GEOLOGY OF THE KULUMADAU INTERMEDIATE SULFIDATION EPITHERMAL DEPOSIT, WOODLARK ISLAND, PAPUA NEW GUINEA

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Thank you!!

- All the staff at Kula Gold for their continued support
- Huge thank you to AIG and SMEDG for their generous support

Volcanic successions short course – Ray Cas Nov 2012. Peperitic contact at Cryptodome Cove, South Coast, NSW

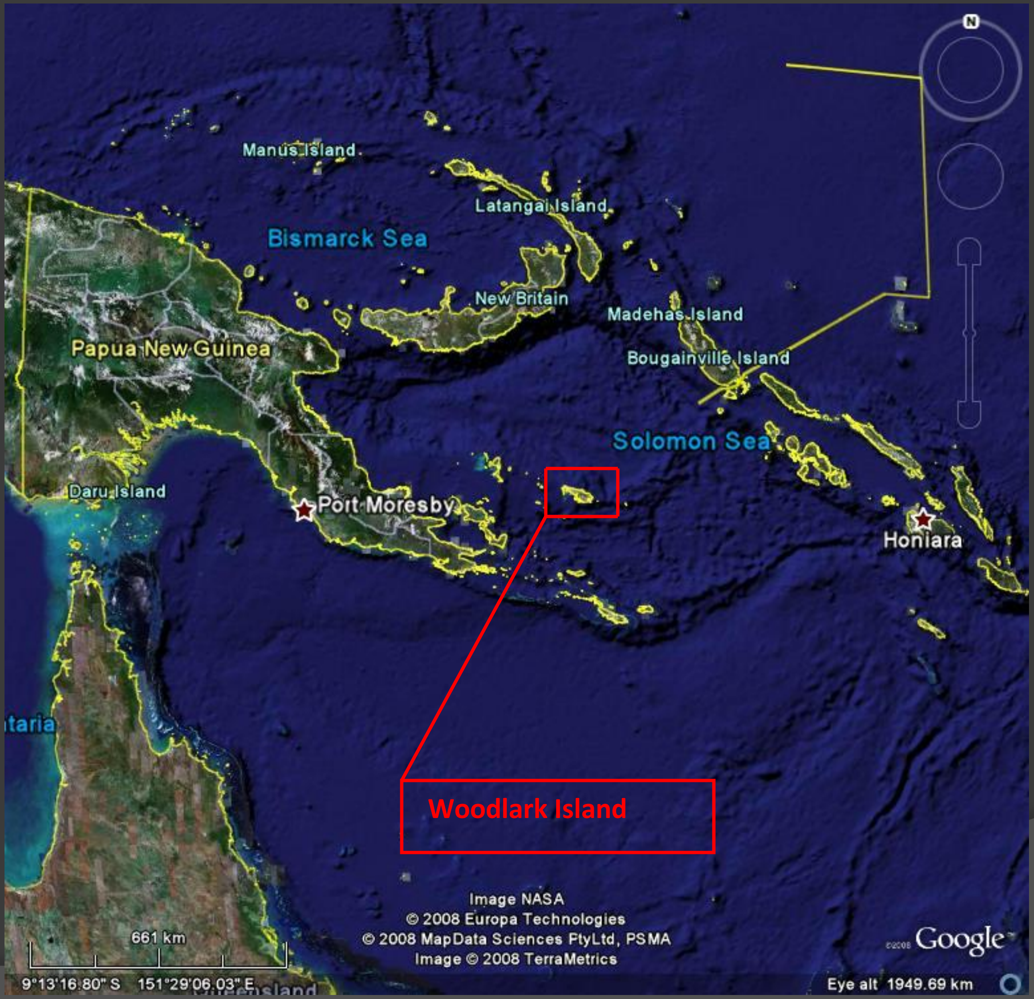
Road Map

- Location and history of Woodlark Island
- Regional Geology
- Mineralisation Styles at Kulumadau
- Local structures
- Stratigraphy
- Chemostratigraphy
- Alteration and relationship with Au-BMS
- Revised structural model

Introduction and Location

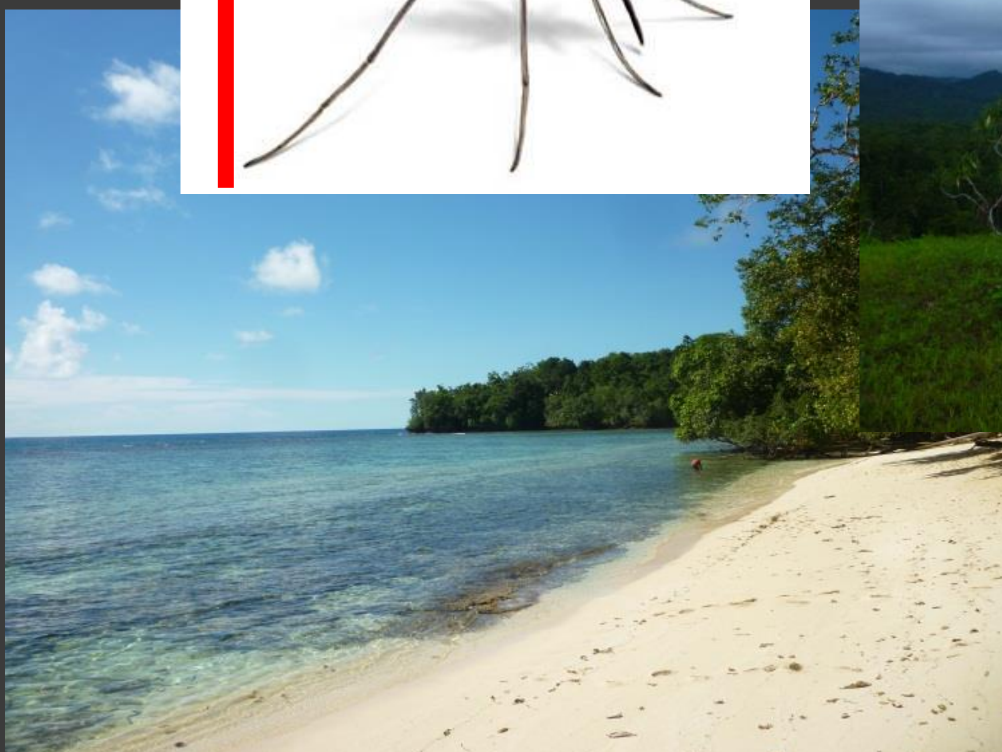
Location

~ 650 km east of Port Moresby



Woodlark Island

1 m



Woodlark Island on a good day

… 20 minutes later

Climate

Over 5 metres of rain annually

Summer – up to 40C

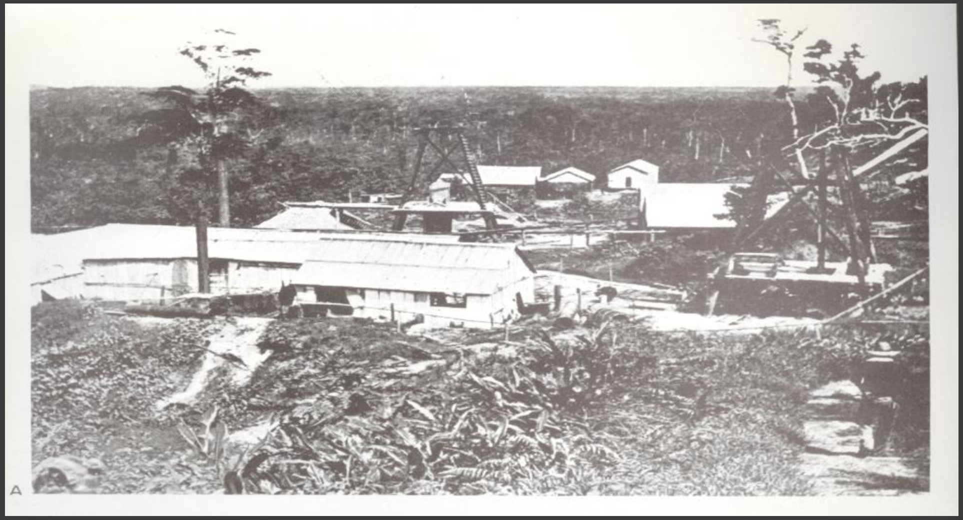
Winter – averaging 30 C

Moderately dense tropical jungle

Rapid vegetation growth

History of Woodlark Island

- Alluvial gold first discovered on Woodlark in 1894, hard rock mining commenced in 1899
- By 1910, contributed over 43 % of all gold mined in PNG
- Historic production of 220,000 oz Au



Kulumadau Mine 1912

Kulumadau History

- Kulumadau mine 80 000 oz @ 16 g/T Au
- Currently in the advanced stages of exploration
- First continuous hardrock gold mine in Papua
- First mine in Papua to pay dividends
- Deepest mine in Papua until 1922
- Recently little to no detailed research by universities or industry

Visible gold 04BKD003 – 282 m

Kulumadau in operation

Previous Work

Stanley 1912. Report on the geology of Woodlark Island. Government Printer, Port Moresby.

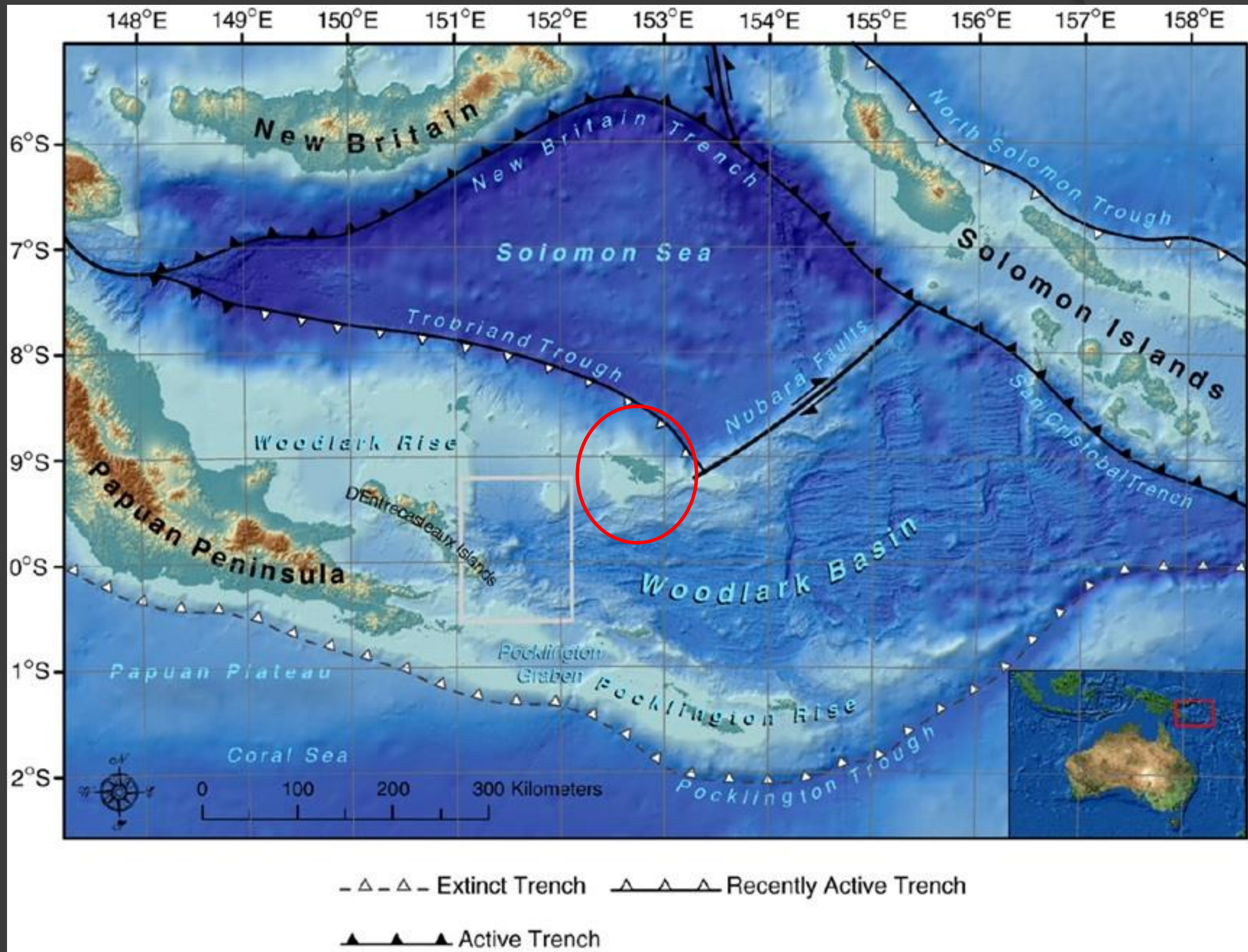
Trail 1967. Geology of Woodlark Island, Papua New Guinea. Australian Bureau of Mineral Resources Report 117.

McGee 1978. Contributions to the geology of Woodlark Island. Geological Survey of Papua New Guinea Report 78/10.

Ashley and Flood 1981. Low-K tholeiites and high-K igneous rocks from Woodlark Island, Papua New Guinea. Journal of the Geological Society of Australia 28: 227-240.

Williamson 1984. Gold mineralisation on Woodlark Island, Milne Bay Province. Geological Survey of Papua New Guinea Report 84/10.

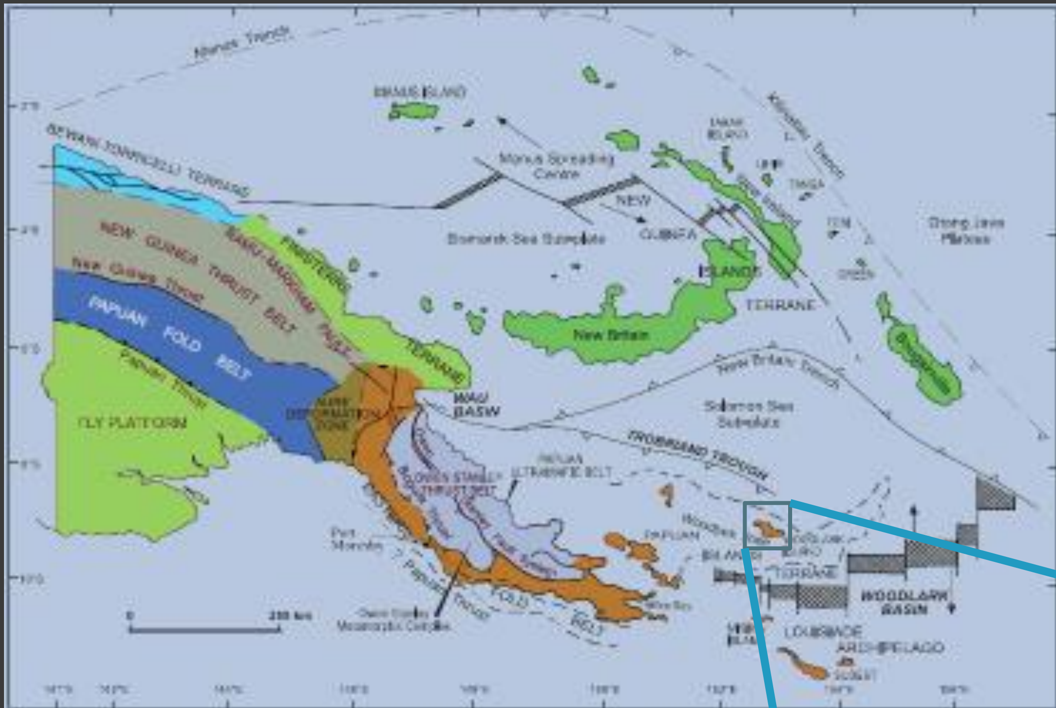
Regional Geology

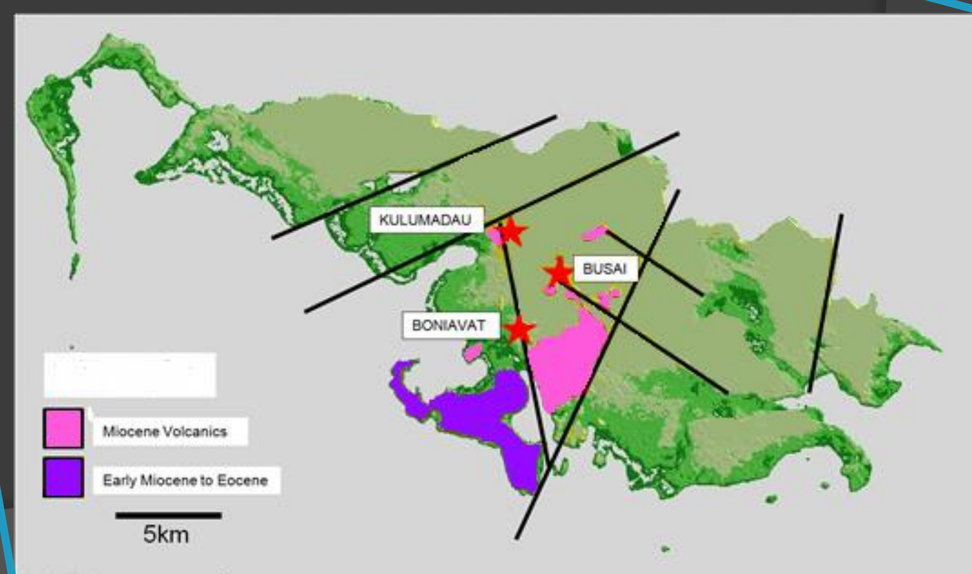


Volcanism is related to opening of Woodlark basin (Ashley and Flood 1981)

(Kington and Goodliffe 2008)

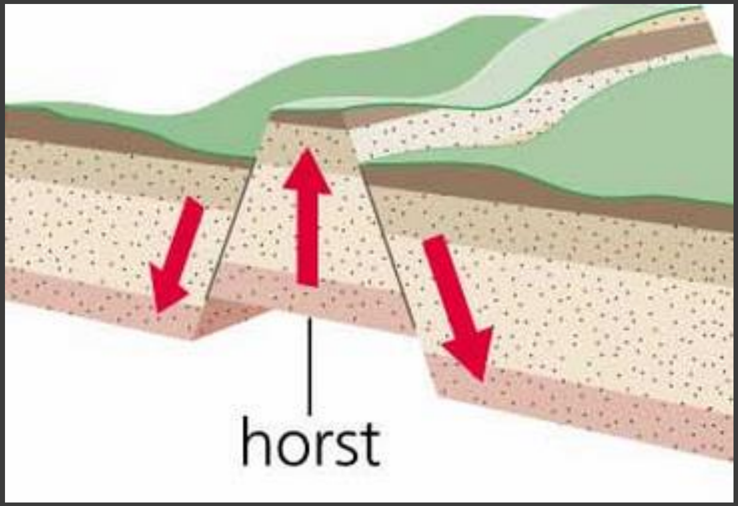
Woodlark Island – Regional Geology



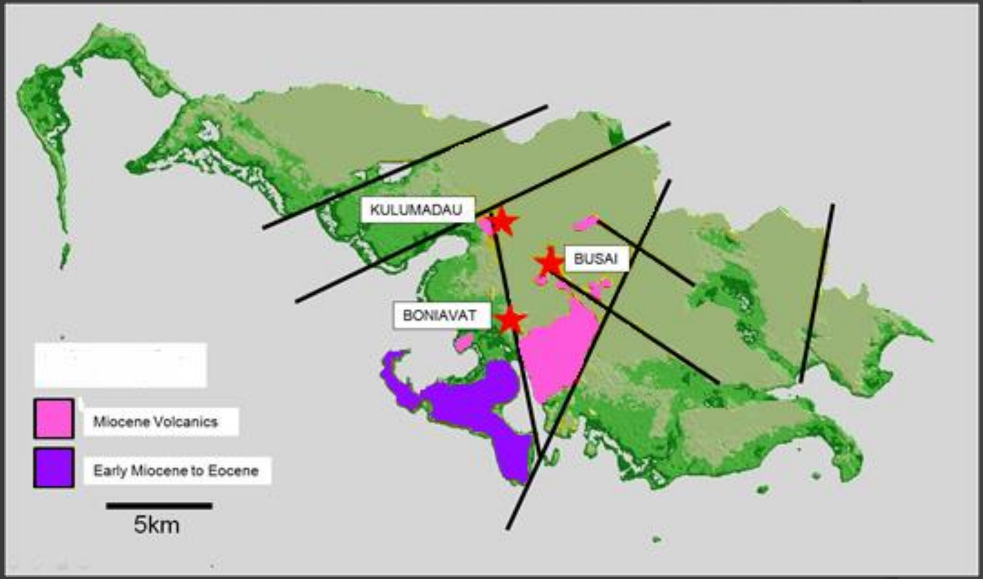


- **Pleistocene Kiriwina Formation** shallow marine limestones (covers >70 % of the island!!)
- **Miocene Okiduse Volcanics** are equivalent to calk-alkaline volcanics in the northern peninsula and mainland of PNG
- **Eocene Loluai Volcanics** equivalent to the onshore Papuan Ultramafic belt

Central uplifted horst block



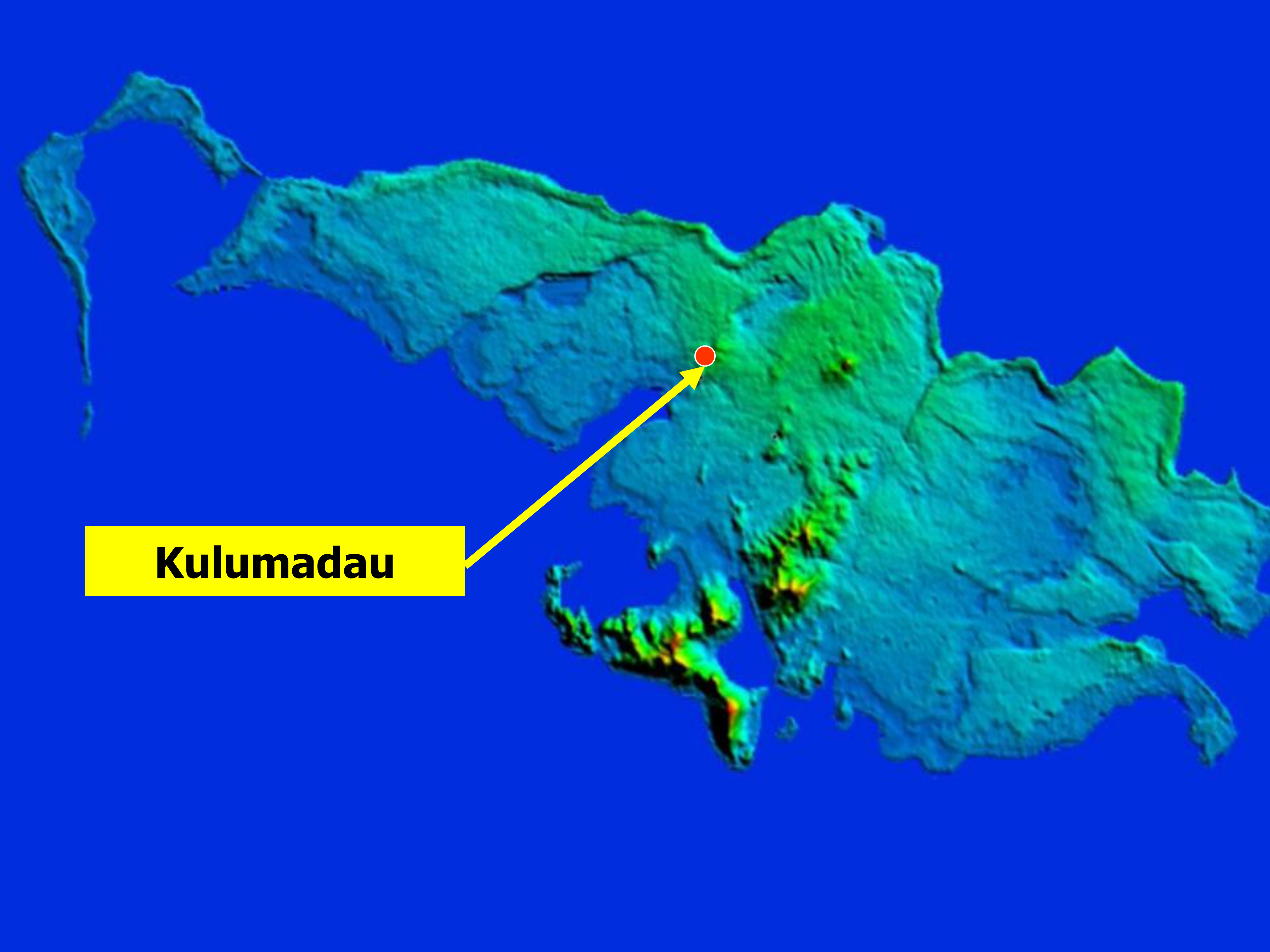
www.answers.com



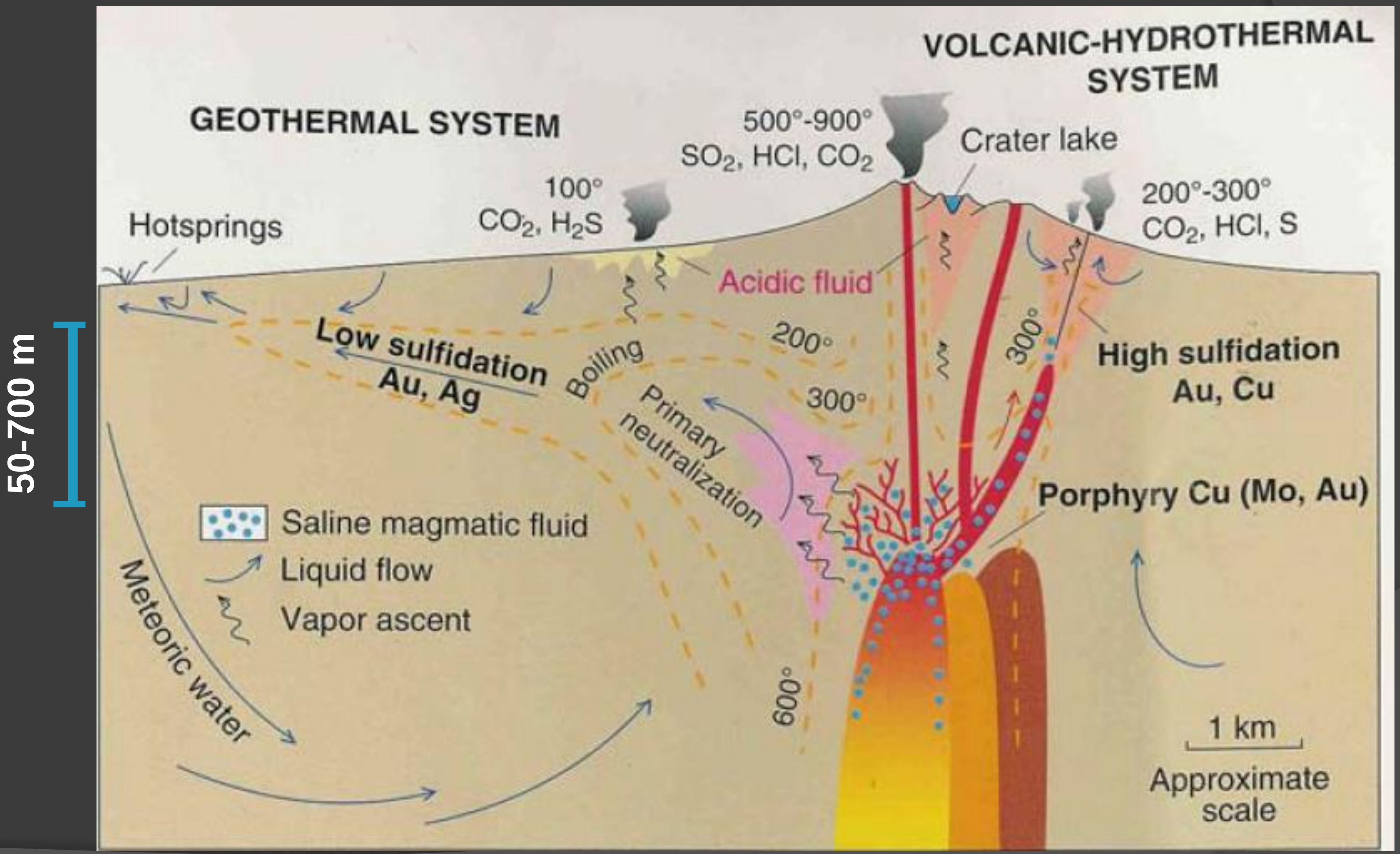
Pleistocene Kiriwina Formation

Miocene Okiduse Volcanics

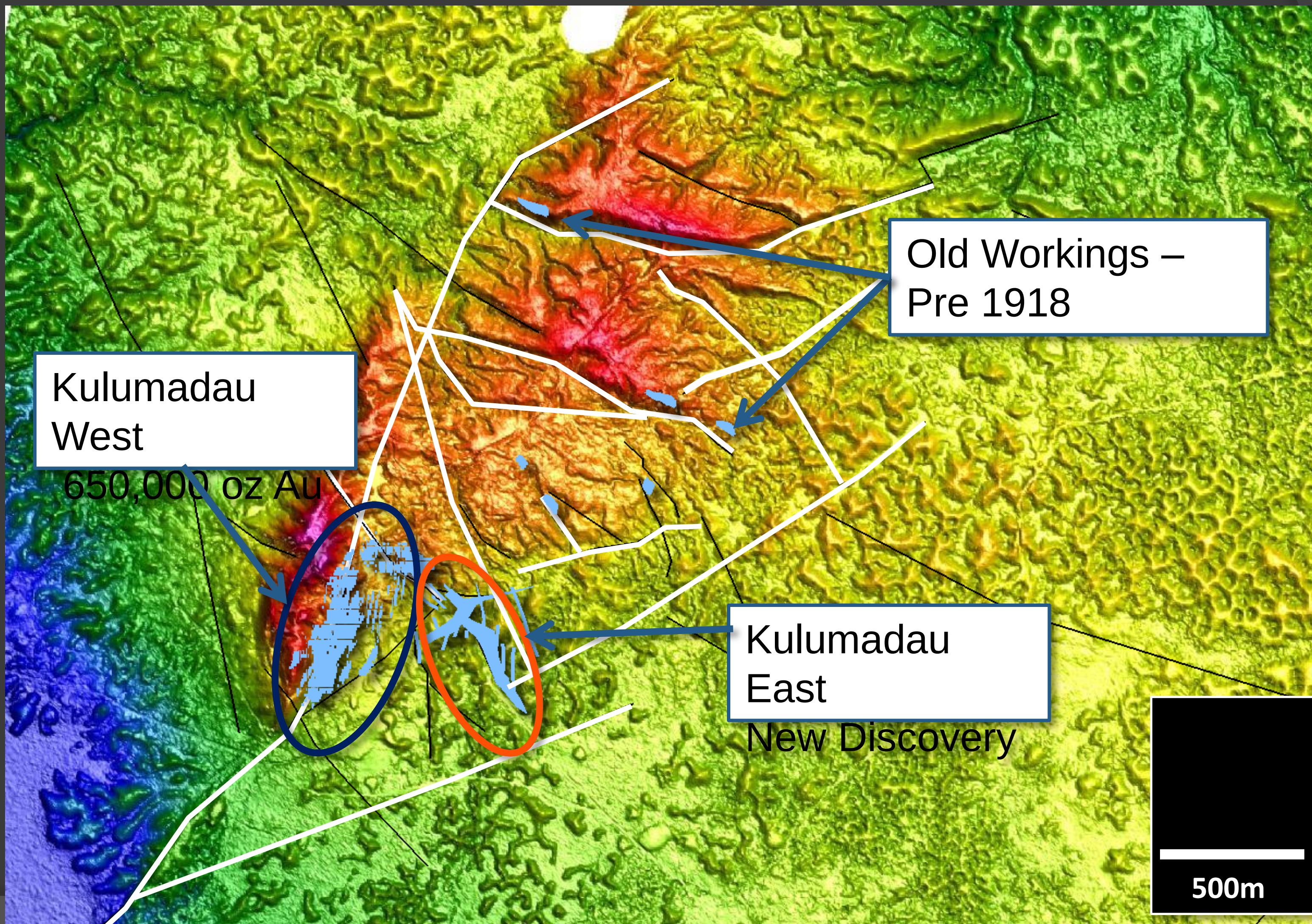
Early Miocene to Eocene


Kulumadau

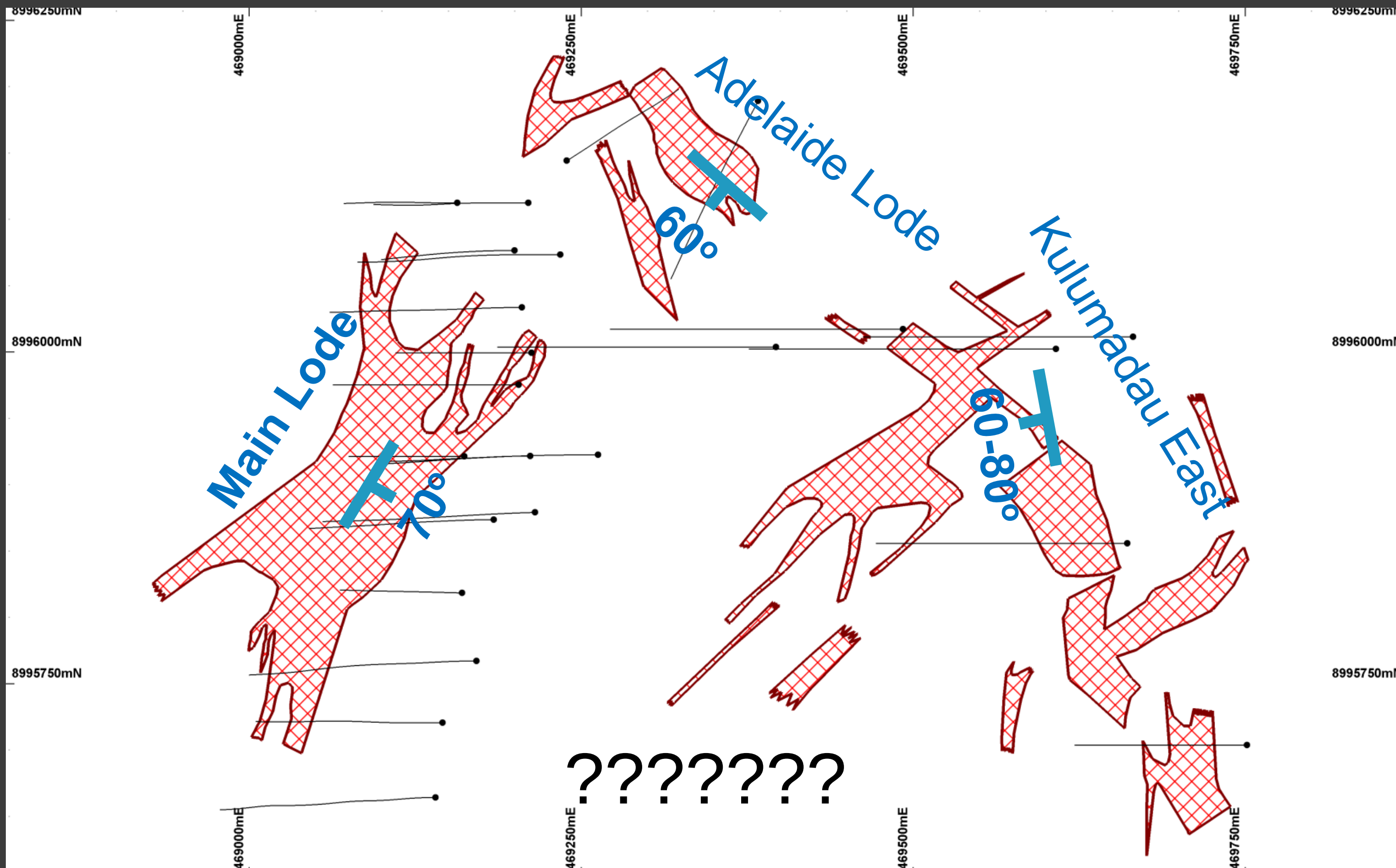
Epithermal Deposits



Mineralisation at Kulumadau



Kulumadau mineralisation map – holes utilised in the current study



Detailed logging of over 8000 m of diamond core

Mineralisation open to the south

Mineralisation styles at Kulumadau

Bx-hosted mineralisation (bulk of the ore)

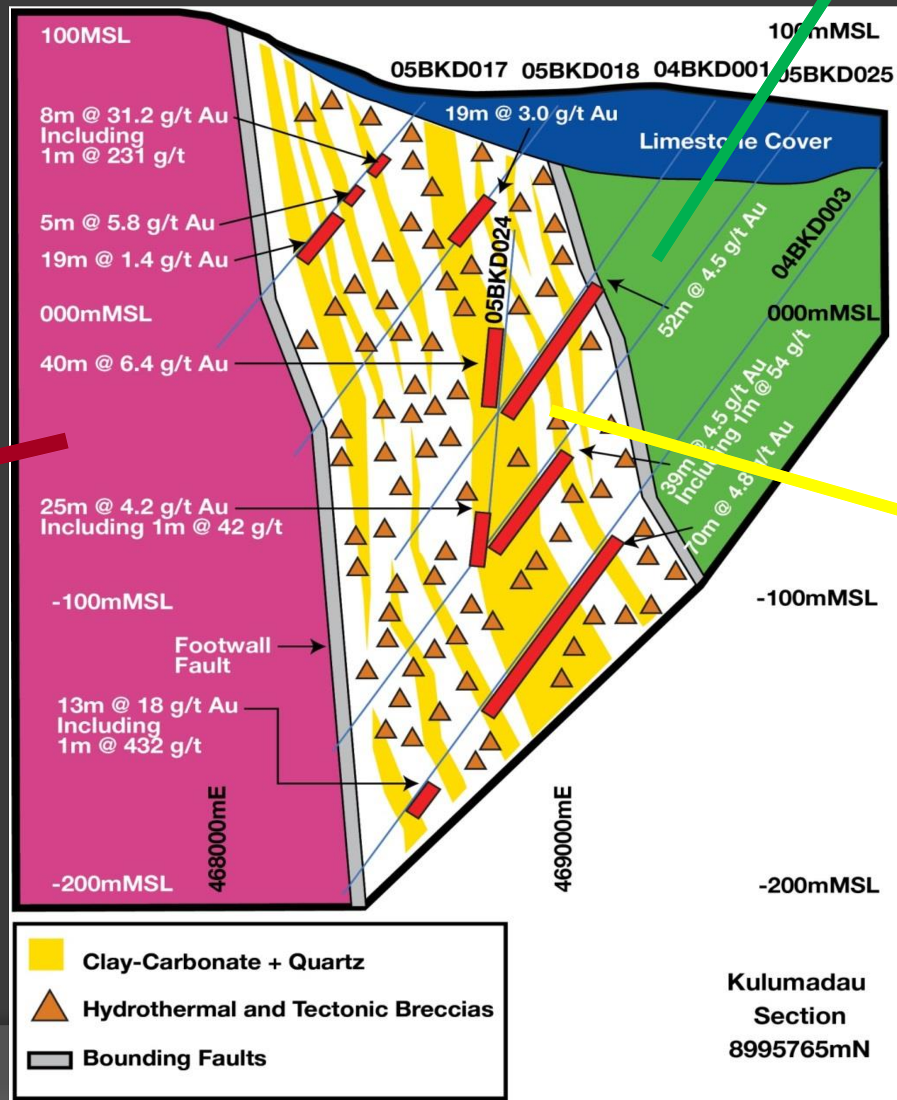
Vein-hosted mineralisation

Qtz-ank-BMS veins 11WKUD7

Breccia and vein-hosted mineralisation

Veined mineralisation
In adjacent wall rock

Hematite altered footwall (barren.. For most part)



Breccia hosted mineralisation
Steeply dipping argillic lenses

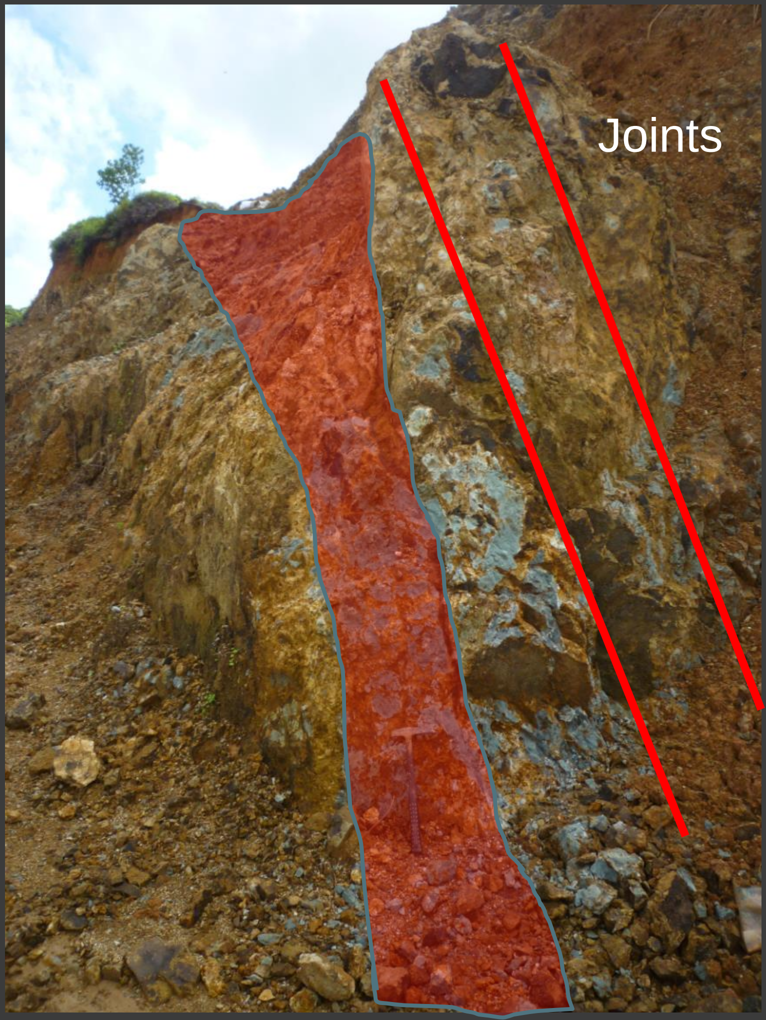
Bx style mineralisation Main and Adelaide Lodes

- Milled matrix brecciation (phreatic brecciation) → polymictic clasts in an argillic altered matrix
- More prevalent in the Main and Adelaide Lodes

BKUD3 53 m

Bonanza Au BKUD3

Milled matrix breccia in the field



Milled matrix breccia lense from the Adelaide Lode

Poorly sorted, matrix supported, polymictic milled matrix breccia

XRD Analysis of milled matrix breccias – Main and Adelaide Lodes

Mineralised

Proximal inner

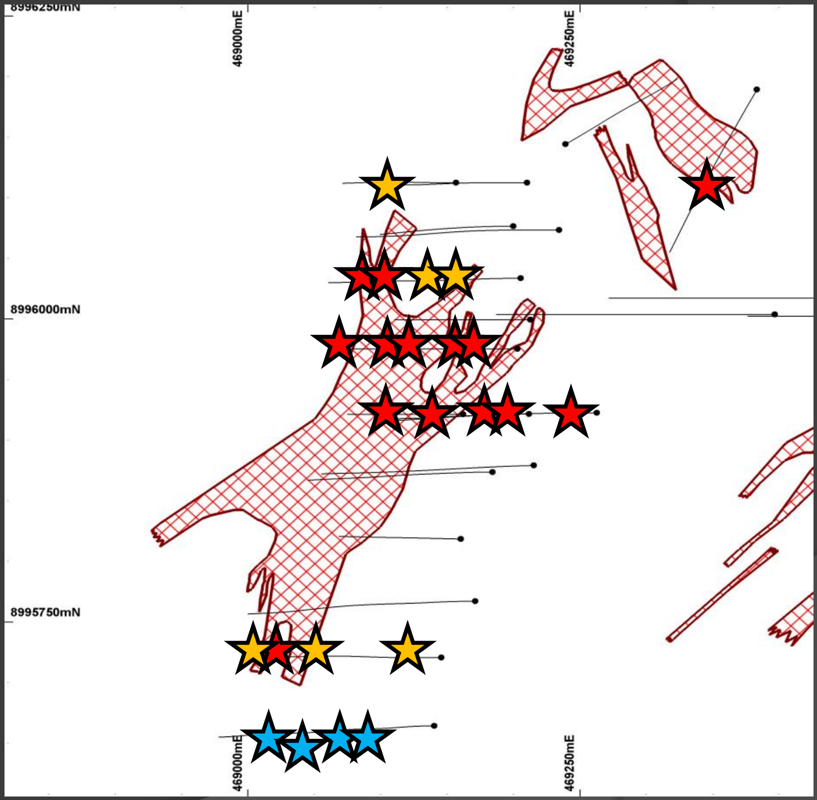
- Chlorite-quartz-illite-**adularia-pyrite+/-albite**+/-calcite

Proximal outer

- Chlorite-quartz-illite-**albite-anhydrite**+/-calcite
- Anhydrite suggests more oxidising conditions

Barren

Quartz-chlorite-illite-pyrite



Bx style mineralisation Eastern Lode

- Hydrothermal breccia
- Still retains tectonic fabric, no large scale hydrothermal overprint like in main lode

Clay-carbonate-quartz hydrothermal breccia 11WKUD007 227 m

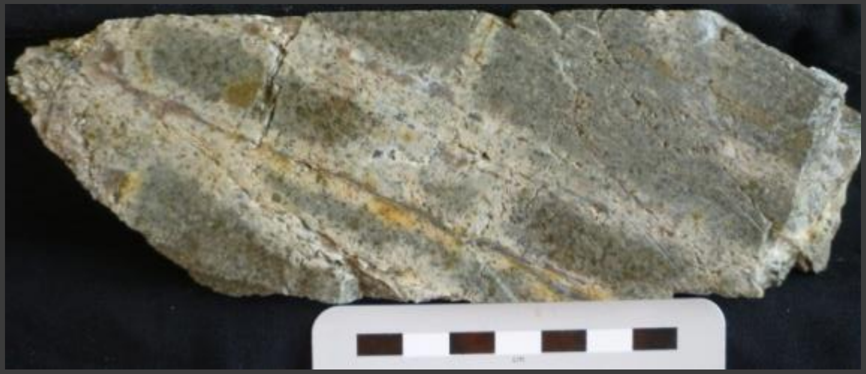
Vuggy quartz-silicified illite hydrothermal breccia

25 m 11WKUD012 arg-carb-BMS bx with tectonic fabric

Vein styled mineralisation - Main Lode

- Small (5-10 mm wide) quartz-calcite veins with phyllic or K-spar selvages
- Massive (20-1000 mm wide) anhydrite veins, patchy distribution

Qtz-carb-BMS vein with K-spar altered selvages12WKD1 282 m



Qtz-carb-BMS vein with phyllic altered selvages BKD33 166 m

Massive anhydrite veining BKD32 293 m

Vein styled mineralisation – Kulumadau East Lode

- Larger veins quartz-ankerite BMS

Qtz-ank-BMS veins 11WKUD7

Hydraulic fracturing/hydrothermal breccia with qtz-ank matrix fill and silicic alteration at clast margins 11WKUD15 149 m

Mineralisation style

- Typical carbonate base-metal Au intermediate sulfidation mineralisation
- Base-metals comprise pyrite, Fe-poor sphalerite (pale yellow) and galena… similar to Kelian but with low Ag
- Despite locally high base-metal content gold displays a high fineness with **Au-Ag of the order of 5:1**

Bonanza grade Au with BMS in quartz-carb hydrothermal breccia BKD3

Relationship between Au and BMS??

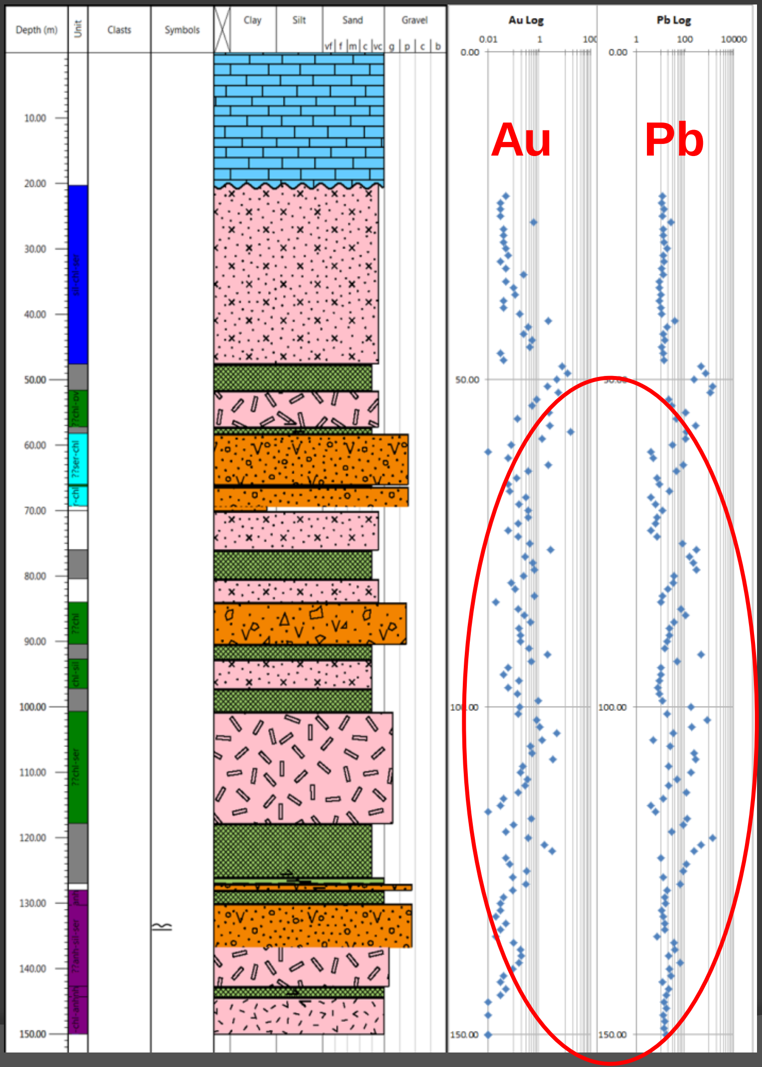
- Assays show there isn't a strong correlation between Au and base-metals…
- But, high Au is often associated with high BMS
  - This agrees with the literature on many deposits which reports an early BMS phase followed by a cooler Au-BMS phase

Pyrite → BMS → BMS + Au → Au

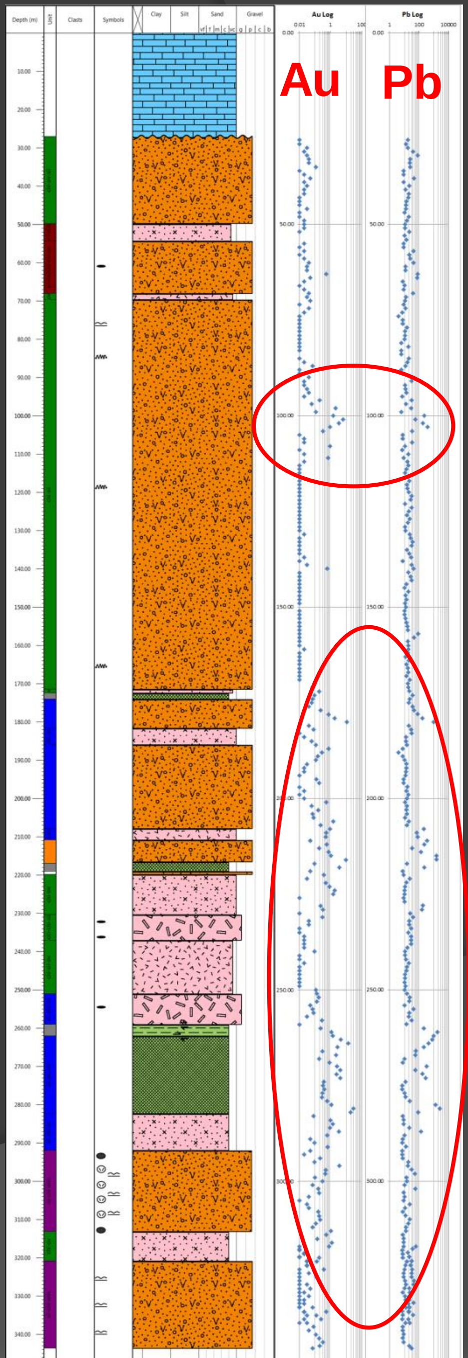
Qtz-carb BMS vein
11WKUD12 70 m

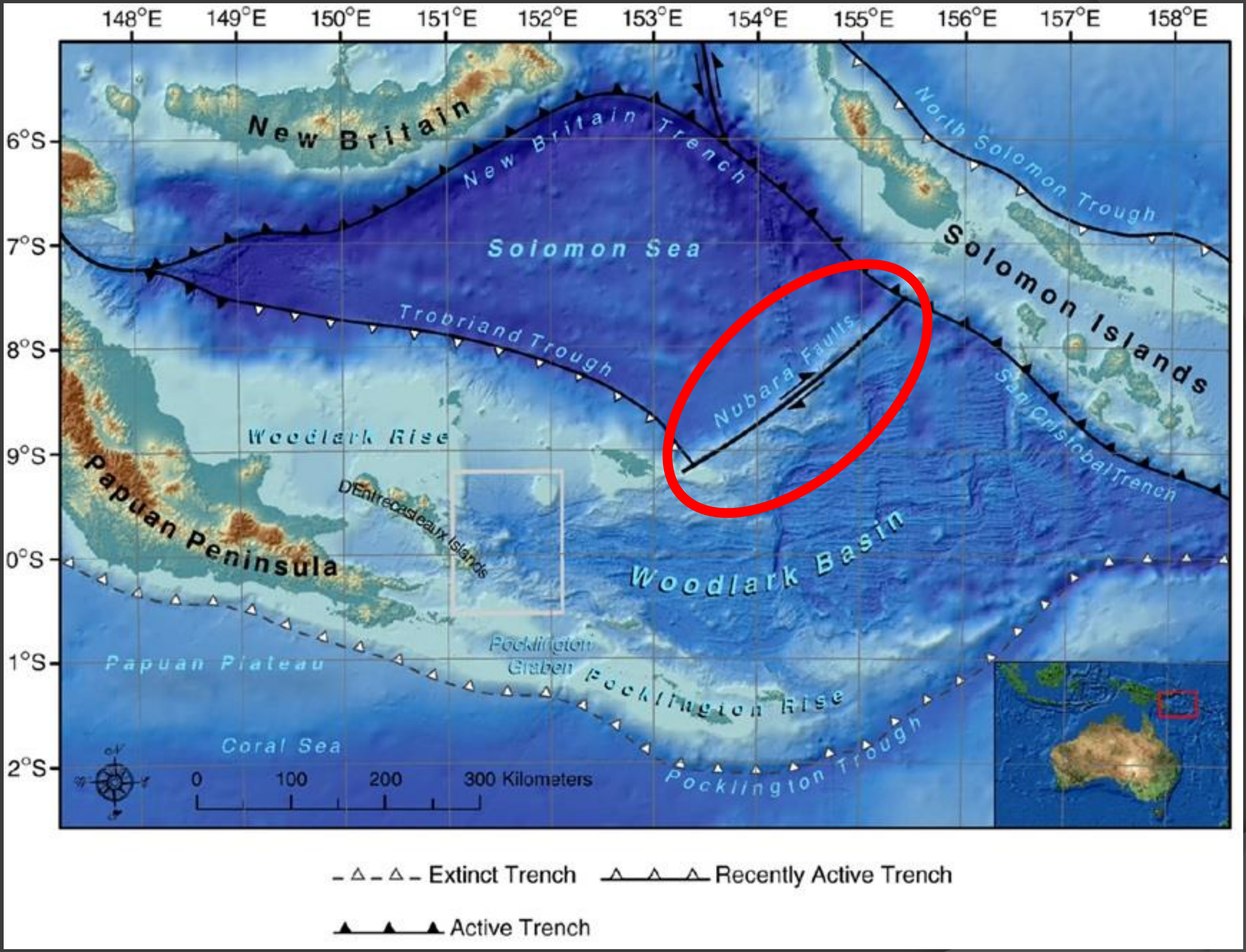
Log values for Au and Base-metals

05BKD18



06BKD33

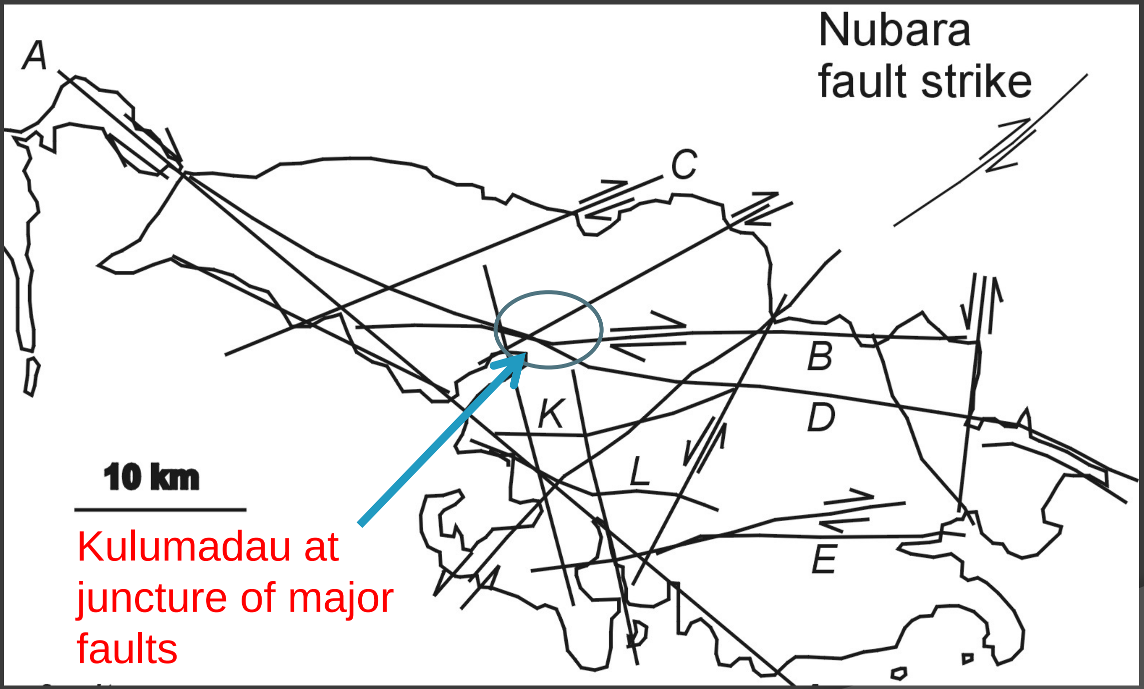




NE trending Nubara strike slip transform fault (Kington and Goodliffe 2008)

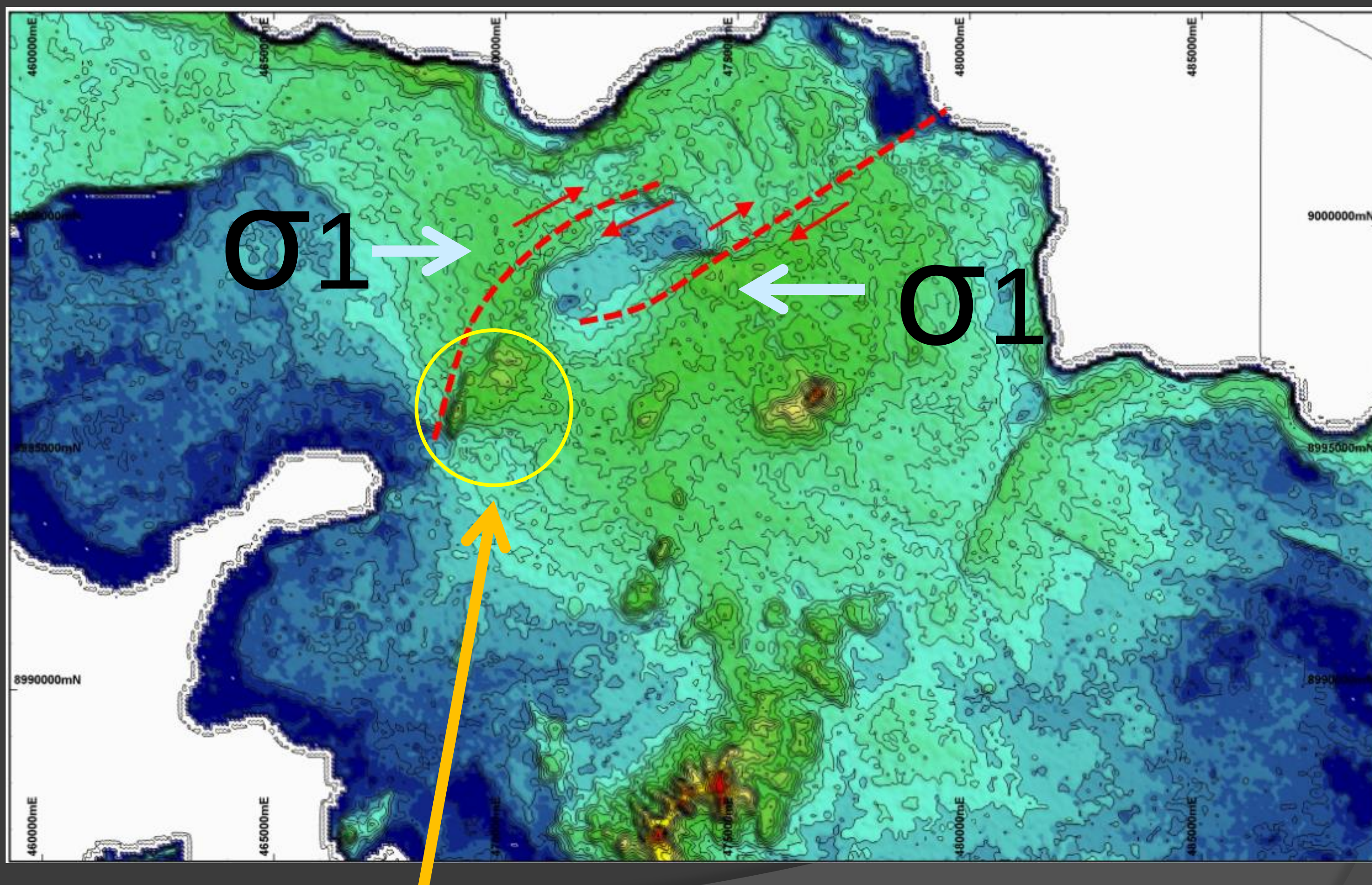
Regional structures

- Strong NE oriented fault orientation parallel to Nubara fault
- Kulumadau sitting on the juncture of regionally significant faults



Faults based on structural analysis by Lennox (2009)

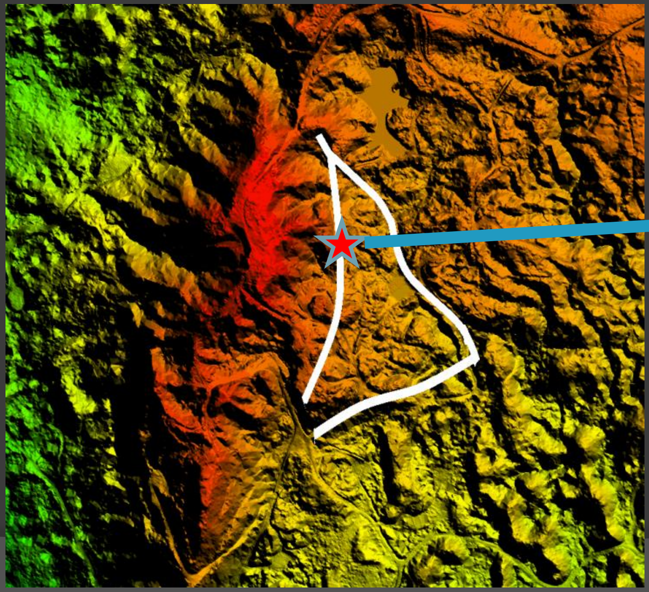
Regional structures – deposit scale



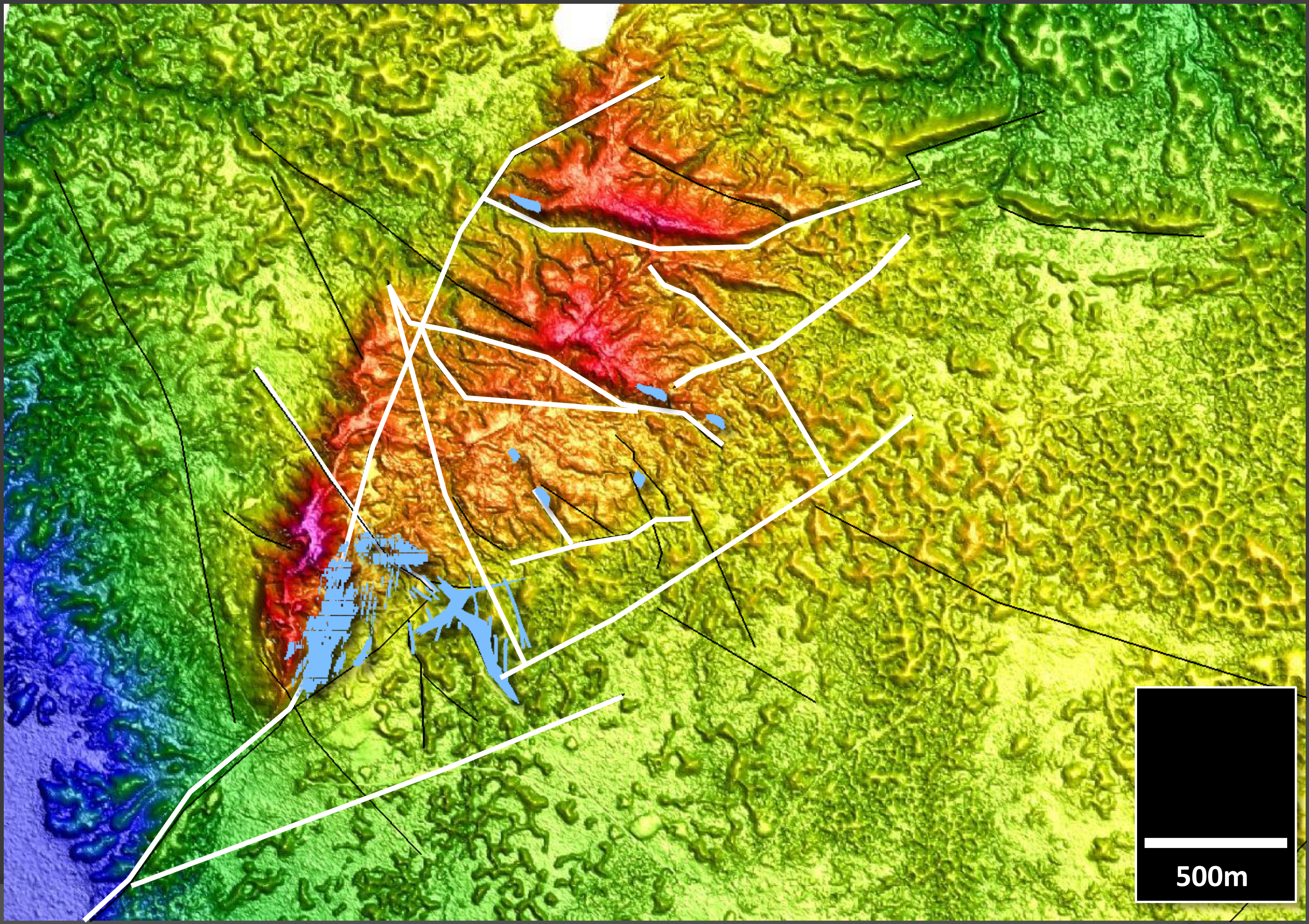
Currently on the edge of a pull apart basin in a compressional regime

Field observations

- … Not much to see. Thick package of Kiriwina covering the deposit (> 80 %), with exception to a small area in the west
- Significant post Kiriwina faulting – low angle thrust faulting



LiDAR imagery of Kulumadau



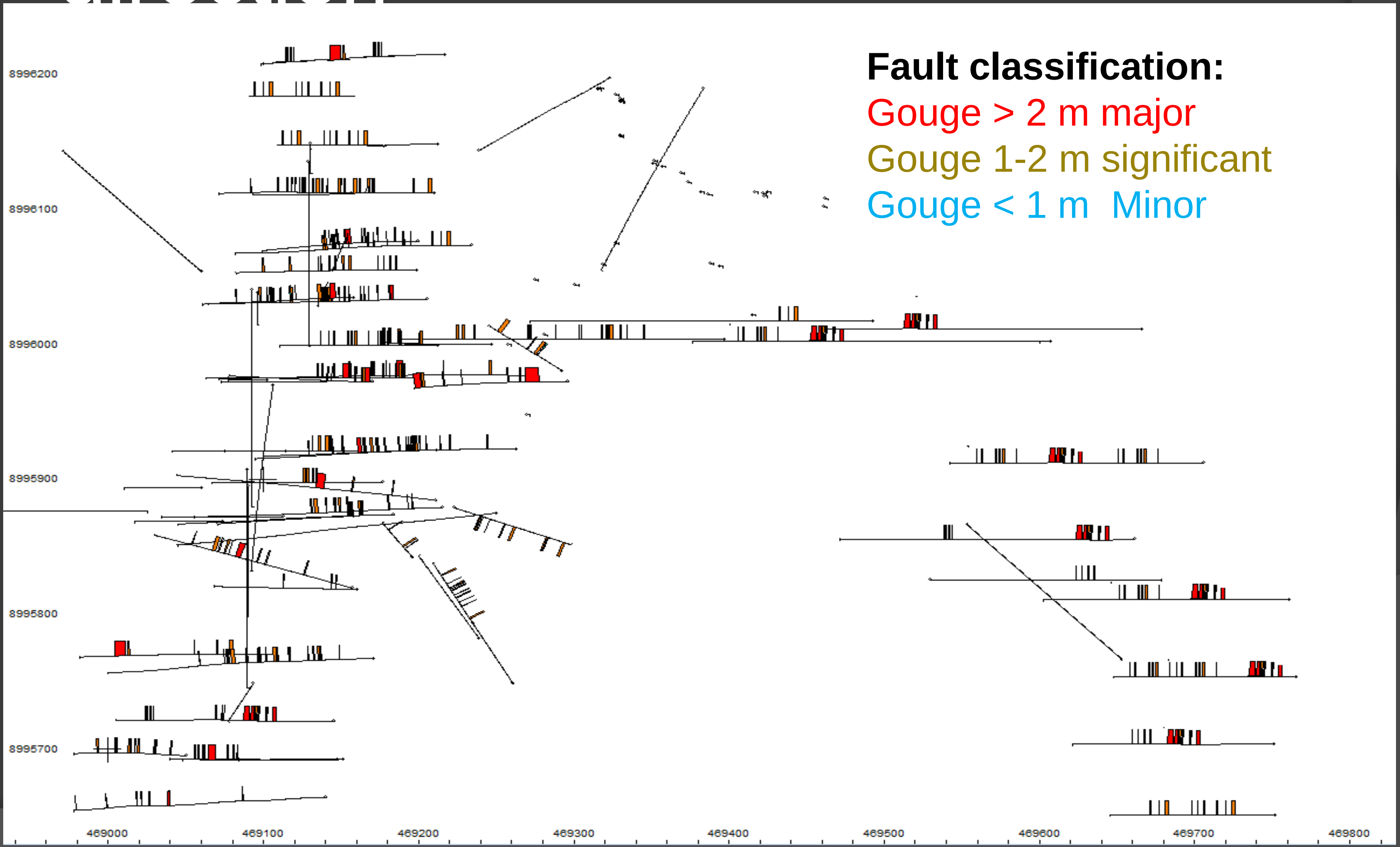
LiDAR

- Sub-metre resolution
- Can easily pick major faults intersecting mineralisation… but locally??
  - Numerous faults in all directions
- LiDAR only shows post Kiriwina Formation faulting; may represent reactivation of old faults but may not. Also significance of faults can only be inferred.

Correlating faults in drill core

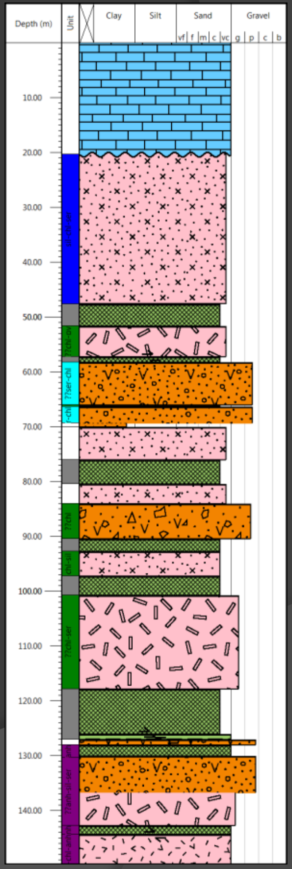
- Faults can be drawn in any direction
- Cannot distinguish faults in drill core from argillic altered fractures

Faults in drill core post logging… can be drawn in any direction



Stratigraphy is the key to unravelling structure on the deposit scale

BKD18



- Detailed diamond drill core logging of over 8000 m of core and over 1200 samples collected
  - Volcanic textures **<u>(thank you AIG!!!)</u>**, mineralogy and alteration
  - XRD and petrographic analysis
  - Structural measurements where possible

Variable alteration of ash bands

Base surge deposit

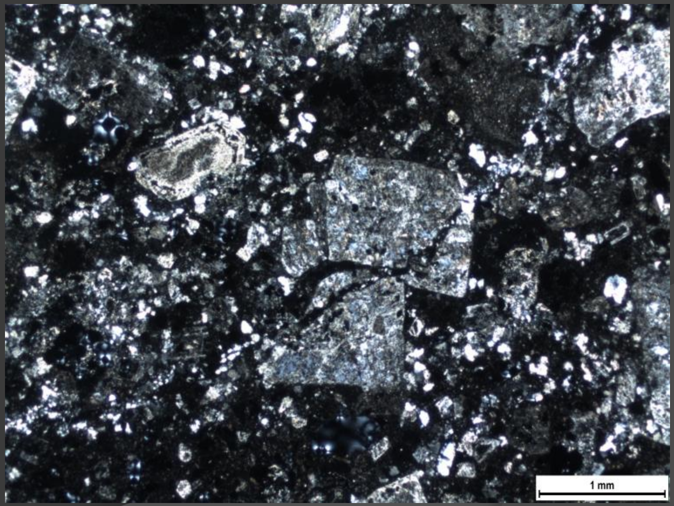
Main rock-types

- Plagioclase-rich andesitic tuff
- Moderate plagioclase-rich andesitic tuff
- Mafic andesitic tuffs
- Polymictic breccias

Coarse-grained plagioclase-rich tuff

- Medium to coarse-grained zoned plagioclase-rich (albite after andesine) hornblende-bearing tuff
- Volcanic origin:
  - Presence of cuspate shards, broken crystal fragments, accidental lithics and high primary porosity
- Origin: pyroclastic flow deposit
  - Lack of alignment in crystal orientation suggests pyroclastic flow deposit

BKD3 303 m



Broken plagioclase crystal BKD3 303 m

Accidental lithic 12WKD1 400 m

Epiclastic equivalent

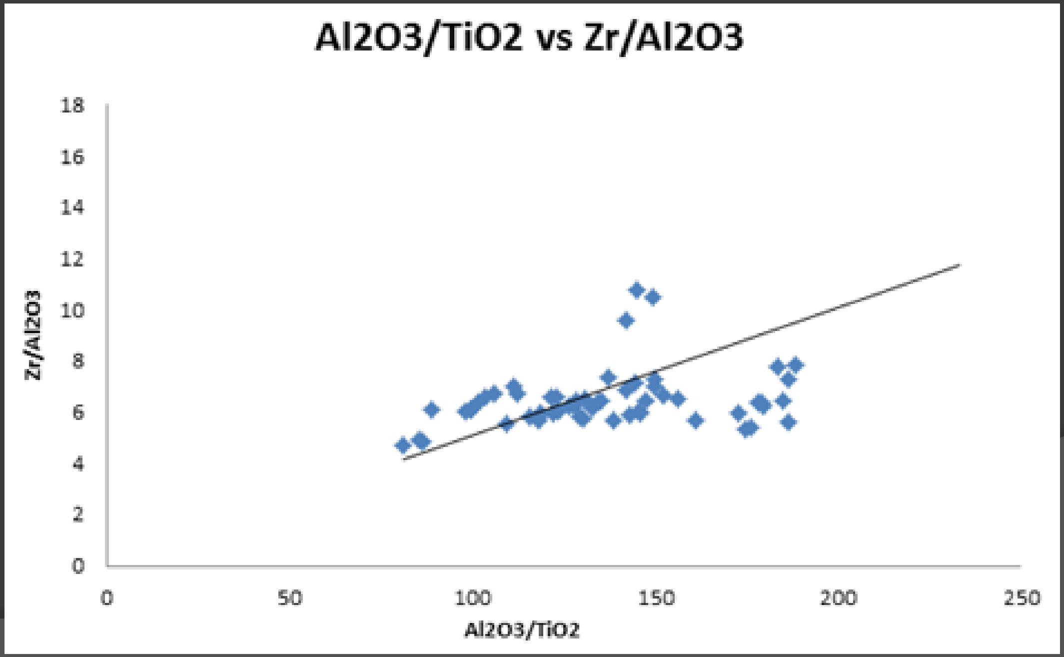
- Resediment-syneruptive volcaniclastic
- Monomictic composition
- Blurred boundaries between clast and matrix material

BKD5 323 m

BKD18 143 m

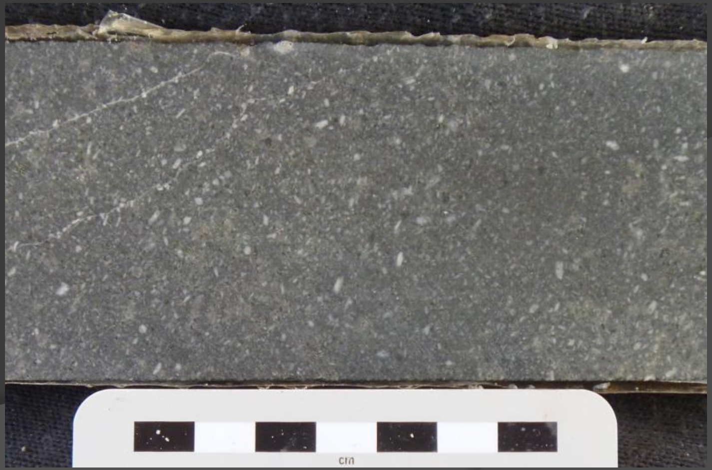
pXRF Analysis of epiclastic equivalent

- Immobile-immobile ratio plots show a narrow range in clast composition for the aforementioned epiclastic



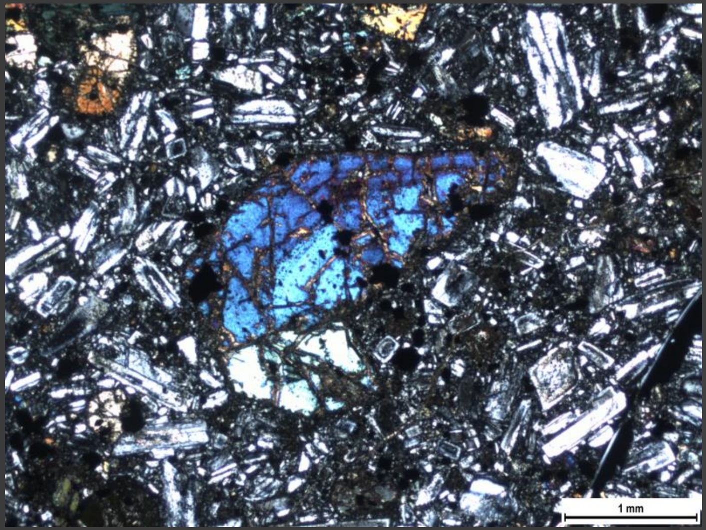
Medium-grained plagioclase-rich tuff

- Fine to medium-grained plagioclase-rich hornblende-bearing tuff.
- Similar in petrography to aforementioned tuff, but coarser grained and restricted to the east portion of the deposit



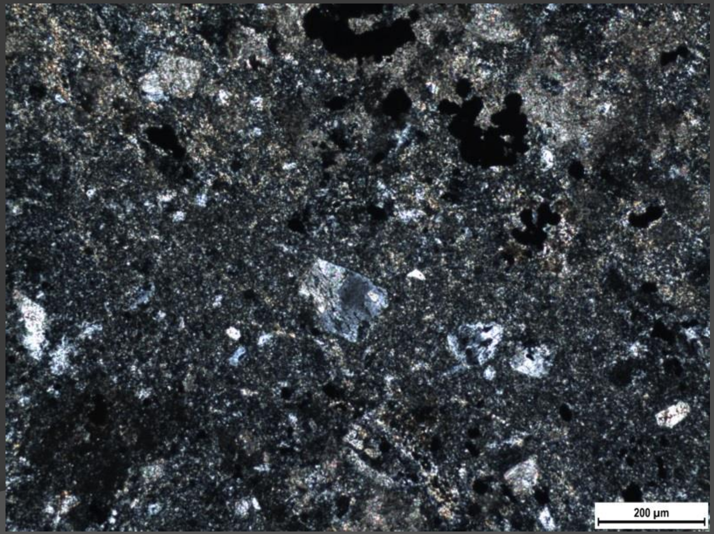
Fine-grained mafic tuffs

- Fine-grained plagioclase-rich (andesine >70 %) augite (20 %) bearing tuff.
- Volcanic origin:
  - Cuspate shards, broken crystal margins
- Origin: blocks of pyroclastic flows intercalated within epiclastic breccia bodies and polymictic breccia bodies
  - Lack of alignment in crystal orientation suggests pyroclastic flow deposit



Plagioclase-rich augite-bearing tuff

BKD5 – 263.2 m



Crystal and glass shards

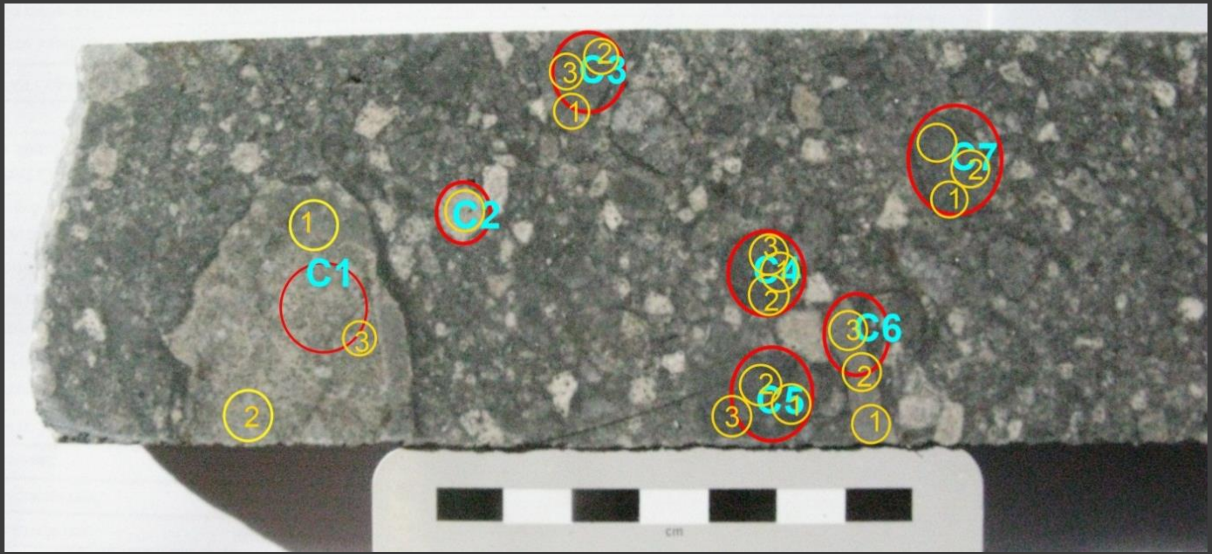
Polymictic breccia

- Hosts plagioclase-rich and mafic tuffs as well as intrusive clasts
- Polymictic with regards to protolith and alteration

Chlorite altered mafic clasts and phyllic altered plag-rich clasts

K-spar altered intrusive clast

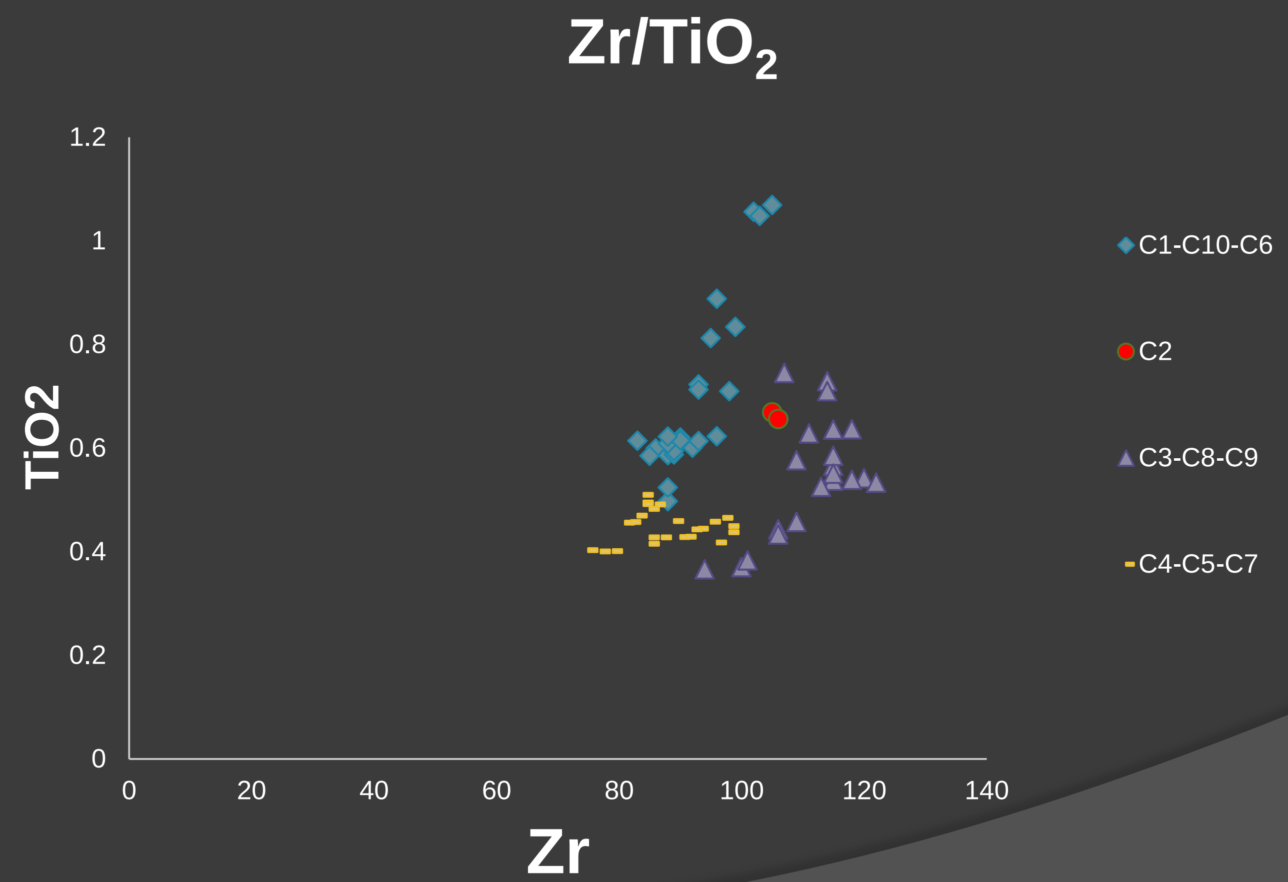
Polymictic alteration and protolith



11KUD008 326 m – clast C2
K2O 4.40 wt%
Cu 380 ppm, Zn 367 ppm
Zr 105 ppm, Mo 4 ppm

12WKUD001 @ 395 m depth
K2O up to 3 wt%
Mo 13 ppm, Zr 130

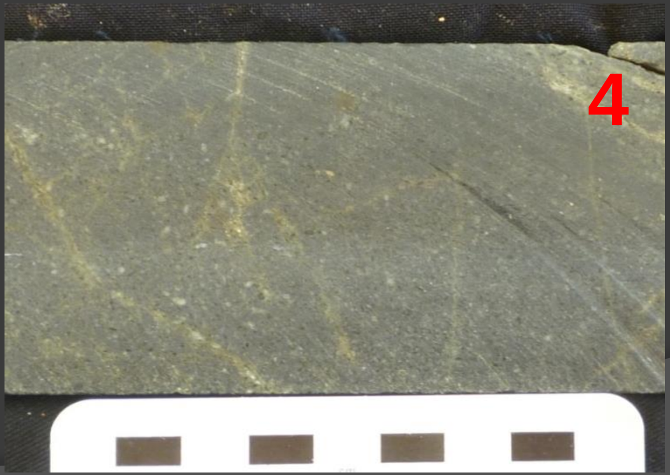
Evidence for polymictic composition



Where least altered these units are easily distinguished from one another… but

Much of the ore-body looks like this

Based on petrography and geochemistry which of these two rocks is the same??



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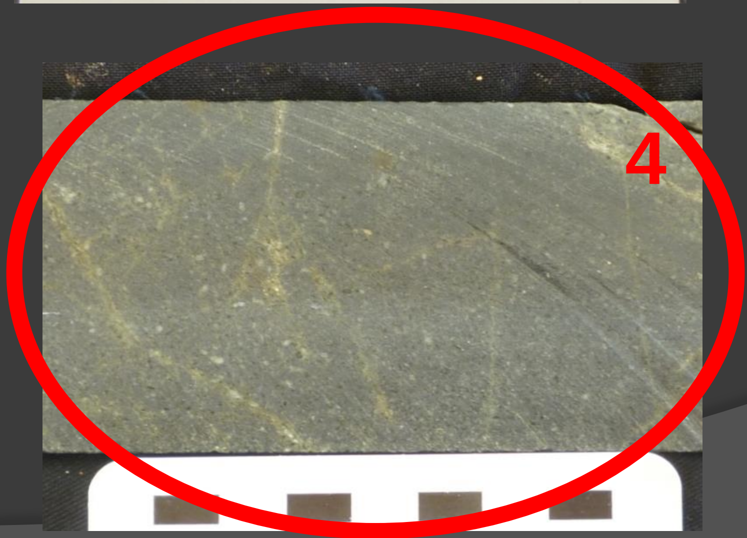
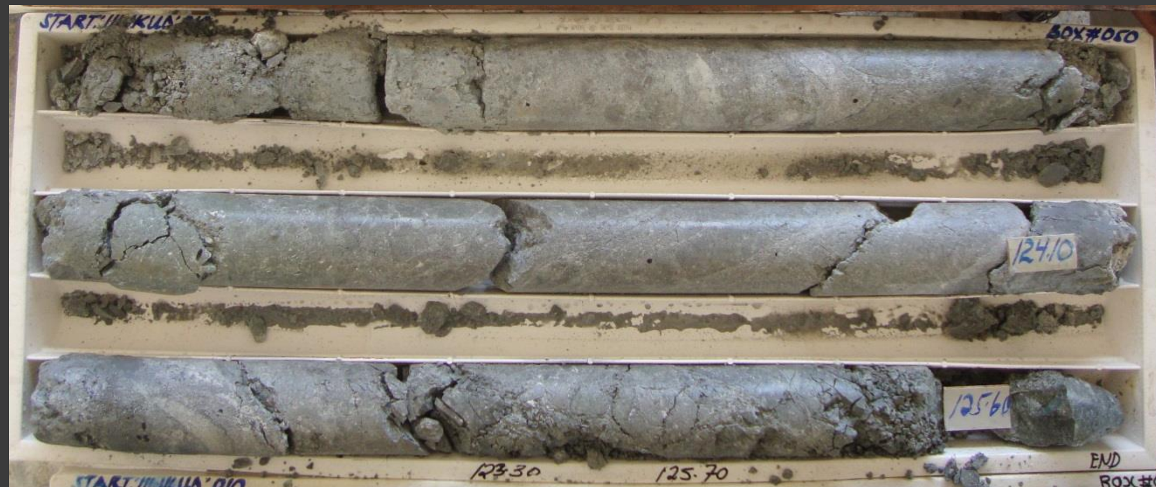
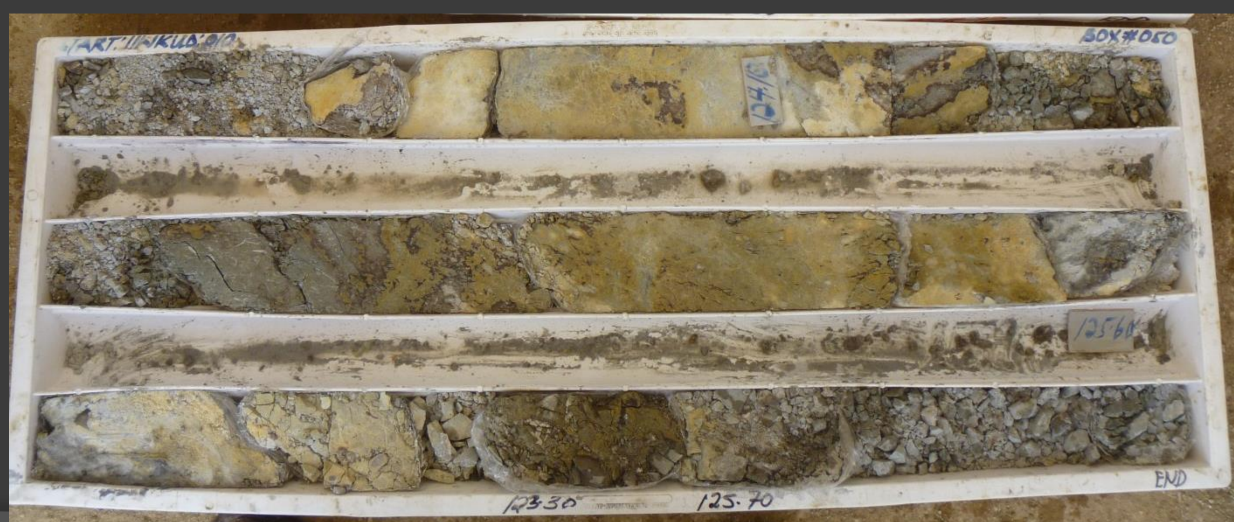


Deposit almost completely under cover

8 years later…..



After 2 years…

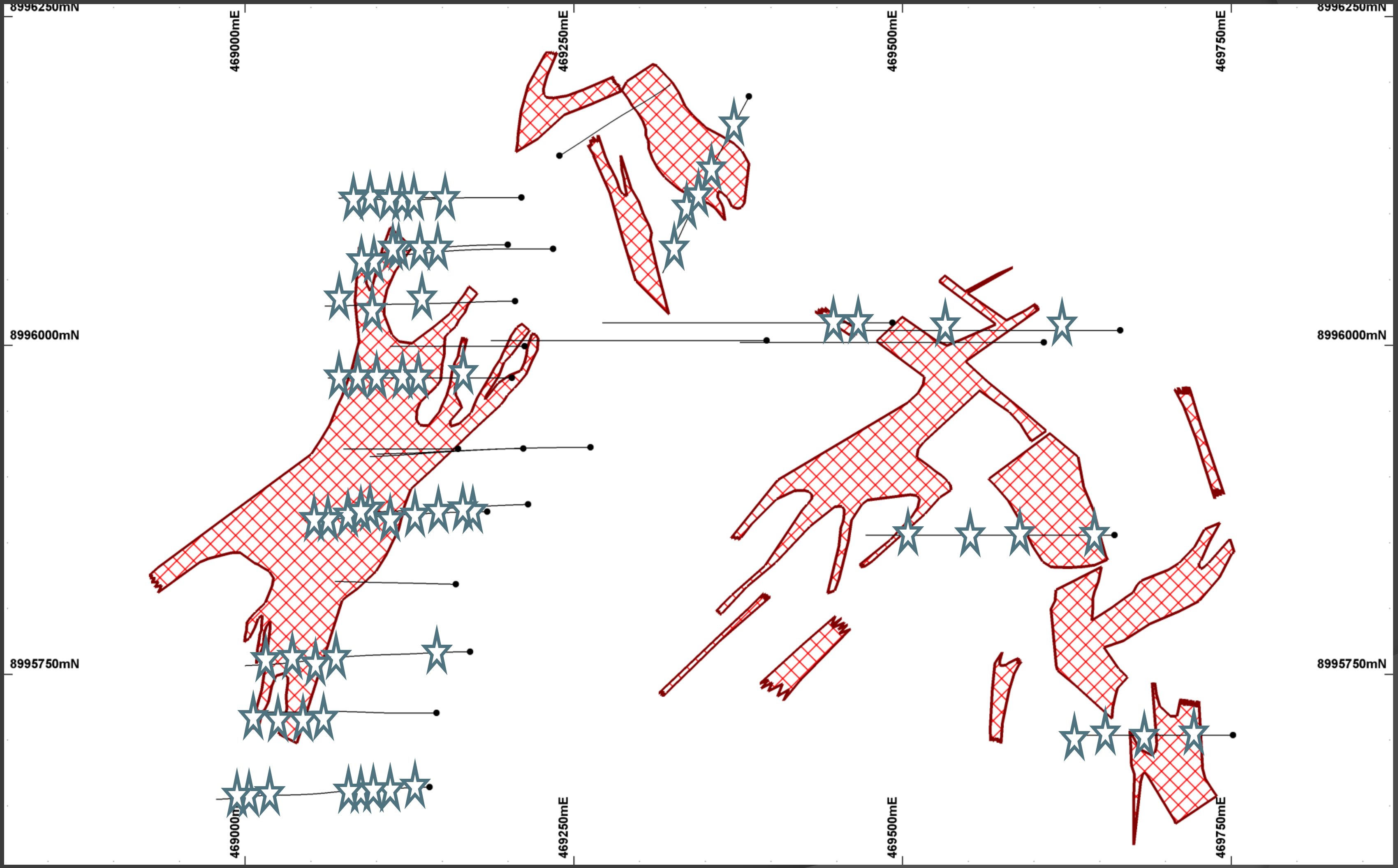


Less than 12 months later…..

Chemostratigraphy

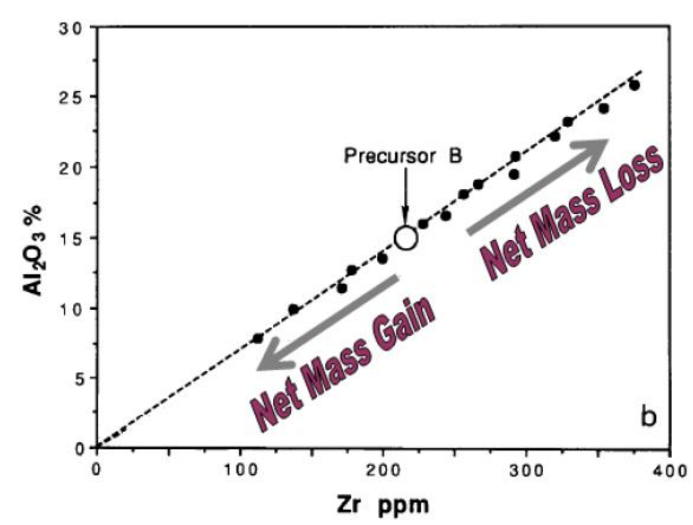
- Conventional approach
  - Immobile-immobile element analysis
- Less conventional techniques
  - Log-ratio cluster analysis
  - Ternary diagrams of subcomposition Ti, Cr, Zr after centring

pXRF sample locations

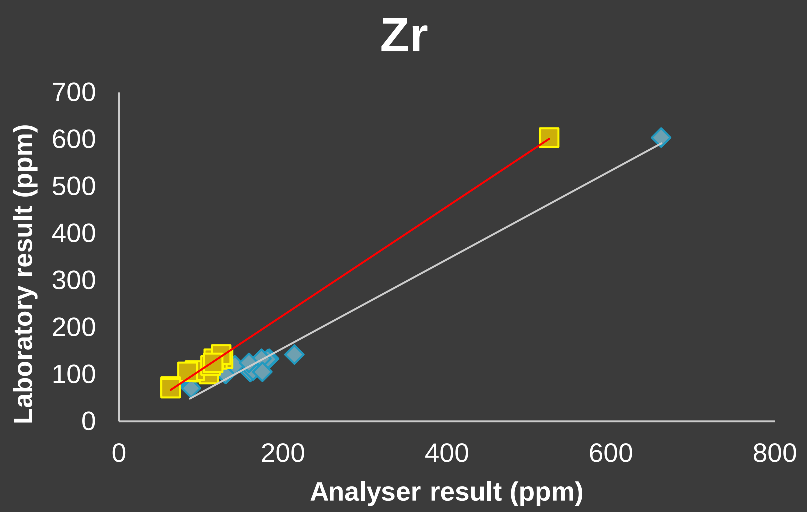


Immobile-immobile element analysis

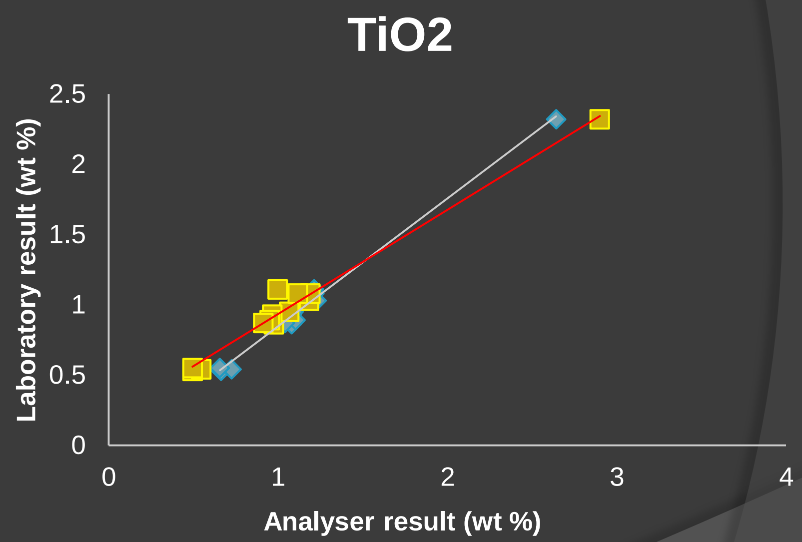
- Barrett and MacLean (1994) precursor approach
- Ratio of incompatible-immobile with compatible-immobile elements to determine the rock type



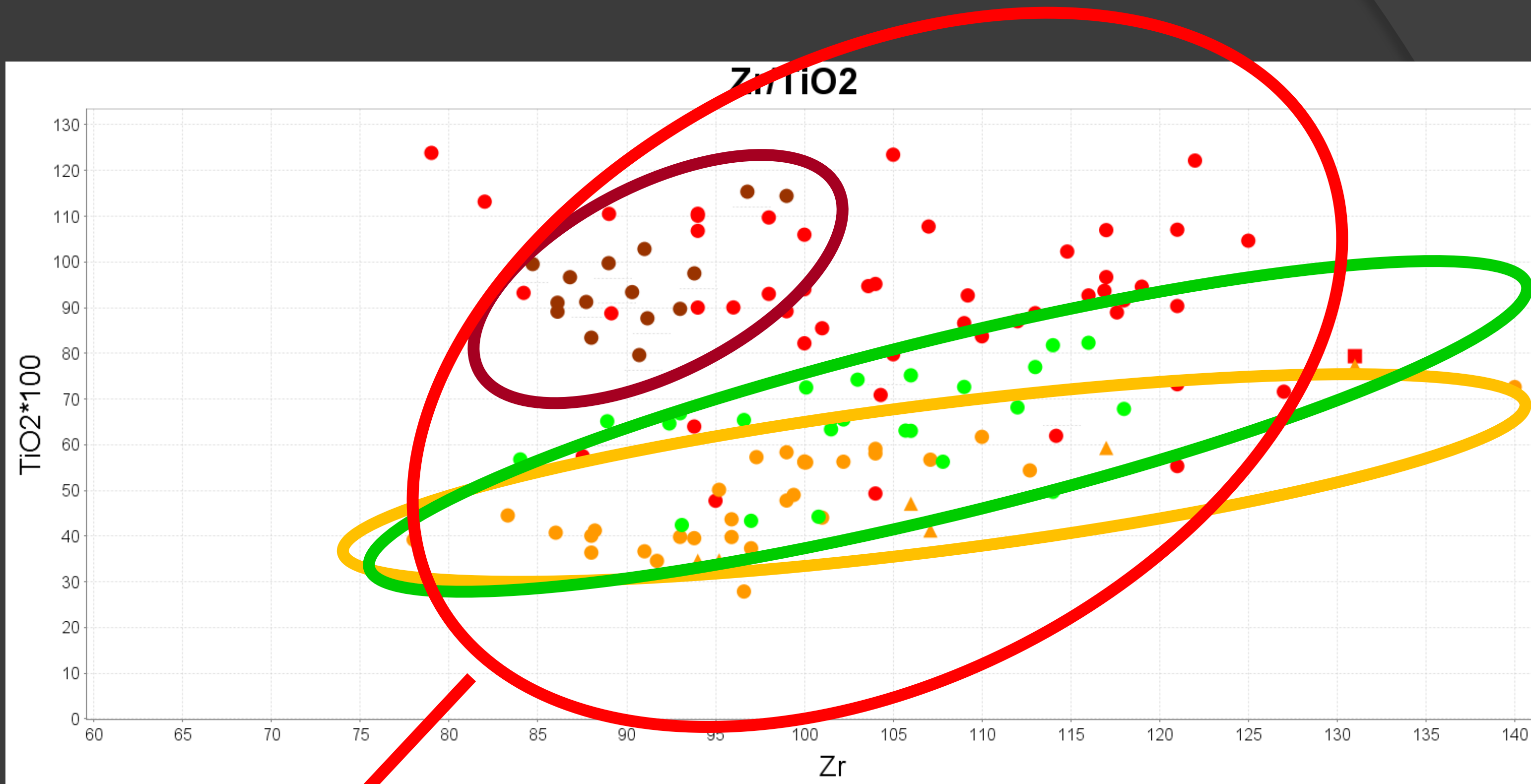
Verifying pXRF with Lab XRF



$R^2 = 0.99$ $R^2 = 0.98$



$R^2 = 0.98$ $R^2 = 0.99$



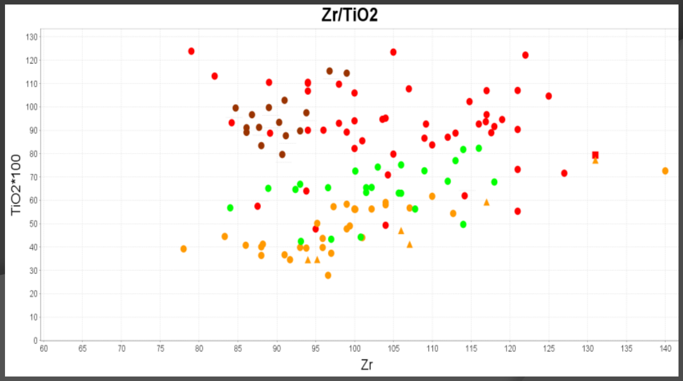
Can identify units after the fact with petrography and XRF.. But is it field ready??

Mafic blocks occur in both epiclastic and polymictic breccia facies

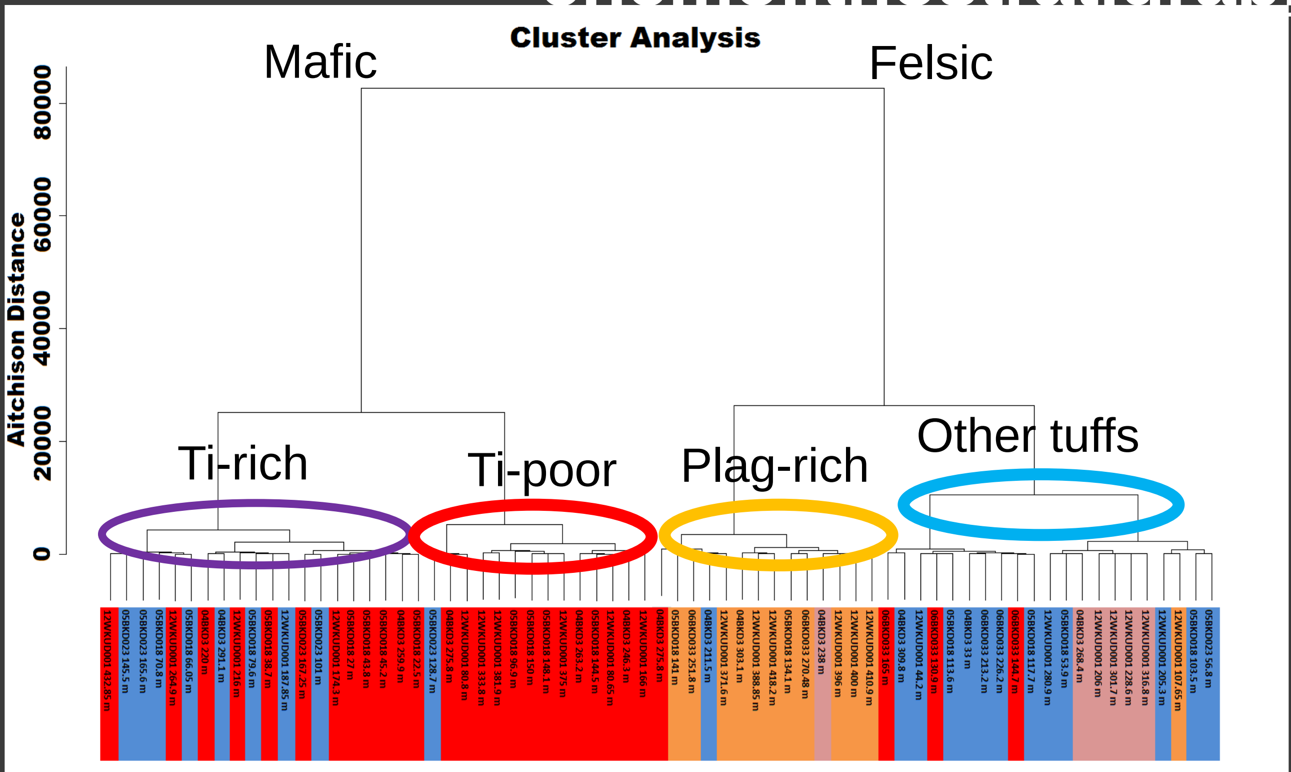
- Footwall fine-grained mafic tuff
- Fine-grained mafic tuff
- Coarse grained plag-rich tuff
- Epiclastic coarse-grained plag-rich tuff
- Medium-grained plag-tuff

Results of immobile-immobile

- 3 chemostratigraphic units with reasonable correlation but the andesites are of a similar composition (and inferred source)
  - Therefore highly altered units cannot be distinguished solely on the basis of immobile-immobile element pairs geochemistry



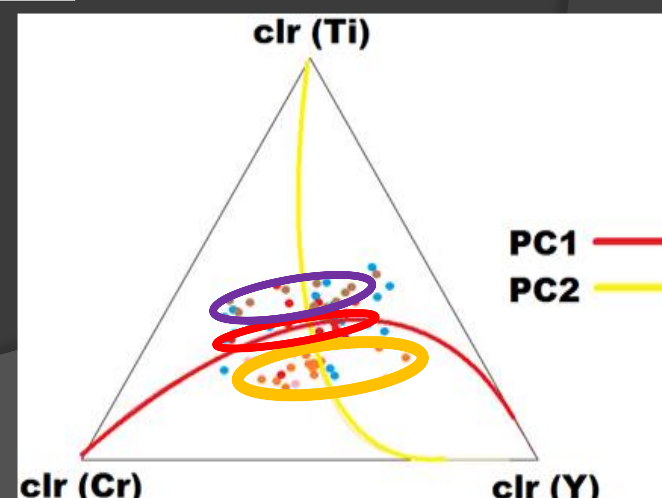
Non-Conventional approaches to chemolithostratigraphy



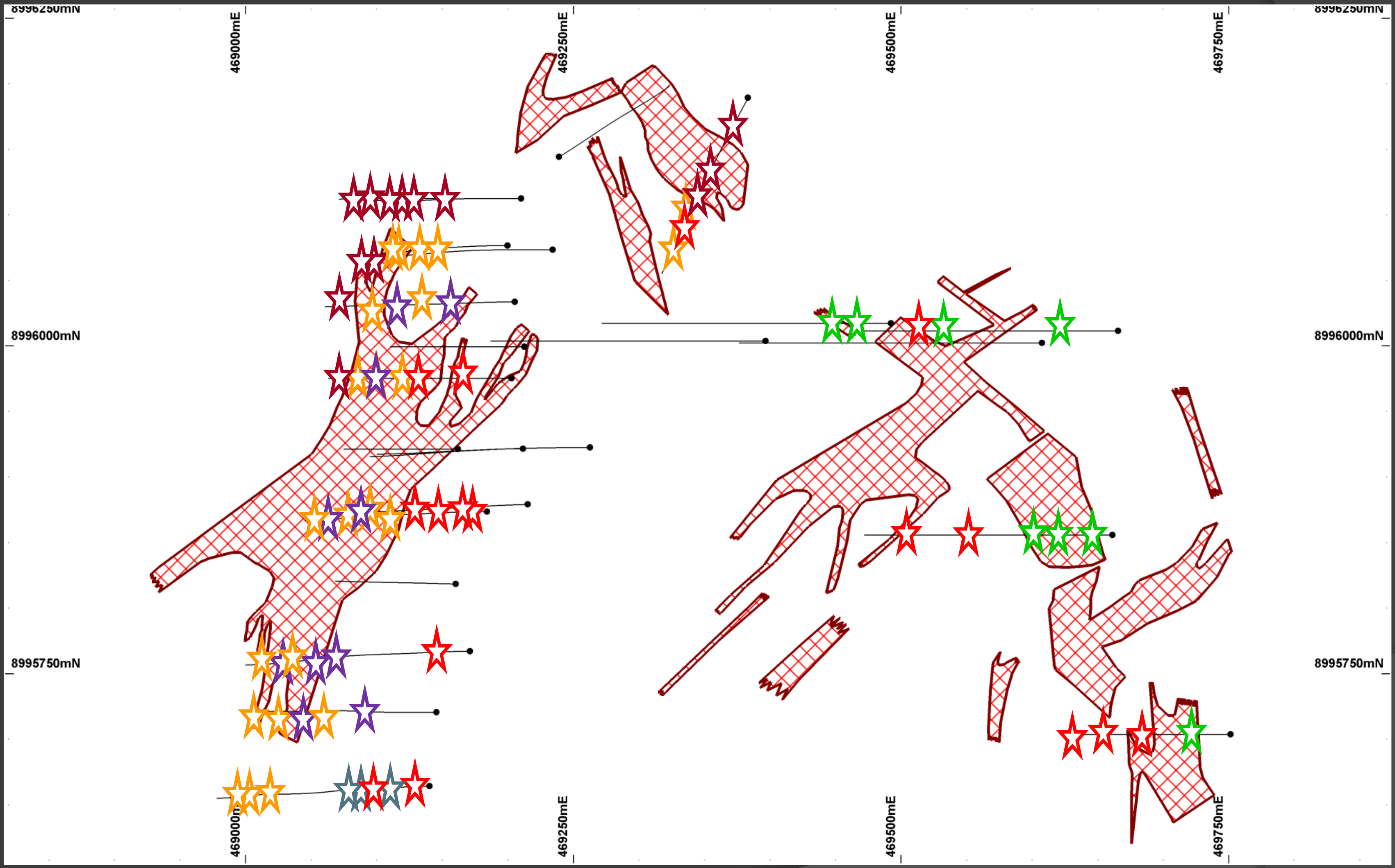
Cluster analysis using centred log-ratio transformed data

ABLE TO DISTINGUISH UNITS QUITE WELL

Ternary diagram of subcomposition Ti, Cr, Zr after centring data

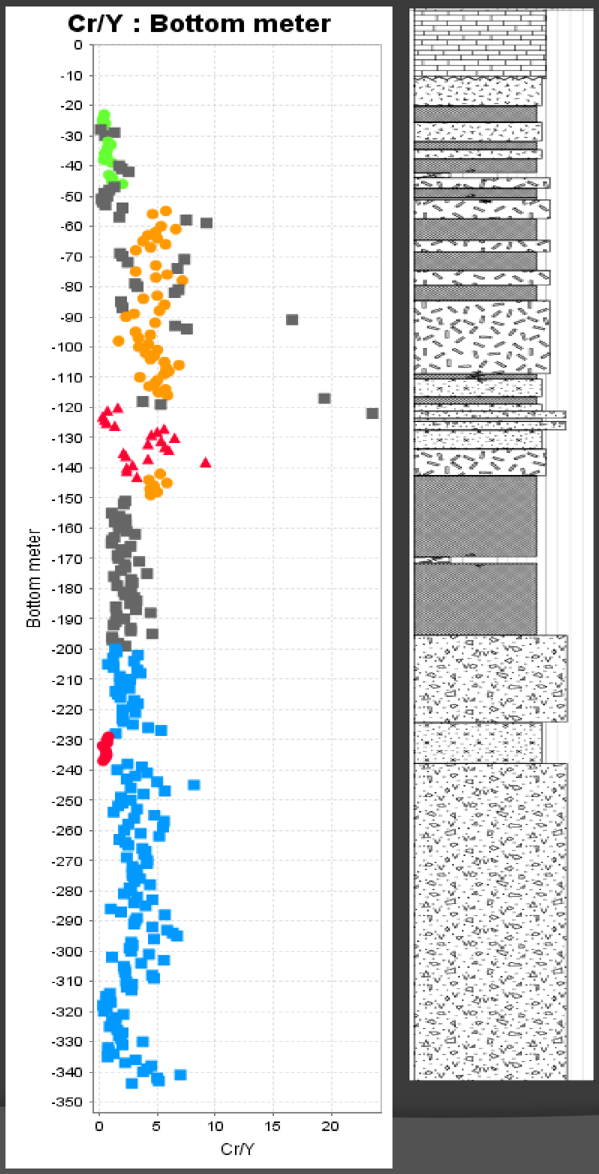


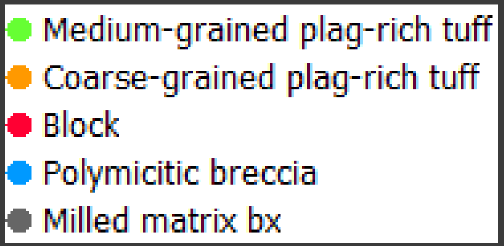
Distribution of the different units on the basis of pXRF



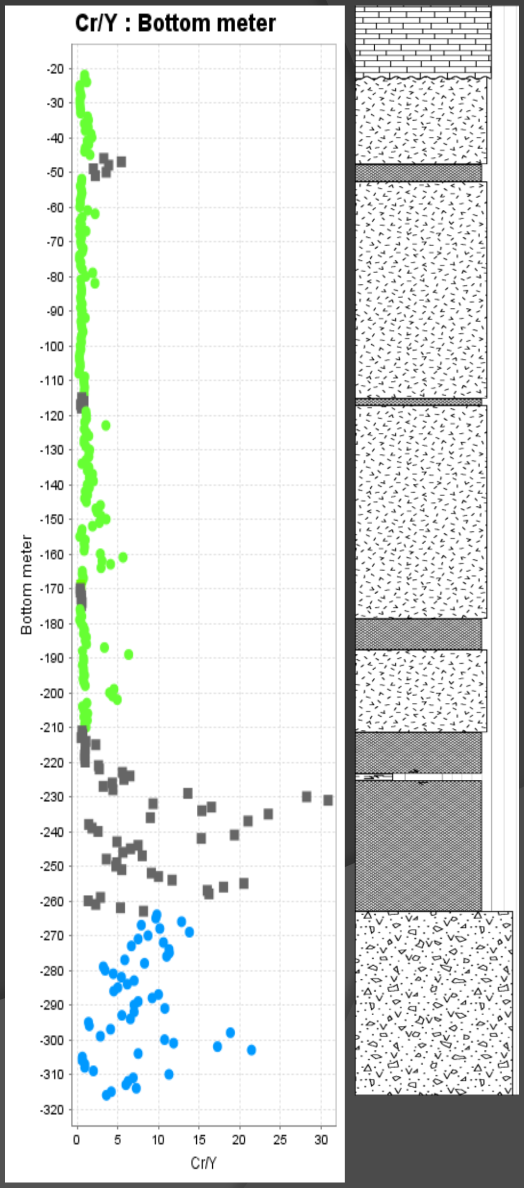
High resolution whole rock geochemistry with detailed core-logging

11WKUD008



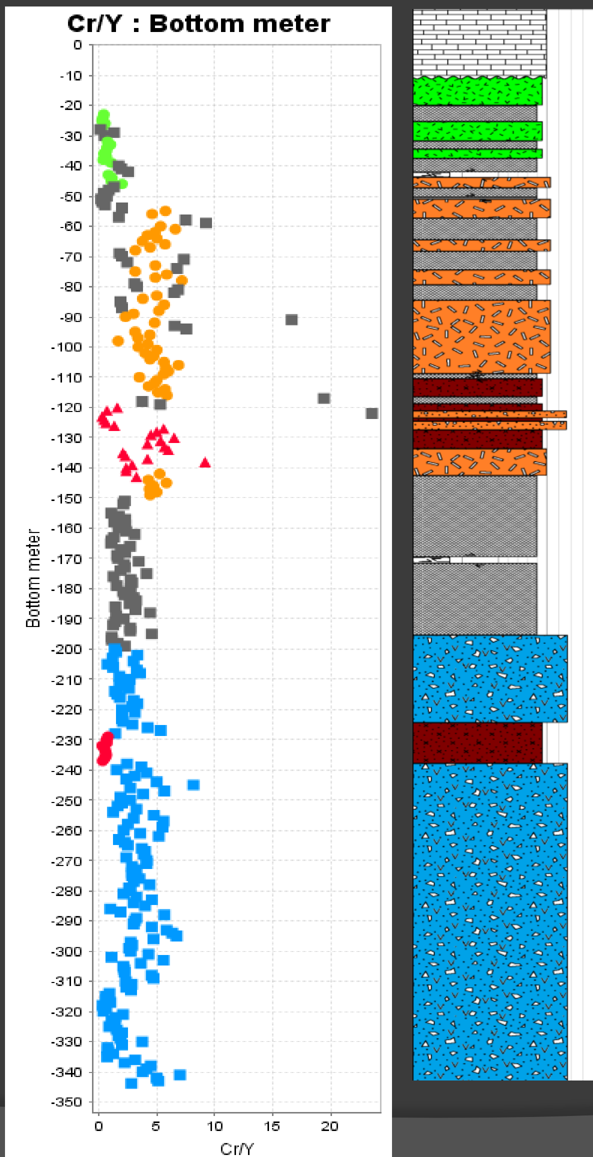


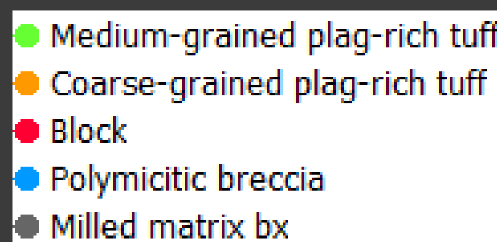
11WKUD007



High resolution whole rock geochemistry with detailed core-logging

11WKUD008





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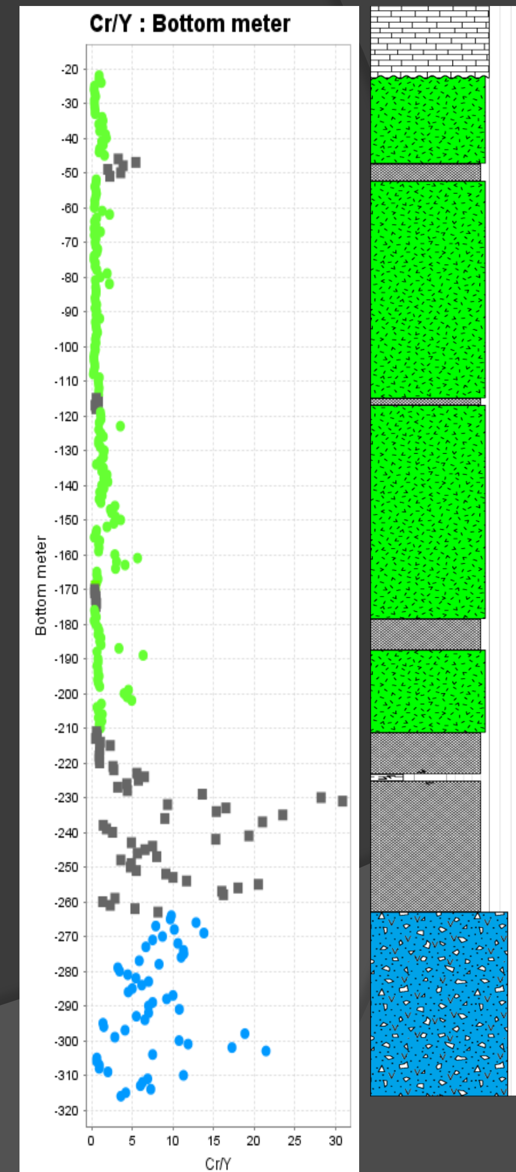
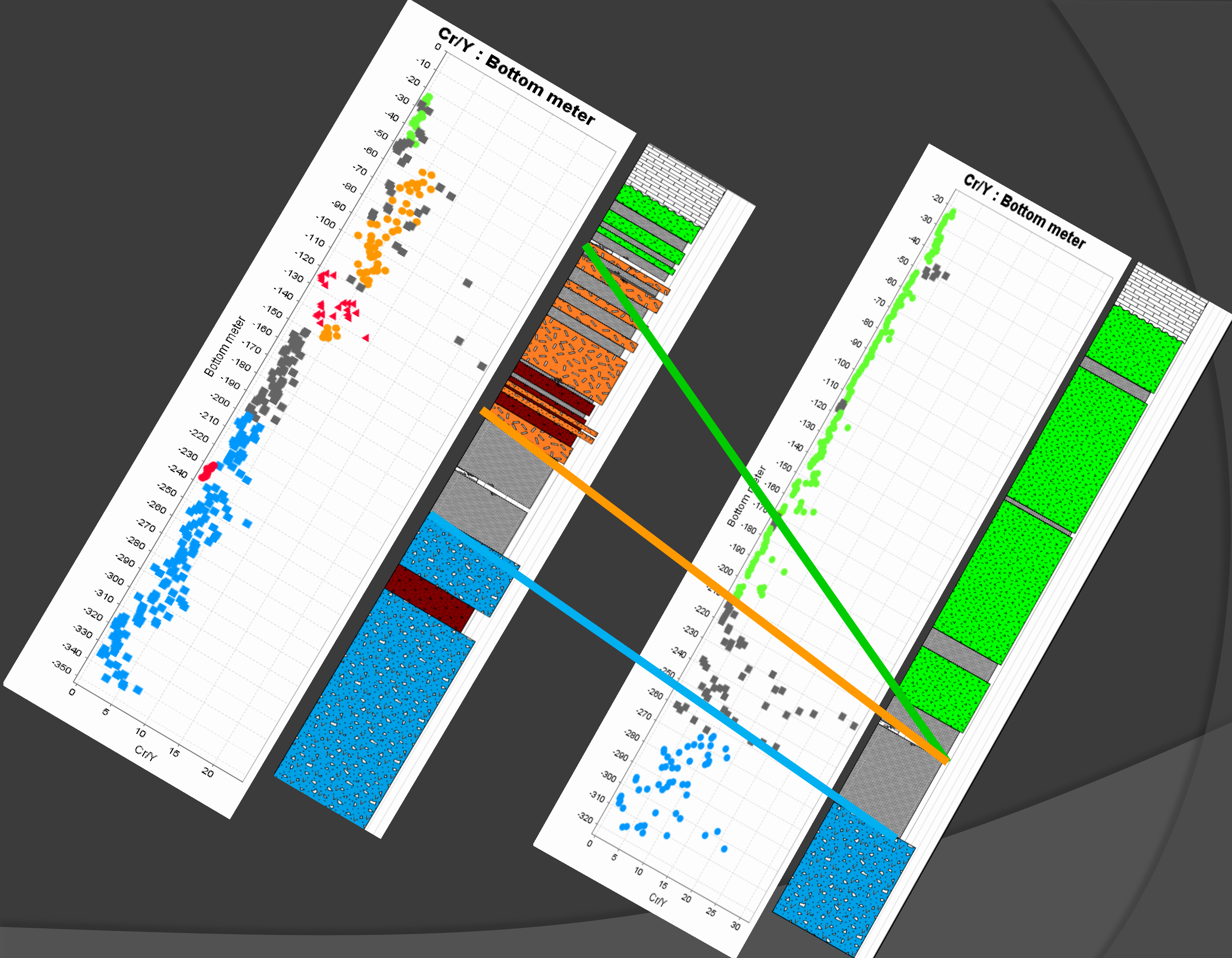
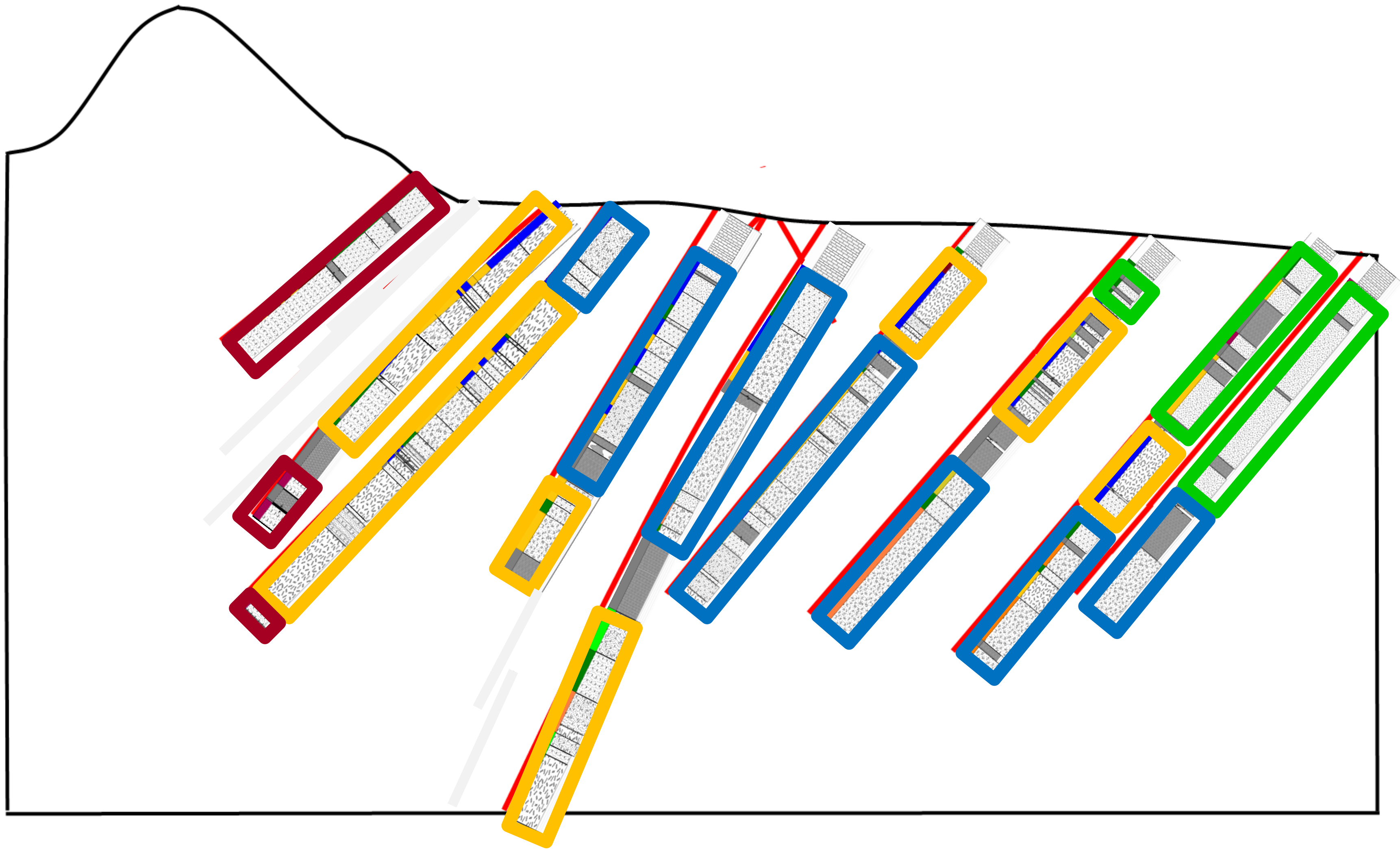



Cr/Y : Bottom meter
Bottom meter
Cr/Y
Cr/Y : Bottom meter
Bottom meter
Cr/Y

Chemostratigraphy outcomes

- Stratigraphy is a complex, numerous altered rock types throughout the deposit.
- Geochem can differentiate mafic blocks within breccias to differentiate epiclastic package from polymictic package
- Changes in rocktypes can than be evaluated to determine what is the nature of the fault.

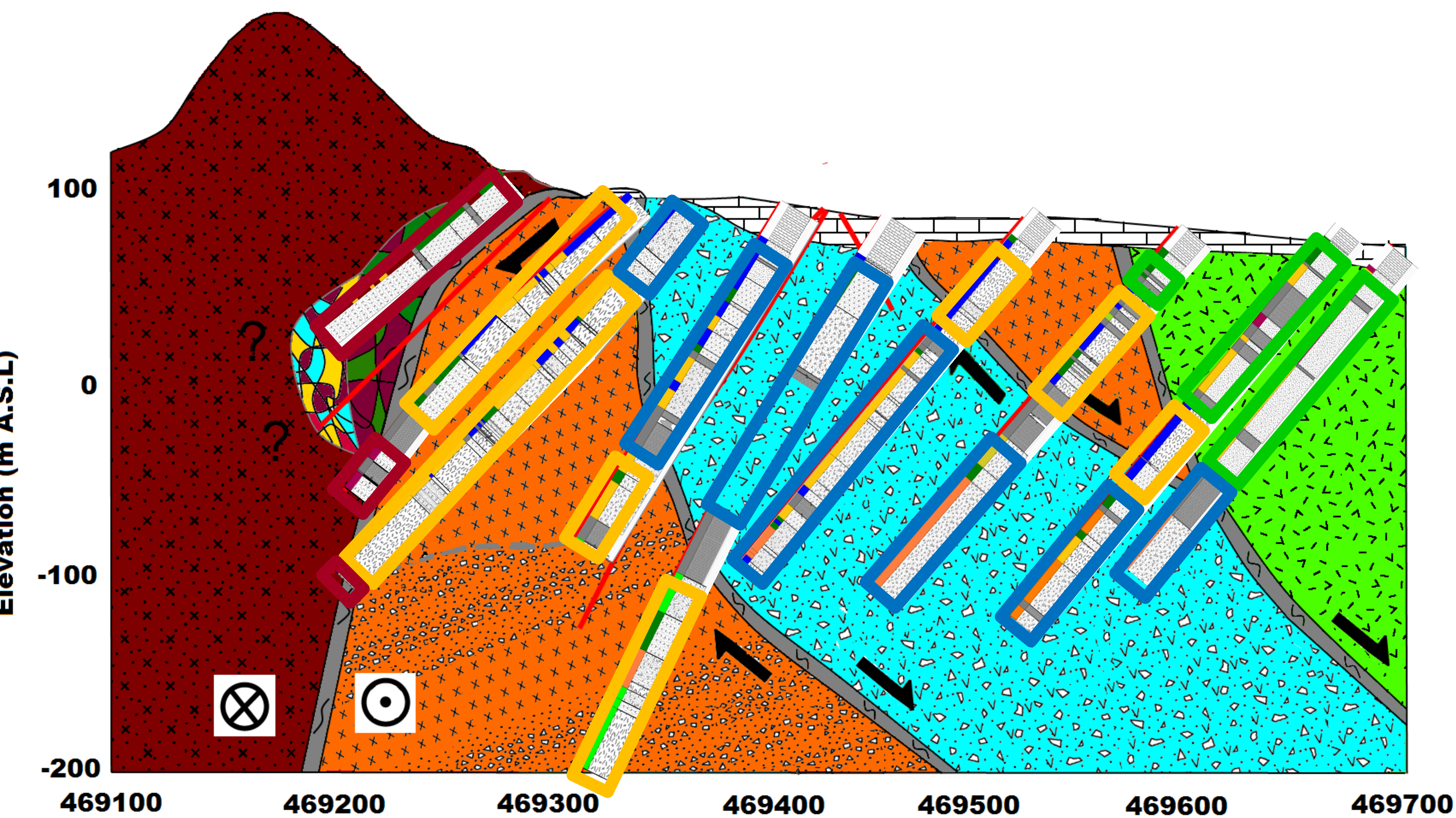


Mafic tuff

Polymictic breccia

Coarse-grained plag-rich tuff

Medium-grained plag-rich tuff(chl)



Mafic tuff

Polymictic breccia

Coarse-grained plag-rich tuff

Medium-grained plag-rich tuff(chl)

Alteration facies – rock buffered (meteoric derived)

- Propylitic chlorite: meteoric fluids distal to mineralisation
- Propylitic hematite: meteoric fluids proximal to mineralisation

Propylitic chlorite
Chlorite-quartz+/-calcite+/-pyrite

Propylitic hematite
Hematite-chlorite+/-calcite

Alteration facies – fluid buffered (magmatic dervied)

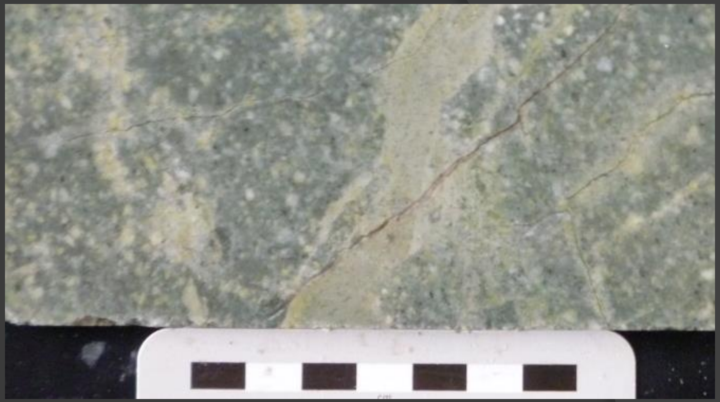
- Argillic alteration restricted to milled matrix breccia and adjacent wall rock
- Phyllic alteration forms envelops to argillic alteration at high levels

Argillic
Chlorite-quartz-illite +/-adularia+/-anhydrite

Phyllic
Illite-quartz-pyrite

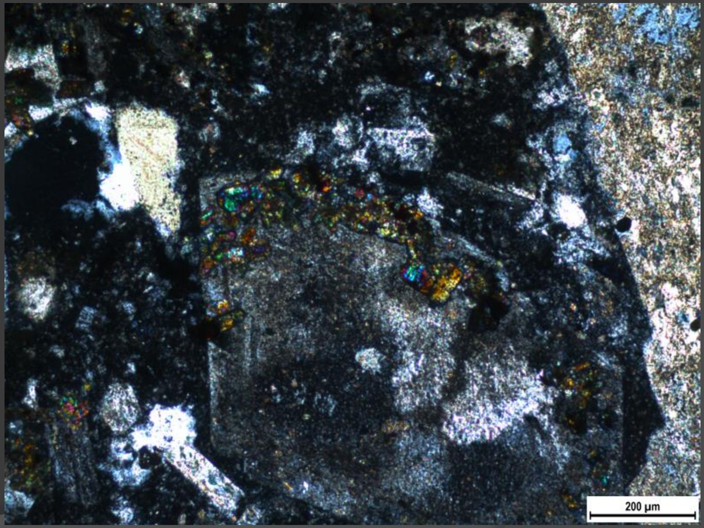
Alteration facies – fluid buffered (magmatic dervied)

- K-spar and epidote alteration typically deeper level alteration



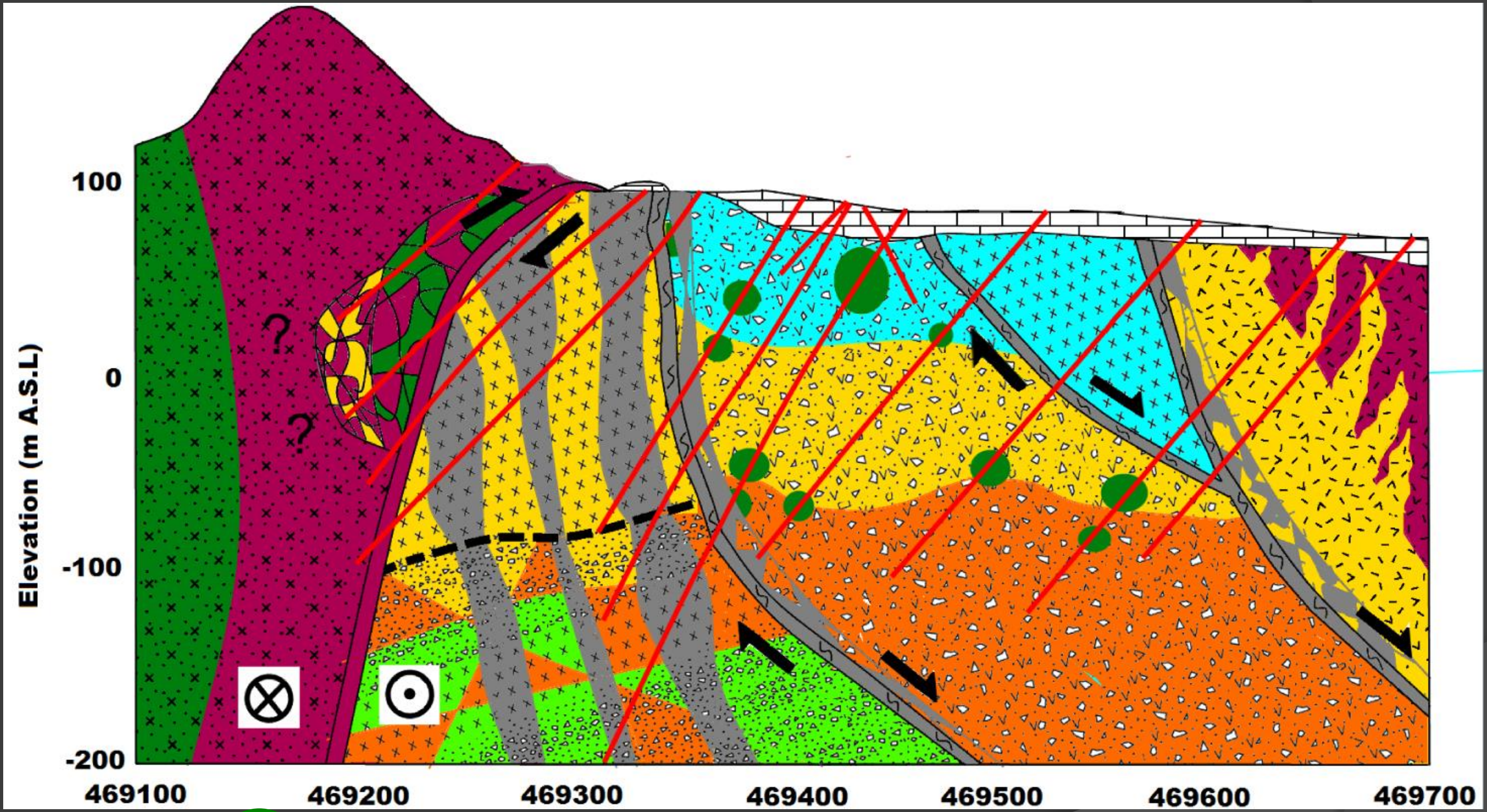
Epidote
Epidote-quartz+/-adularia

K-spar
Adularia-chlorite-quartz+/-illite+/-epidote



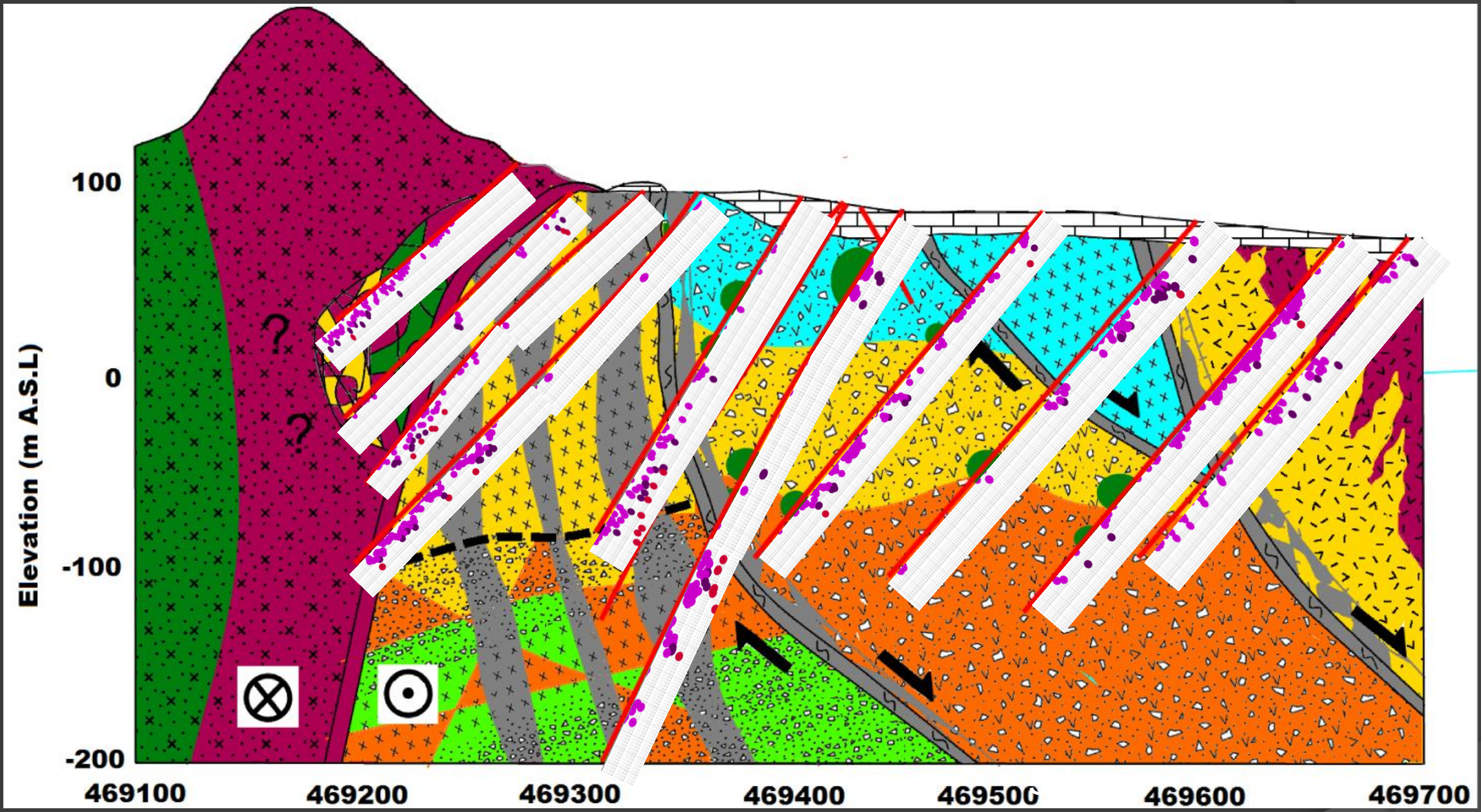
Epidote after plagioclase

Alteration model – Long Section



Prop (chl)
Phyllic
Silicic
Argillic
Prop (hem)
K-spar
Epidote

Linking alteration to grade



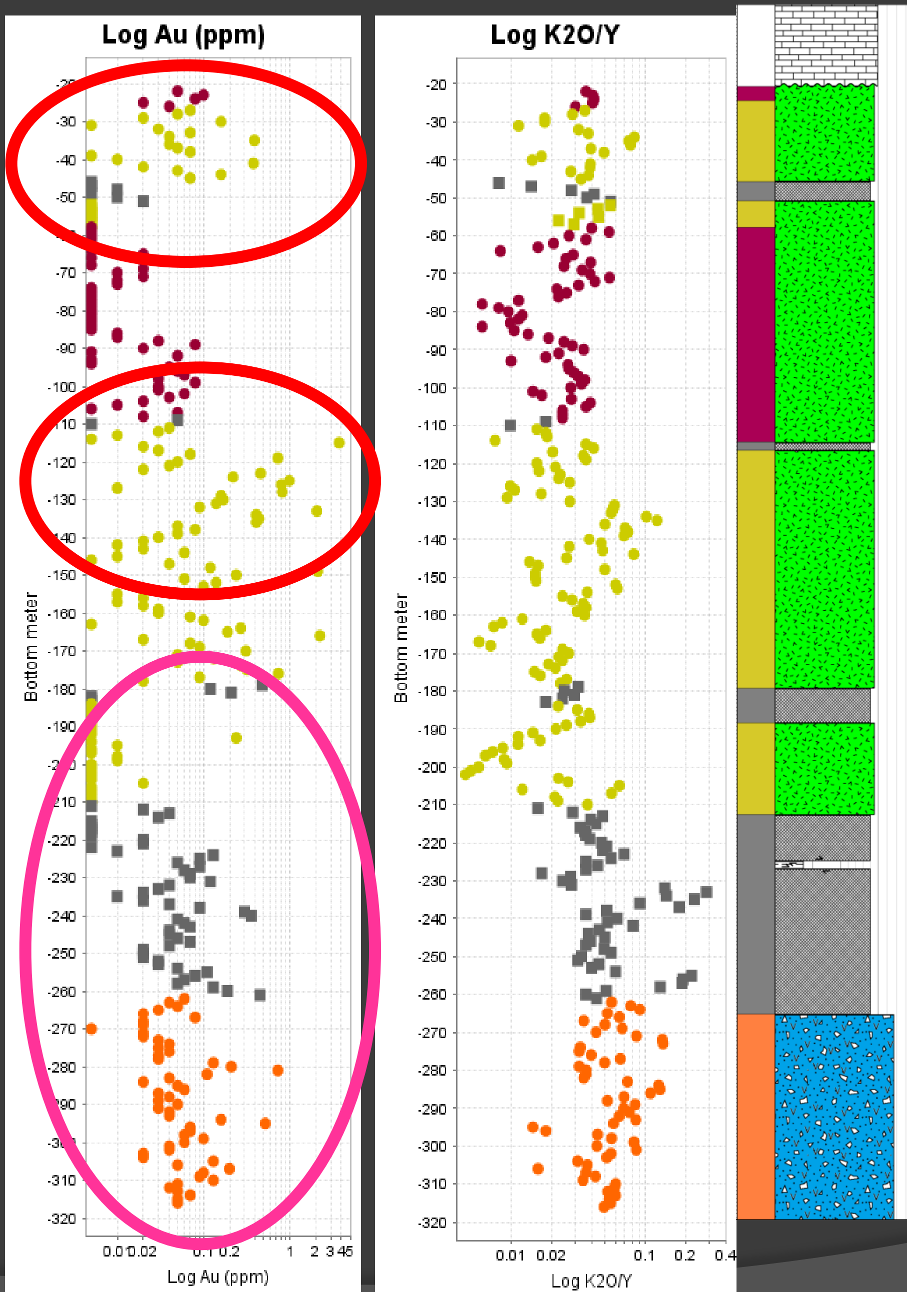
Grade

- 0.25 - 1 g/t
- 1 - 4 g/t
- > 4 g/t

Alteration facies

- Prop (chl)
- Prop (hem)
- Phyllic
- K-spar
- Silicic
- Epidote
- Argillic

Fluid Mixing



But zones near the juncture of meteoric derived propylitic assemblages and phyllic/K-spar assemblages host the highest grade… FLUID MIXING!!

Phyllic and K-spar altered zones exhibit elevated Au (> 0.1 g/t magmatic derived fluids)

Prop (chl)

Prop (hem)

Argillic

Phyllic

Phyllic

Fluid mixing – 06BKD038

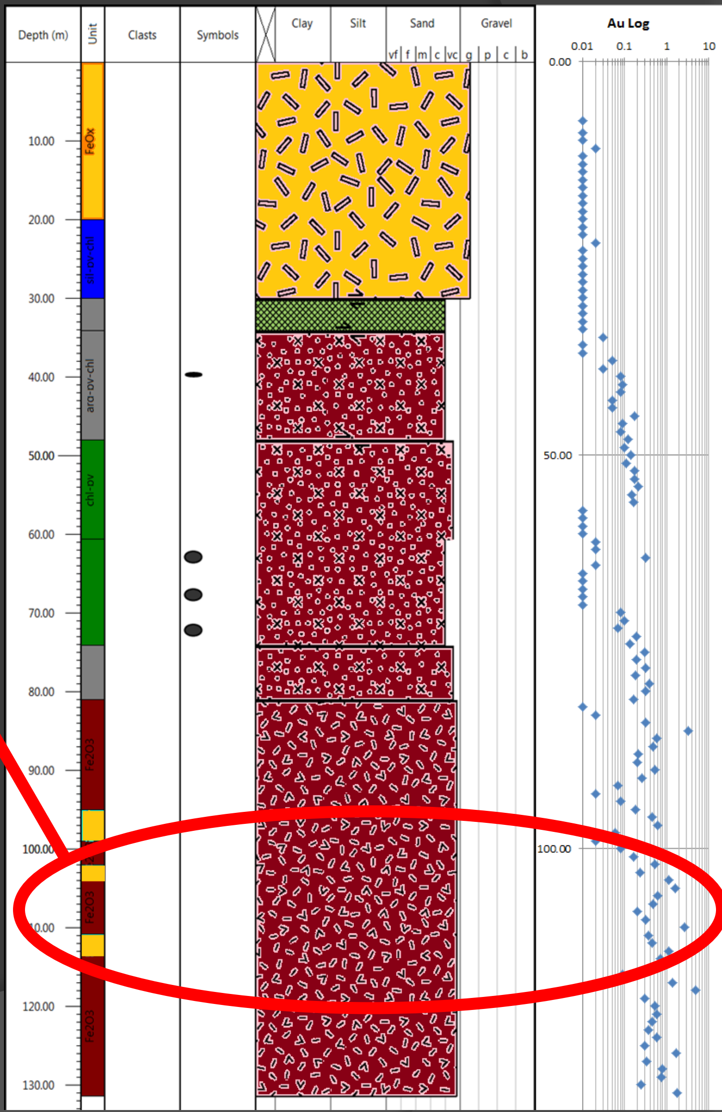
Prop (chl)

Prop (hem)

Argillic

Phyllic

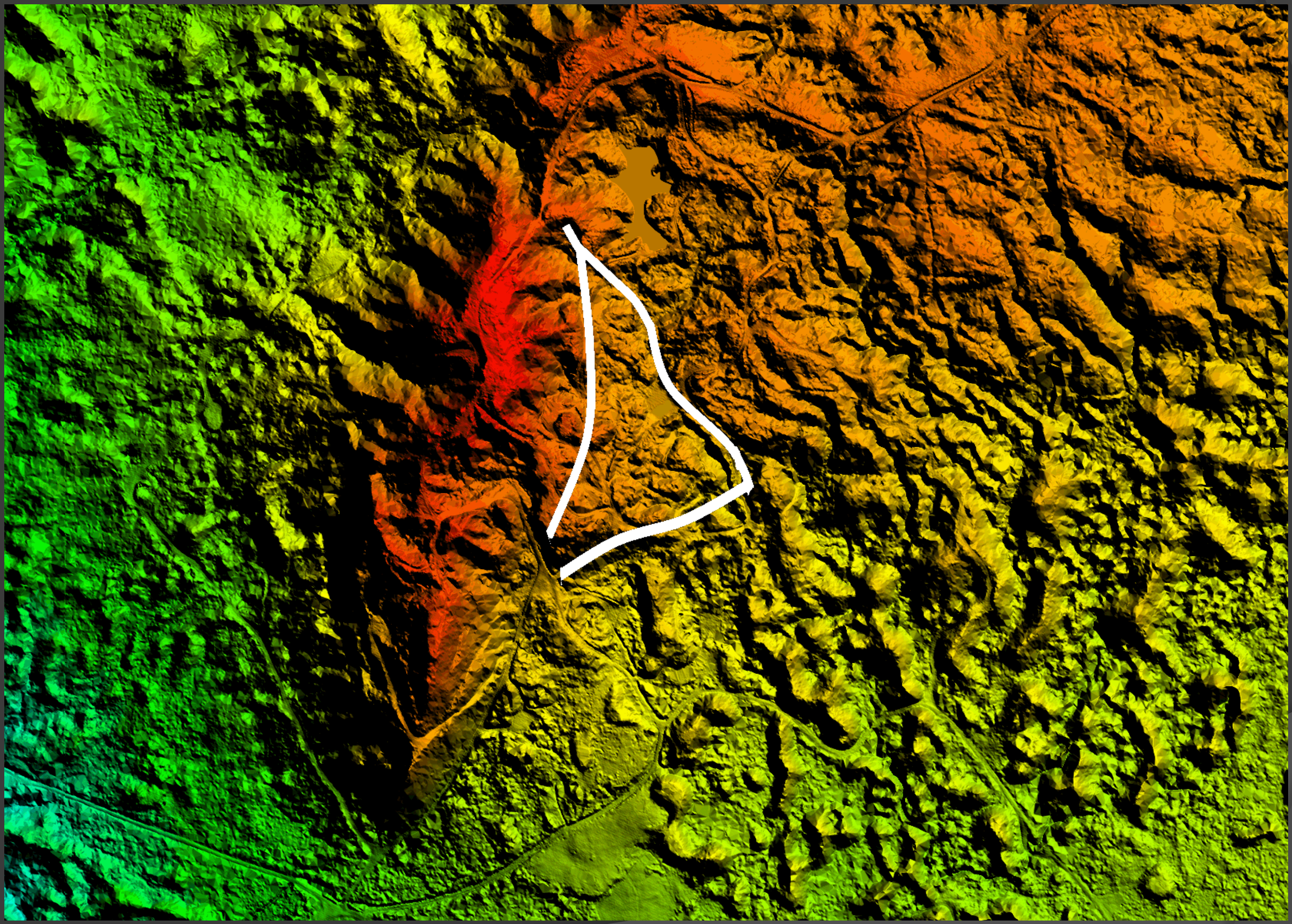
Highest grades at juncture between phyllic alteration and hematite alteration



Mixed hematite phyllic altered zone

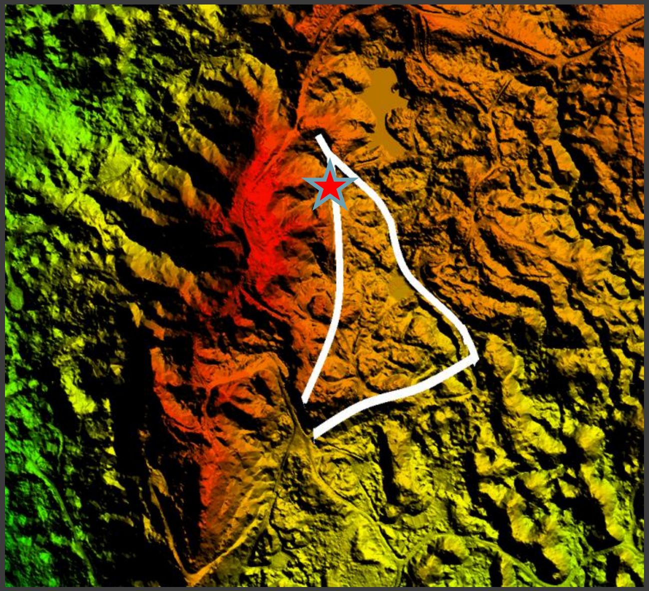
Finally….. Identification of structures - local scale structures!!!

Structures identified in the field



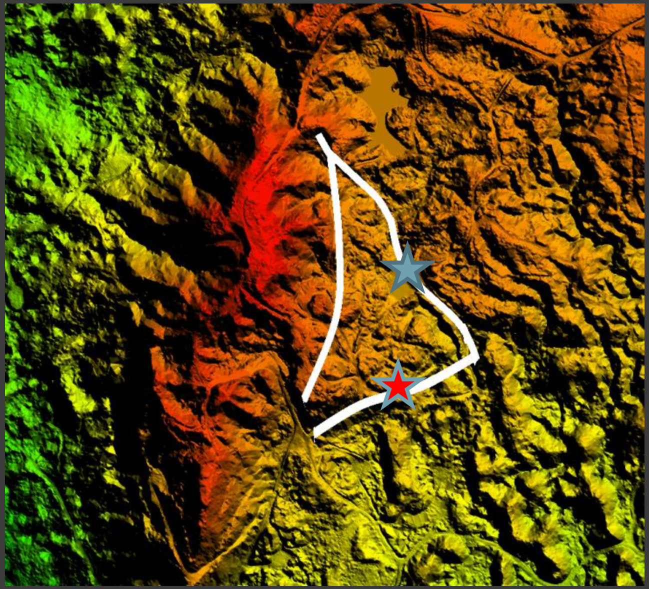
Volcanics thrust over Kiriwina

- Curved nature in LiDAR along strike reflects shallow dip of thrust



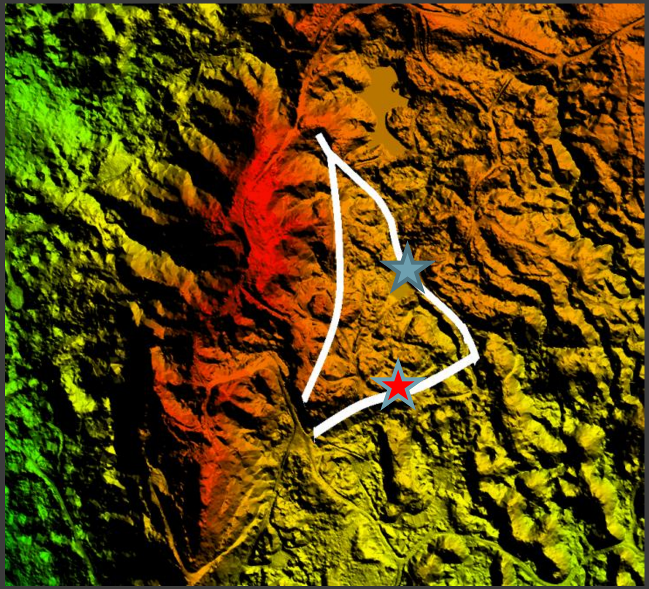
Thrust fault looking South, at least 6 m of throw

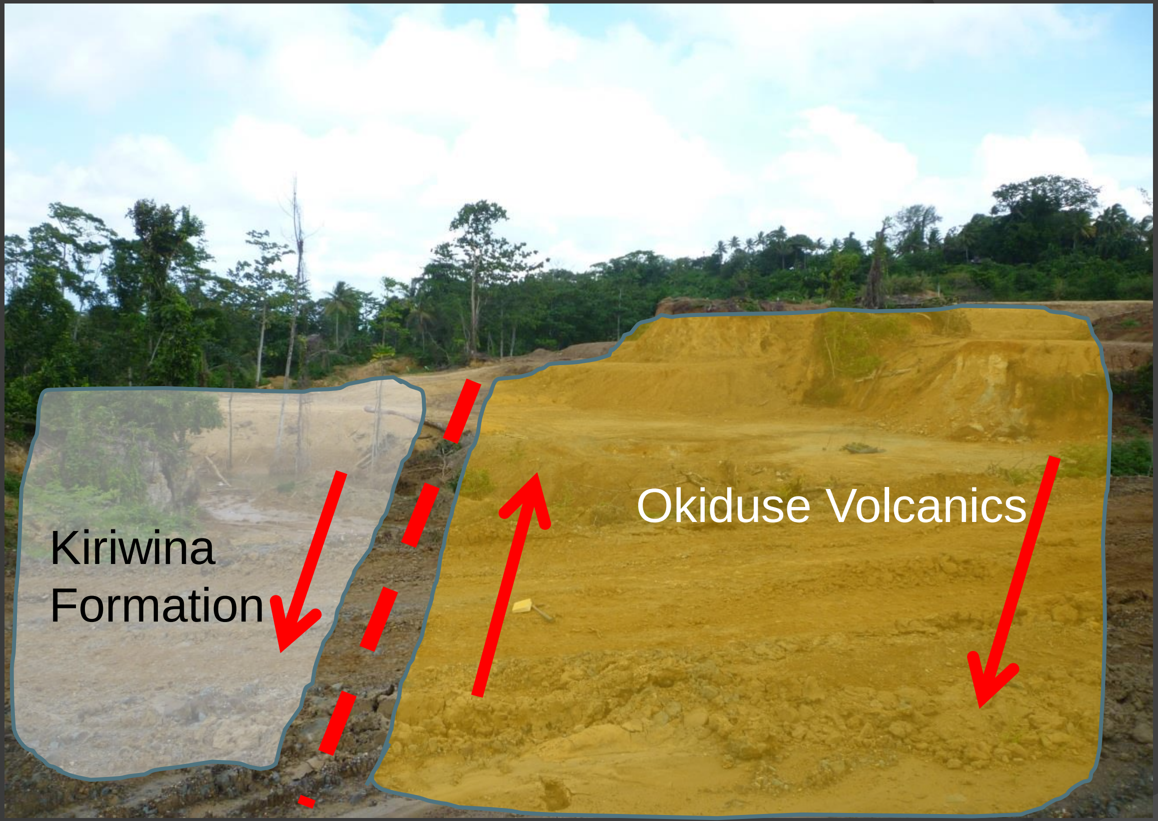
Steeply dipping normal faults



- Looking southwest, bedding in orange unit dipping back towards the west suggesting rotation of fault blocks
- Not as curved in LiDAR imagery suggesting a step dip along strike

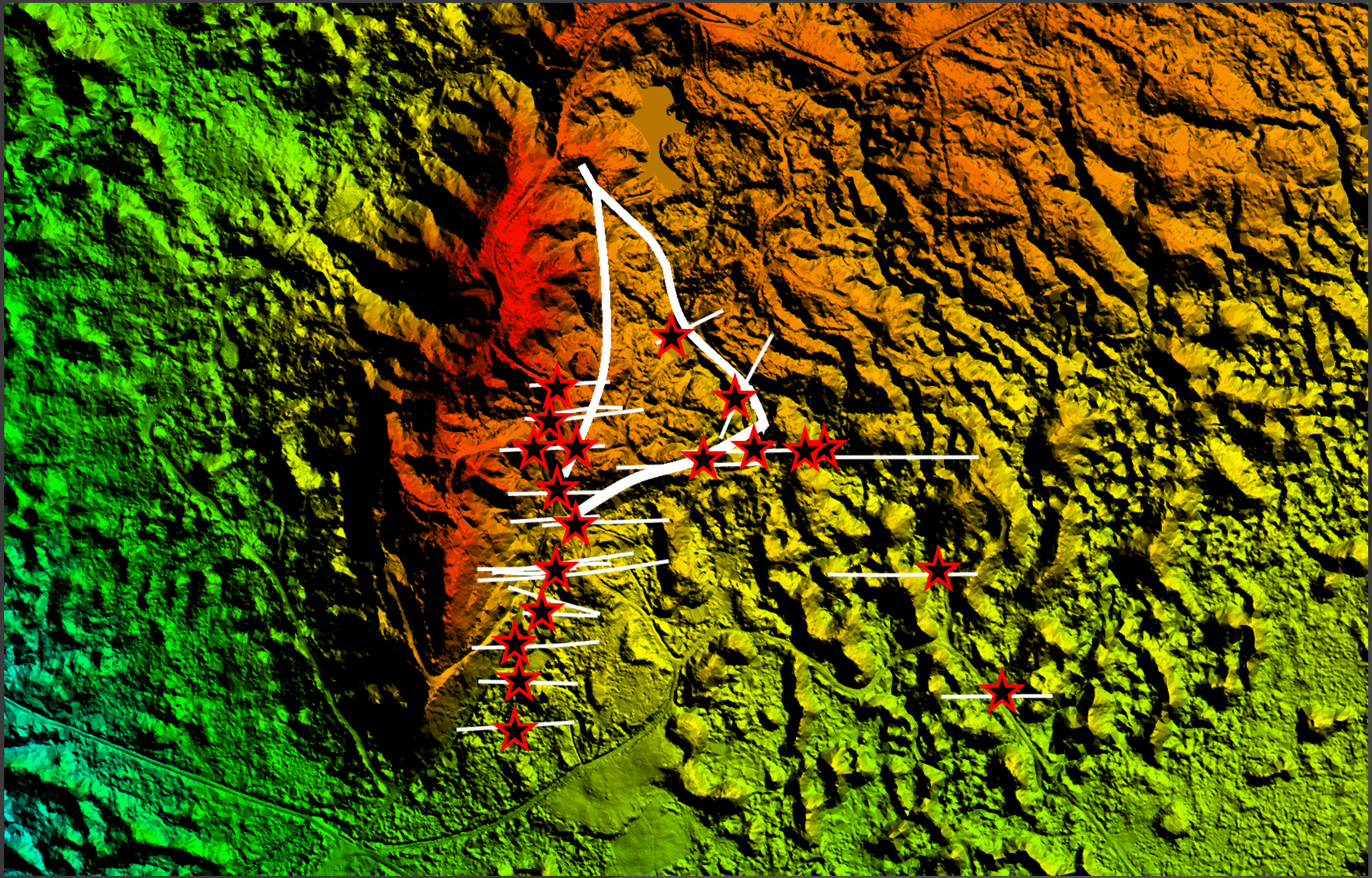
Steeply dipping normal faults



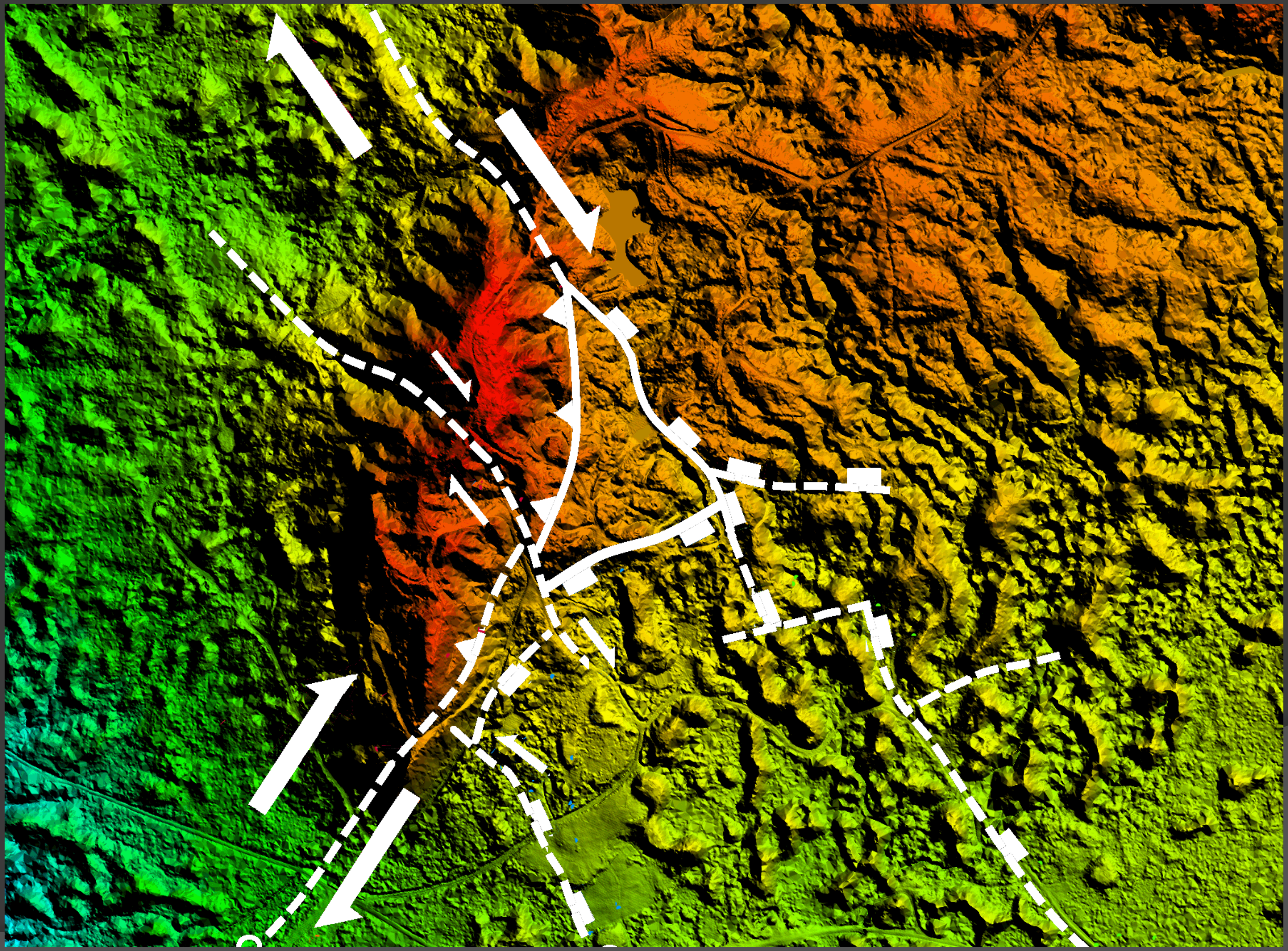


- Looking southwest, bedding in orange unit dipping back towards the west suggesting rotation of fault blocks
- Not as curved in LiDAR imagery suggesting a step dip along strike

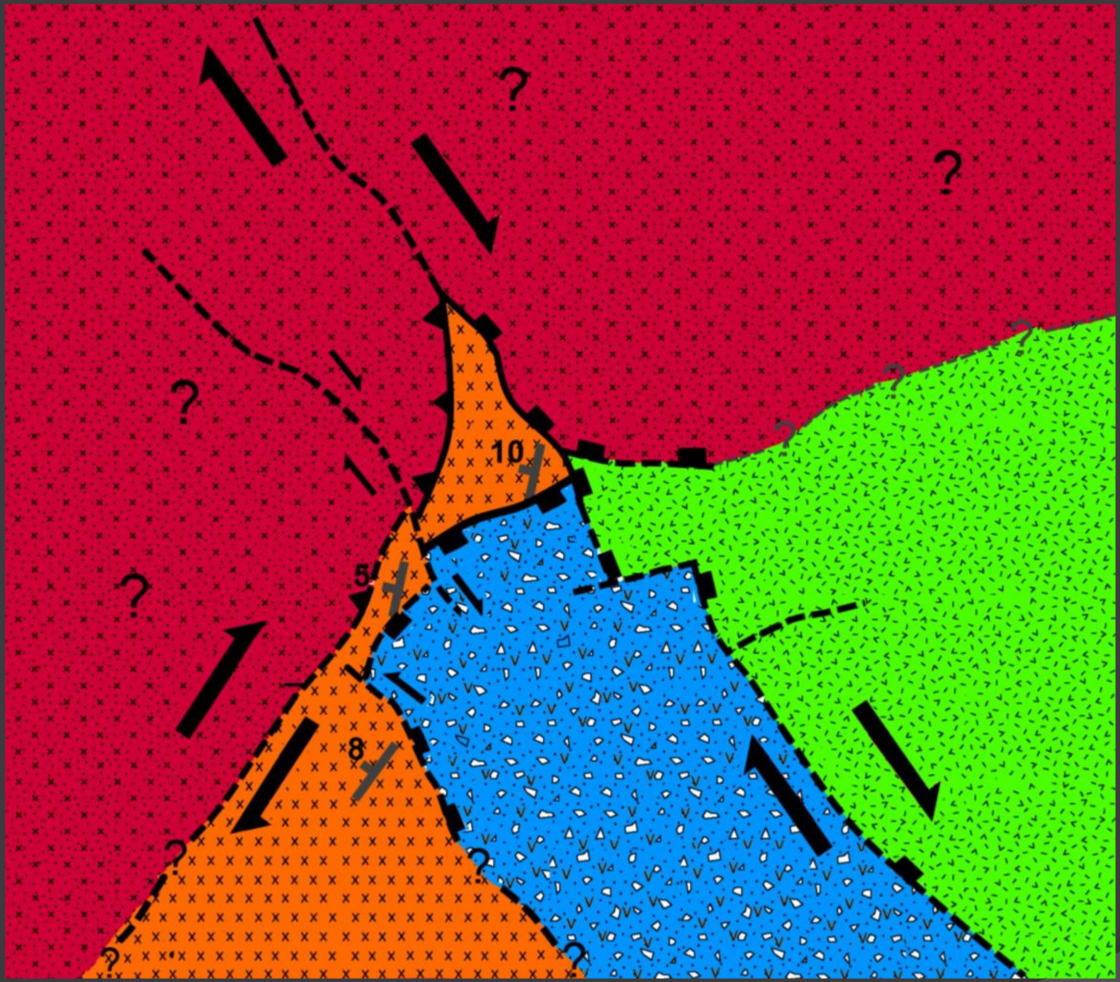
Significant Faults identified in drill core… after chemostratigraphy



Projecting structures and extrapolating structures using Lidar



Structure and lithology



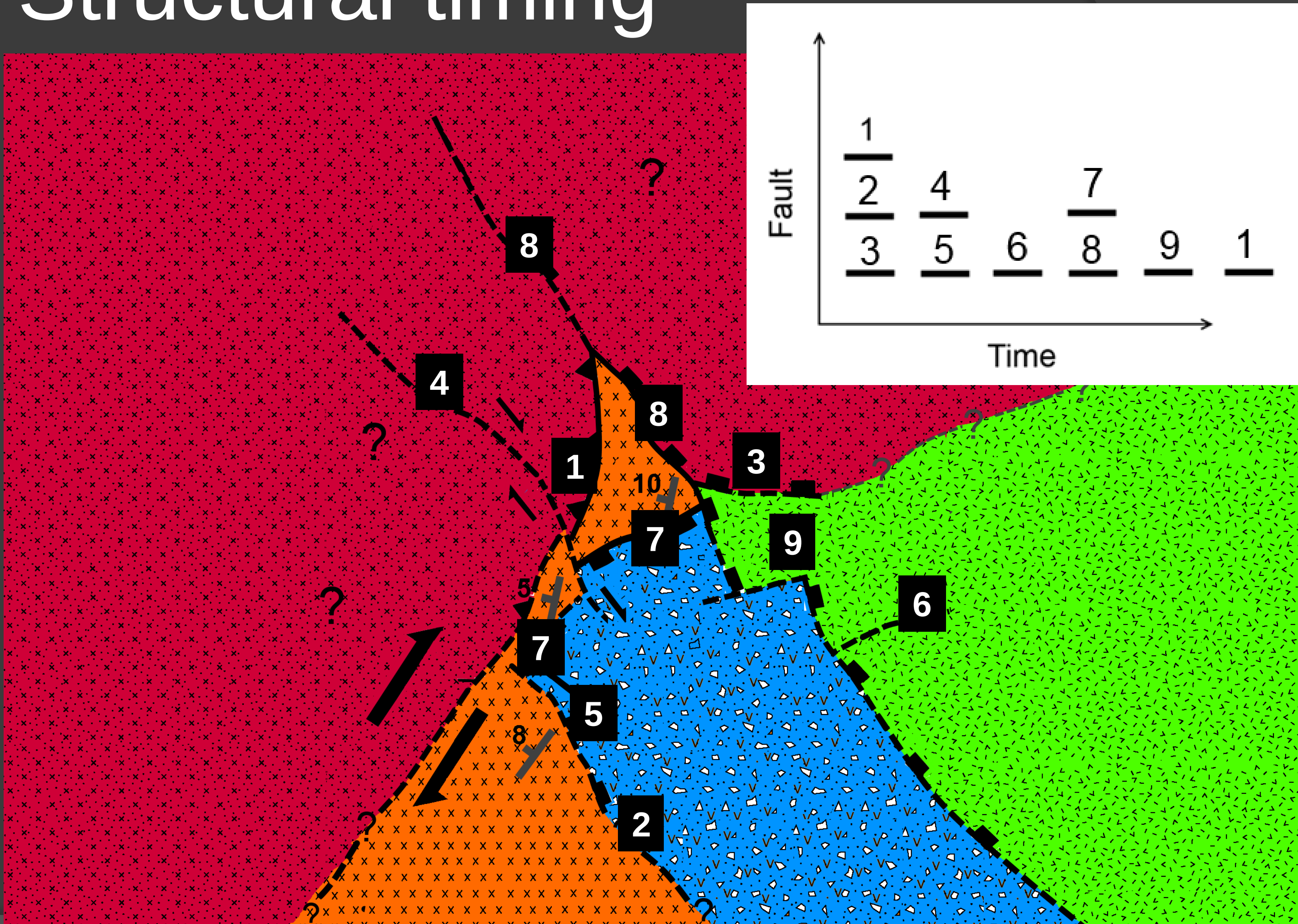
Mafic tuff

Coarse-grained plag-rich tuff

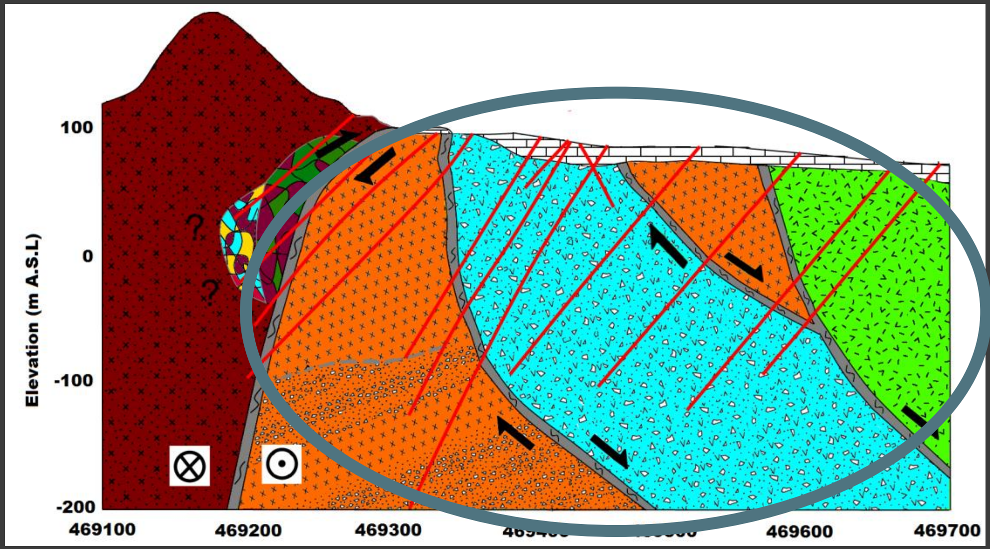
Medium-grained plag-rich tuff

Polymictic breccia

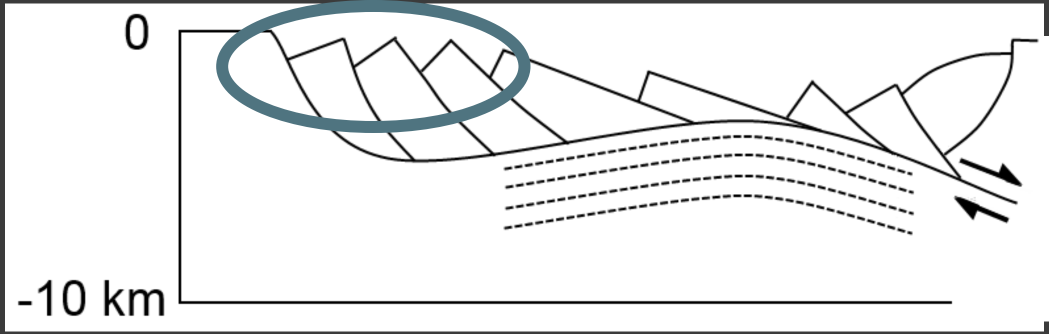
Structural timing



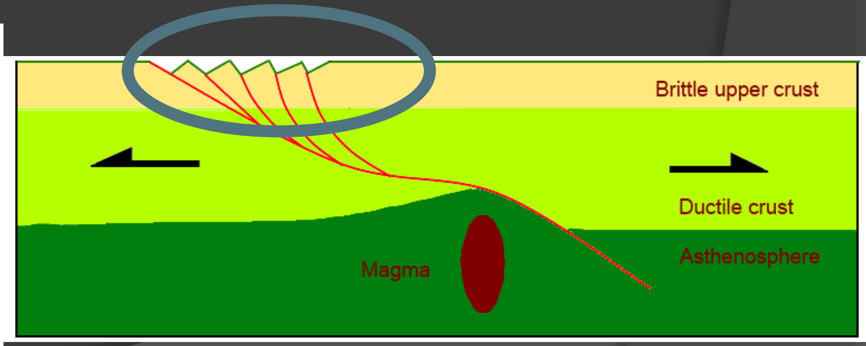
Early extension: asymmetric listric normal faulting



- Evidenced by dips of rock-types in drill core
- Steep nature of the faults

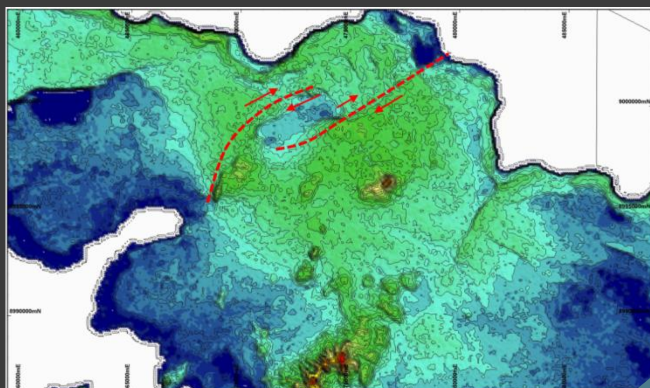


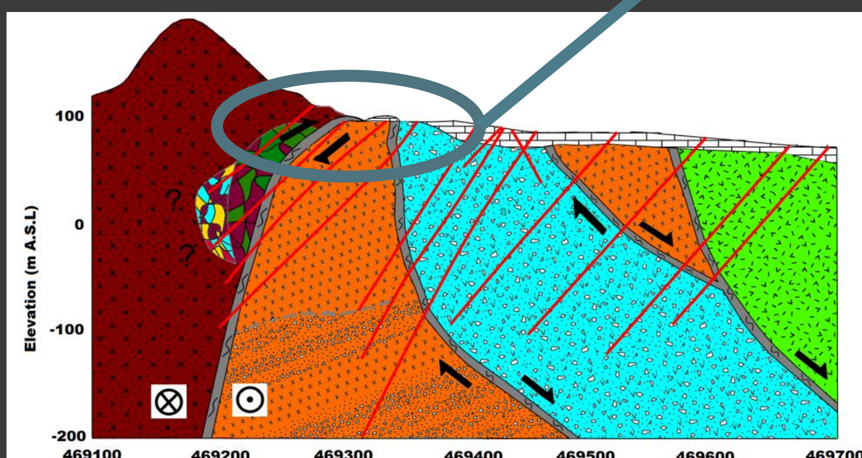
Rolling hinge detachment (Gessner *et al.* 2001)

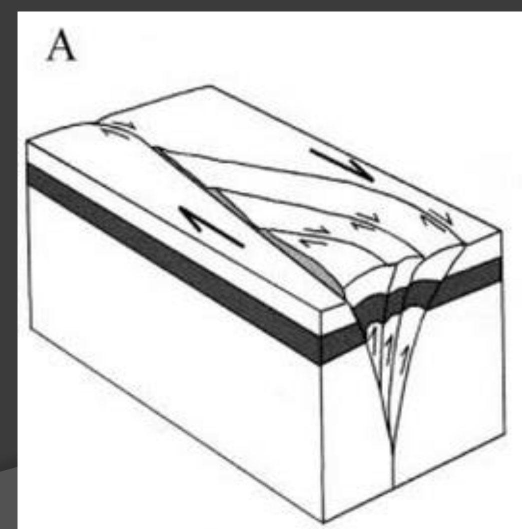


Wernicke simple shear model (www.le.ac.uk)

Recent thrust faulting related to positive flower structure parallel to Nubara fault



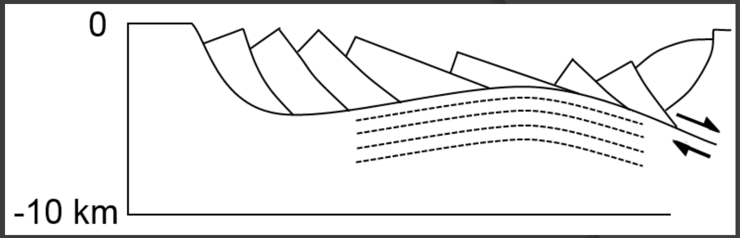


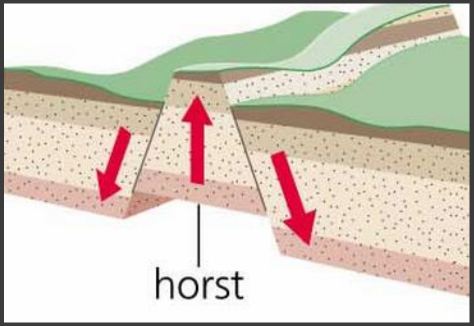


www.maps.unomaha.edu

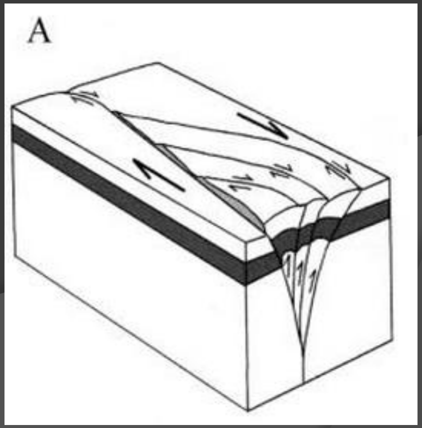
Structural Timing

- Early asymmetric listric normal faulting
- Compressional tectonics responsible for uplifted horst block post Pleistocene (Kiriwina Formation).
- Later compression post Kiriwina responsible for pull apart structure parallel to Nubara fault (flower structure thurst faulting)





www.answers.com



Questions?