**
Orientation	**Dip orientation of fault - cardinal directions**
Displacement	**Displacement on fault**
Basement Character	**Is the fault basement involved or detached?**
Dyke	**Is the fault accommodating a dyke?**
Initiation Age	**The initiation age of the fault (defined by the user)**
Reactivation History	**Age event columns to document a fault's event history**

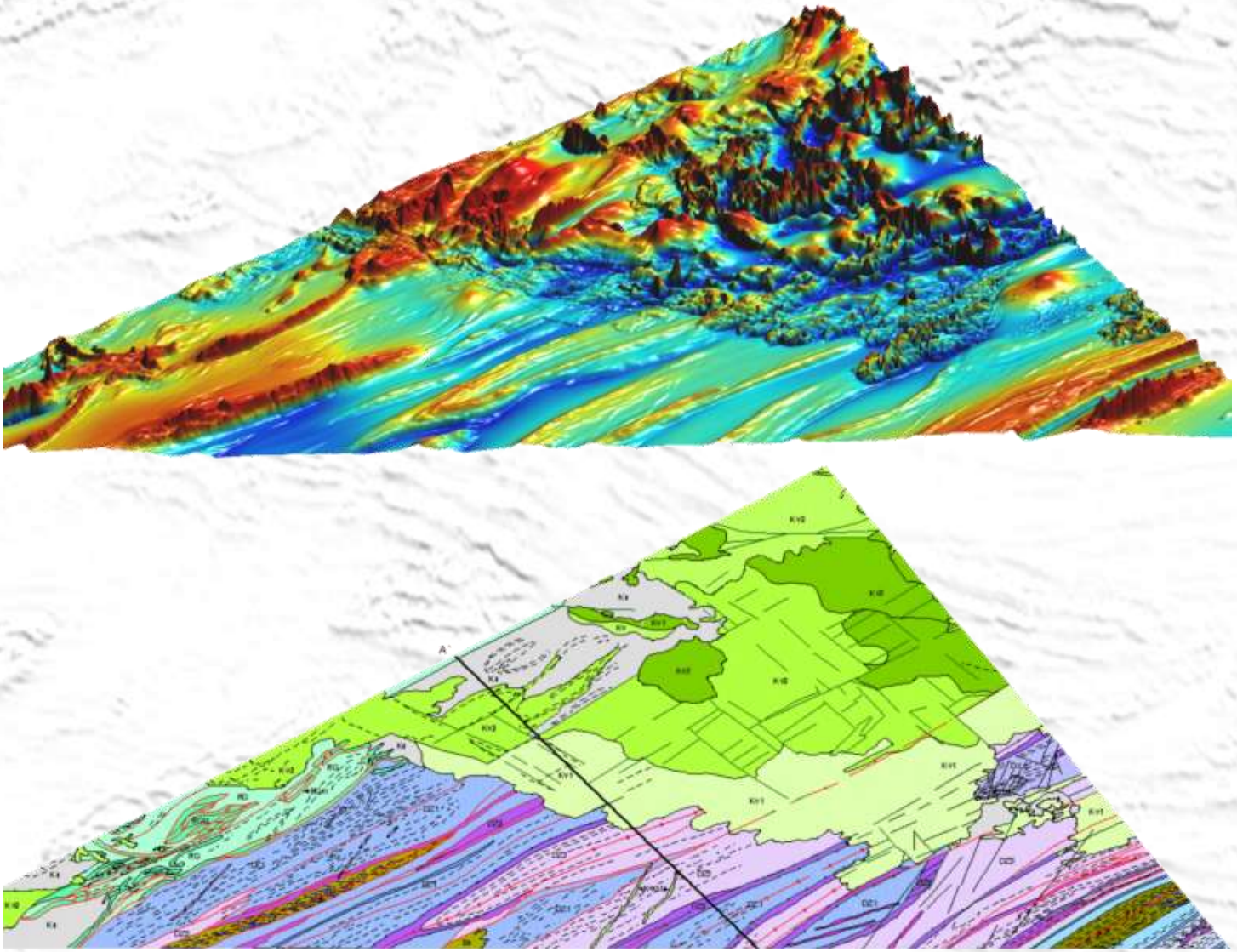
SRK's Structural Toolkit





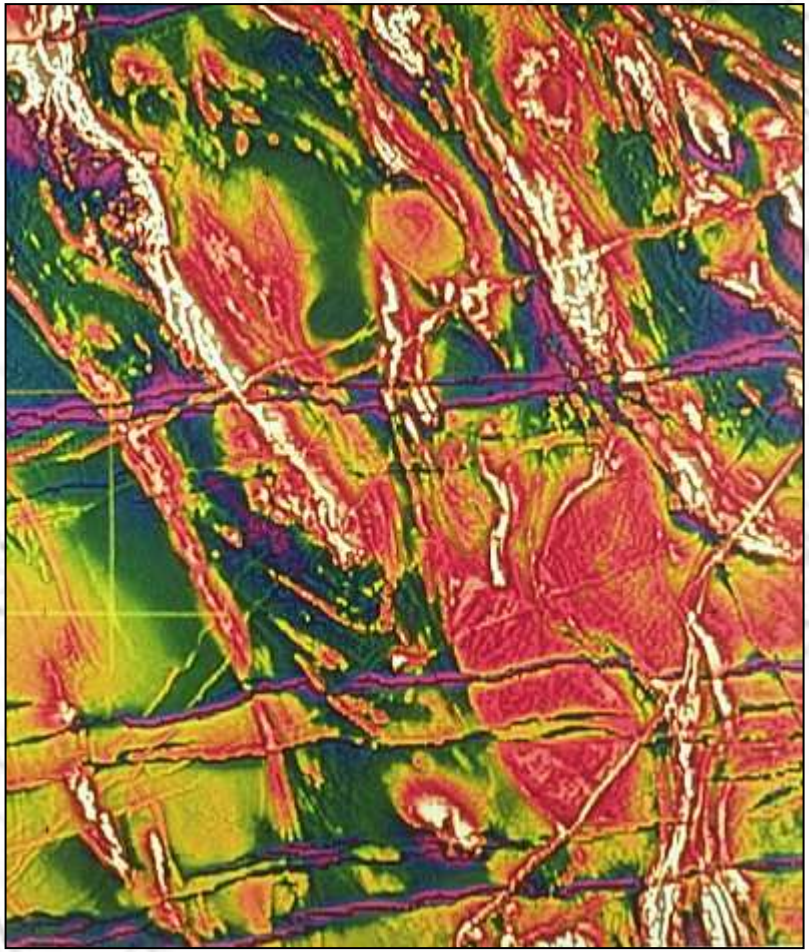


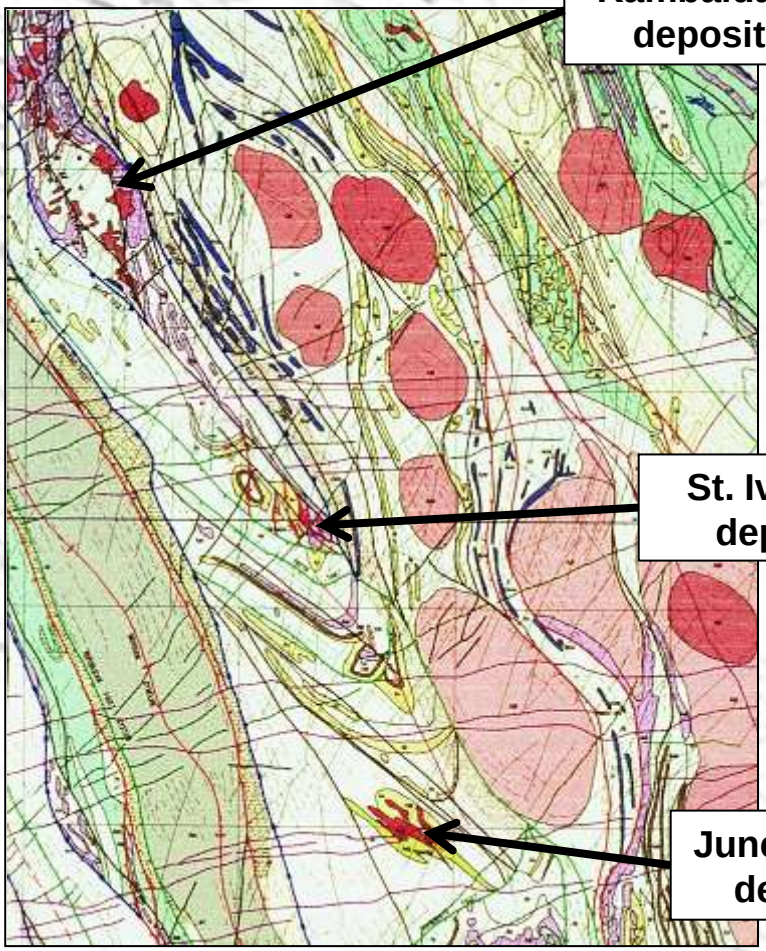
Example of final geological maps



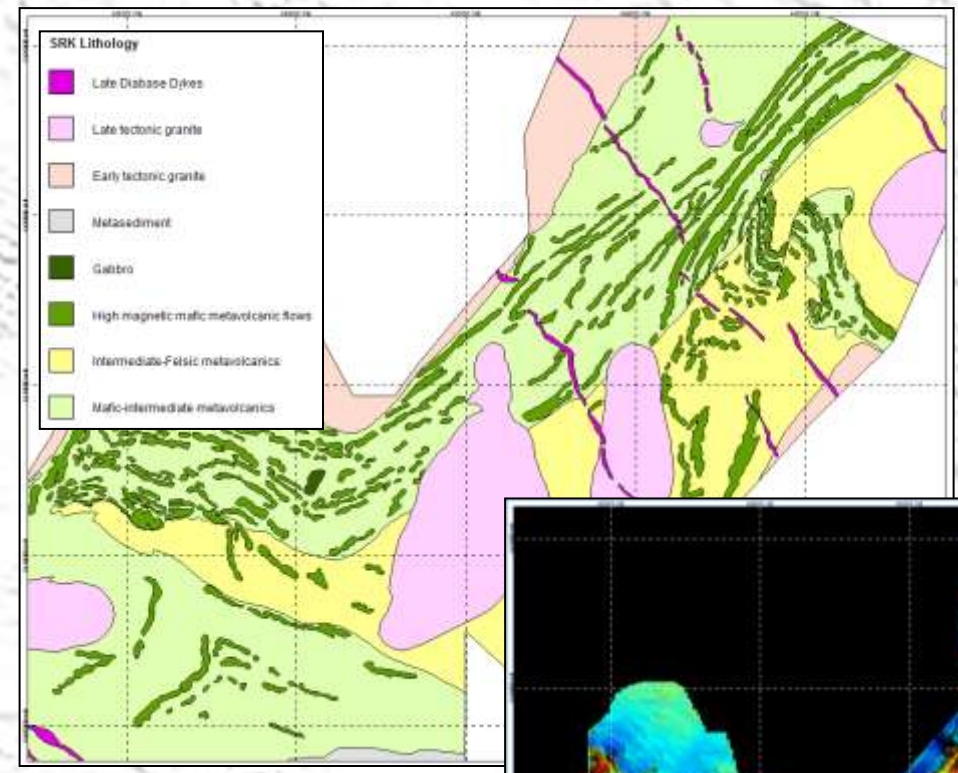
Example of final geological maps - Yilgarn

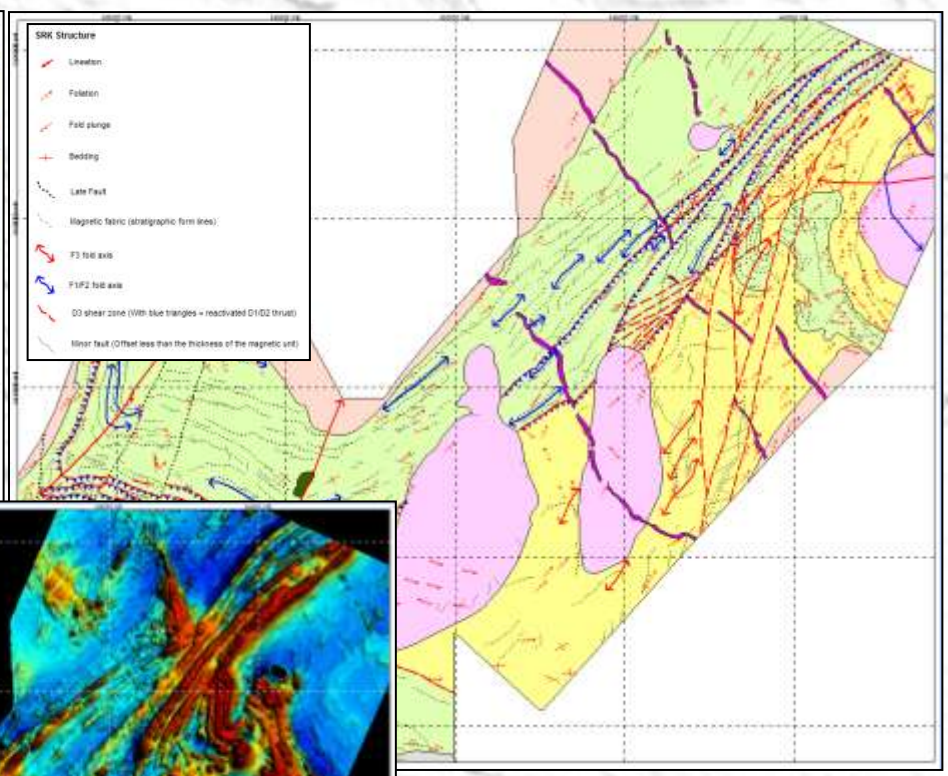
- The Yilgarn Craton in Western Australia is like the Superior Province of Canada - a Late Archean Granite-Greenstone craton - there are many similarities and many differences.

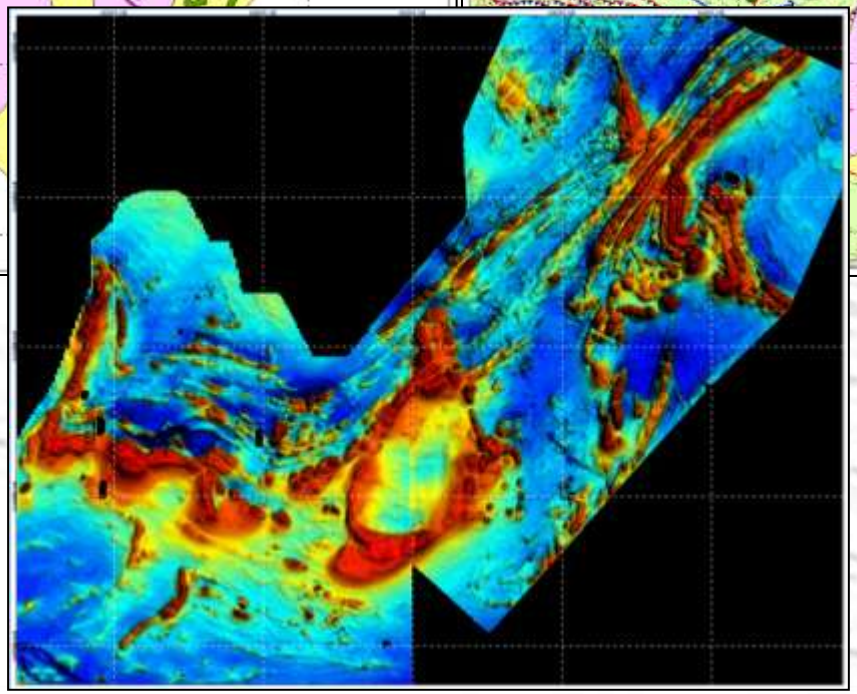




Example of final geological maps - Superior







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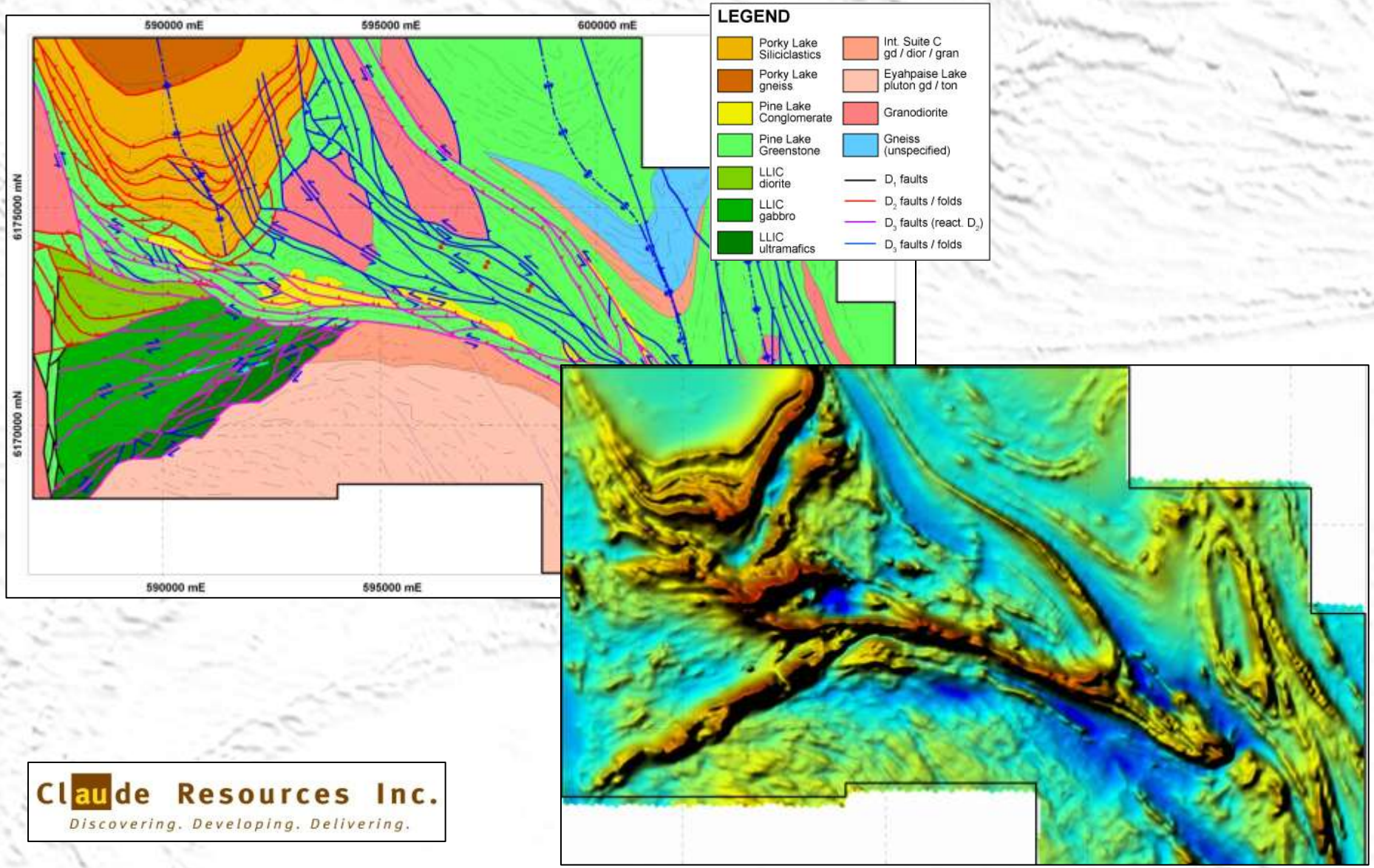
Example of final geological maps – SK



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Conclusions

- To produce an accurate, applied geological interpretation:
  - Think geologically – process/controls when defining geological elements from aeromagnetic data;
  - Focus your interpretation with an understanding of potential controls on the distribution of mineralization first;
  - Incorporate reality – structural settings/geometries, known geological relationships in the area (e.g. stratigraphic relationships);
  - Define your geological and structural history; and
  - Incorporate multiple datasets, e.g. existing geological mapping, drillhole data.