



# The Geophysical Response of Intrusion Related Gold with an Example from Okvau, Cambodia

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# Outline



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- Gold deposit types and gold
- Intrusion related gold
- Fort Knox (8 Moz)
- Muruntau (200 Moz)
- Donlin Creek (30Moz)
- Okval (+1.2Moz?)
- Summary



# Deposit Types and Contained Gold

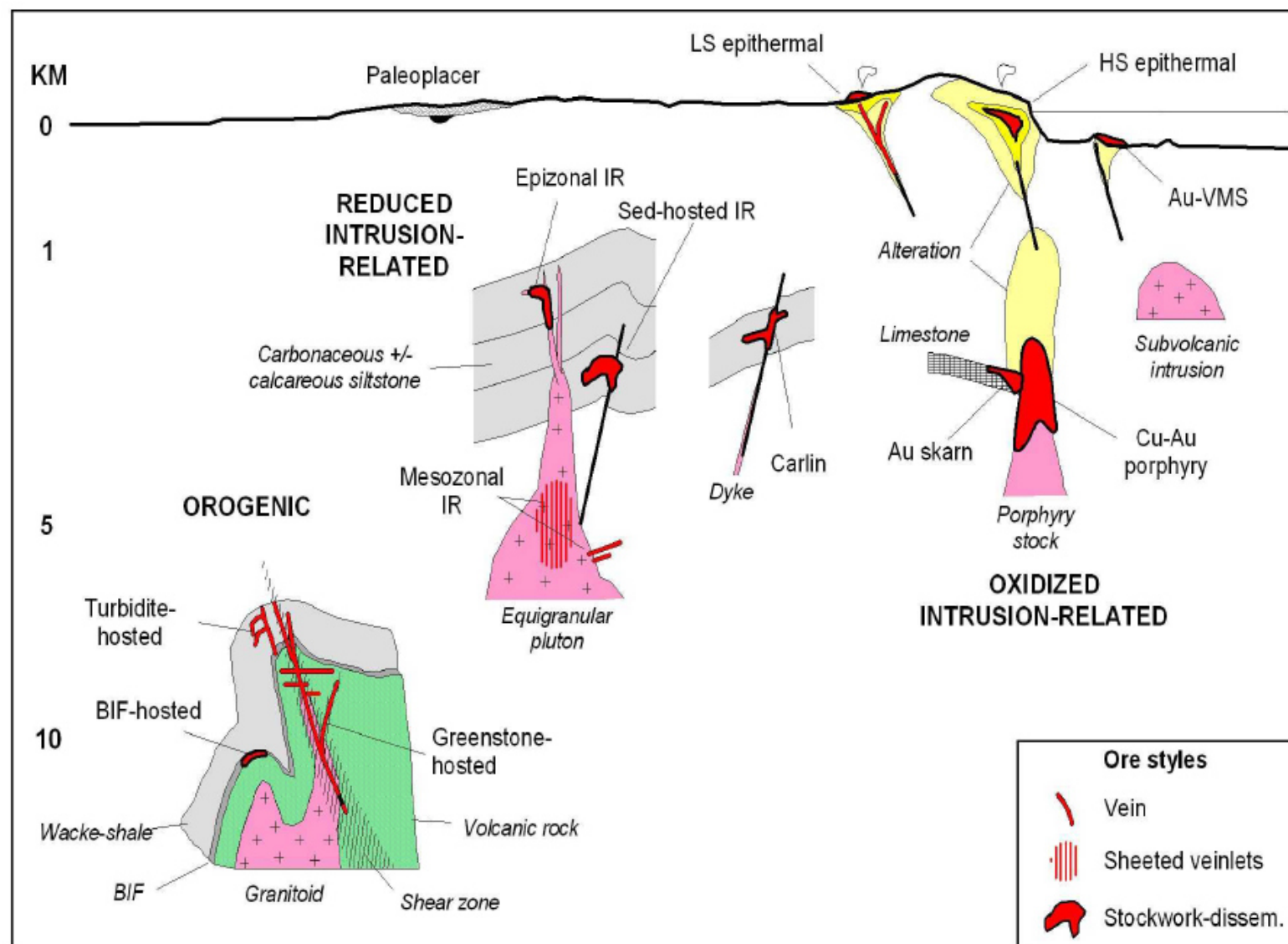


| Deposit Clans and Types | No of deposits >10 Moz | Contained Au (Moz) |
|-------------------------|------------------------|--------------------|
| <b>Orogenic</b>         | 20                     | 425                |
| Greenstone              | 14                     | 285                |
| Turbidite & BIF         | 6                      | 140                |
| <b>Reduced IR</b>       | 13                     | 434                |
| Intrusion-hosted        | 4                      | 75                 |
| Sediment-hosted         | 8                      | 359                |
| <b>Oxidized IR</b>      | 39                     | 1104               |
| Porphyry (skarn)        | 27                     | 739                |
| HS-IS Epithermal        | 9                      | 253                |
| LS Alkalic              | 3                      | 112                |
| <b>Other Types</b>      |                        |                    |
| LS- Epithermal          | 7                      | 91                 |
| Carlin                  | 10                     | 245                |
| Au-VMS                  | 2                      | 20                 |
| Witwatersrand           | 8                      | 1260               |
| Greenstone atypical     | 5                      | 113                |

- Distribution of a population of 103 deposits greater than 10 Moz amongst different deposit types
- Preferred target types:
  - High deposit abundance
  - Highest % of population >10 Moz deposits
  - Good economics and mineability

(After Robert et al., 2007)

# Intrusion Related Gold "Reduced"

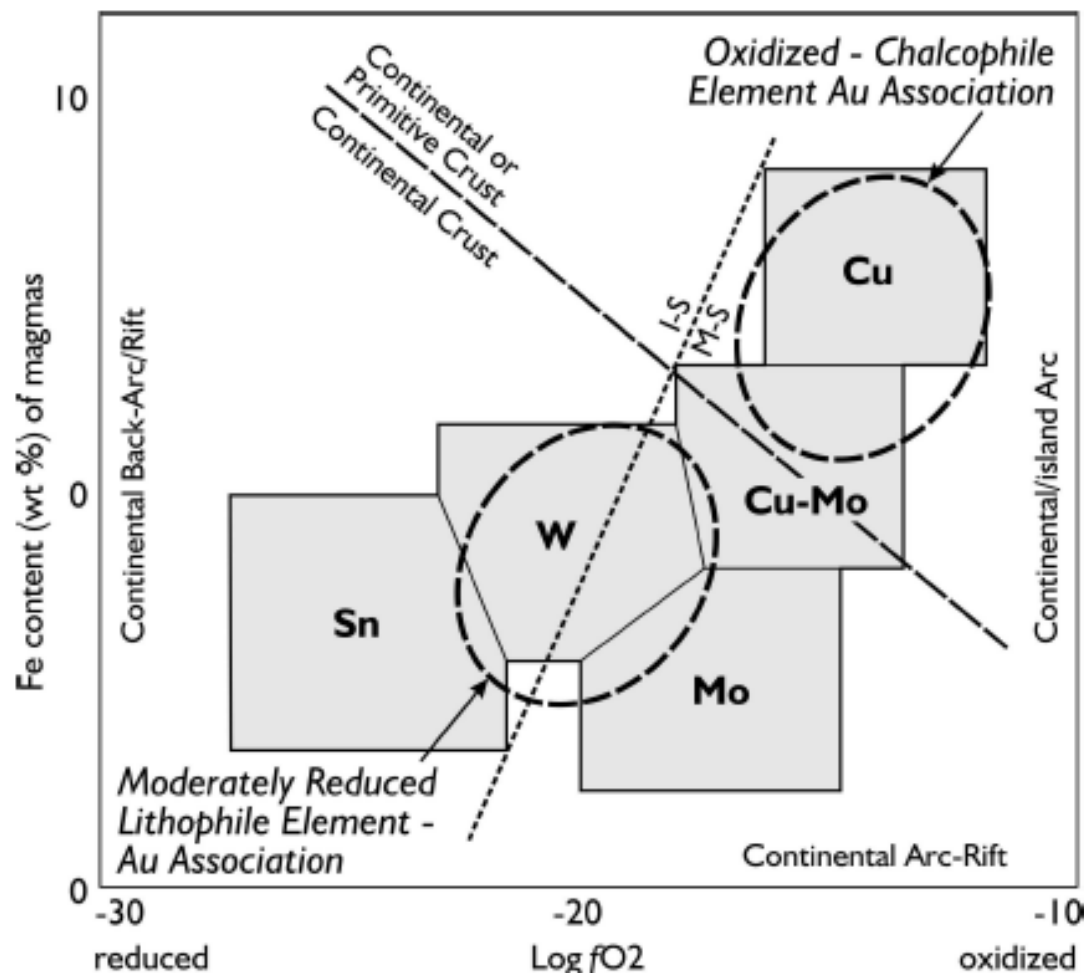


(After Robert et al., 2007)

# Intrusion Related Gold “Reduced”

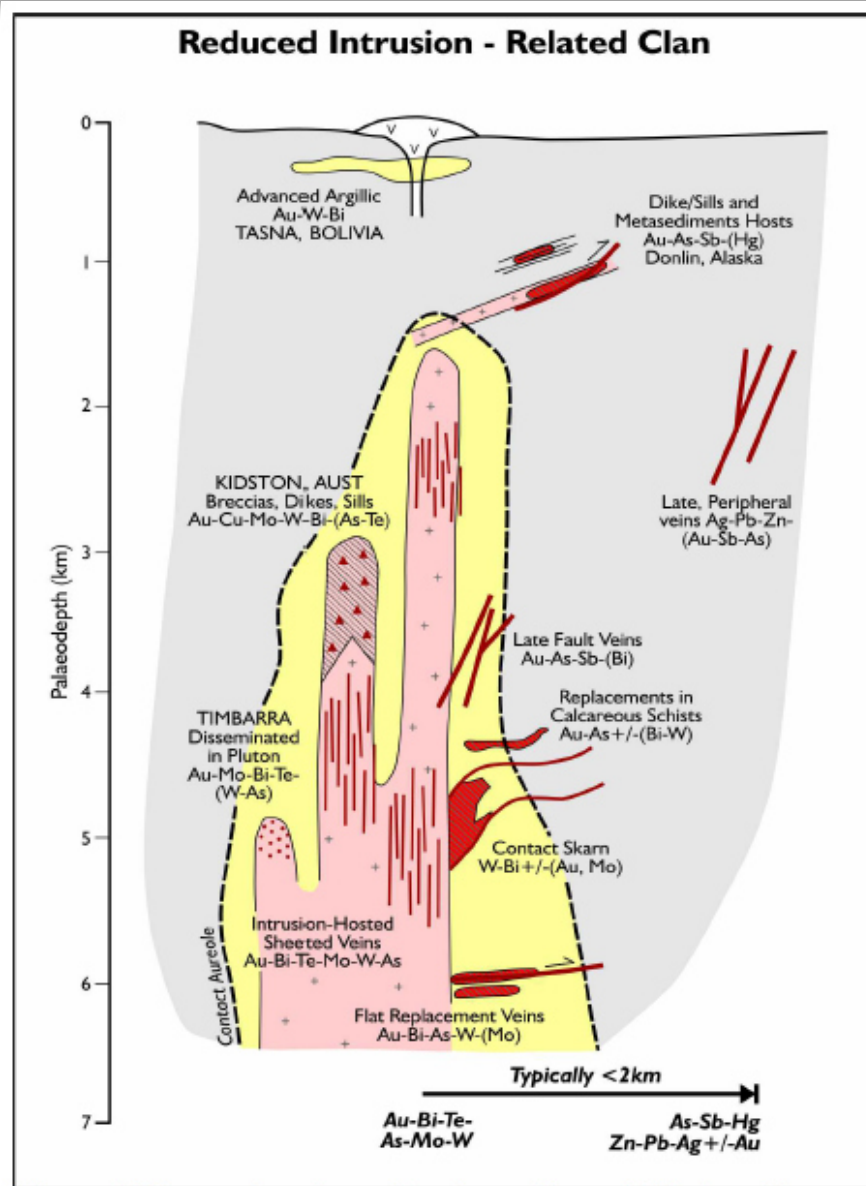


- At regional scale these deposits are best known for tungsten and/or tin deposits
- They occur in tectonic settings well inboard of inferred or recognised convergent plate boundaries
- The IR reduced clan can be moderately reduced or weakly oxidised (but significantly less oxidised than intrusions related to gold rich porphyries)
- Reduced ore mineral assemblage that typically comprises arsenopyrite, pyrrhotite and pyrite and lacks magnetite or hematite.



(After Thompson et al., 1999)

# Intrusion Related Gold “Reduced”



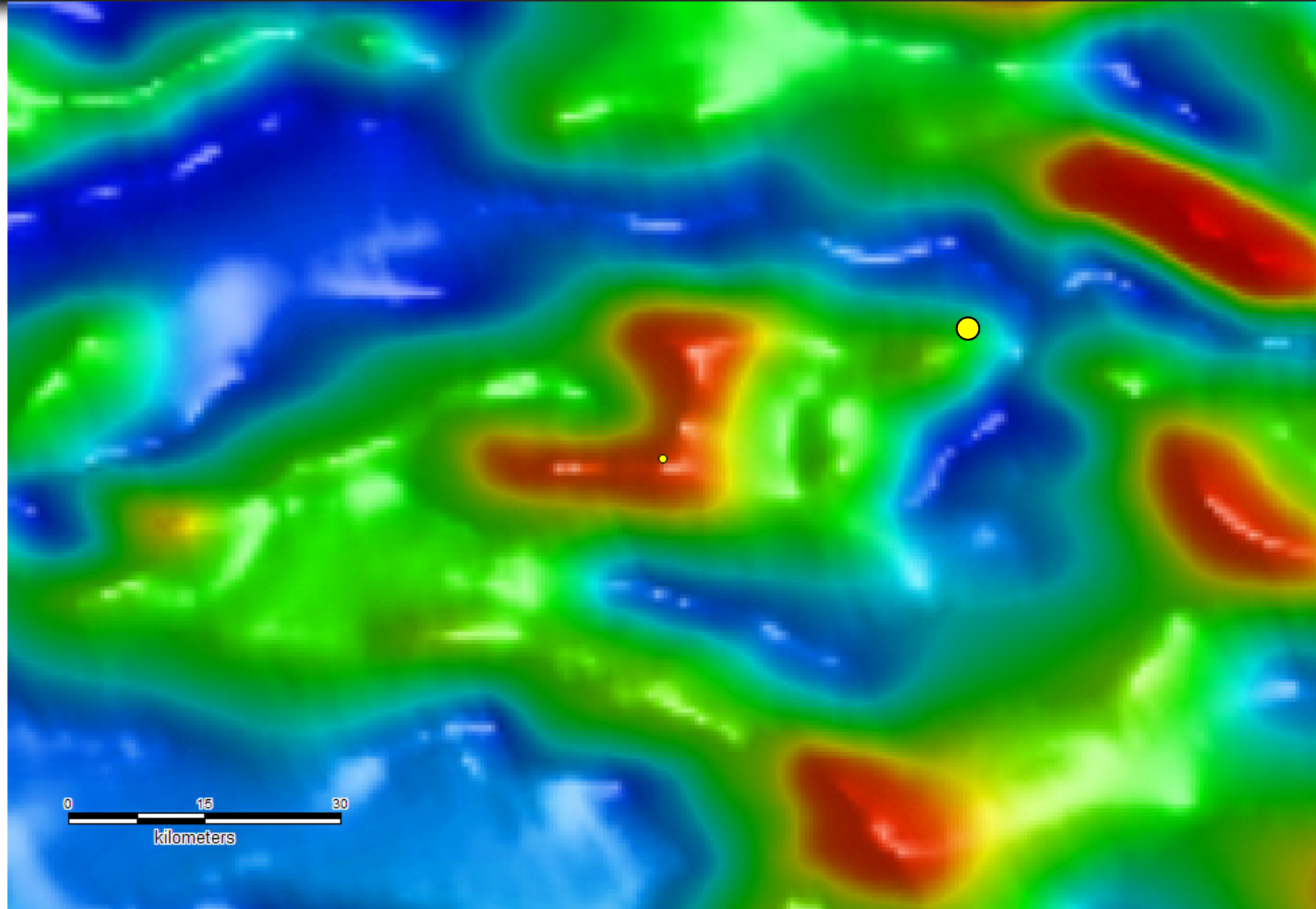
- Epizonal (shallow) stock veinlets, disseminated sulphide or sheeted vein mineralisation in dyke sills or domes eg Donlin Creek 30Moz, Brewery Creek. More commonly refractory and can be associated with antimony and mercury
- Mesozonal (deeper) lower grade bulk mineable sheet veins and disseminated sulphides. Margins or roof zones of small elongate intrusions. Free milling and non-refractory (alluvial mining camps) eg Fort Knox 8 Moz, Vasilkovskoe 12Moz
- Metal assemblages combine gold with variably elevated Bi, W, As, Mo, Te, and/or Sb but low concentrations of base metals.
- Mineralization typically has low sulphide content, mostly <5 vol %

(After Lang et al., 2000)

# Muruntau – TMI 1:500K



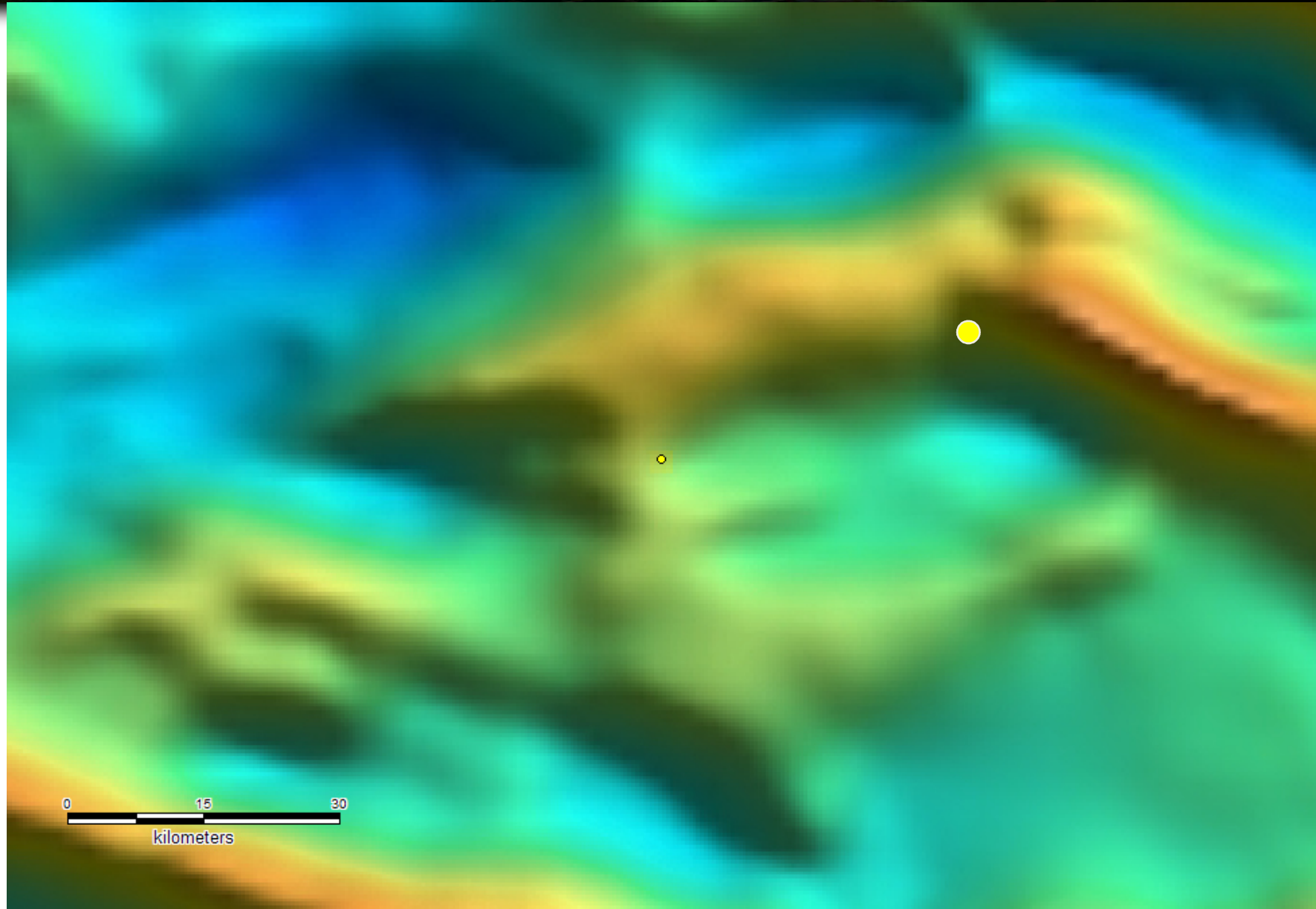
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# Muruntau – Gravity 1:500K



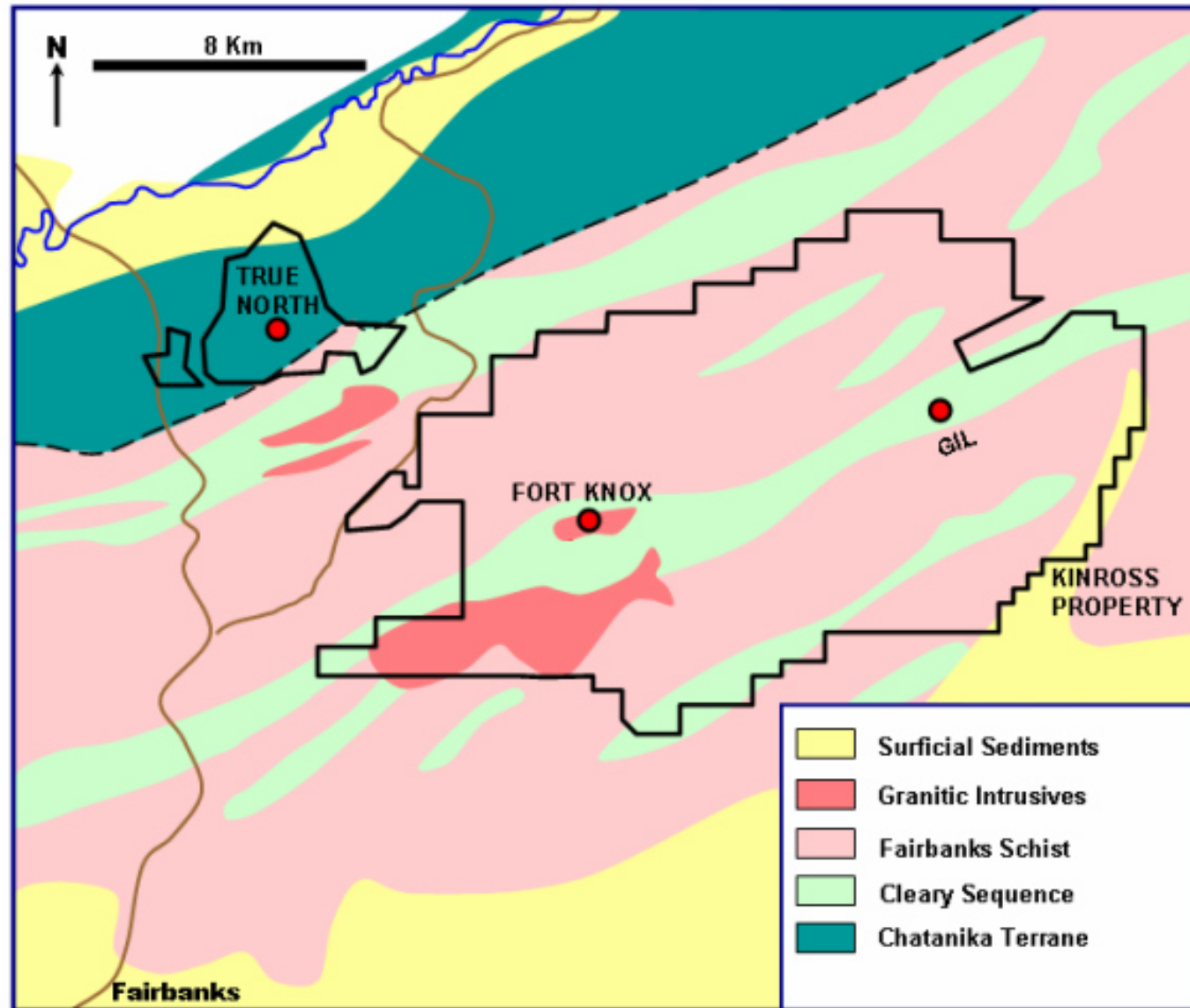
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# Fort Knox - Geology



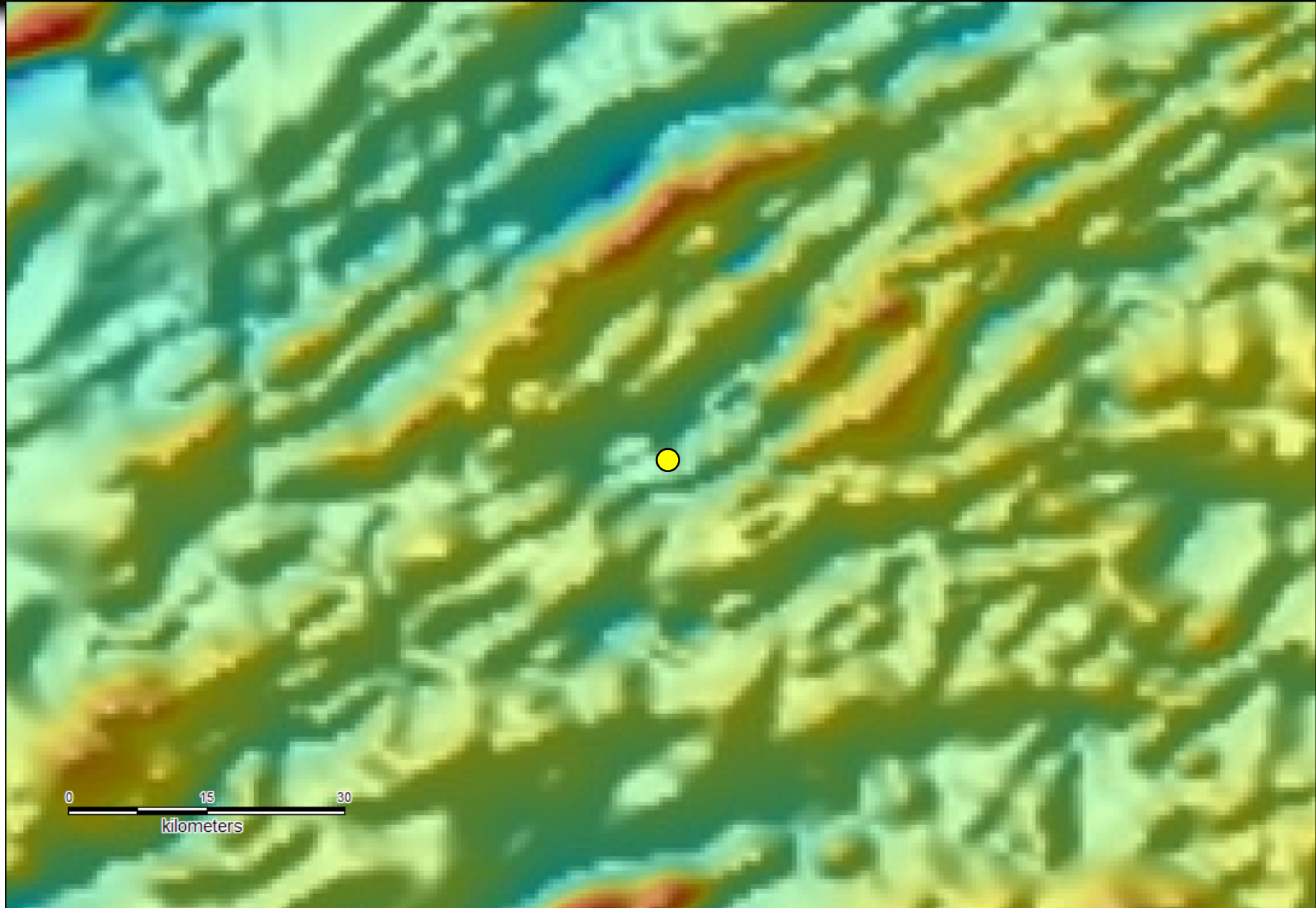
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# Fort Knox – RTP (1:500K)



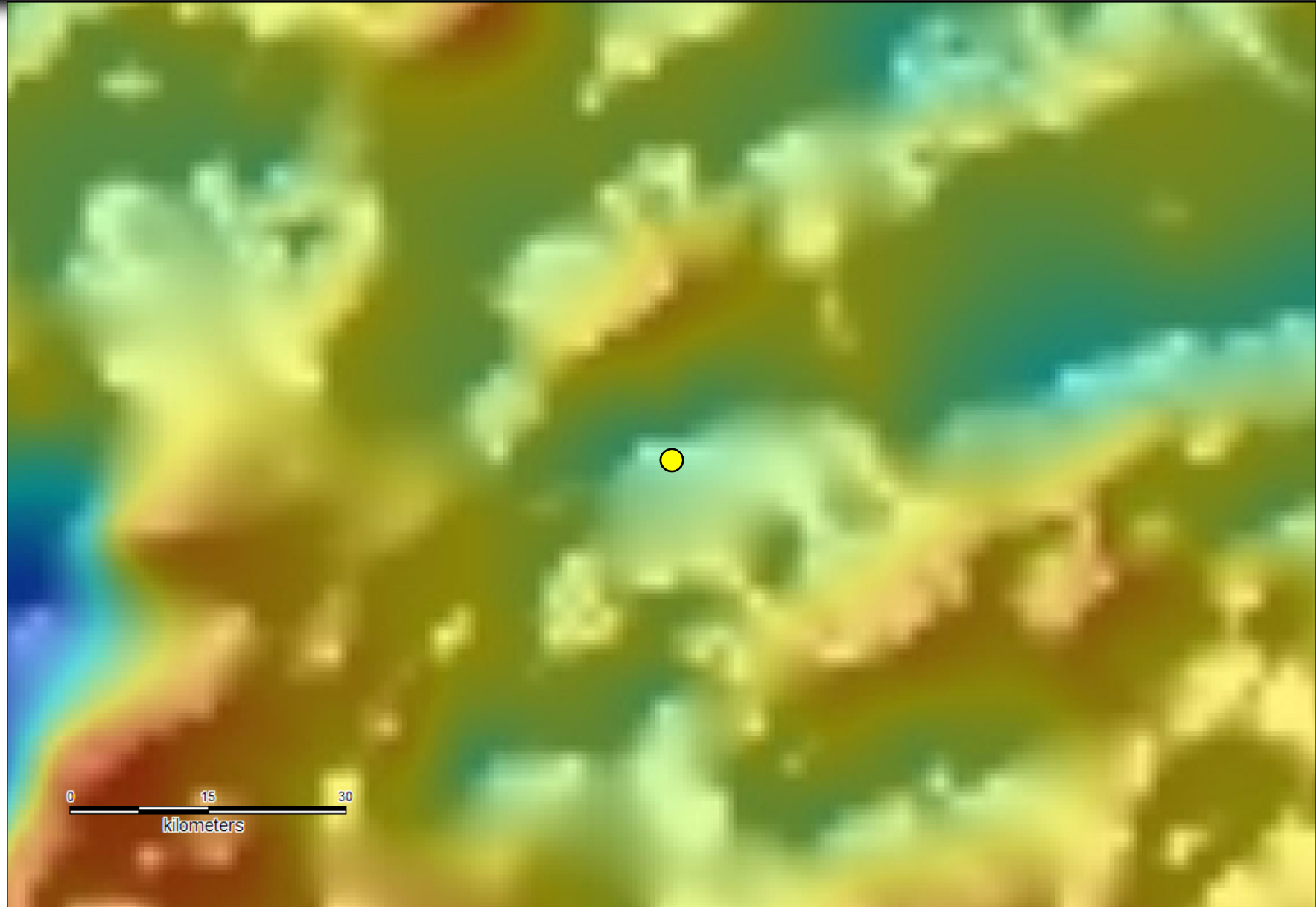
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# Fort Knox – Gravity 1:500K



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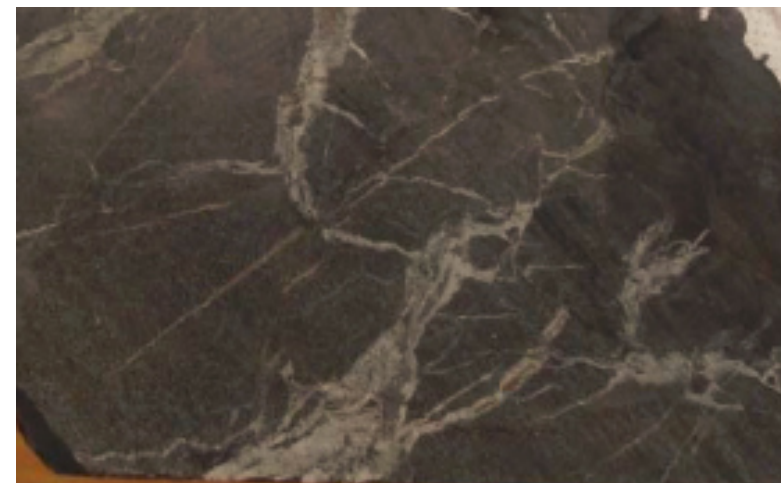
# Donlin Creek - Petrophysics



- The **remnant magnetic** nature of the intrusives at Donlin Creek is well known. Reduced to pole image of the aeromagnetic data shows a dominantly reversed magnetic anomaly coincident with the intrusive trend, rimmed by a positive anomaly from the metamorphosed sediments. This has been confirmed by samples with Koenigsberger ratios  $>1$  in alteration and host intrusive
- **Magnetic susceptibilities** measured are very low (1 to 40 SI) and explain the very subtle magnetic anomaly associated with the Donlin Creek intrusives. Alteration associated with mineralisation is magnetite destructive (for weakly oxidised hosts)
- Some mineralised samples have **high chargeabilities** (max 100 msec) and the IP method has proven to be an effective exploration targeting tool. Background chargeability from the intrusions can have low/moderate responses (5-10msec). Altered sediment can be also have moderate chargeabilities ( $>10$ msec) so some awareness required when targeting IP features in the IR environment.

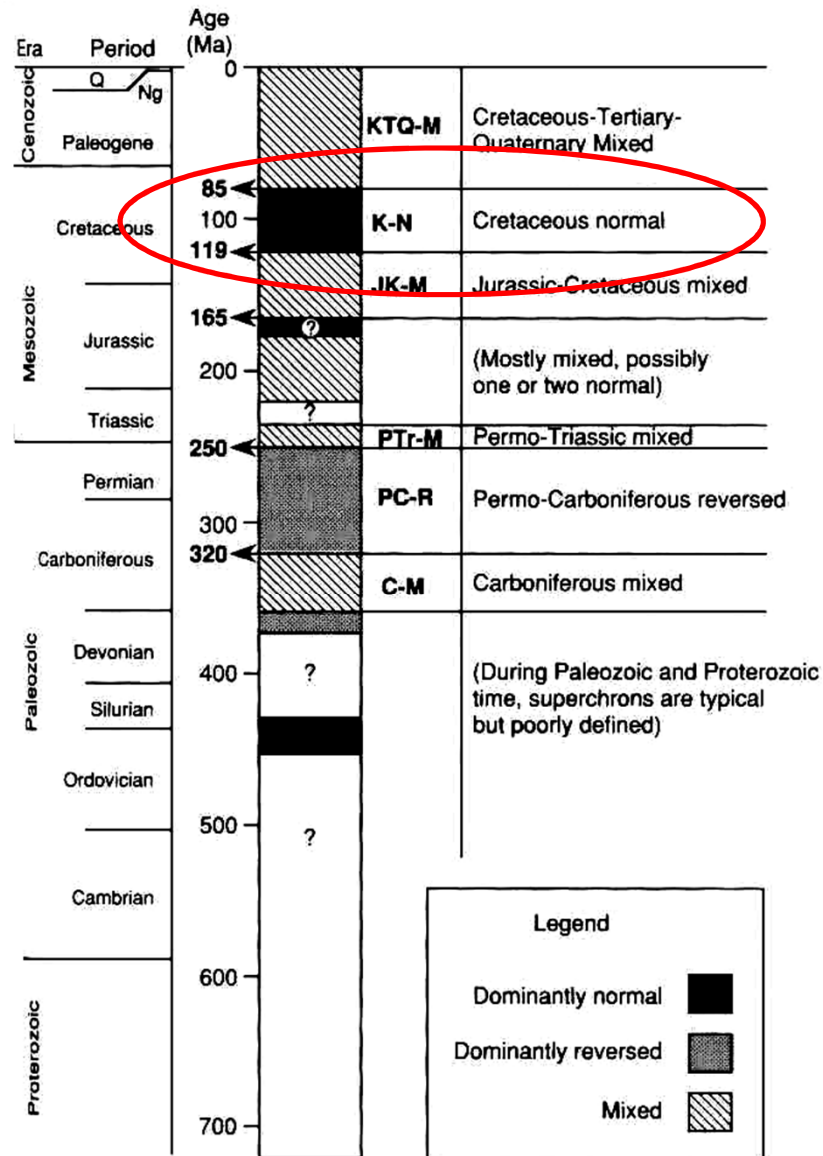


~6 g/t Au in intrusive (fine veinlets and disseminations of As and Py)



~12g/t Au in sediment

# Magnetisation – Cretaceous/ Early Tertiary

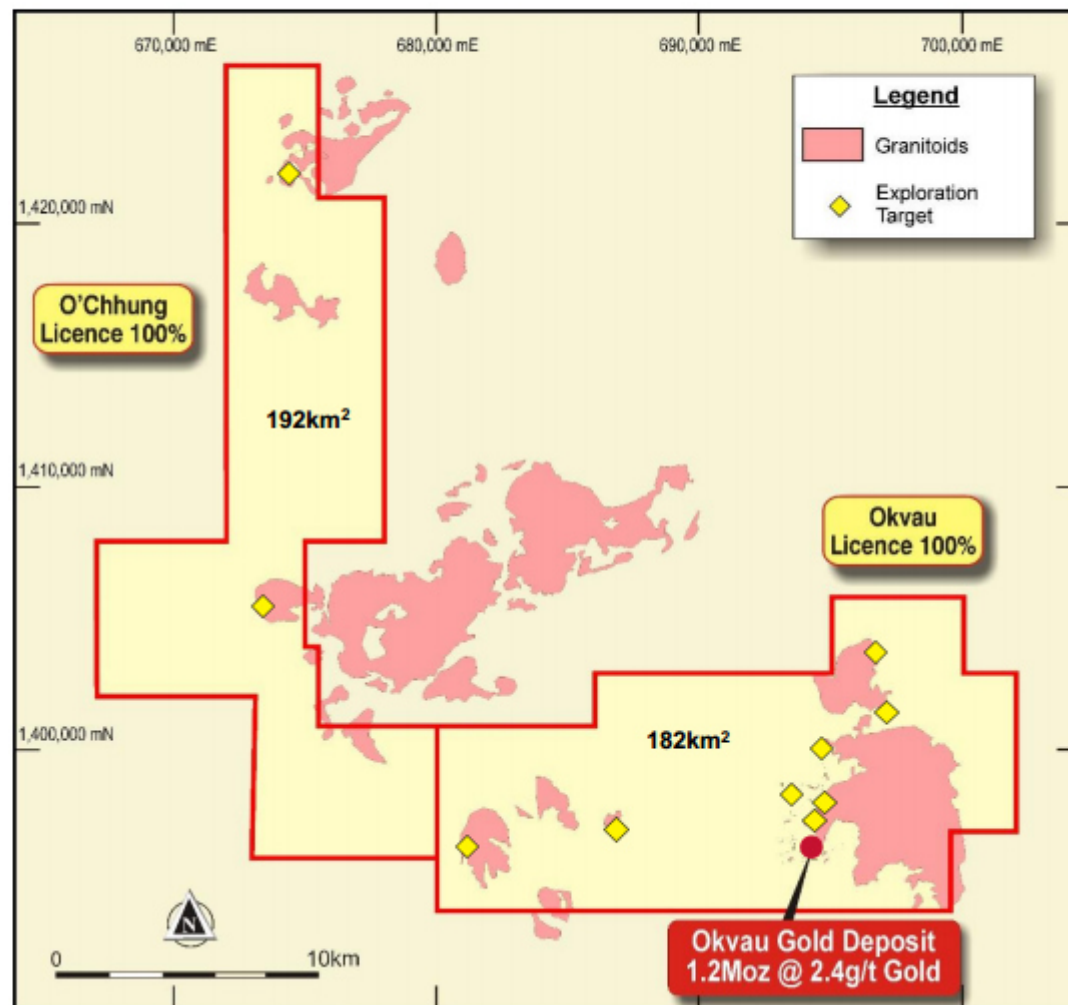


- Donlin / Okval – Cretaceous (late)

# Renaissance – Okvau Project



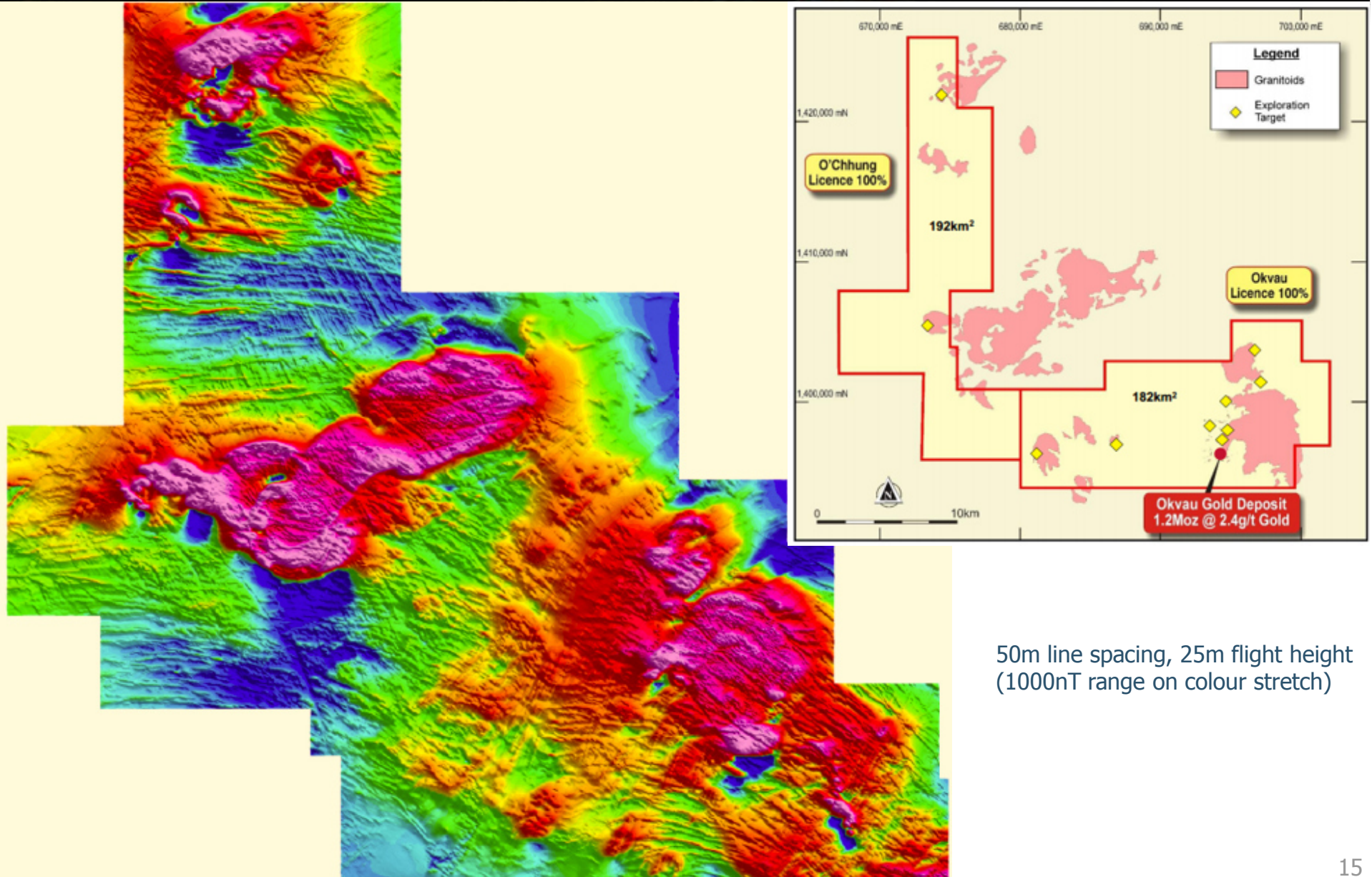
- Cretaceous age (100Ma) granitoid intrusions
- Gold occurrences have direct associations with granitoid intrusions
- Classic Intrusive Related Gold geochemical signatures (gold, arsenic, bismuth, tellurium)
- **Strong geological analogue to the large IRG deposits in the Tintina Belt (Alaska-Yukon):**
  - Donlin Creek >30Moz
  - Fort Knox >4Moz
  - Pogo >6Moz
  - Livengood >20Moz



# Renaissance – Okvau Project Magnetics (RTP)



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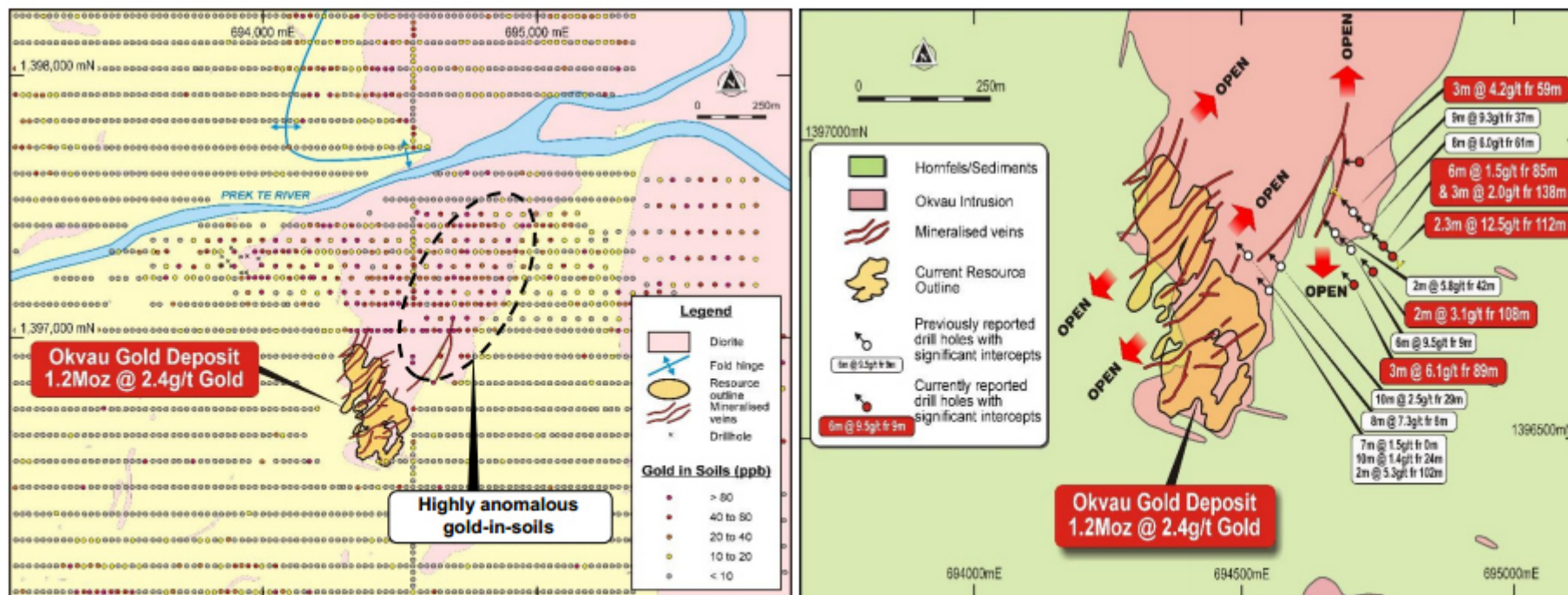


# Renaissance – Okvau Deposit



- Remains 'open', growth inevitable | significant potential for high grade, shallow extensions
- North-east strike extension of over 250 metres along prospective diorite-sediments contact
- Recent results from extensional drilling outside resource envelope include<sup>1</sup>:
  - 6m @ 9.5g/t gold from 9m
  - 8m @ 6.0g/t gold from 61m
  - 8m @ 7.3g/t gold from 6m
  - 9m @ 9.3g/t gold from 37m
  - 10m @ 2.5g/t gold from 29m

## ■ Drilling underway (results pending)



<sup>1</sup> Refer ASX announcement dated 10 February 2014, 3 April 2013, 23 June 2014 and 21 July 2014

# Renaissance – Okvau Host and Mineralisation



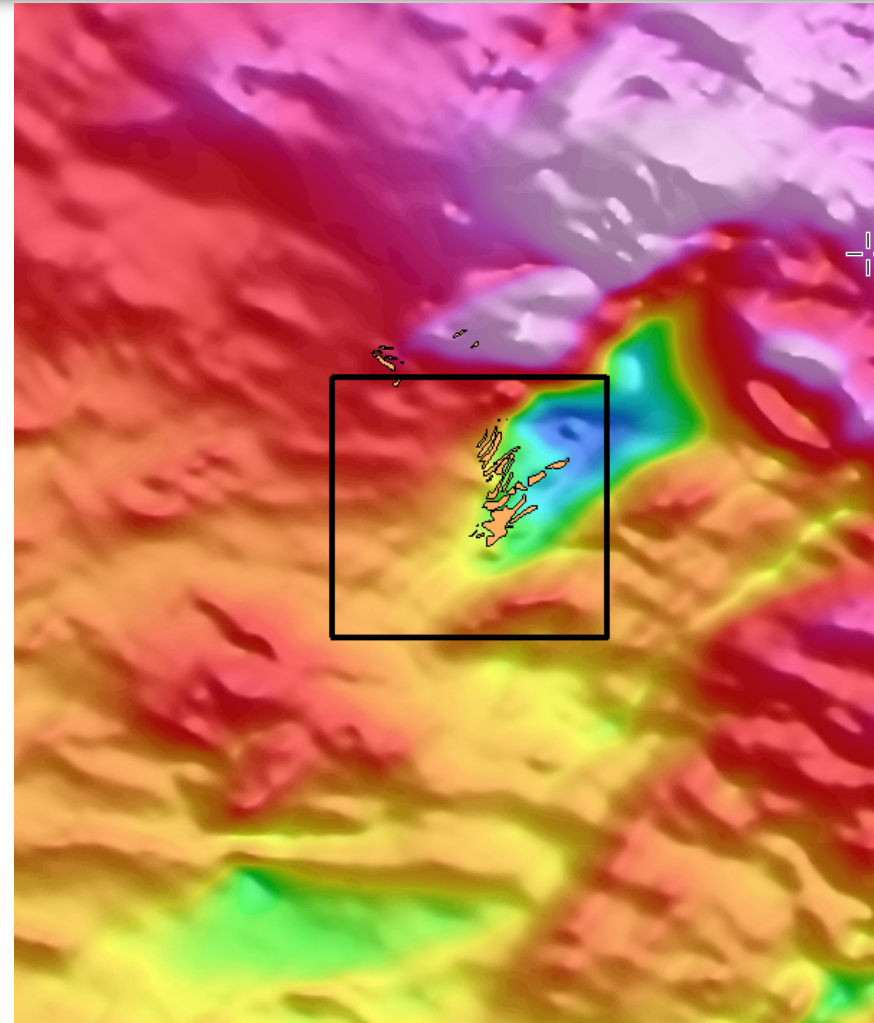
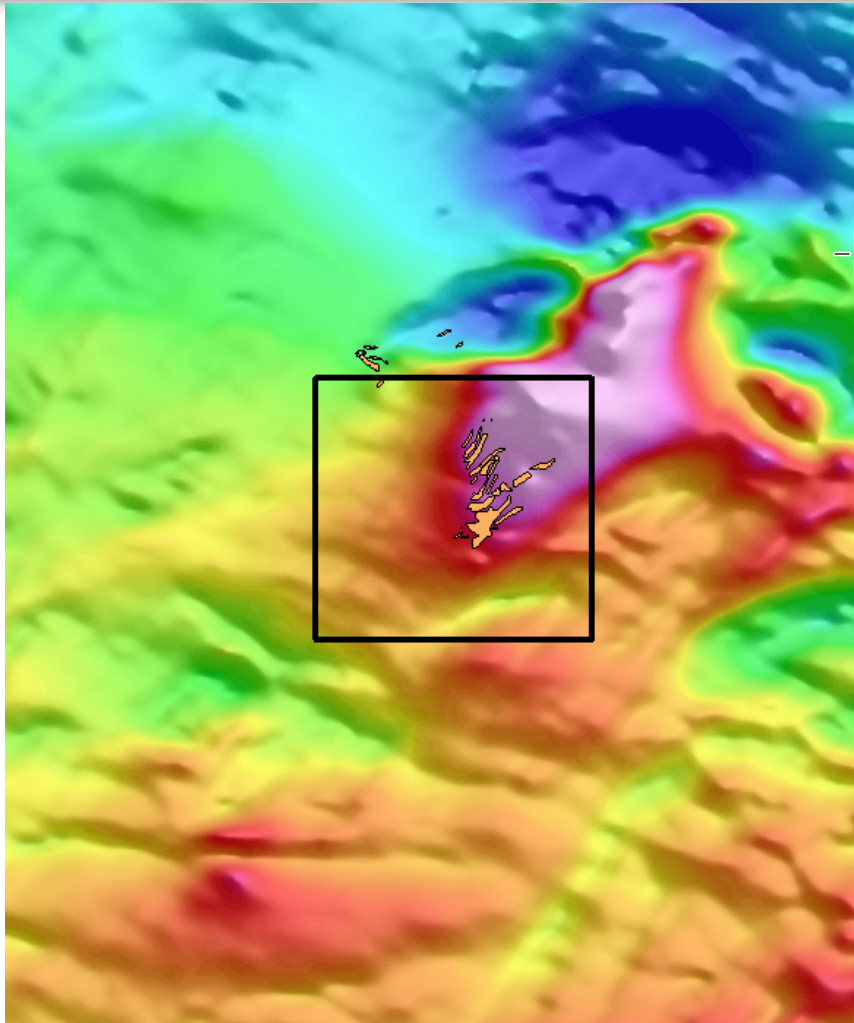
Micro diorite

132m - 133m 2.98g/t Au  
Within 22m @ 5.58g/t Au from 117m



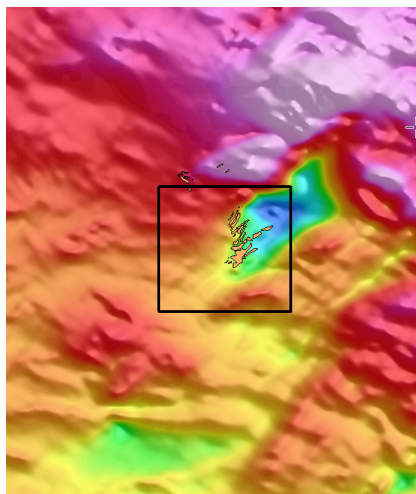
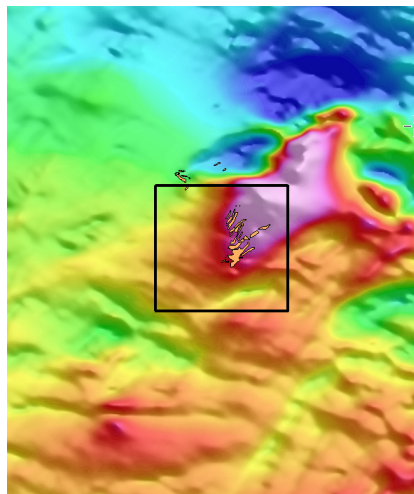
Main mineralisation

# Renaissance – Okvau Airborne Magnetics

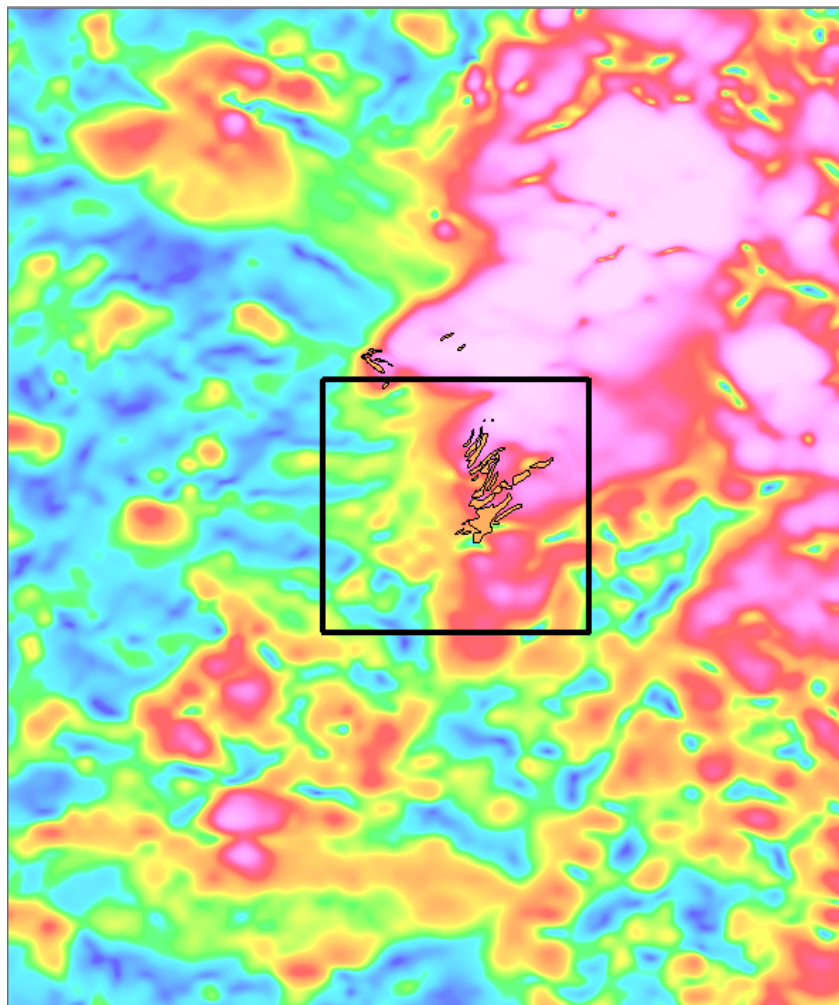


**Airborne Magnetics – Total field (left) and reduced to pole (right) shown with area selected for MVI inversion. Outline of mineralisation shown (500nT range shown on image)**

# Renaissance – Okvau Airborne Magnetics

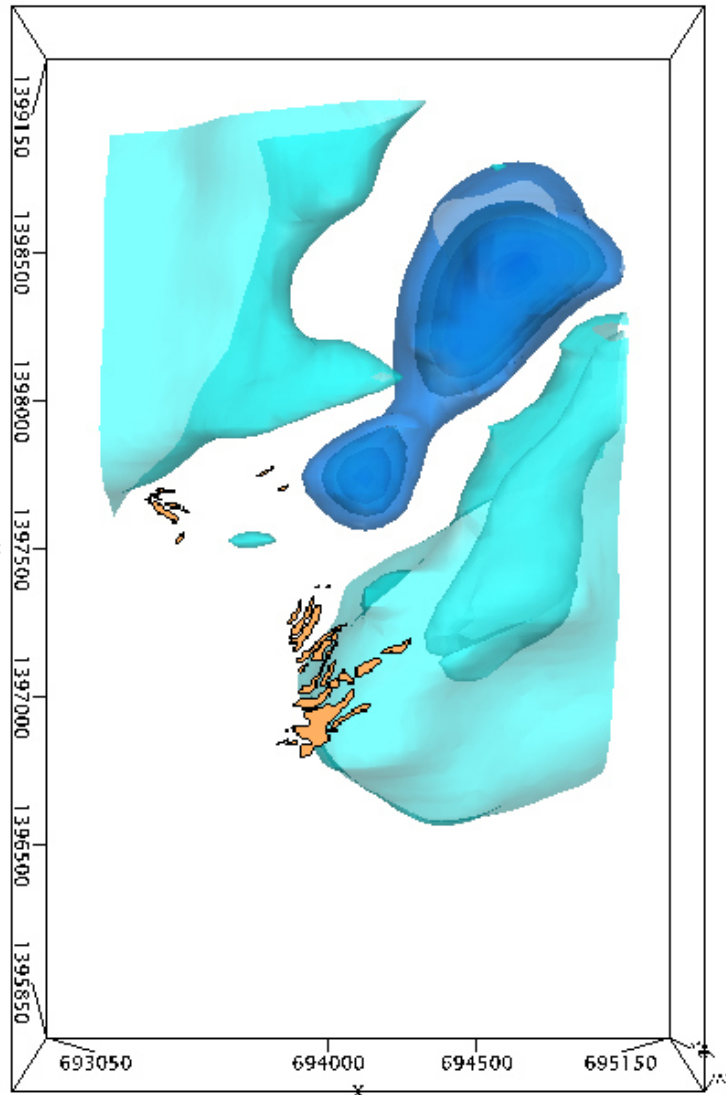


**Airborne Magnetics – Total field (top) and reduced to pole (bottom) shown with area selected for MVI inversion. Outline of mineralisation shown**



**Airborne Magnetics – Analytic signal image shown with area selected for MVI inversion. Analytic signal image suggests the negative feature in the RTP image is remanent part of intrusive**

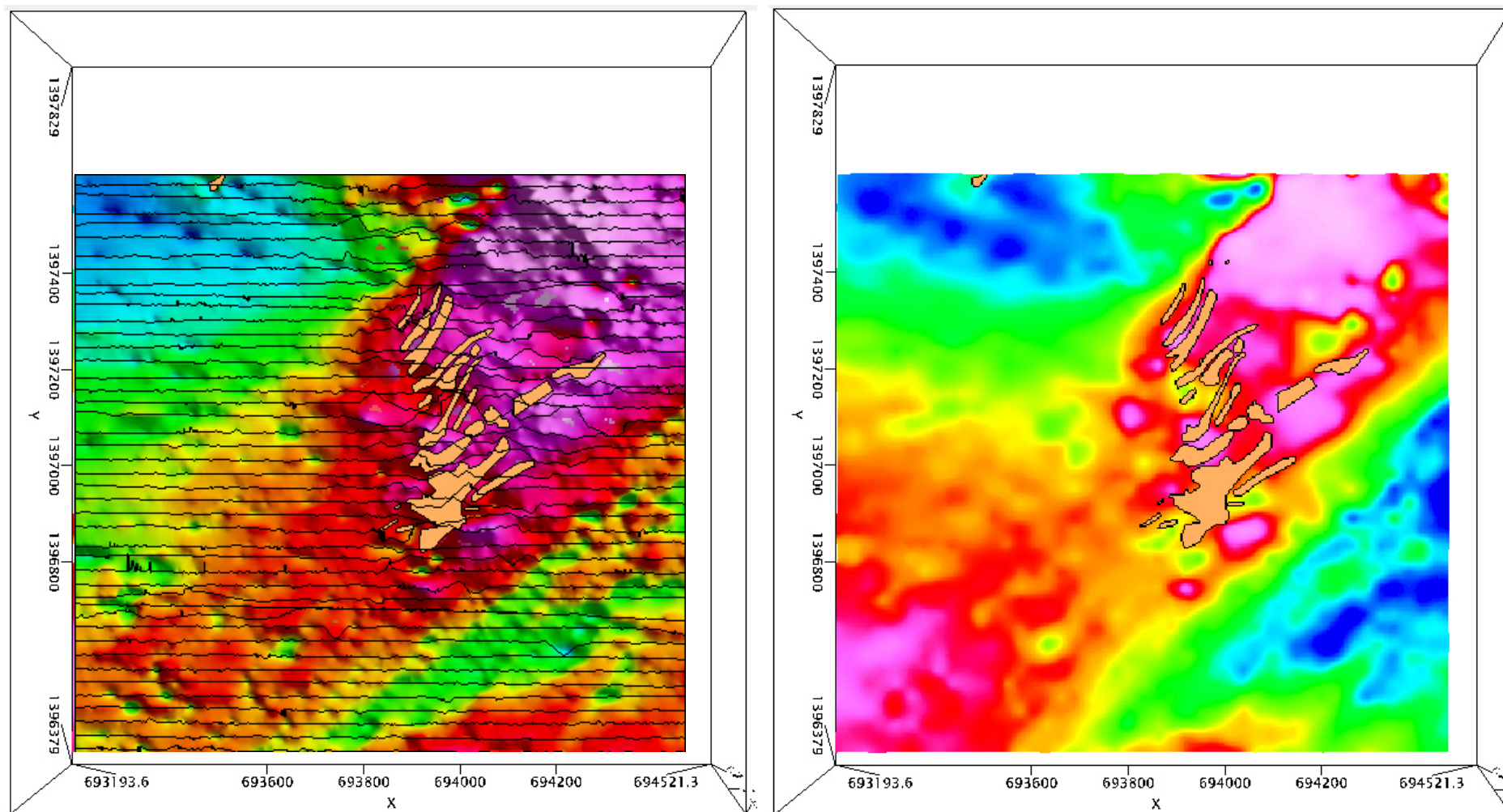
# Renaissance – Okvau Airborne Magnetics



**Magnetics (blue) – Isosurfaces of susceptibility,  $+5 \times 10^{-3} \text{ SI}^*$  in blue**

- Conventional susceptibility model of 50m (25m height) airborne magnetic data showing in blue
- Dark blue positive susceptibility and light blue negative susceptibility. Negative susceptibility used to model magnetic lows in lieu of accounting for remanence.
- It was noted at an early stage that the detailed ground magnetic data was going to be required to model at the deposit scale. Initially it was thought that the 50m airborne data might be adequate.
- Due to the low latitude and low amplitude of magnetic field, magnetic modelling very sensitive to parameter changes

# Renaissance – Okvau Ground Magnetics



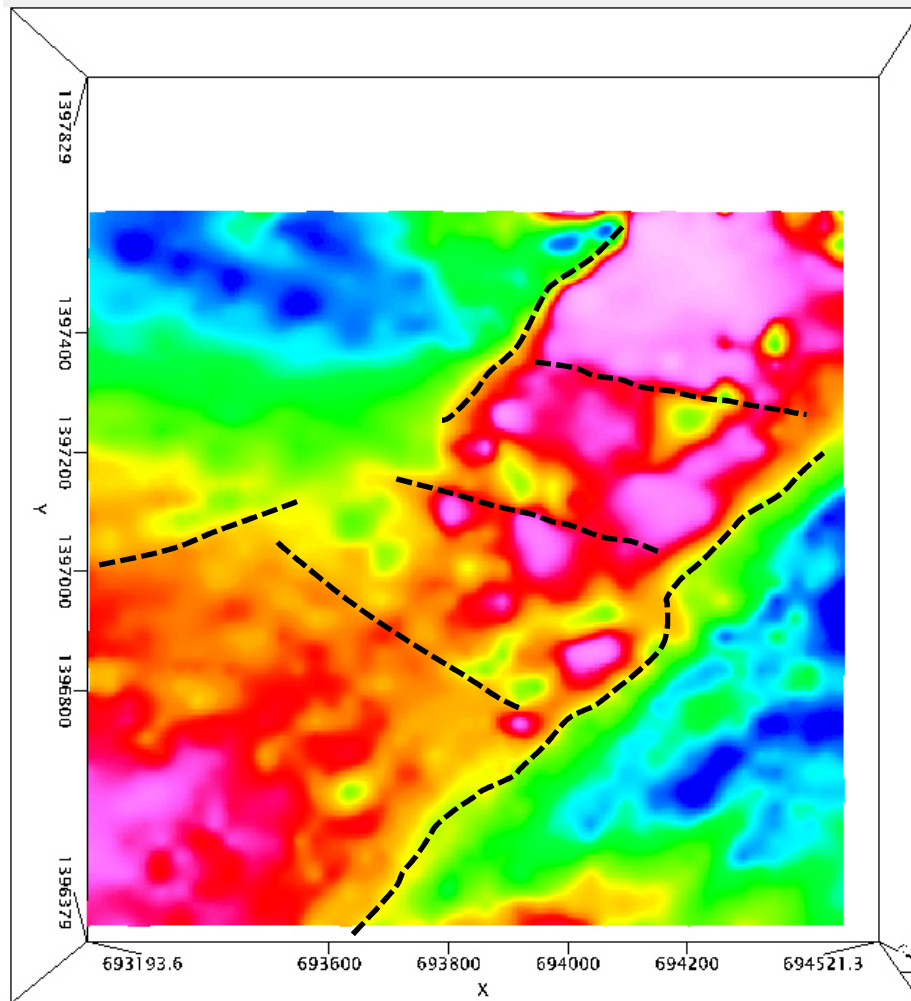
**Residual Magnetics – Total field data used for magnetic inversion from 25m ground data. Mineralisation shown in right image (500nT range in colour)**

# Renaissance – Okvau Magnetic Modelling

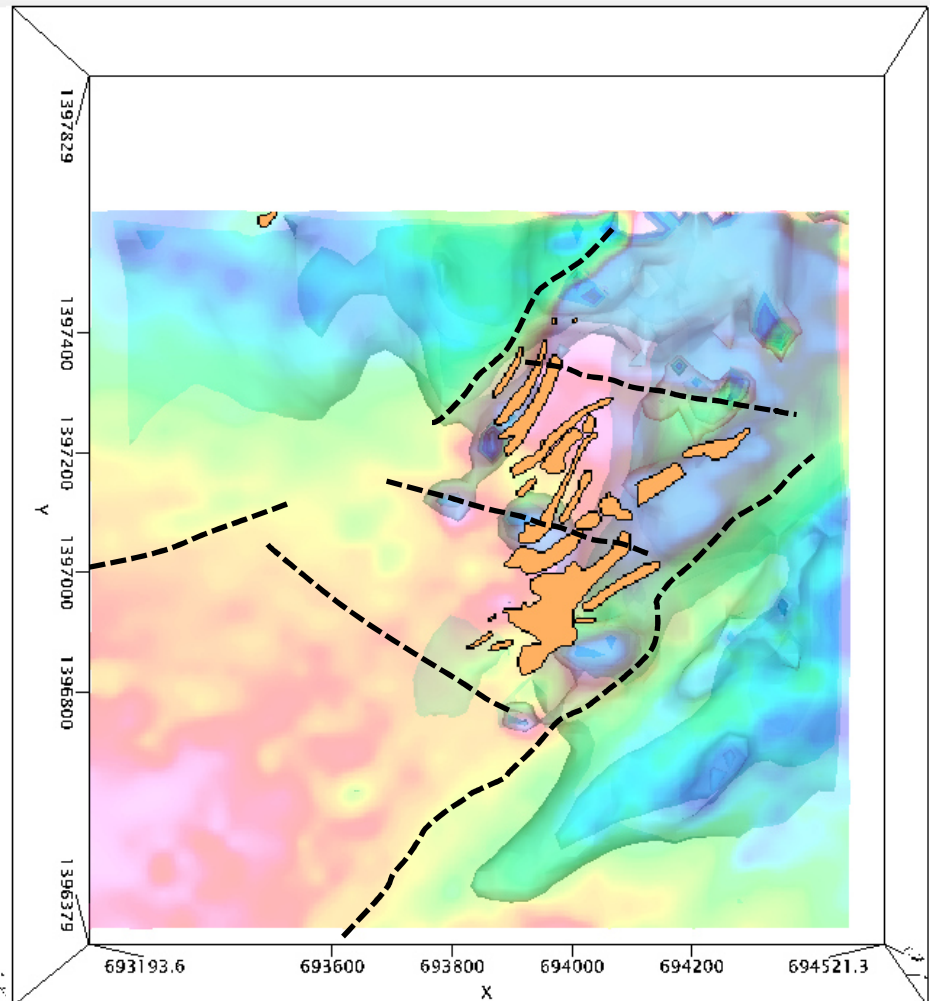


- Detailed magnetic modelling using Magnetic Vector Inversion (Ellis, 2012)
- MVI directly models the vector of magnetization based only on anomalous TMI data
- The method allows the modelling optimization process the freedom to orient the direction of magnetization to best fit the observed data
- Allows the interpreter to model features that may contain combination of remanent magnetization, demagnetization or anisotropy of magnetic minerals
- MVI allows modelling of the different orientation of the magnetic field caused intrusive
- MVI modelling using 25 x 25 x 12.5m voxel, on 25m ground magnetic data

# Renaissance – Okvau Magnetics

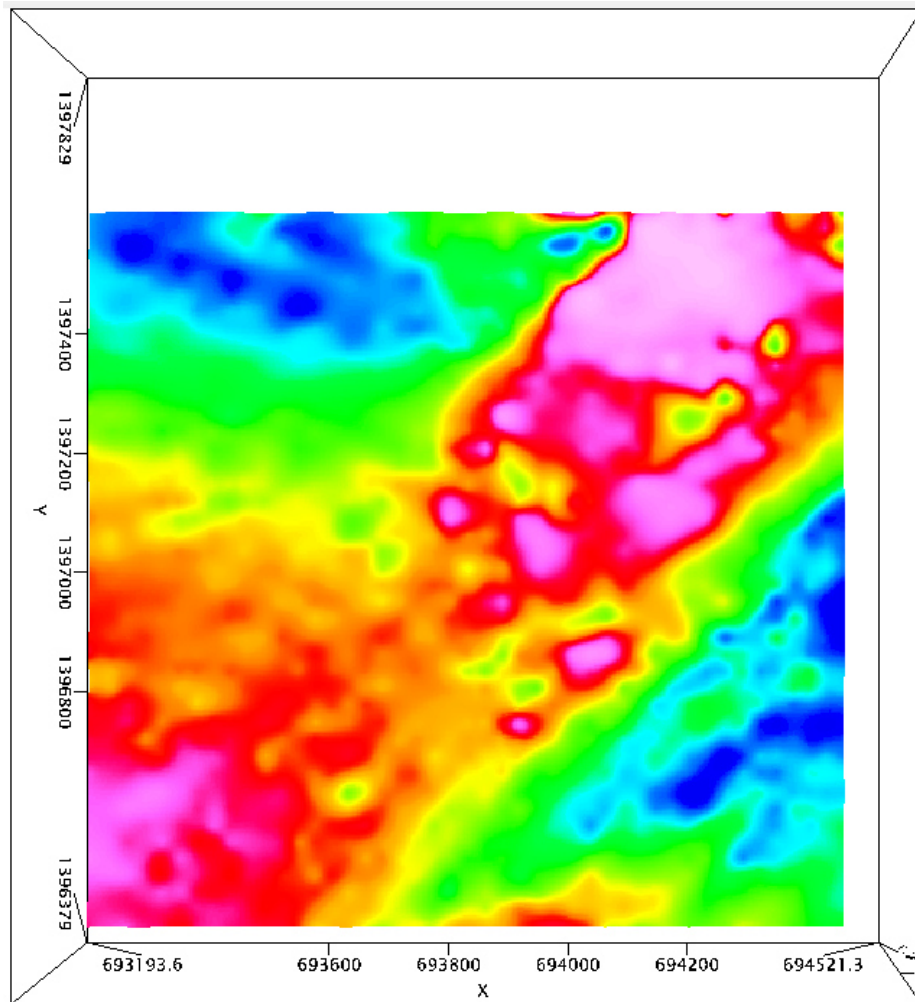


**Residual Magnetics – Total field data used for magnetic inversion from ground data**

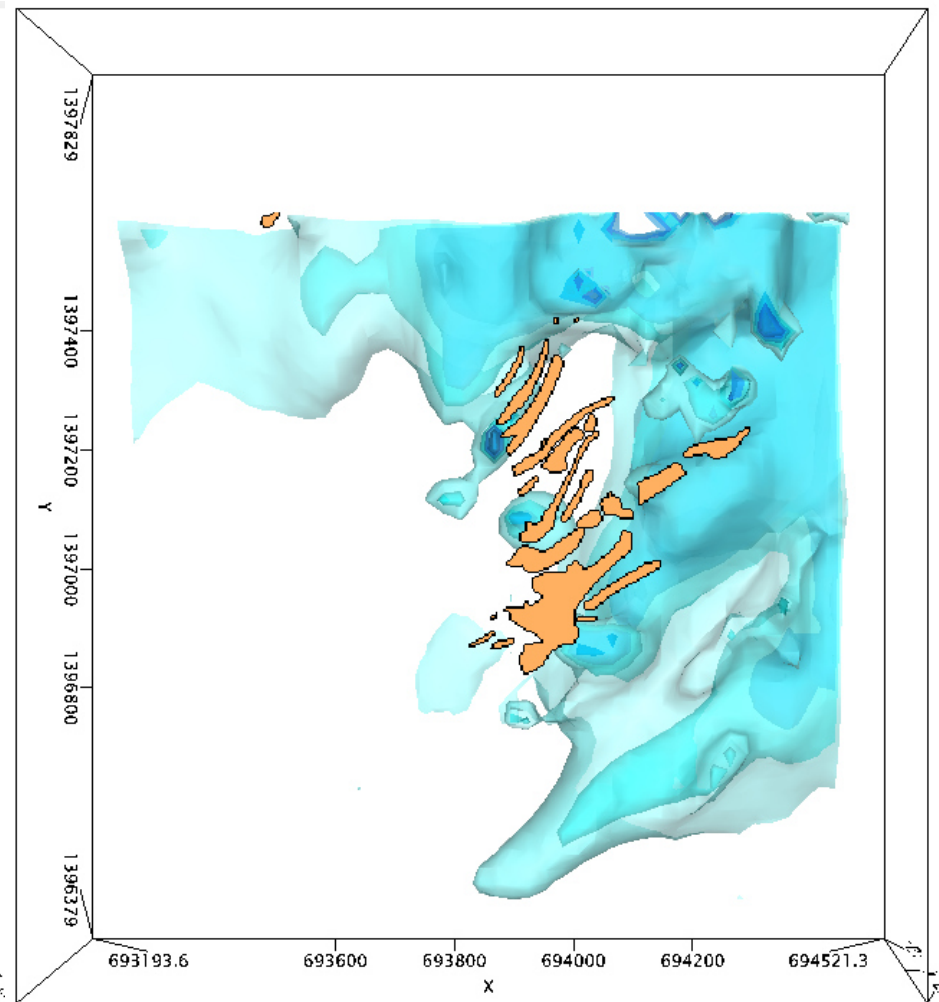


**Total field magnetics with  $+5 \times 10^{-3}$  SI\* isosurface from the 3D MVI inversion in grey underneath.**

# Renaissance – Okvau Magnetics

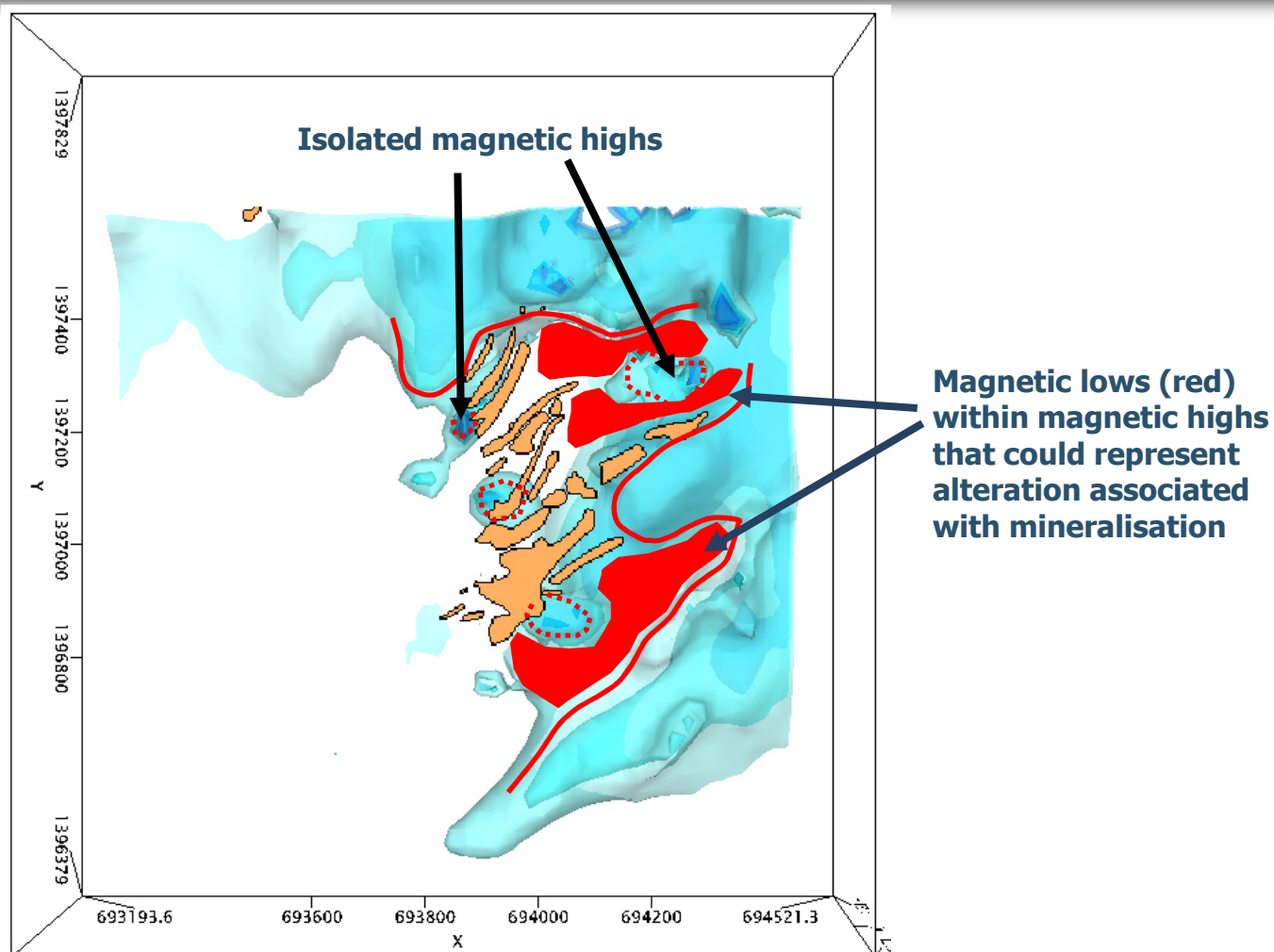


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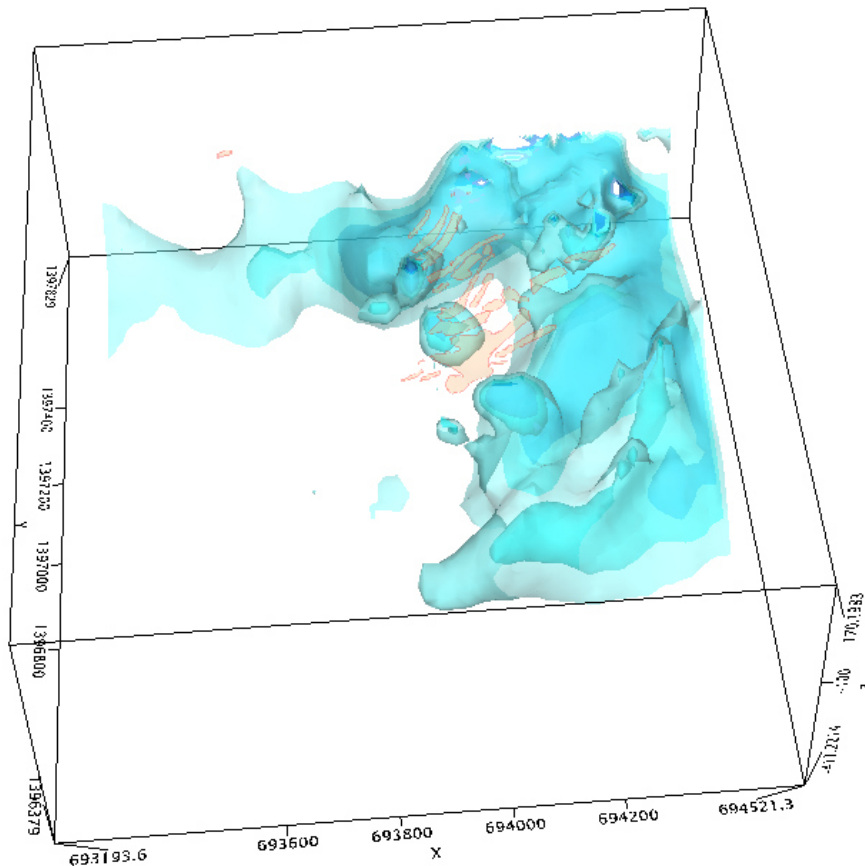
**Total field magnetics with  $+5 \times 10^{-3} \text{ SI}^*$  isosurface from the 3D MVI inversion in grey underneath.**

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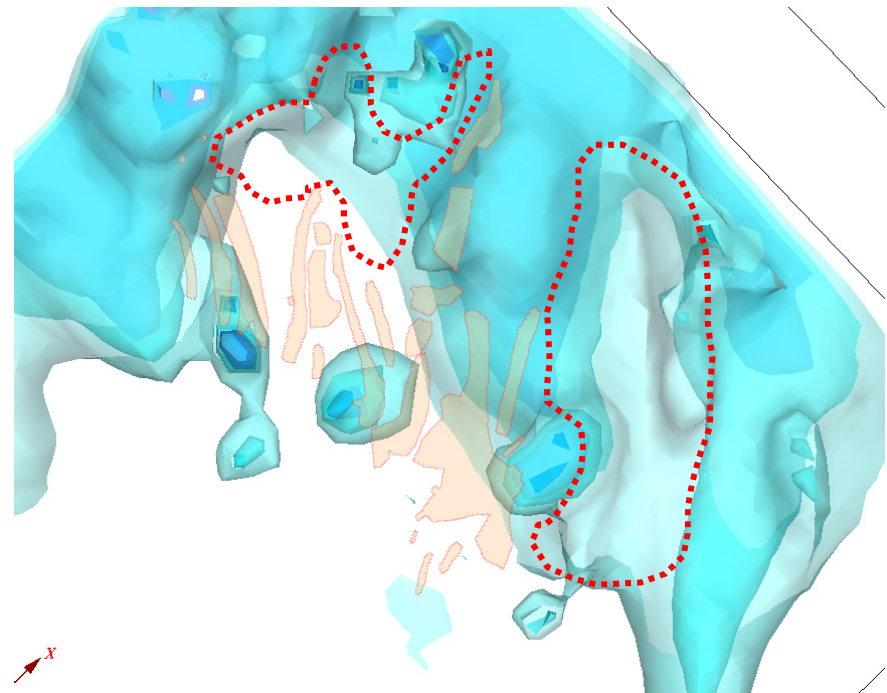


**Magnetics (blue) – Isosurfaces of susceptibility,  $+5 \times 10^{-3} \text{ SI}^*$  in blue.**

# Renaissance – Okvau Magnetics

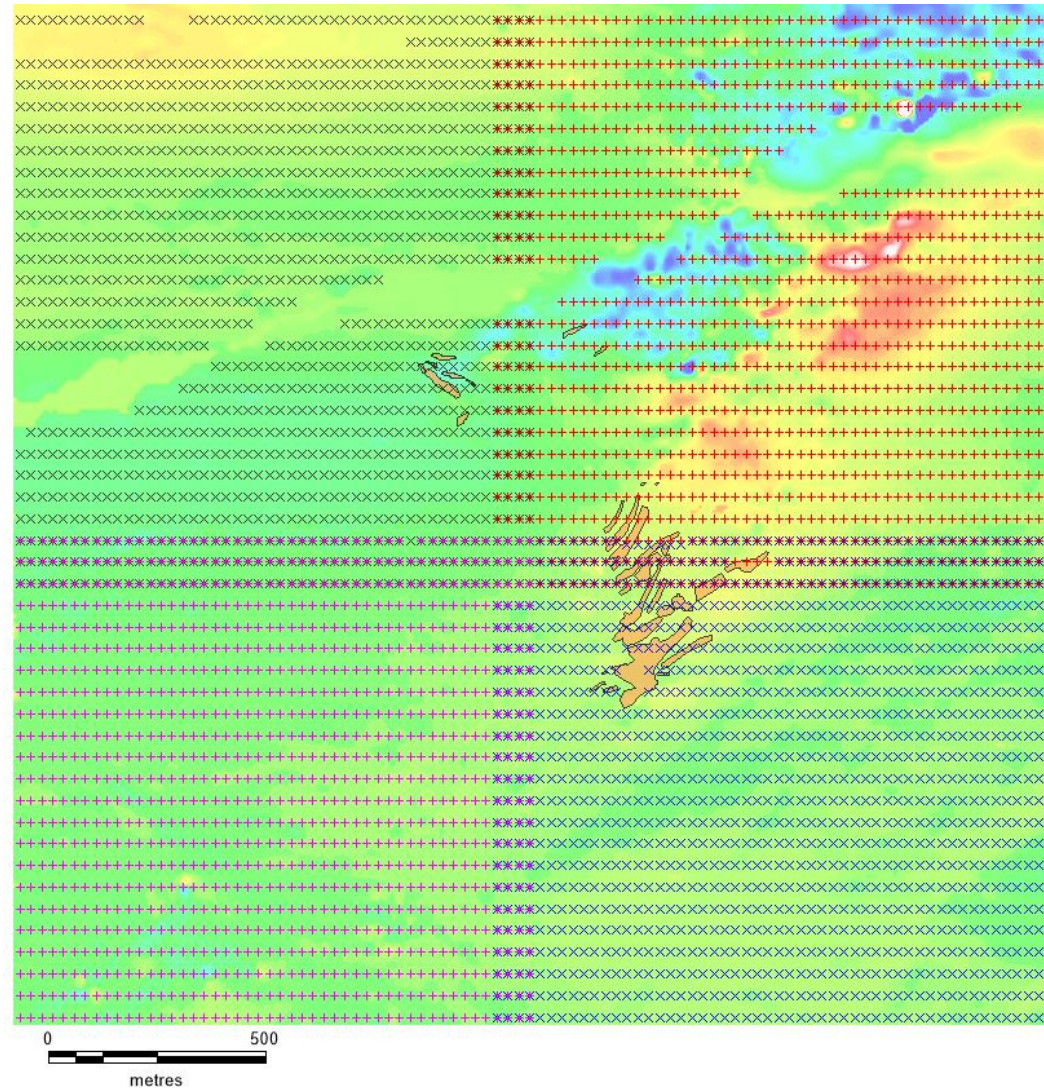


**Magnetics (blue) – Isosurfaces of susceptibility,  $+5 \times 10^{-3} \text{ SI}^*$  in pink.**



**Modeled magnetics with  $+5 \times 10^{-3} \text{ SI}^*$  isosurface from the 3D MVI inversion in blue.**

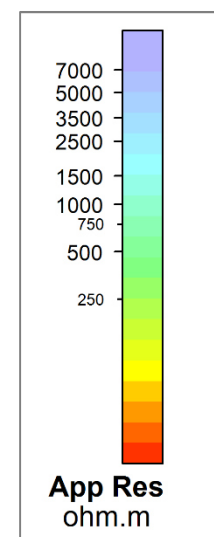
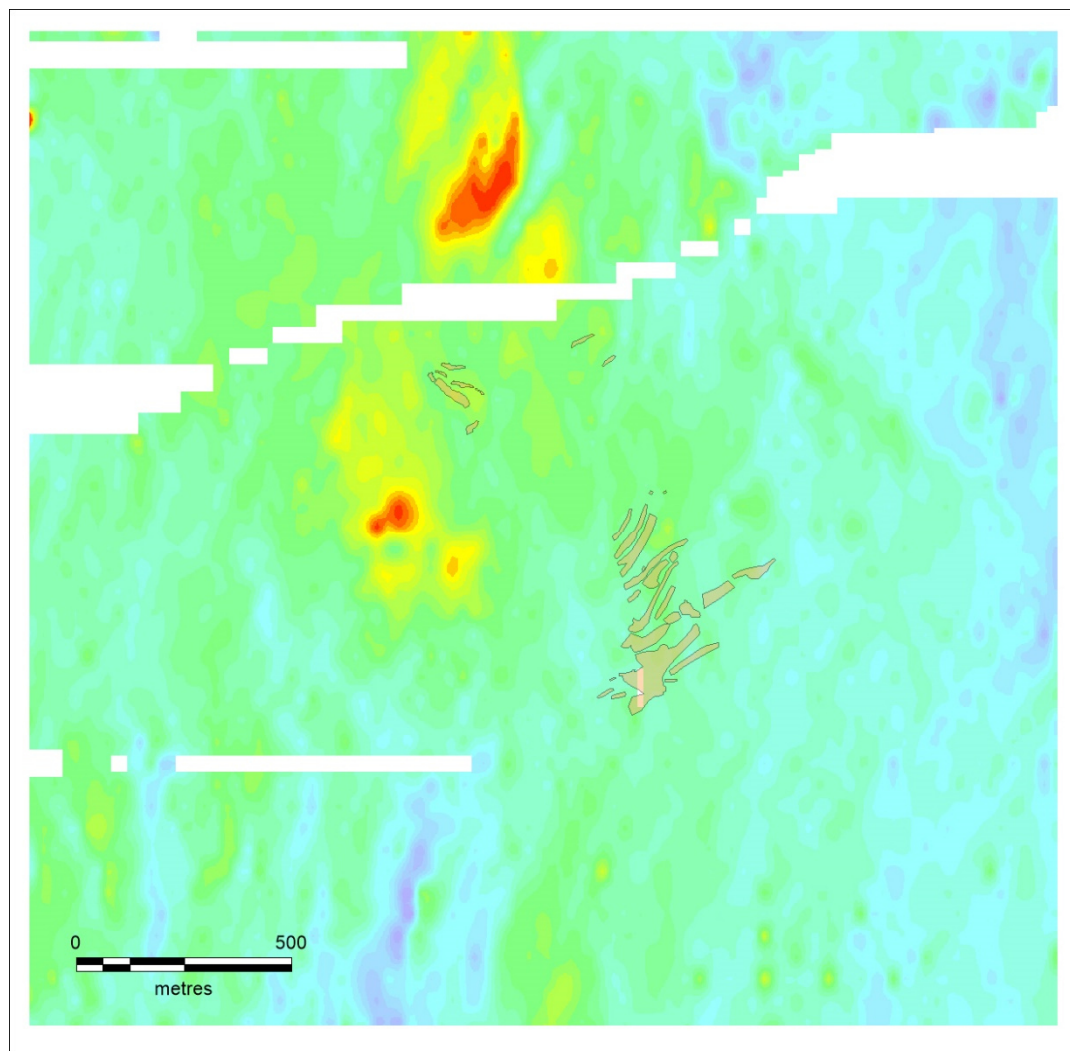
# Okvau – Gradient IP



**2006 gradient IP station locations, shown over TMI magnetics and mineralisation outline.**

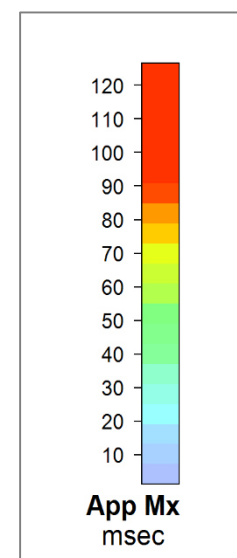
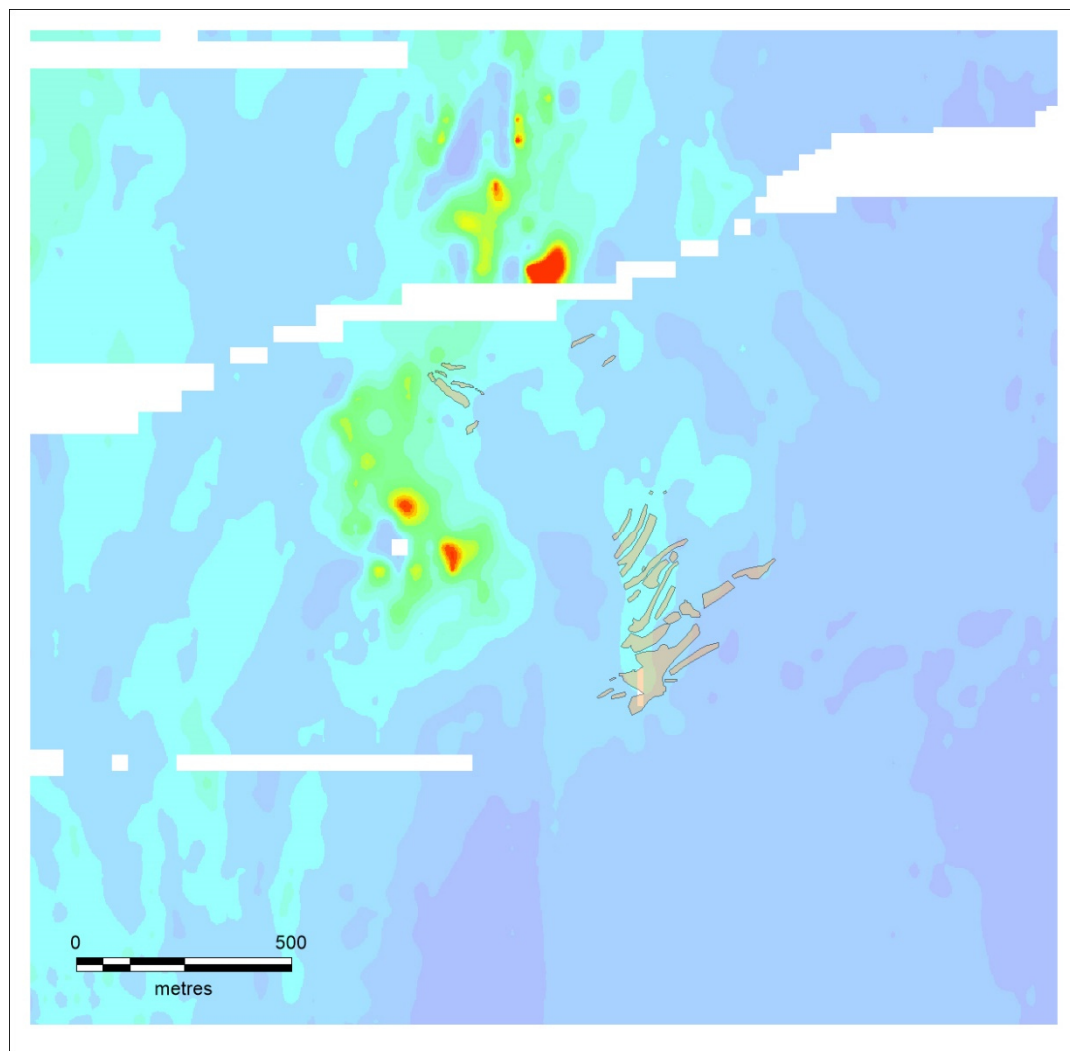
- + Block 1 Station
- x Block 2 Station
- x Block 3 Station
- + Block 4 Station

# Okvau – Gradient IP Data



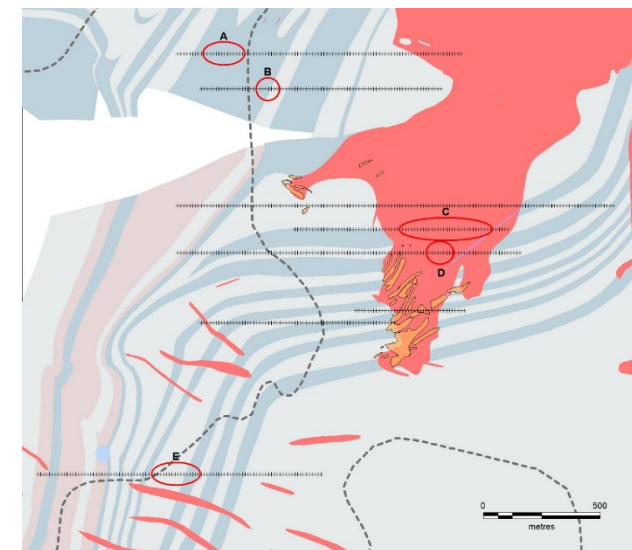
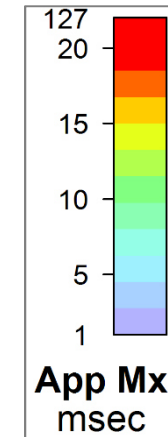
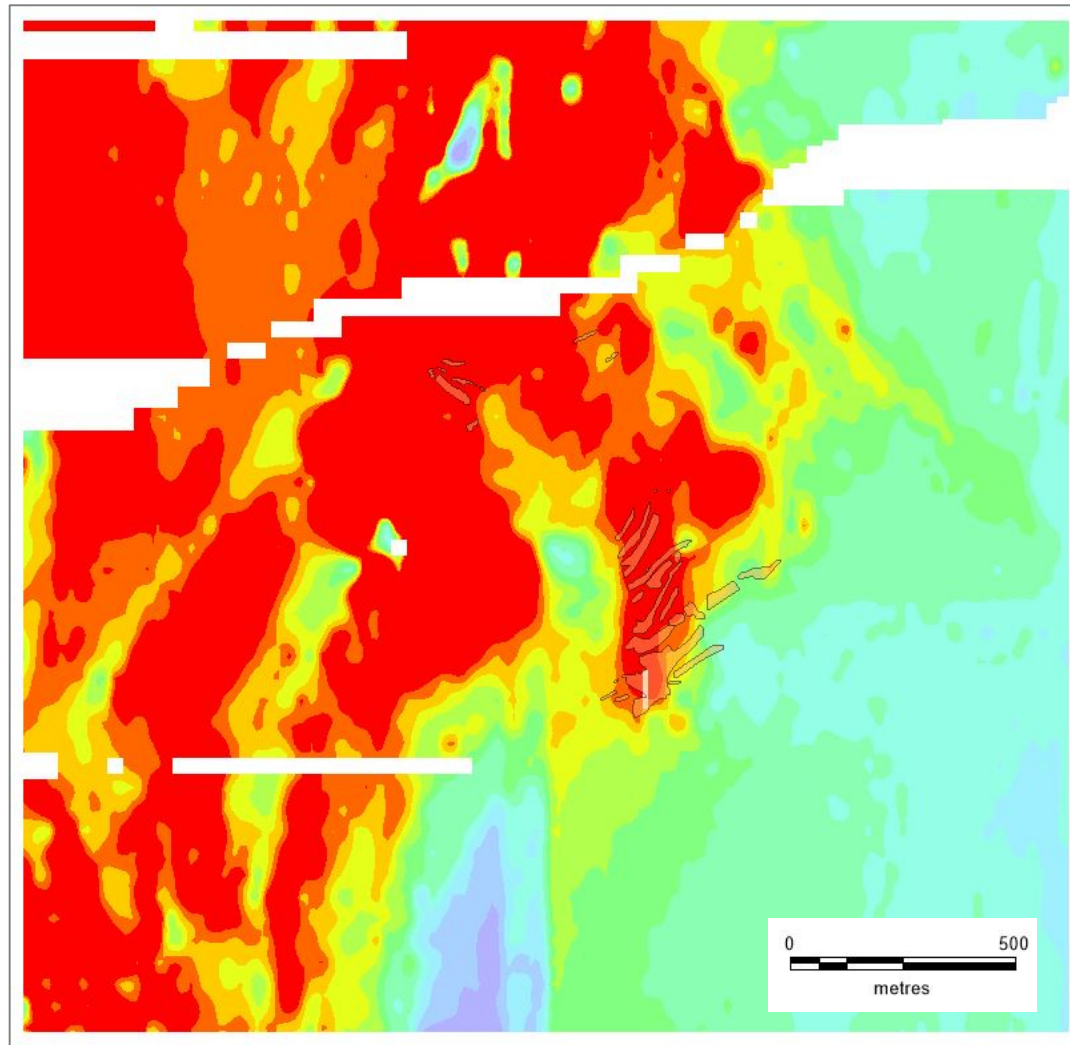
**2006 gradient IP – apparent resistivity.  
Mineralisation outline is overlain.**

# Okvau – Gradient IP Data



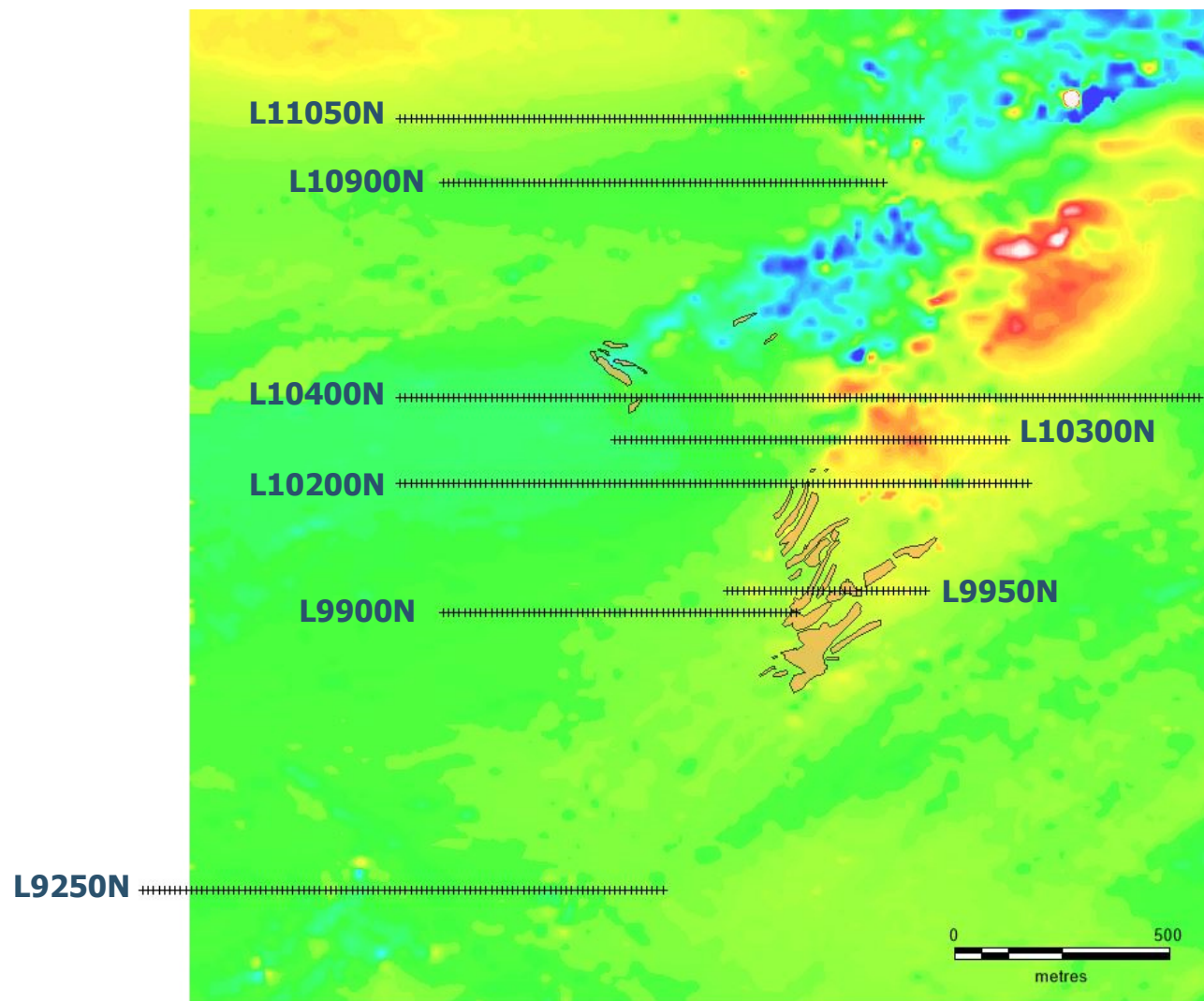
**2006 gradient IP – apparent chargeability.  
Mineralisation outline is overlain.**

# Okvau – Gradient IP Data



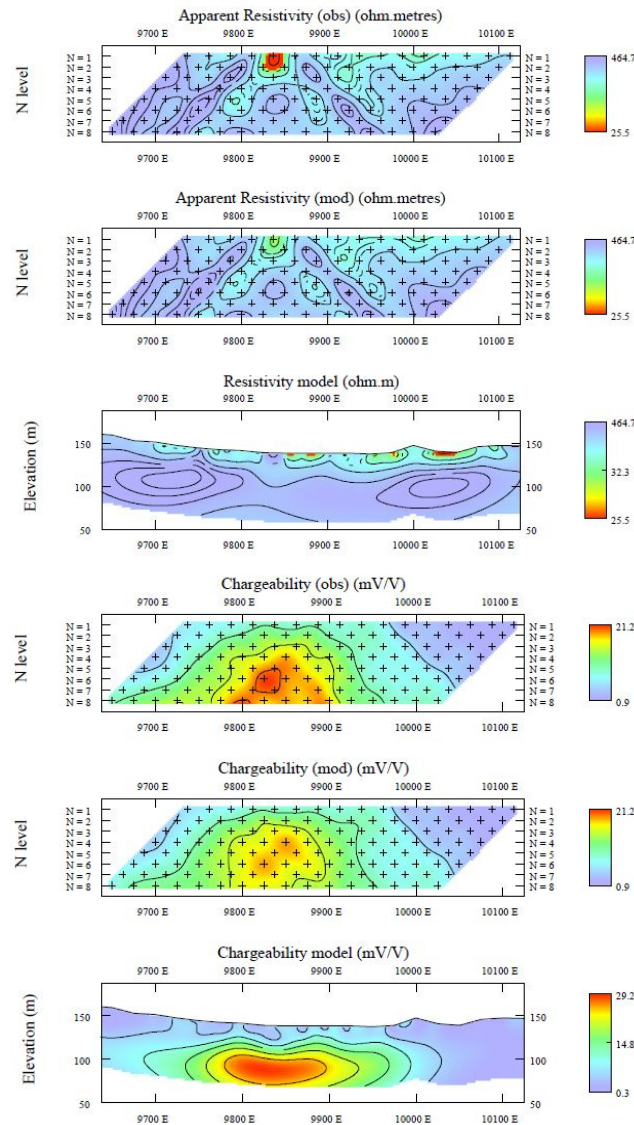
**2006 gradient IP – apparent chargeability.  
Mineralisation outline is overlain.**

# Okvau – Dipole-Dipole IP

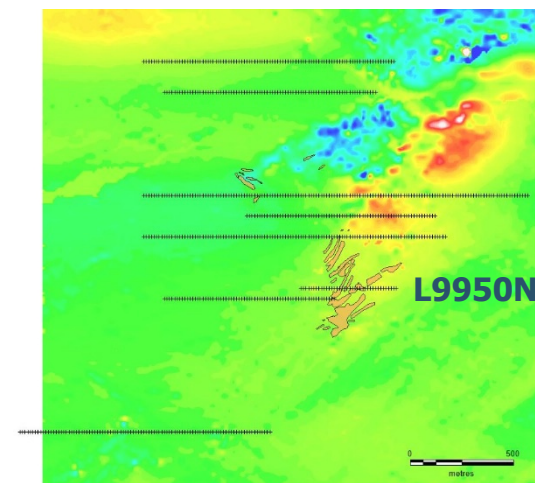


**2007 100m dipole-dipole IP lines, shown over TMI magnetics and mineralisation outline.**

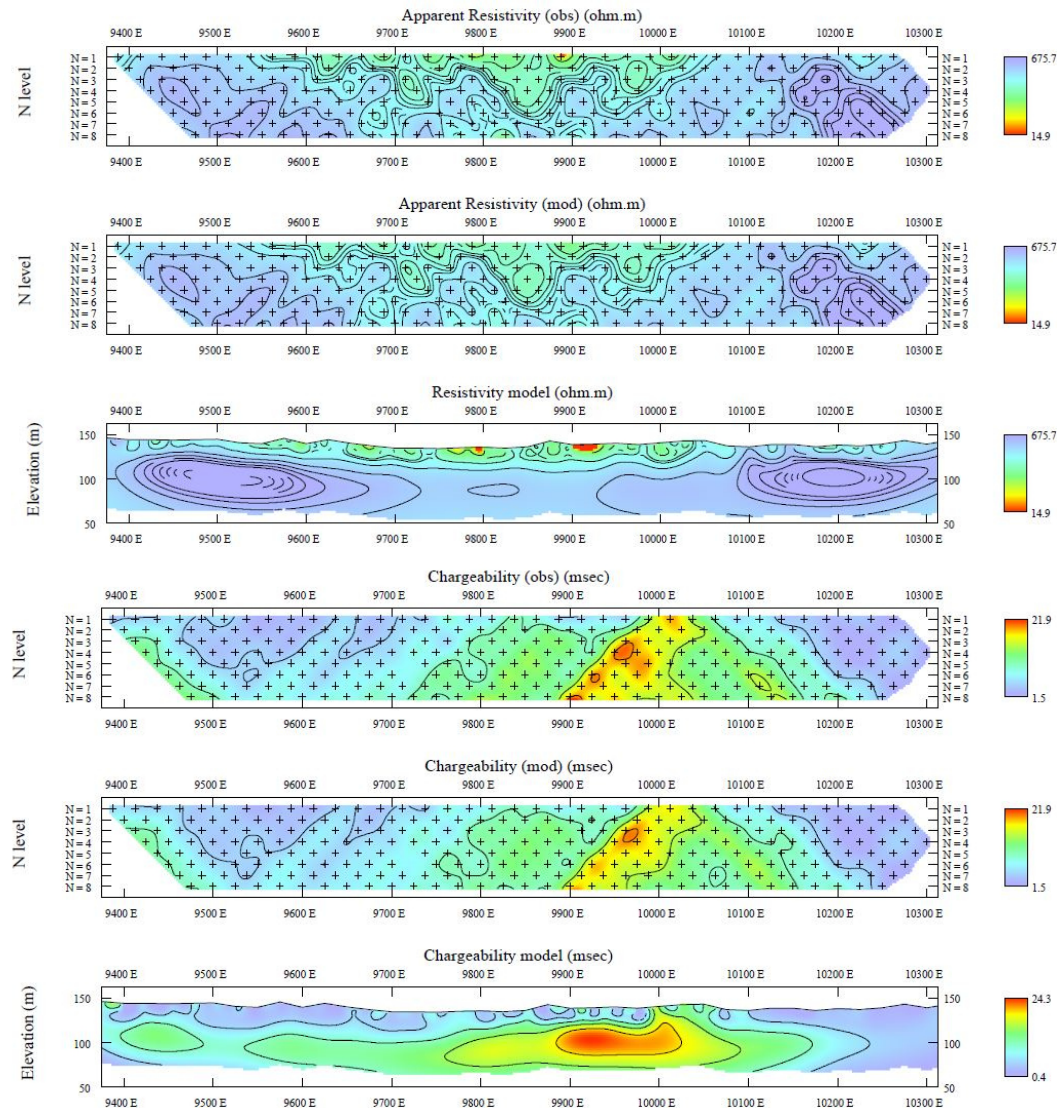
# Okvau – Dipole-Dipole IP Modelling



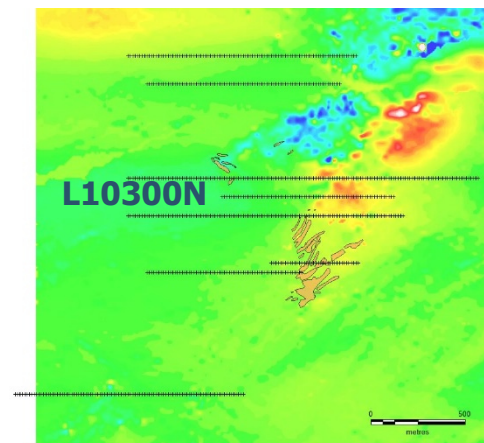
**L9950N modelling results.**



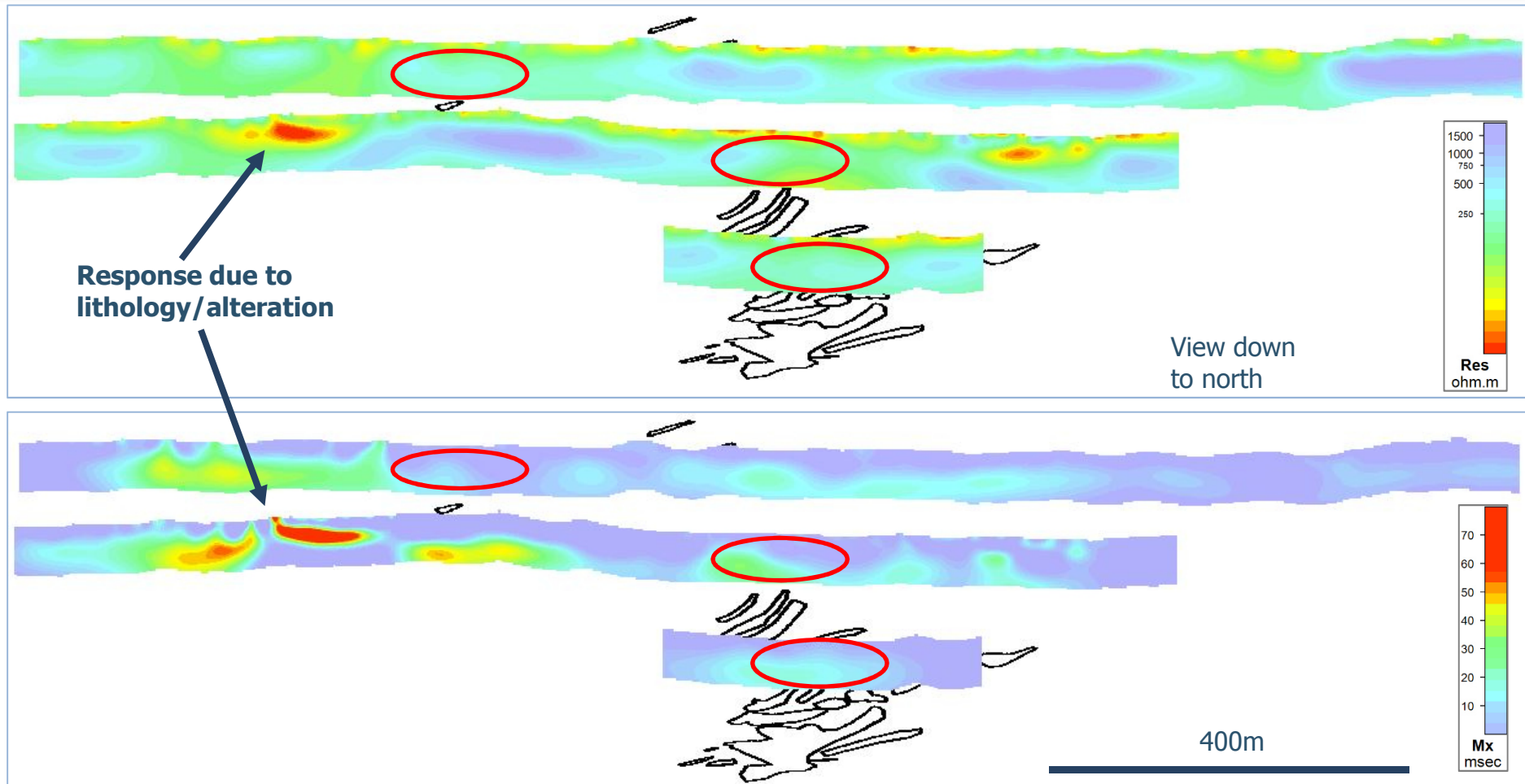
# Okvau – Dipole-Dipole IP Modelling



**L10300N modelling results.**

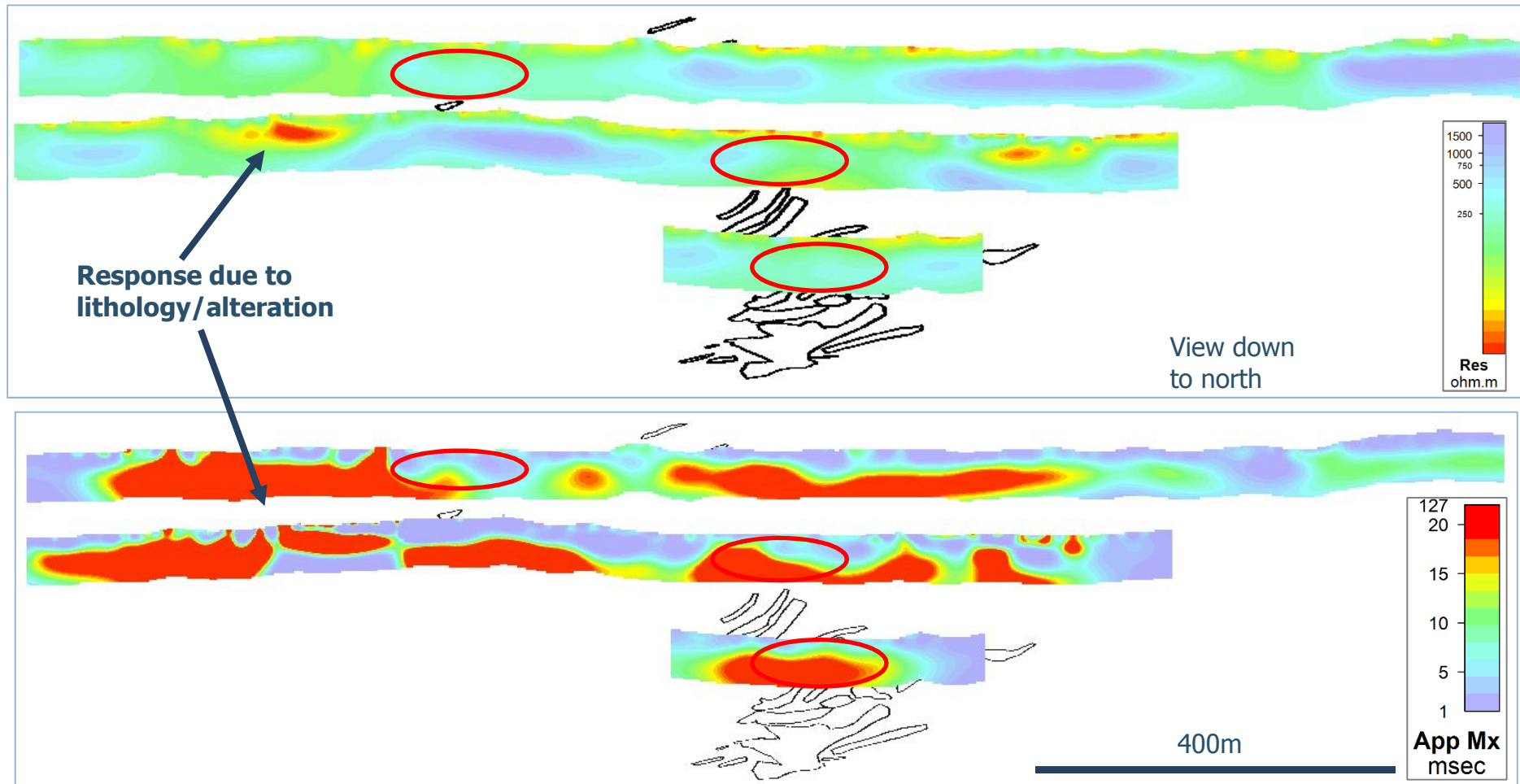


# Okvau – IP Mineralisation Signature



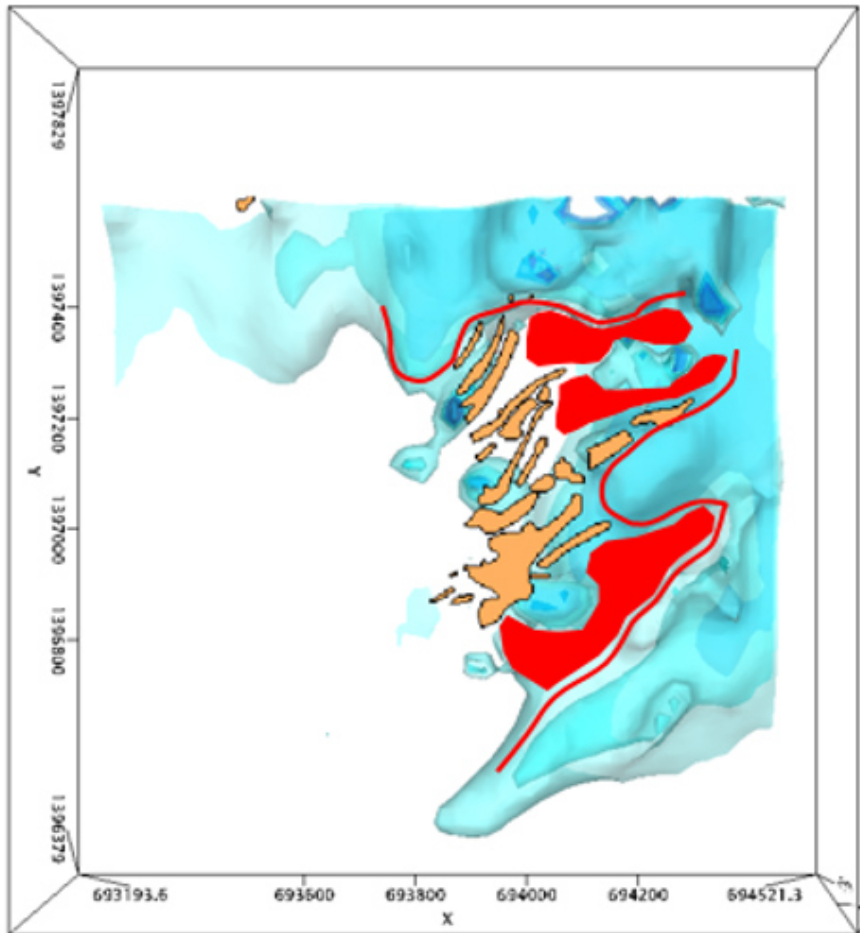
Resistivity (top) and chargeability (bottom) with areas of known mineralisation (red).

# Okvau – IP Mineralisation Signature

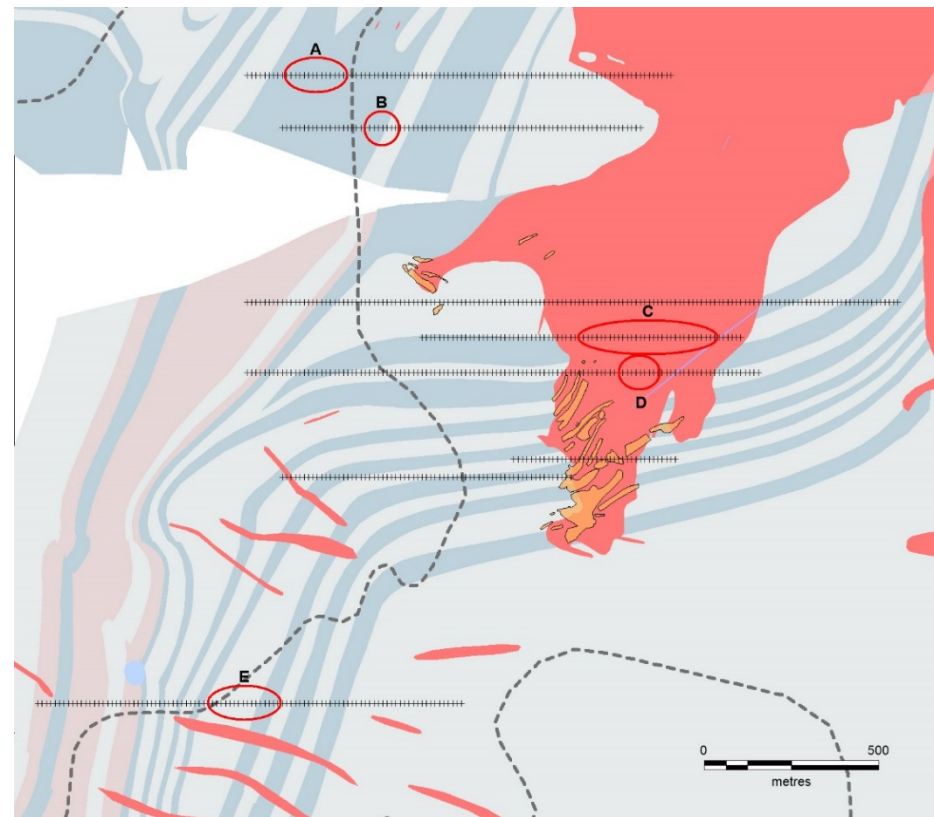


Resistivity (top) and chargeability (bottom) with areas of known mineralisation (red).

# Okvau – Exploration Targets



**Final targets shown over TMI magnetics (top) and interpreted geology (bottom).**



# Conclusions



- Approximately 35 out of 463 gold deposits greater than 3Moz are considered to be in the intrusion related clan. Of those, roughly 10 are greater than 10Moz. The majority of those ounces are within the sediments surrounding intrusions eg Murantau, Telfer
- They occur in tectonic settings well inboard of inferred or recognised convergent plate boundaries (typically continental crust)
- The IR reduced clan can be moderately reduced (non magnetic) or weakly oxidised (magnetic - but significantly less oxidised than intrusions related to gold rich porphyries)
- At regional scale these deposits are best known for tungsten and/ or tin deposits. Reduced ore mineral assemblage that typically comprises arsenopyrite, pyrrhotite and pyrite and lacks magnetite or hematite.

# Conclusions (cont)



- The aeromagnetic data shows remanent magnetisation coincident with the intrusive trend at Donlin Creek and Okval (age dependent). The Dolin Creek and Okval regions also have normally magnetised intrusives in close proximity to mineralisation.
- Magnetic susceptibilities measured are typically very low (1 to 40 SI) and explain the very subtle magnetic features. Alteration associated with mineralisation is magnetite destructive (for weakly oxidised hosts).
- Mineralisation is shown to have high chargeabilities and the IP method has proven to be an effective exploration targeting tool within intrusive bodies. Surrounding sediments can have high to moderate chargeabilities (+10msec) so some awareness required when targeting IP features in the IR environment.
- The resistivity maps the variation in shale content in sediments and alteration around intrusive centres. The dominant resistivity response is in the overburden (weathering/transported fill)
- Ground magnetic data is more effective in mapping alteration associated with IR mineralisation at Okval. Targets have been generated from IP and magnetics using signatures of areas of known mineralisation.



# The Geophysical Response of Intrusion Related Gold with an Example from Okvau, Cambodia

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12<sup>th</sup> August 2015

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