SCIENTIA
MANU ET MENTE

KULA GOLD

WHITE ROCK Minerals Ltd

OLYMPUS®

Use of Portable X-ray Diffraction (pXRD) in the quantitative assessment of mineral systems during routine exploration

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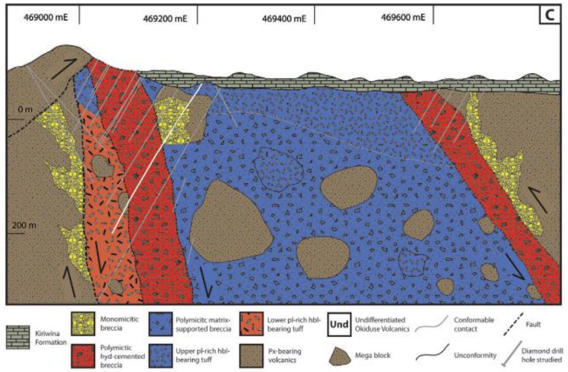
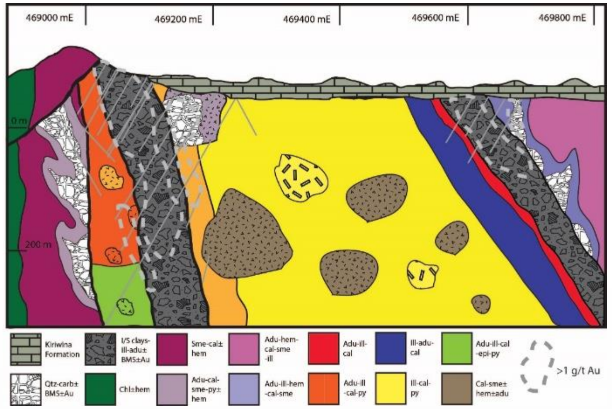
Agenda

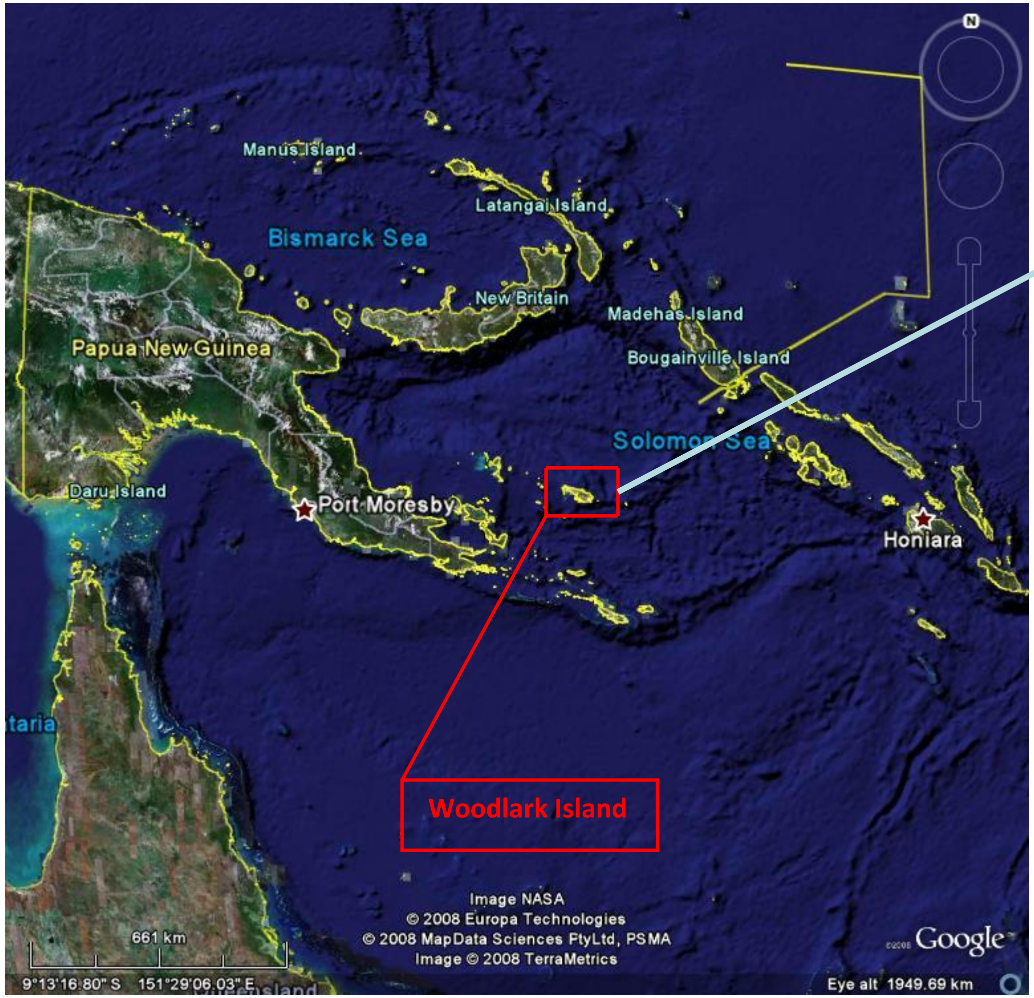
- Study area
  - Why quantitative mineralogy was utilised
- What is XRD?
- Conventional XRD instruments
- Portable XRD
- Verification of portable XRD
- Implications
  - Kulumadau, Woodlark Island, PNG
  - Drake Goldfield



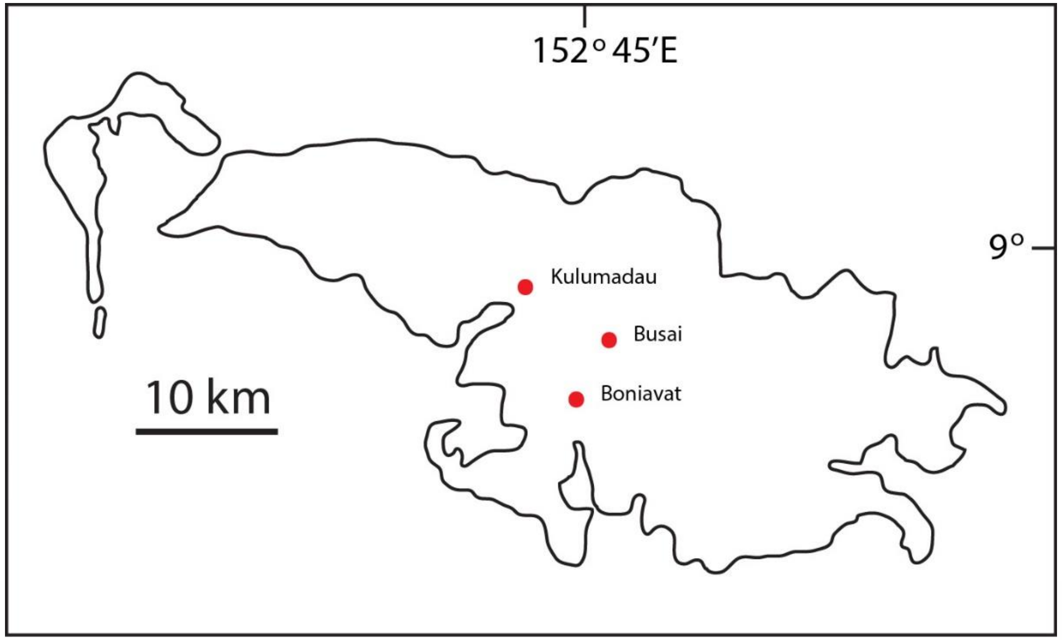


Woodlark Island – Location

~ 650 km east of Port Moresby



70 km by 30 km



History of Woodlark Island

- Alluvial gold first discovered on Woodlark in 1894, hard rock mined in 1899
- By 1910, contributed over 43 % of all gold mined in PNG
- Kulumadau was the first continuous hard rock mine in PNG, produced 80,000 ounces
- Mining lease granted
- Little to no research conducted by universities or industry

Visible gold 04BKD003 – 282 m

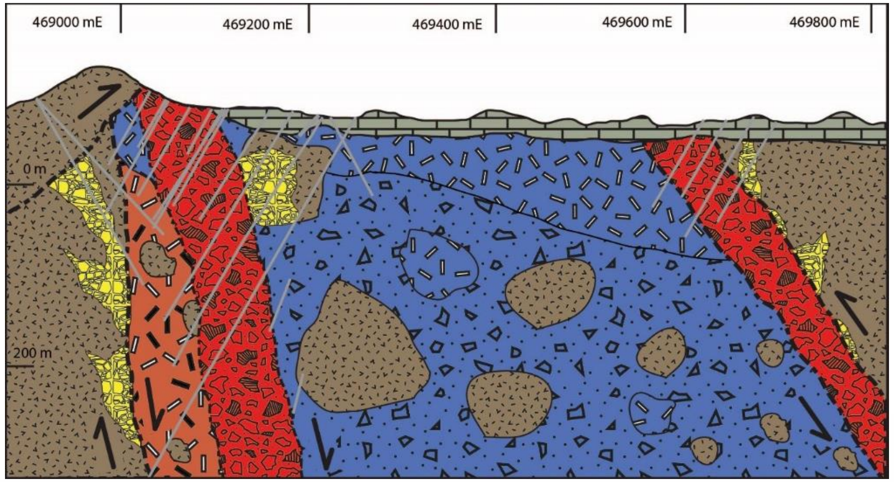
Kulumadau Mine 1912

Kulumadau in operation

Mineralisation – Kulumadau

- Low-intermediate sulfidation deposit with base-metals (chalcopyrite, sphalerite, galena), low As and subordinate Te
  - Could not use As as a pathfinder for Au
- Gold fineness (Au:Ag): based on bulk grade 1:<1, based on microprobe 4:1
- Mineralisation hosted in sub-vertical lenses of poorly-consolidated polymicitc breccias transitional to monomicitc breccias/veins. No coliform banding.

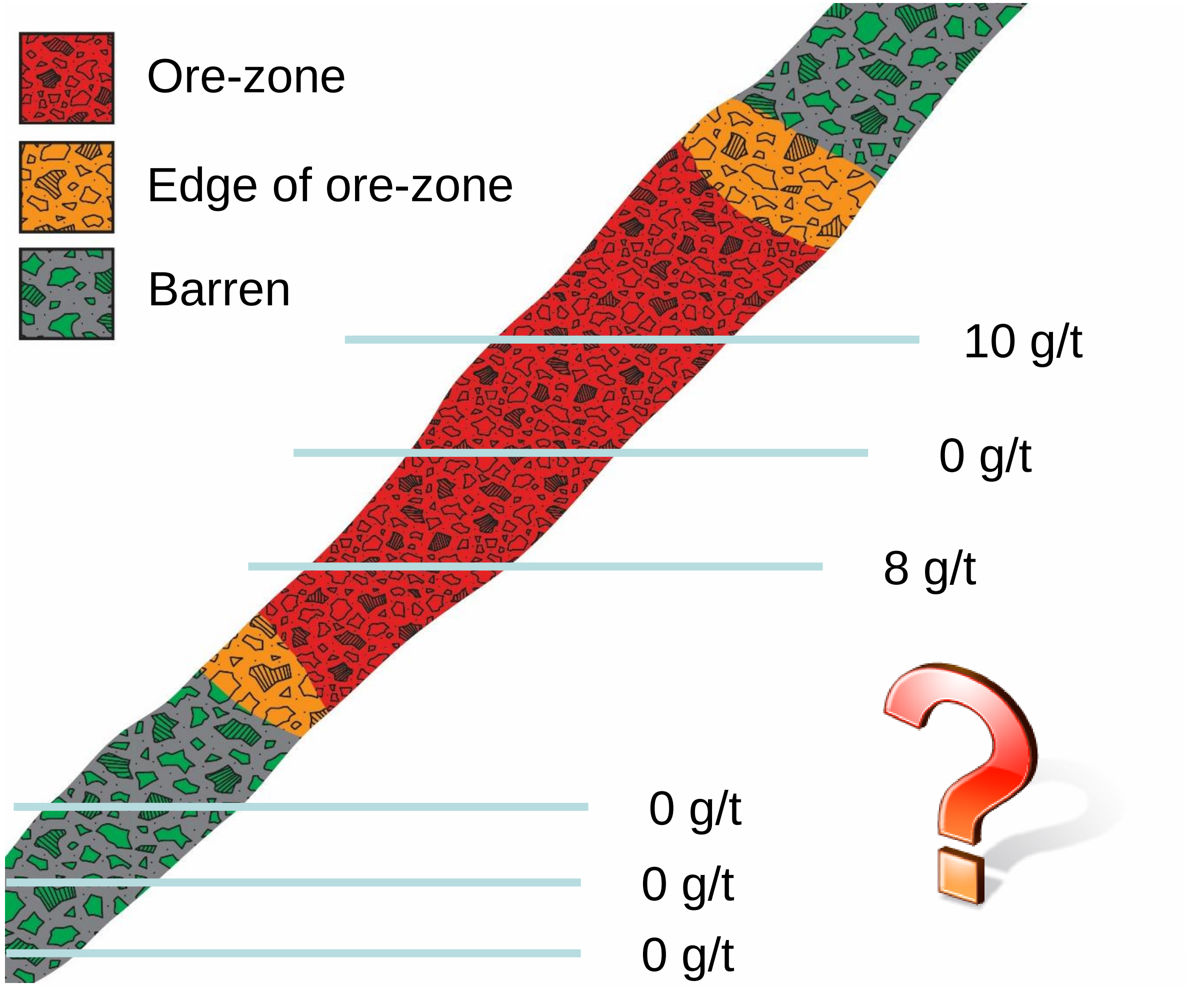
Polymictic breccia lense from the Adelaide Lode



Polymicitic hydrothermal breccias (bulk of the ore)

Monomicitic hydrothermal breccias and veins: quartz-calcite±ankerite±cpy±gn±sph±Au

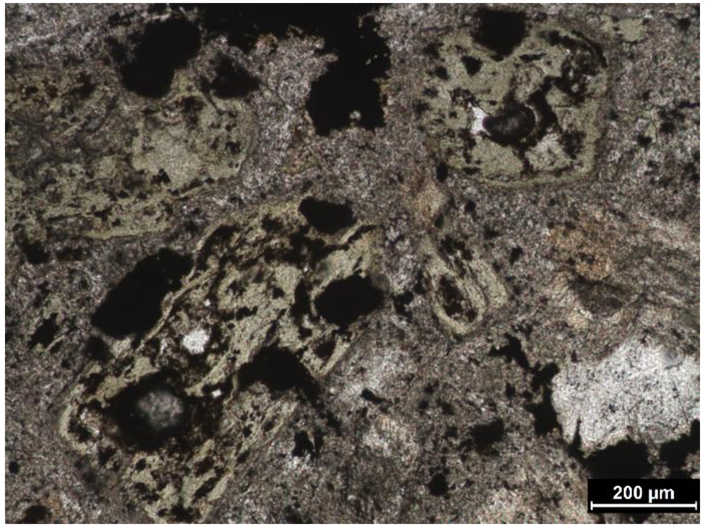
Why is mineralogy important?



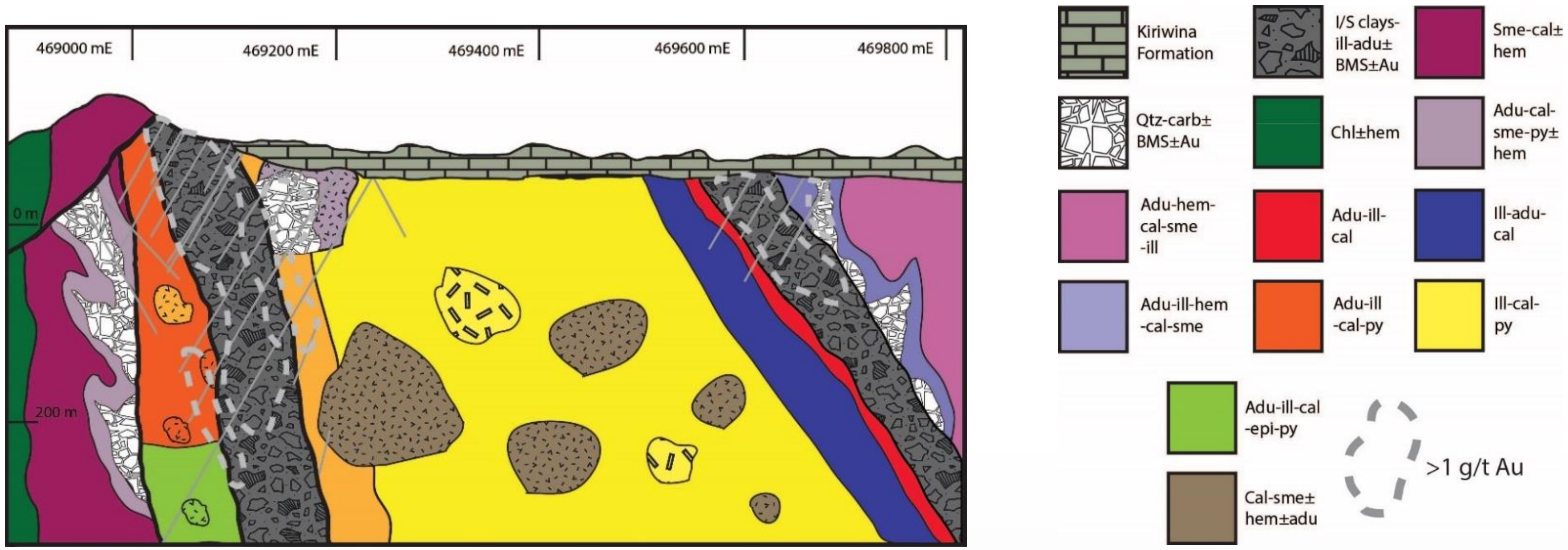
Assay data can take weeks to months to get back

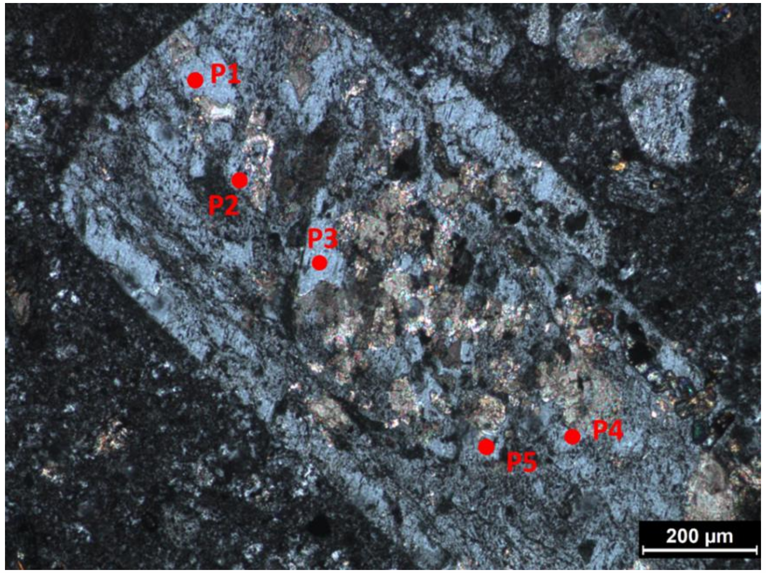
Wall-rock alteration

- Alteration vectors
  - Rock buffered minerals
    - Isochemical: e.g. chlorite after pyroxene
  - Fluid buffered minerals
    - Adularia, no primary K-spar in protolith, therefore K-metasomatism



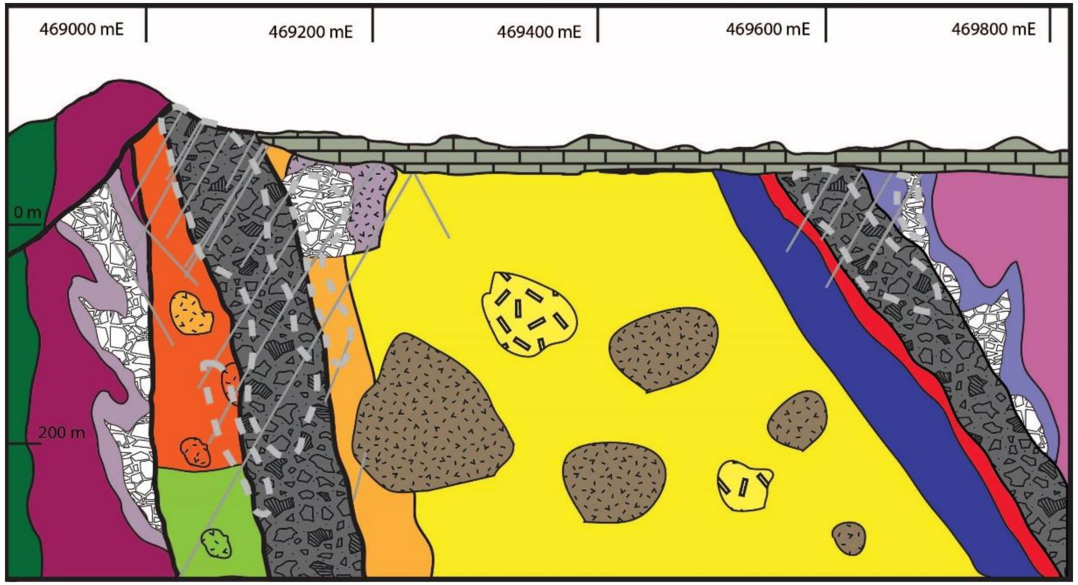
Chlorite after pyroxene



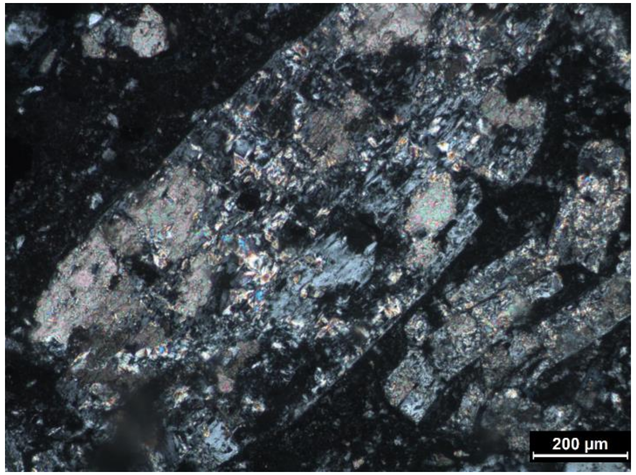


Adularia after plagioclase

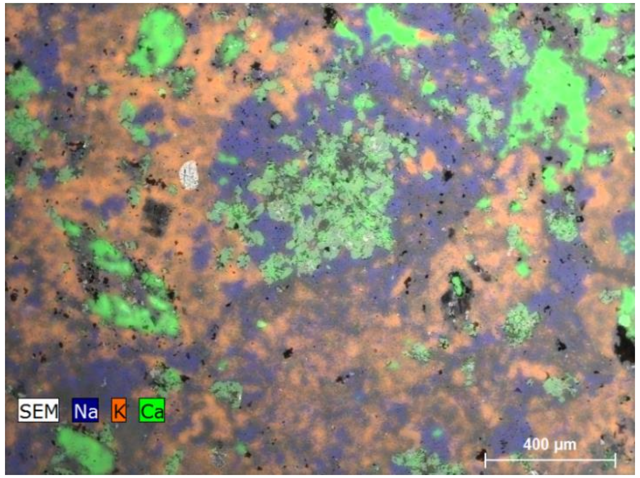
Wall-rock Alteration



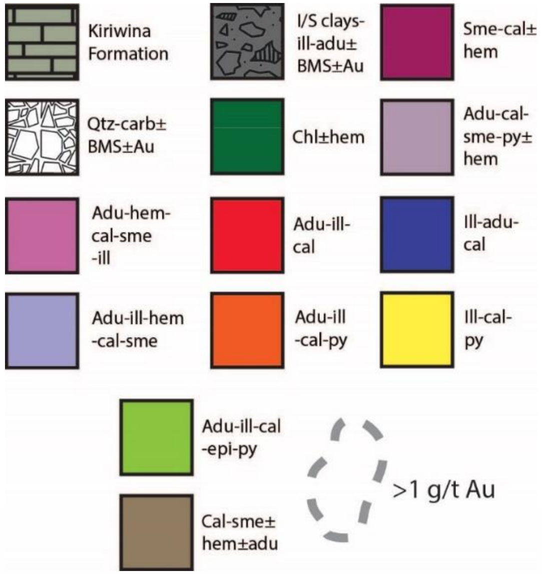
- Rock buffered assemblages
  - Chlorite, smectite, calcite, hematite, **illite**
- Fluid buffered assemblages
  - **Adularia**, ankerite, pyrite and epidote



Calcite and illite after plagioclase

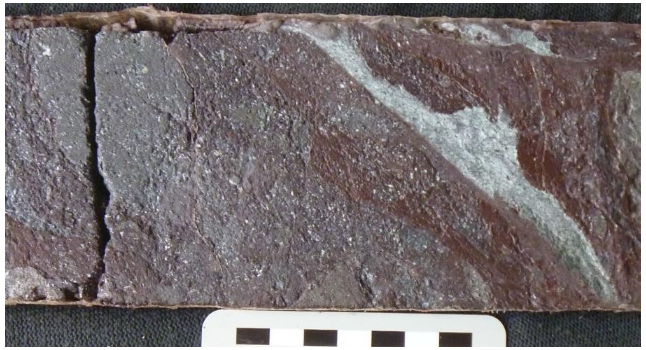


Adularia (orange), epidote (green), albite (blue)

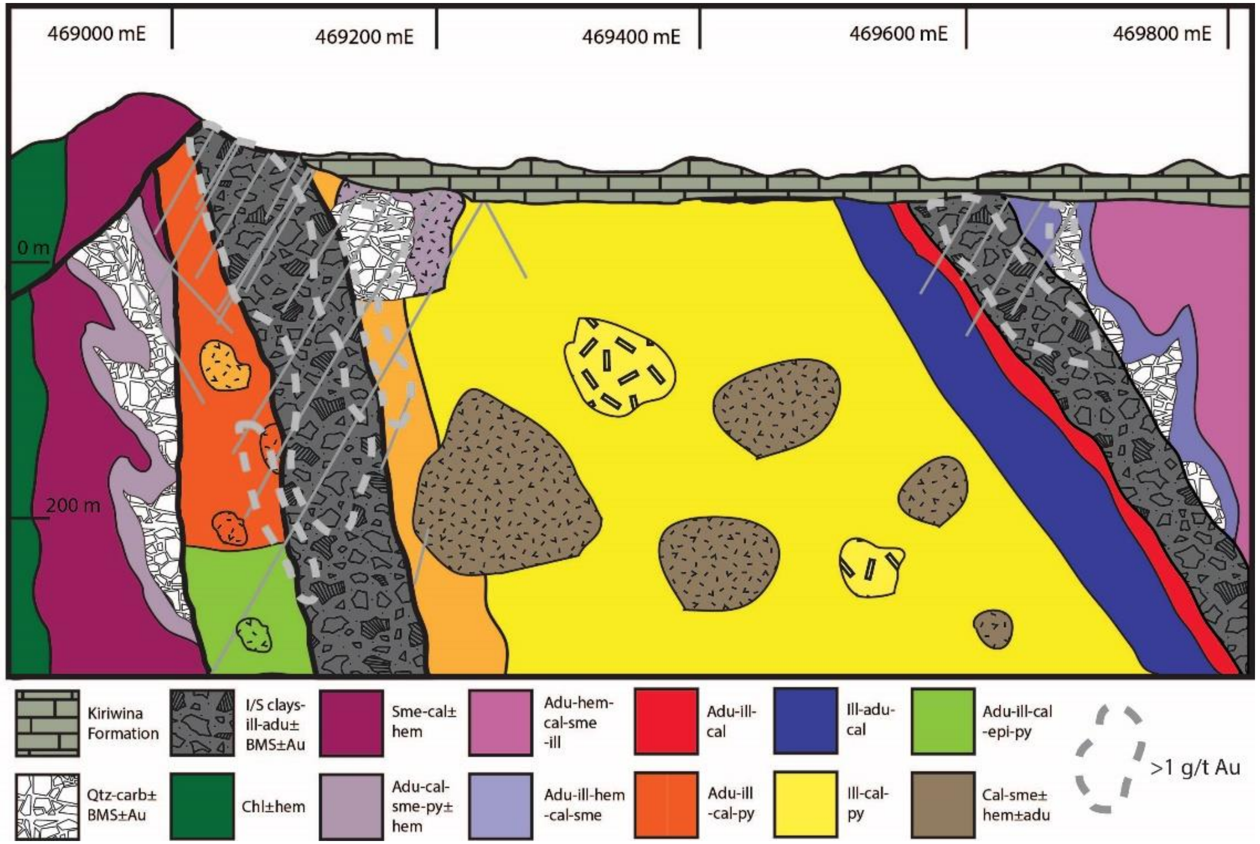


Alteration zonation

Outer propyllitic (chlorite)
Distal to mineralisation
Chlorite-quartz+/-calcite+/-pyrite

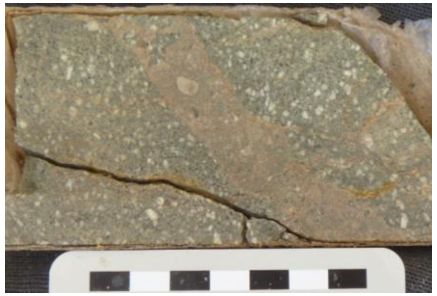


Inner propyllitic (hematite)
Proximal to mineralisation
Hematite-chlorite-smectite+/-calcite



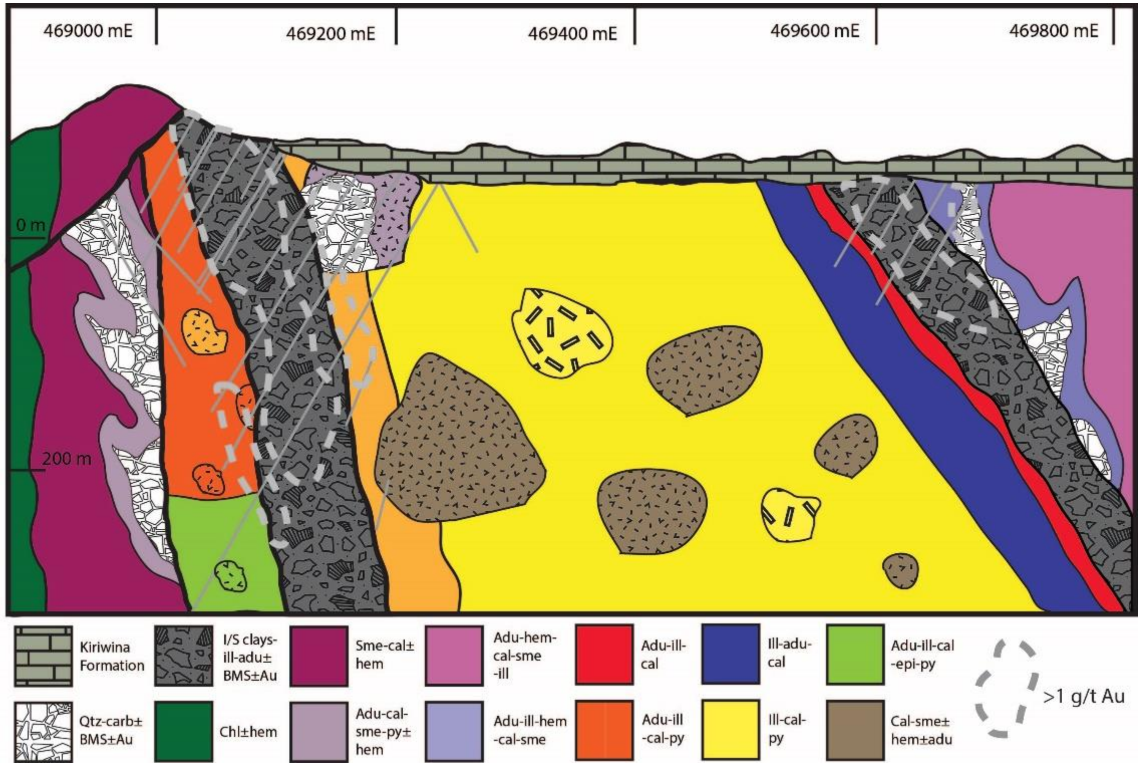
Alteration zonation – fluid to rock buffered

Phyllic
Illite
Rock buffered



Potassic
Adularia-illite-pyrite

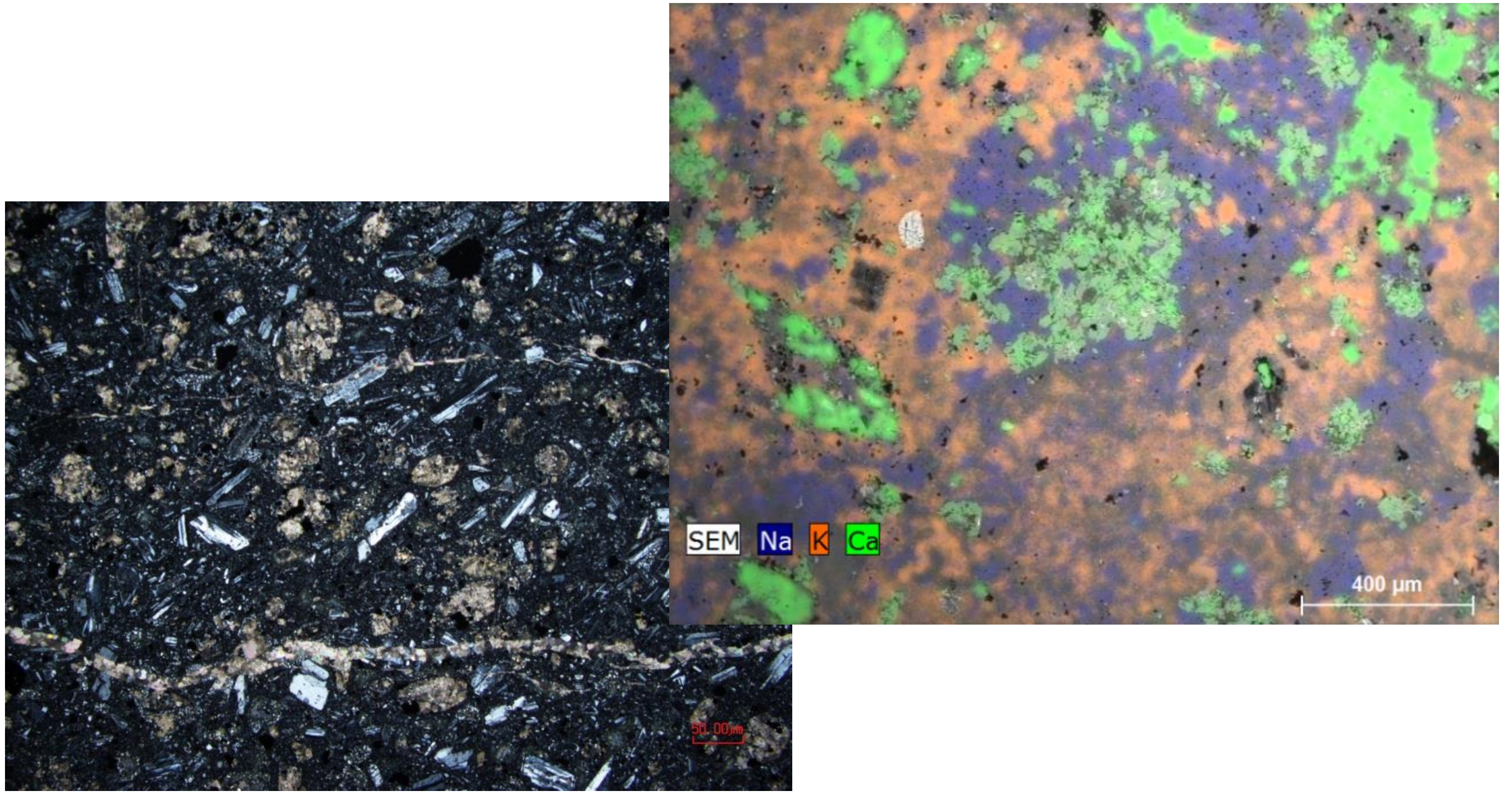
Epidote
Adularia-epidote
Fluid buffered
Higher temperature



Quantification of alteration mineralogy

27 wt % adularia

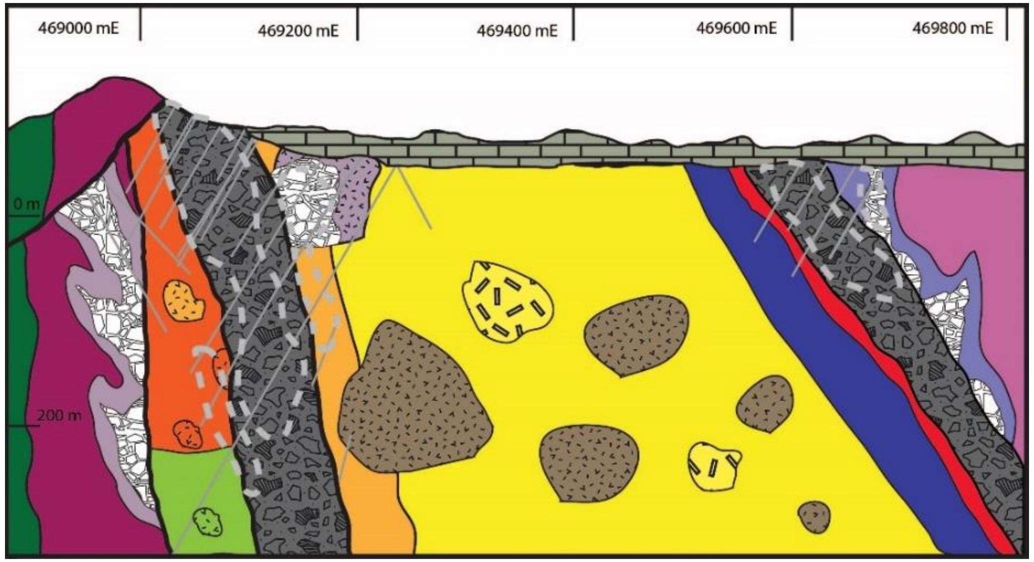
23 wt % adularia
3 wt % hematite

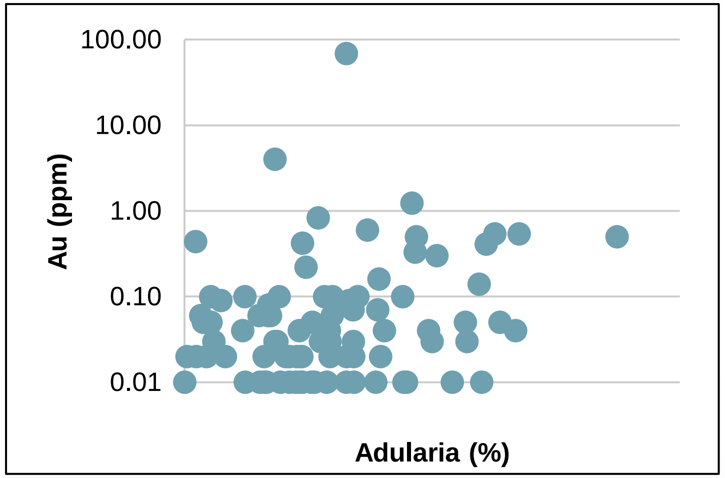


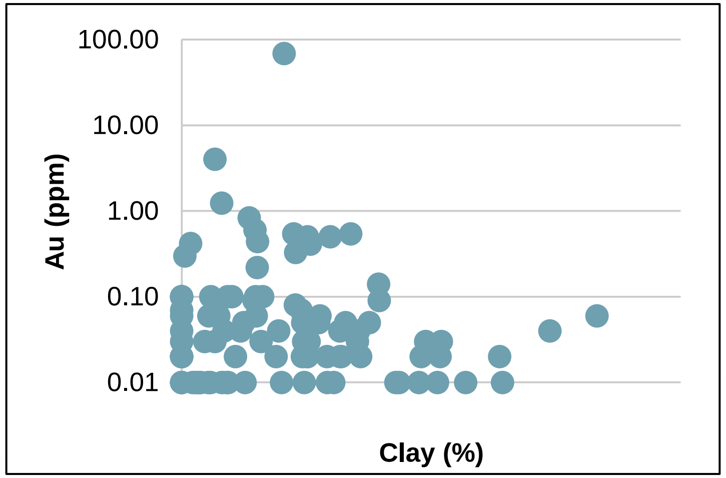
Adularia cannot be identified in this sample, even during petrographic studies (SEM verified the presence of adularia)

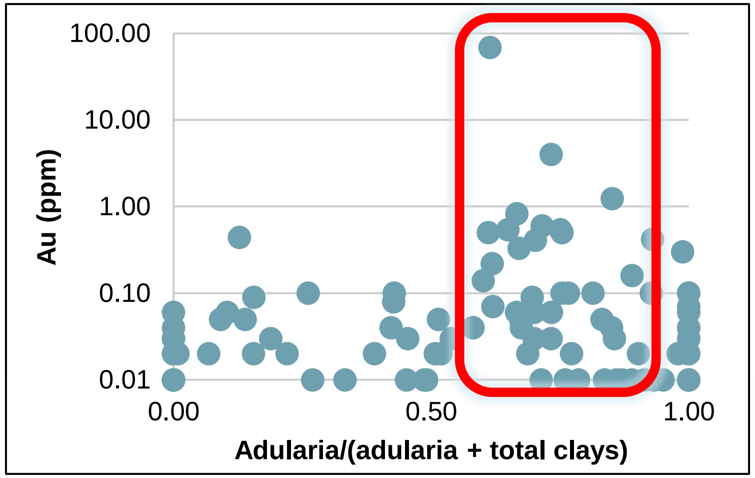
Key findings

- Highest grades encountered in wallrock with a relative proportion of 60-80% adularia to 40-20% clays
- Adularia transitioning outwards to more illite enriched alteration
  - Gold at the transition between adularia to and illite
- Zones hosting hematite often mistaken as zones barren of mineralisation





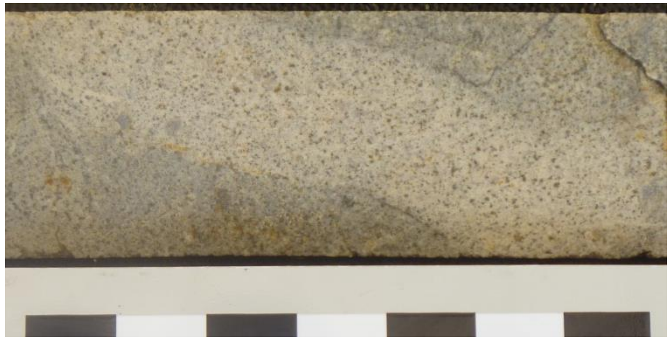




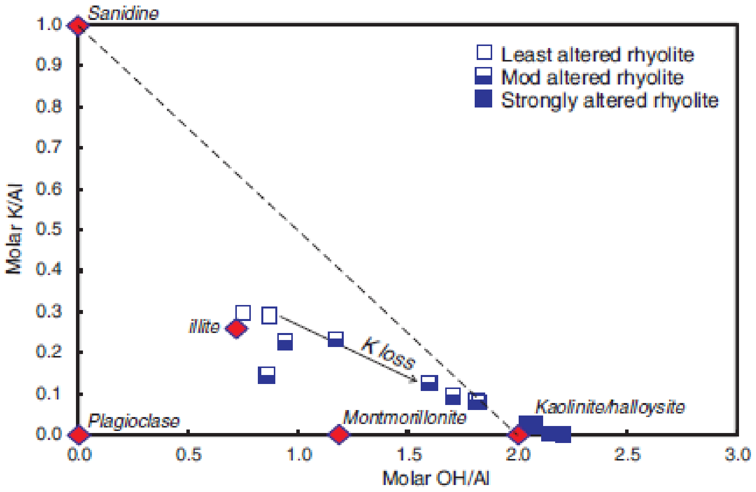
Current methods for mineralogical characterisation and quantification

- Alteration typically logged using a hand-lens
- Alteration is often fine-grained
  - Three-way colour split often used as guide to logging alteration
- Geologists use geochemical data to infer mineralogy rather than quantify it directly

Can roughly estimate mineralogy



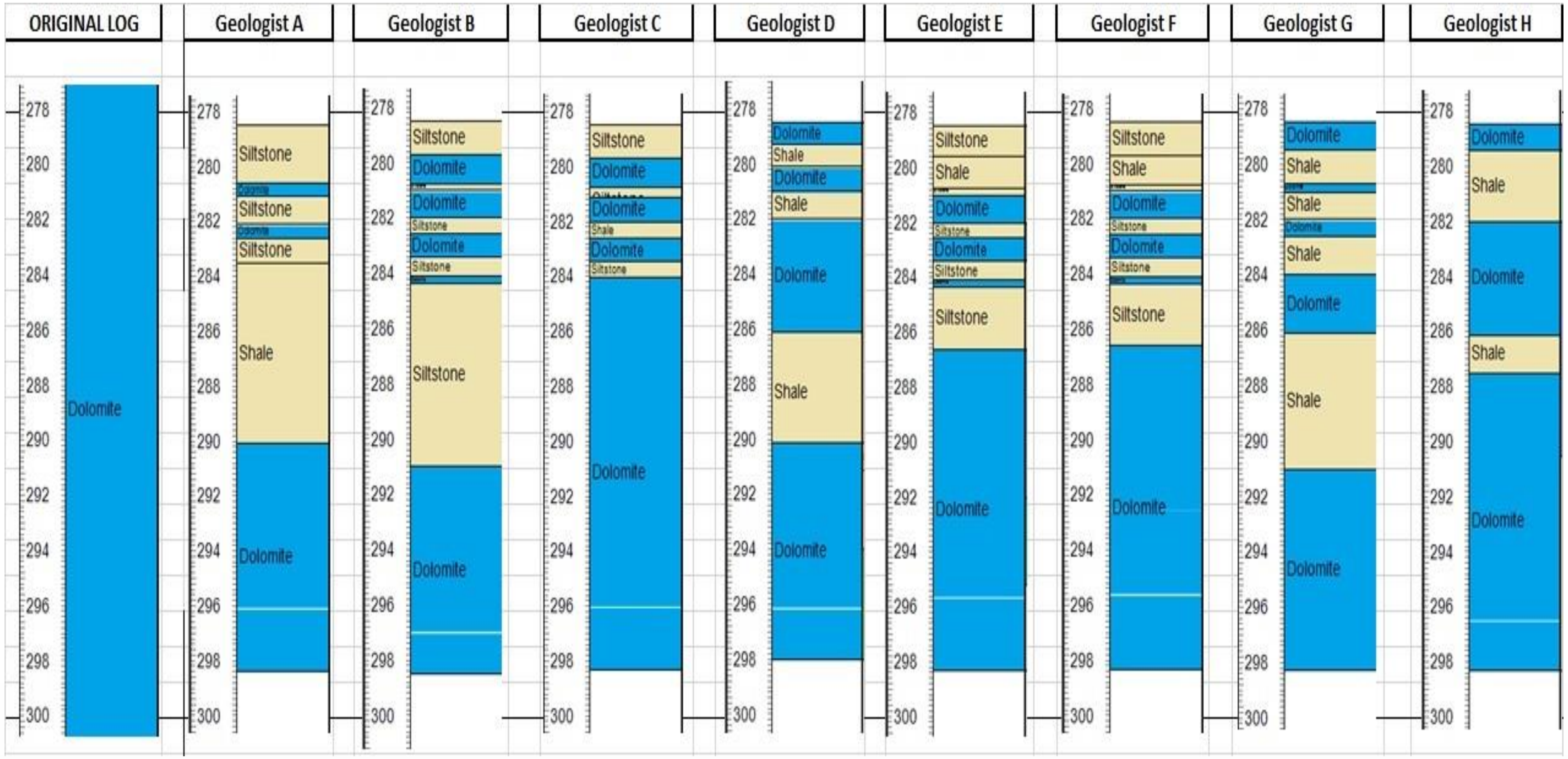
Fine-grained alteration



Brathwaite *et al.* 2014

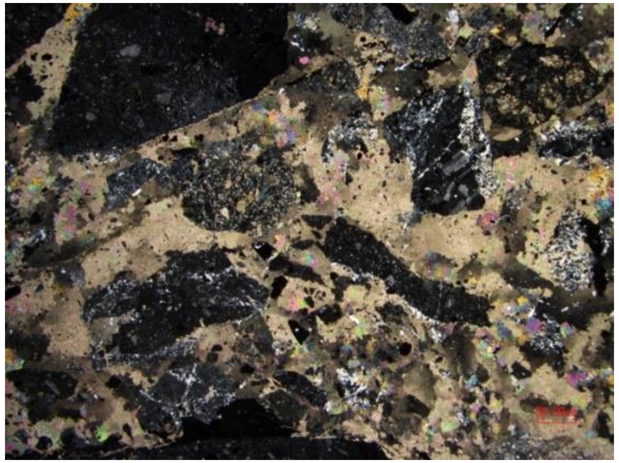
Core logging example

- Democratic republic of Congo
  - 8 different geologists asked to log the same interval of core

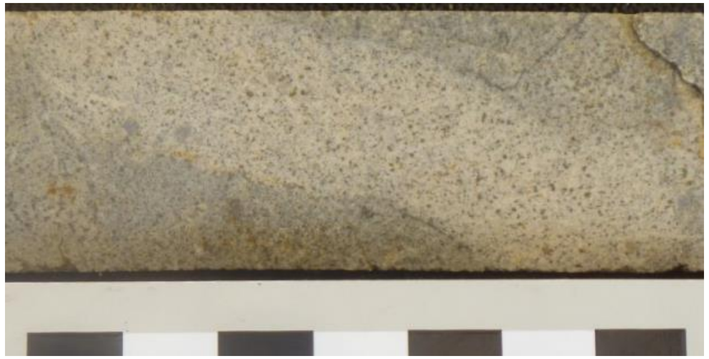


Common methods for mineralogical characterisation and quantification

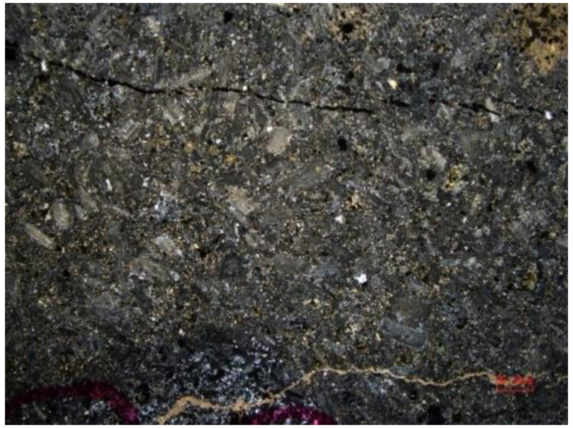
- Petrography
- Expensive, time-intensive and often phases are still too fine-grained to identify/quantify
- Hard to differentiate between species within similar mineral groups
  - Carbonates: calcite, dolomite, ankerite, rhodocrosite
  - Phyllosilicates: illite, smectite, kaolinite



Carbonate alteration



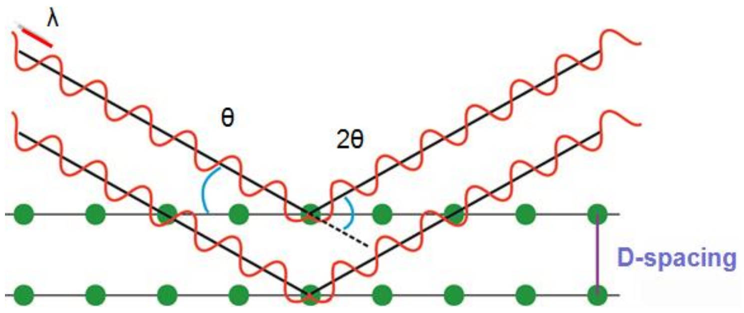
Fine-grained alteration

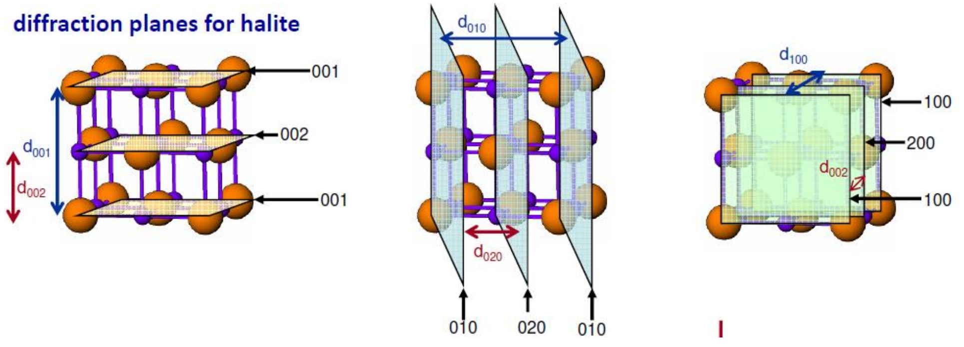


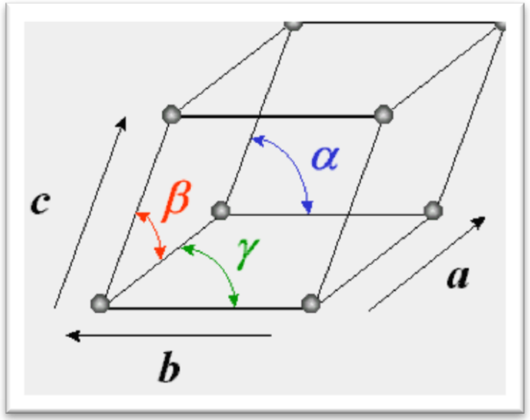
Cannot determine alteration phases under the microscope

What is X-ray diffraction (XRD)

- Method for measuring interplanar spacings between crystallographic planes (d-spacing)
- Can be used for qualitative and quantitative mineralogical analysis
- Can identify all crystalline phases irrespective of reflectance and can be used to quantify amorphous content
- Can be used to determine crystallinity





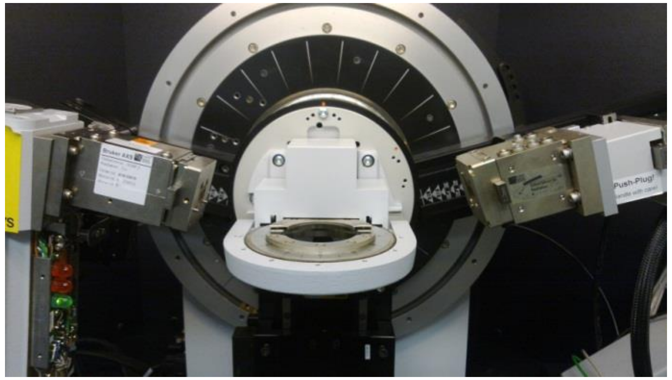


mikeblaber.org

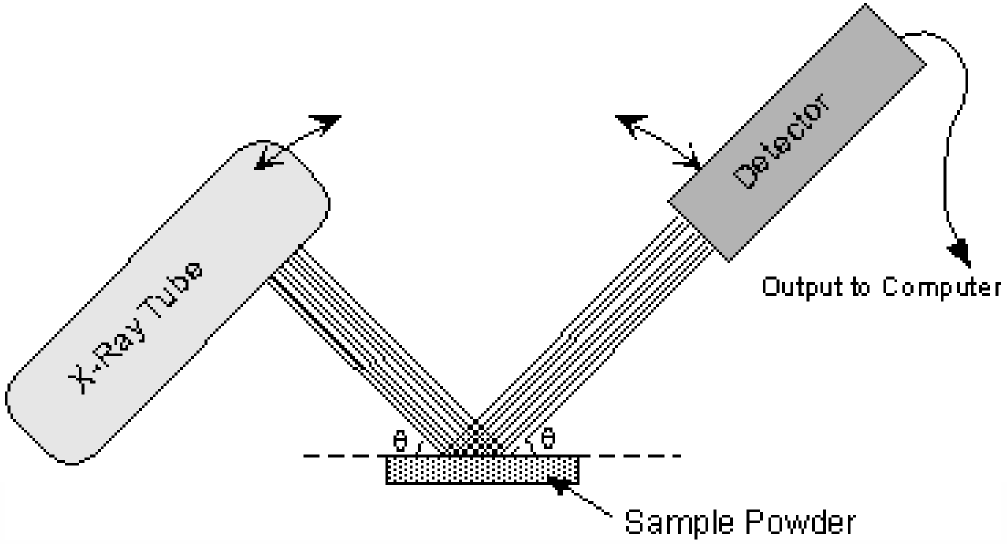
Conventional XRD instruments

- Goniometer
- Large lab-based equipment
- Energy intensive
- External water source

www.sfu.ca/



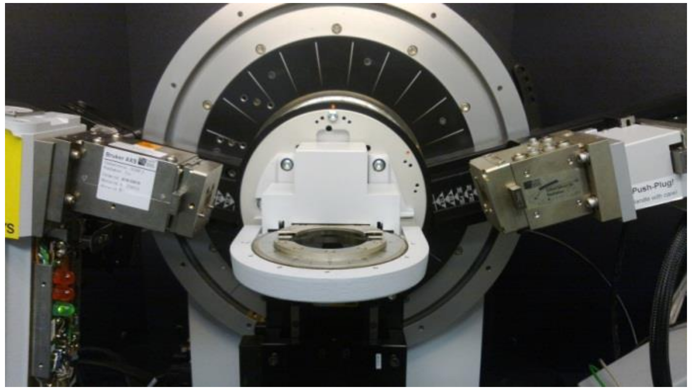
Whitefield (2012)



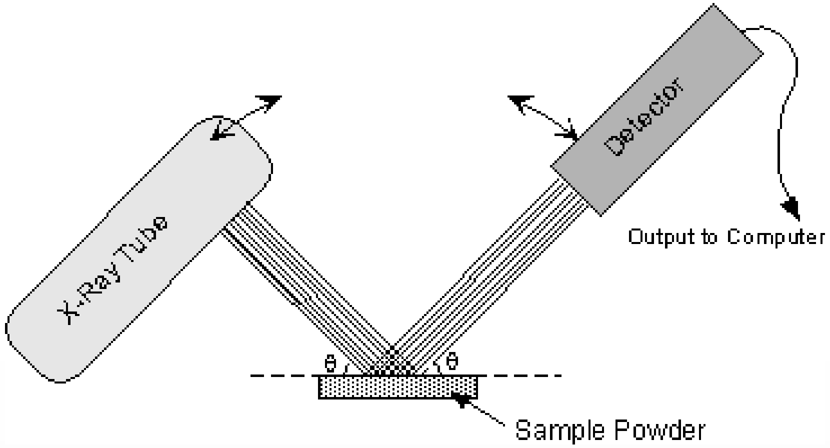
http://www.tulane.edu/

Conventional XRD instruments

- Rotate the tube and detector to measure the angle of diffraction
  - Very small step-size and large angle scans
  - Zero point shifts
  - Low angle asymmetry
  - Need for regular calibrations by technical expert



Whitefield (2012)



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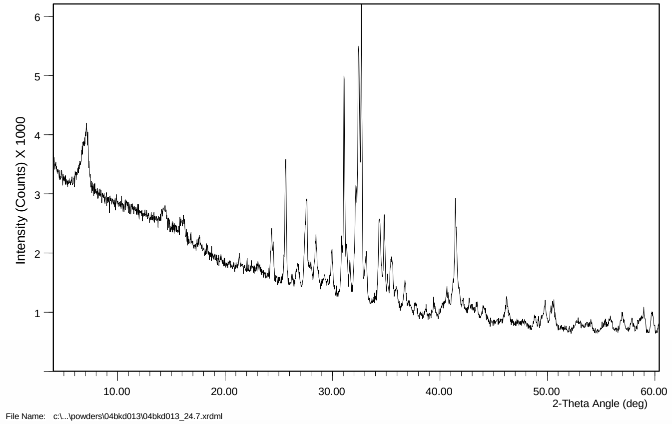
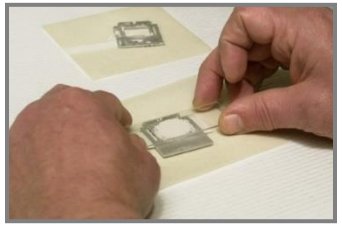


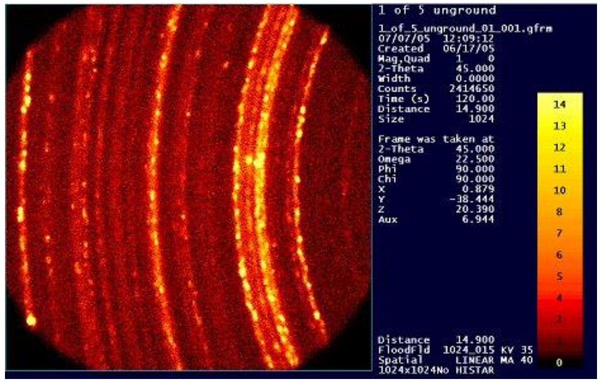
Sample Preparation

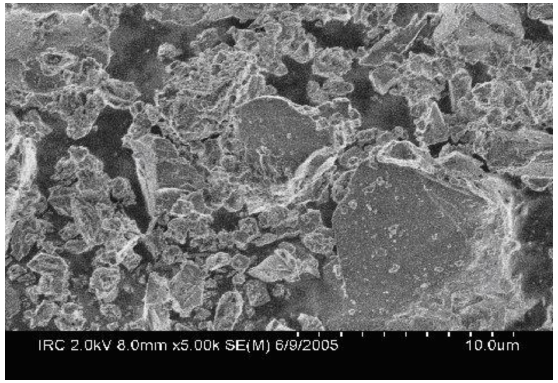
- Pressed pellets
- Dry, < 10 µm, approx 300 mg
  - Can do smaller samples but higher level of technical capability required
- Need for homogenous grainsize
- Assumes random orientation



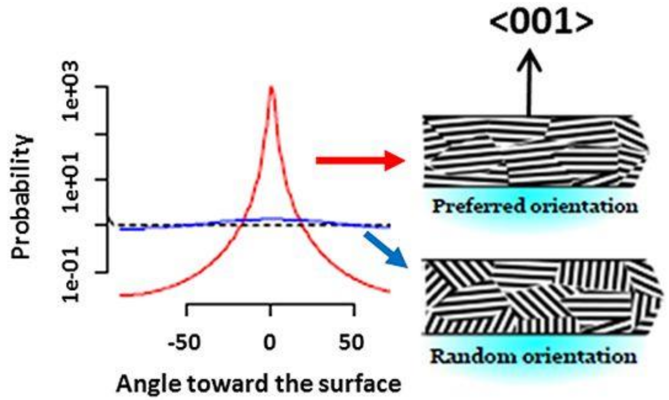






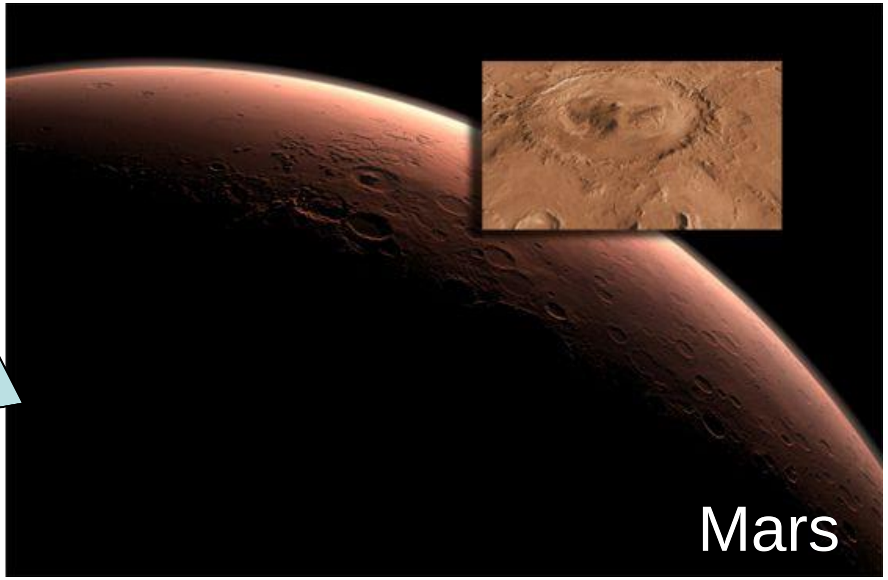
Whitfield (2012)



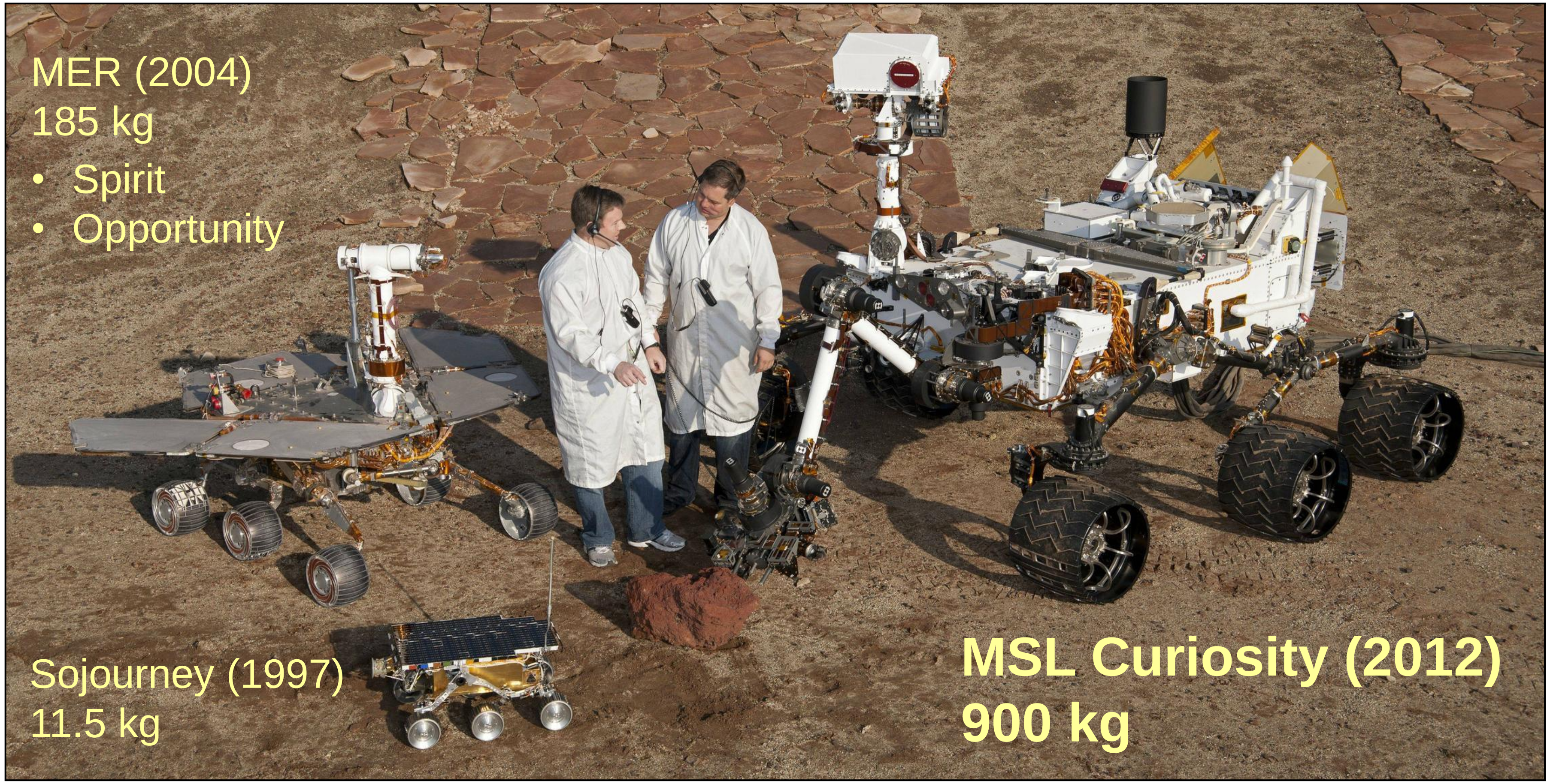
Mdpi.com

XRD on Mars?

- Conventional XRD too large, sample preparation too onerous and energy requirements too large
- Need for an XRD instrument which was light, rugged and without need for regular calibrations

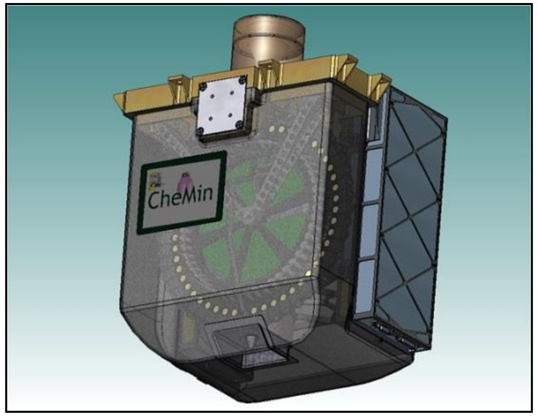


XRD on Mars!!


MER (2004)
185 kg
• Spirit
• Opportunity
Sojourney (1997)
11.5 kg
MSL Curiosity (2012)
900 kg

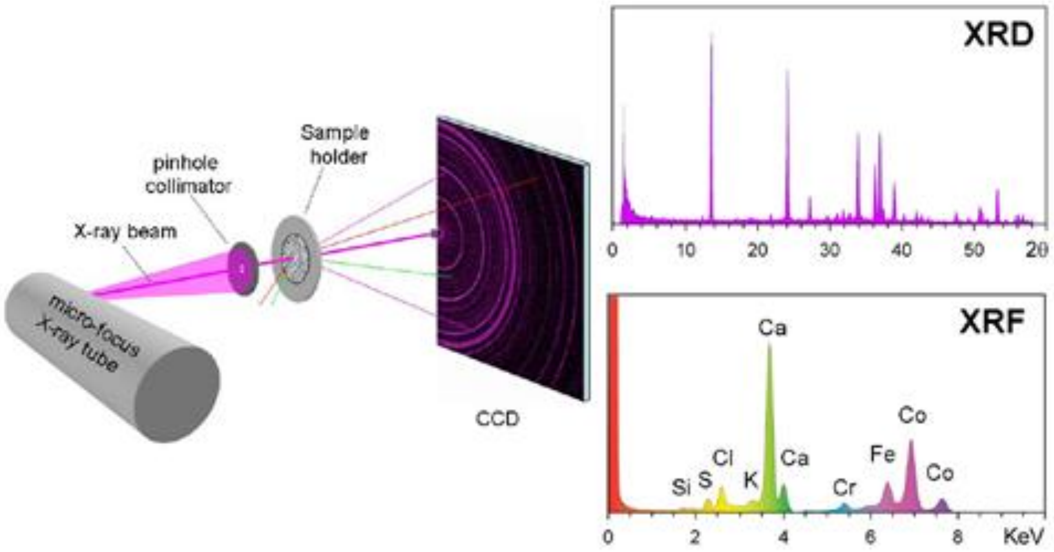
"CheMin"

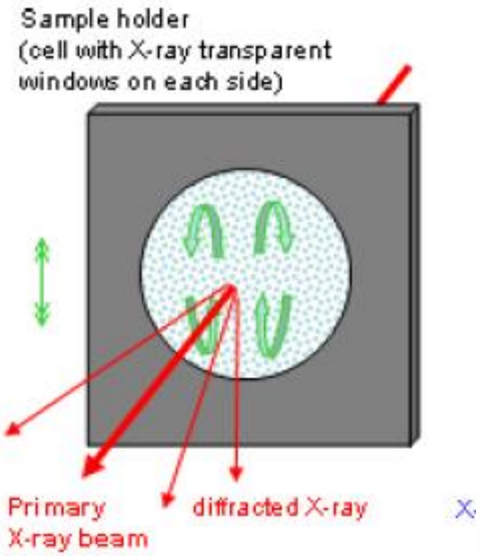
- **Chem**istry = X-Ray Fluorescence (XRF)
- **Min**eralogy = X-Ray Diffraction (XRD)
- Vibrating sample, fixed source and detector
  - No need for calibration



10 kg

- Small 2D CCD detector in fixed position
- Energy discrimination for simultaneous XRF
- Miniature X-ray source
- Transmission geometry
- Proprietary sample handling





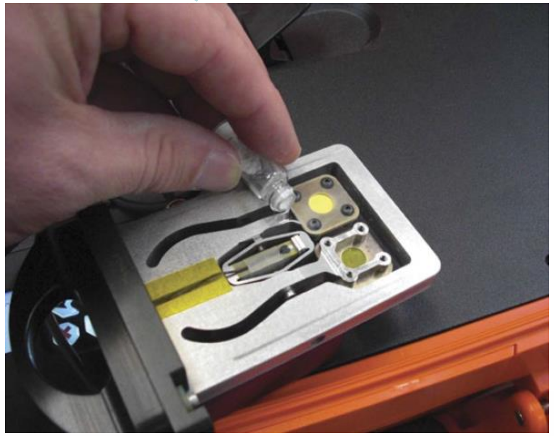
Sararazin *et al*. 2005

How is portable XRD data acquired?

- Olympus Terra portable XRD
  - 15 mg of sample
  - 2-4 minutes
  - < 150 µm

Crush/mill

Sieve



15 mg of sample

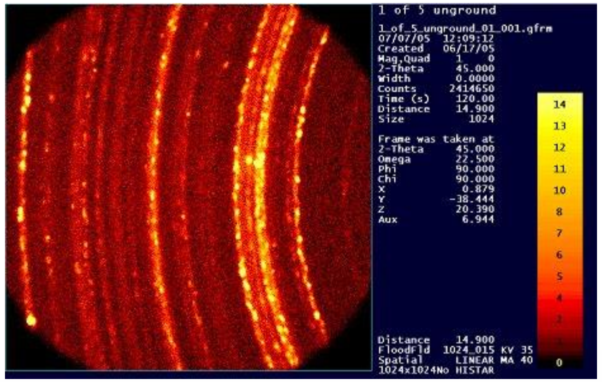
Olympus Terra Portable XRD

Why are the grain-size requirements not as small for pXRD compared to lab XRD??

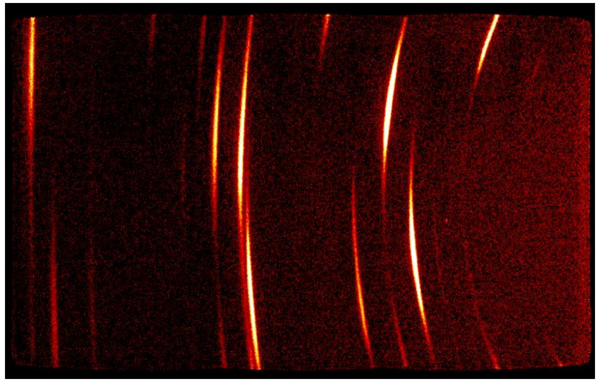
- Conventional XRD recommends powdering to <40 µm (preferably <10 µm)
  - Rotating sample in 1D with reflectance geometry
  - Alleviate grain-size effects and orientation effects
- Portable XRD <150 µm for soils, <75 µm for sulfides and heavy mineral concentrates
  - Vibrating sample with transmission geometry
  - At 150 µm the Terra has particle statistics equivalent to 3 µm

Diameter	40µm	10µm	1µm
Crystallites / 20mm³	5.97×10^5	3.82×10^7	3.82×10^{10}
No. of diffracting crystallites	12	760	38000

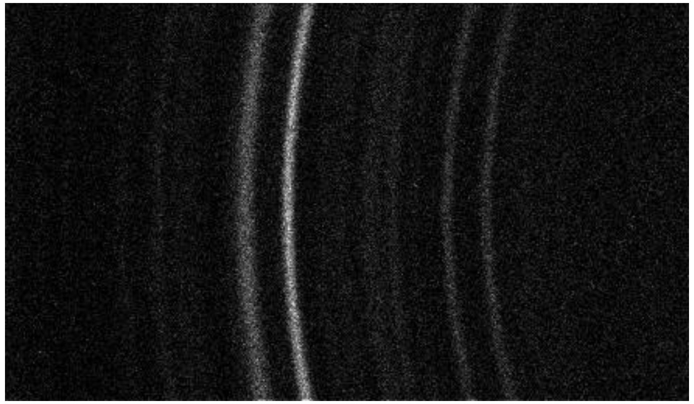
Whitfield (2012)



Grain-size effects
Whitfield (2012)



Orientation effects
prims.mit.edu



pXRD debye rings

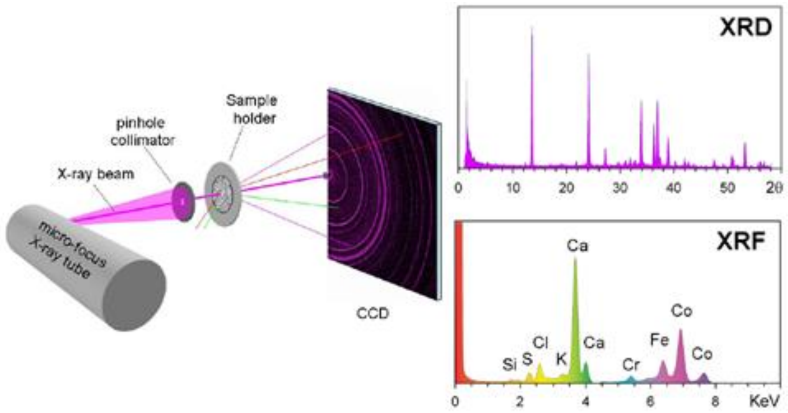
Comparison between technologies: portable XRD

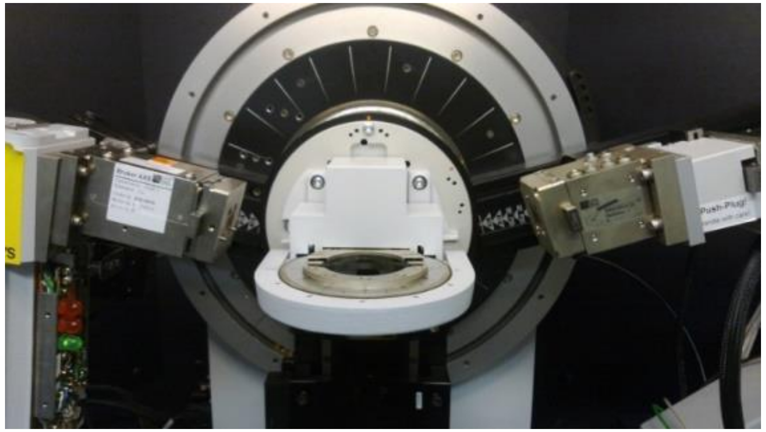
Pros

- Low sample preparation
  - No micronisation needed
- No preferred orientation effects
- Portable
  - Runs of AC power or batteries
- No external water source
- No need for regular realignment of parts
- No low angle asymmetry or zero-point shifts

Cons

- Smaller 2θ range 5-55°
- Lower resolution
  - 0.25º 2θ versus 0.081º 2θ

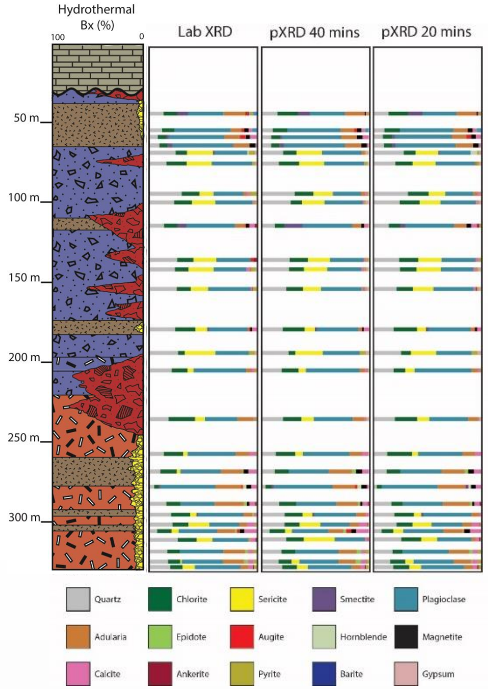


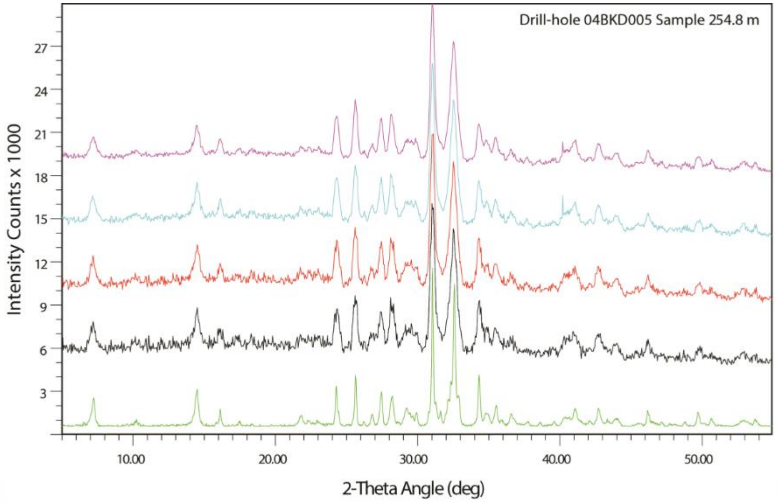


Whitfield (2012)

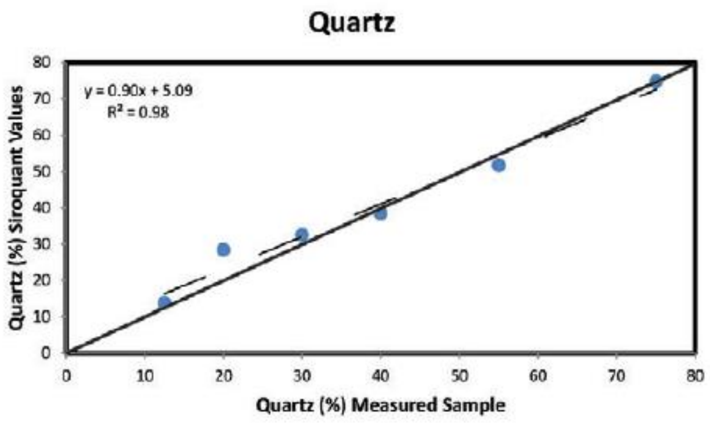
pXRD fit for use for quantitative mineral analysis??

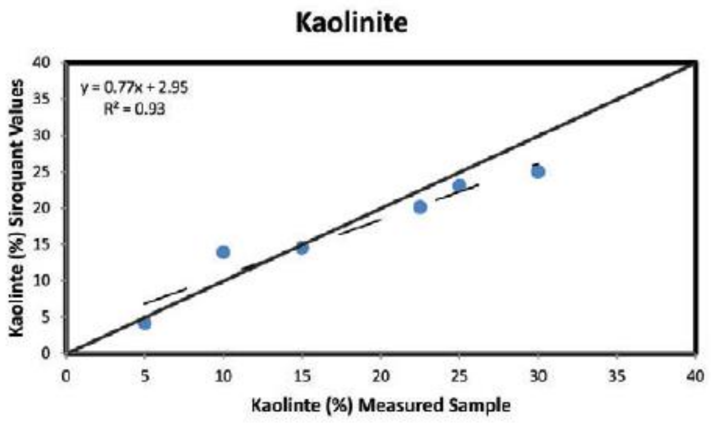
- Developed six synthetic mineral mixtures
- Comparison of results from 27 samples from Kulumadau with lab-based 2 kW XRD system
- Effect of runtime on quantification

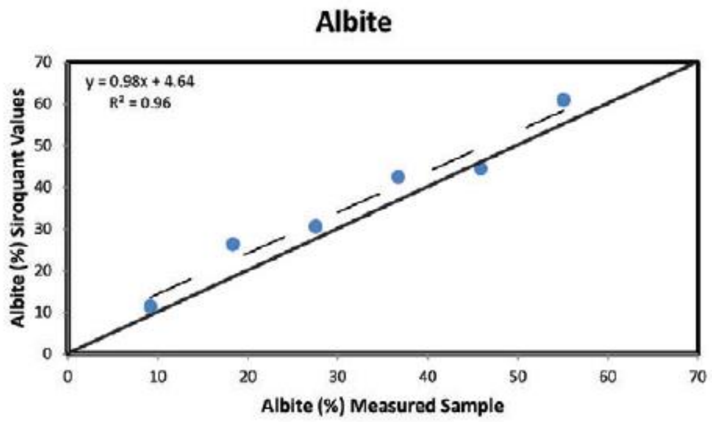


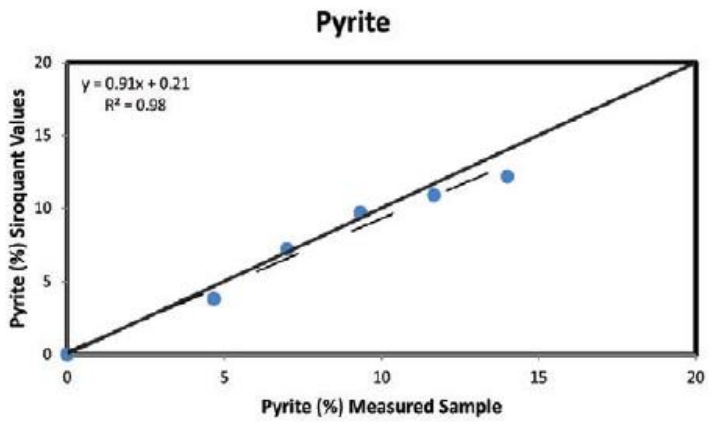


Synthetic mineral mixtures

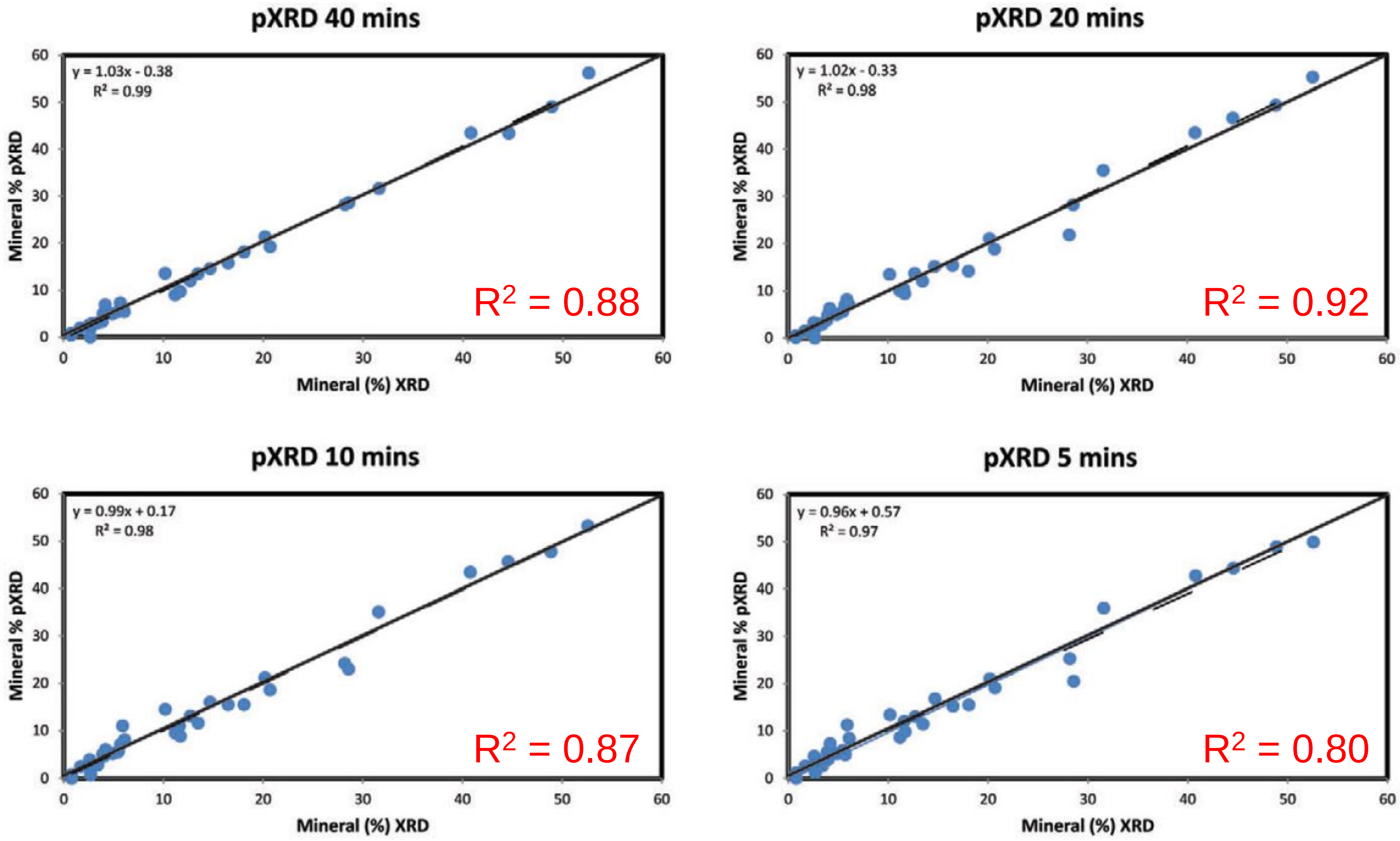




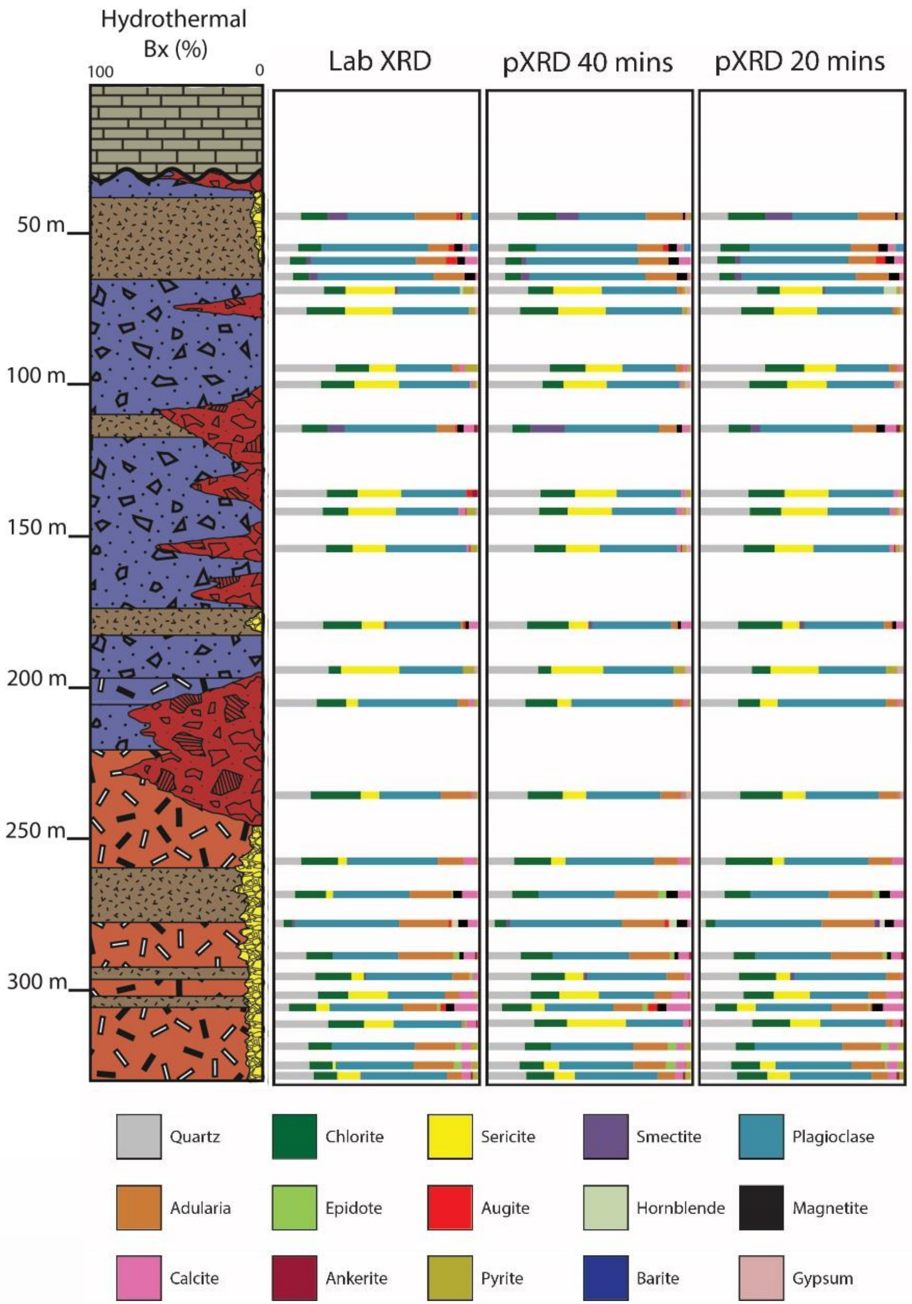


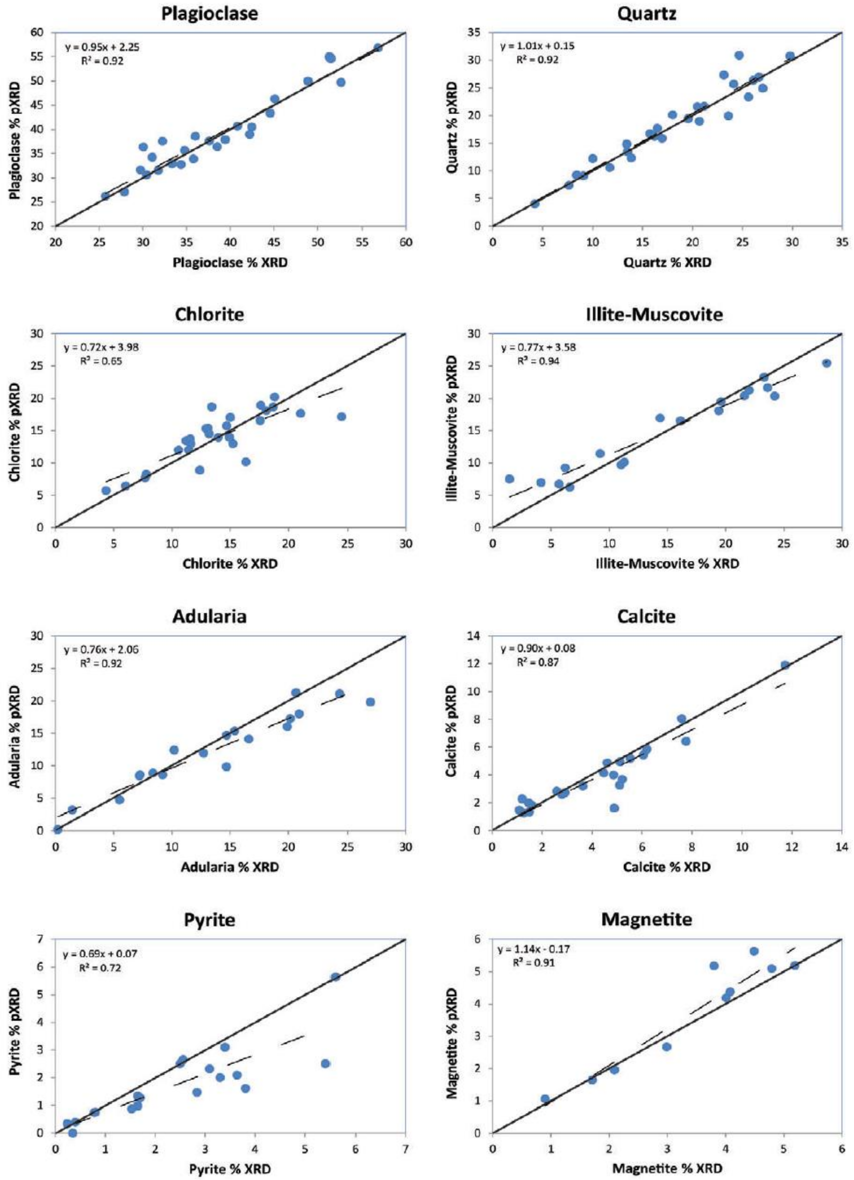


Runtime analysis



Lab-based XRD, 5 mins, 10 mins, 20 mins, 40 mins



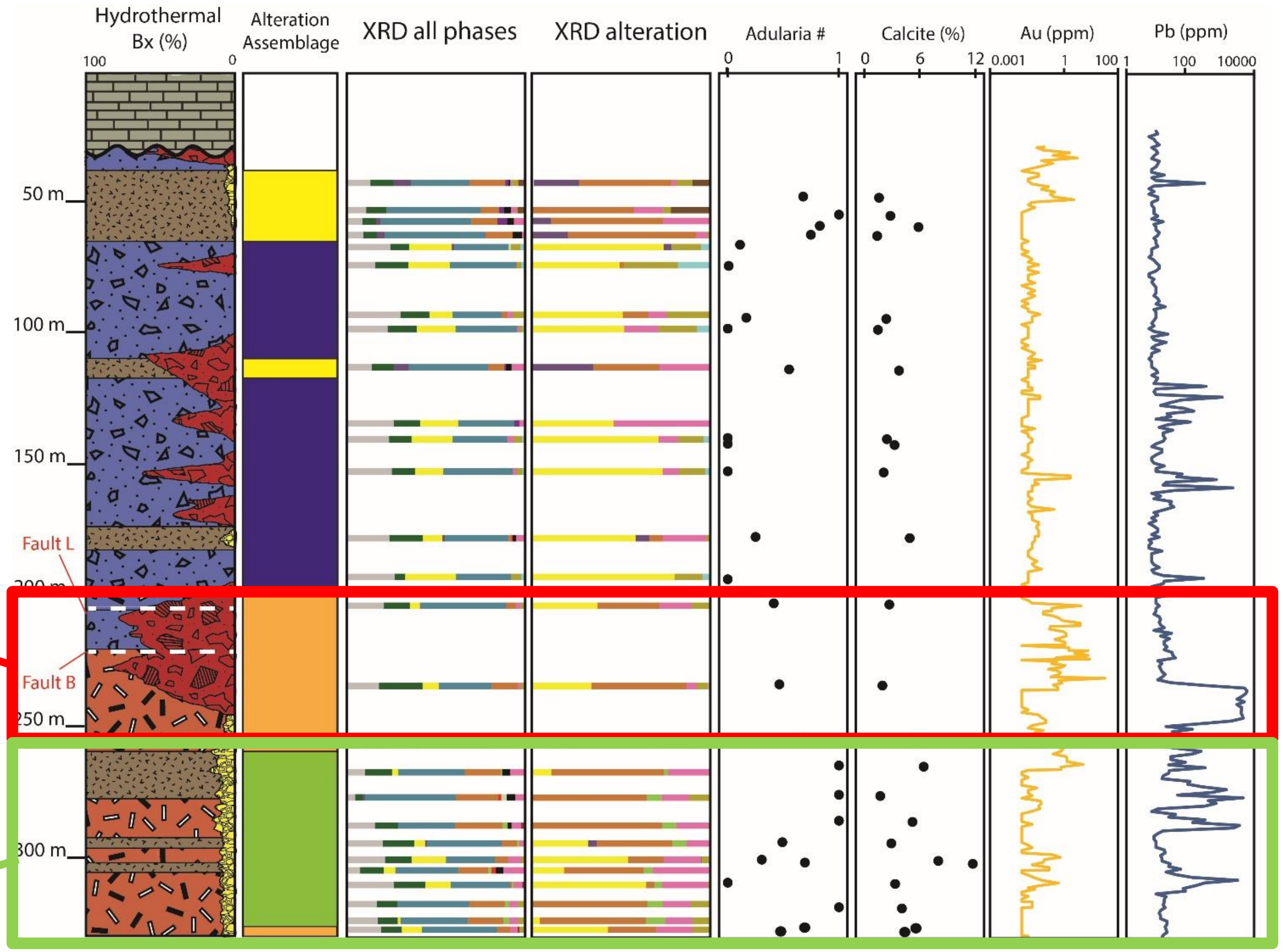


20 minute dataset

Using quantitative mineralogical data

- Adularia number = adularia/(adularia+clays)

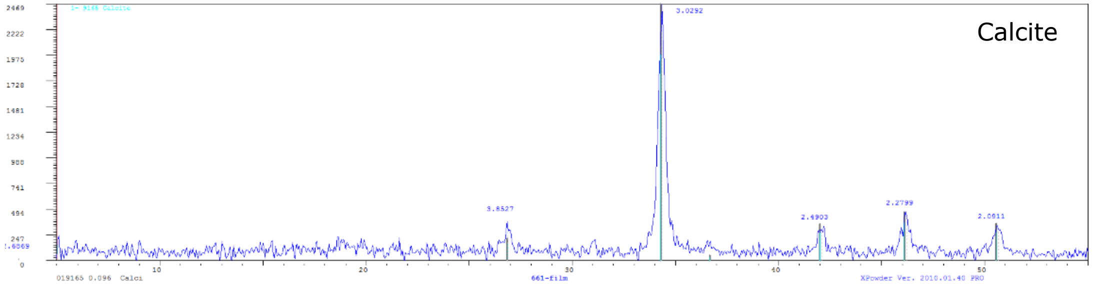
Economic grades within the transition between adularia-rich and illite-rich zones

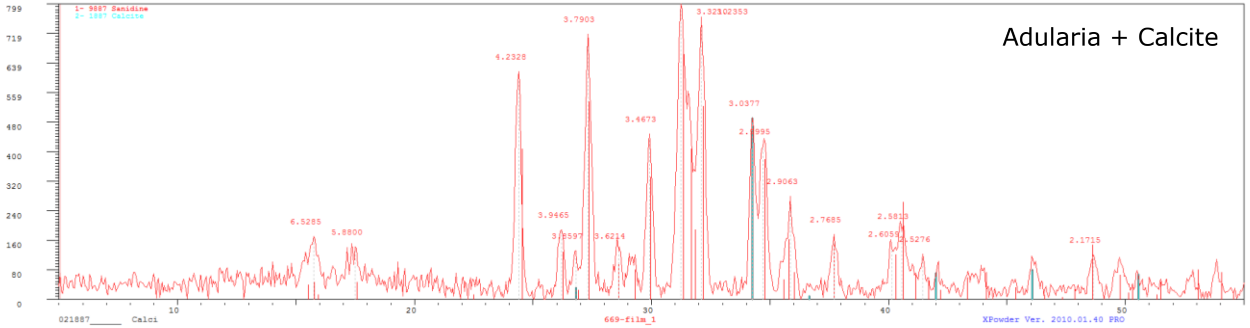


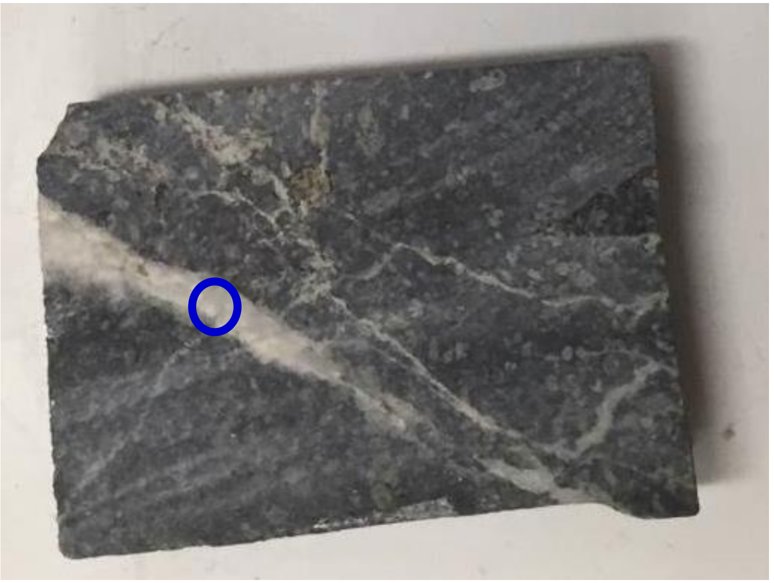
Elevated grades associated with higher temperature minerals (epidote) and higher adularia

Selective sampling

- Can easily selectively sample (8 – 15 mg)
- Analysing small samples requires greater level of technical capability with conventional XRD instruments

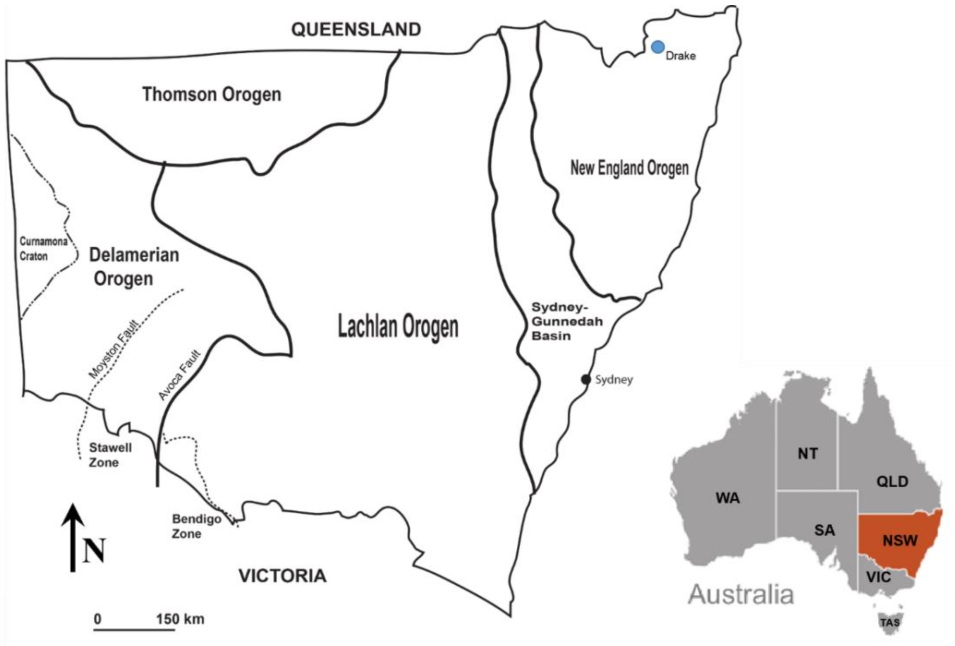


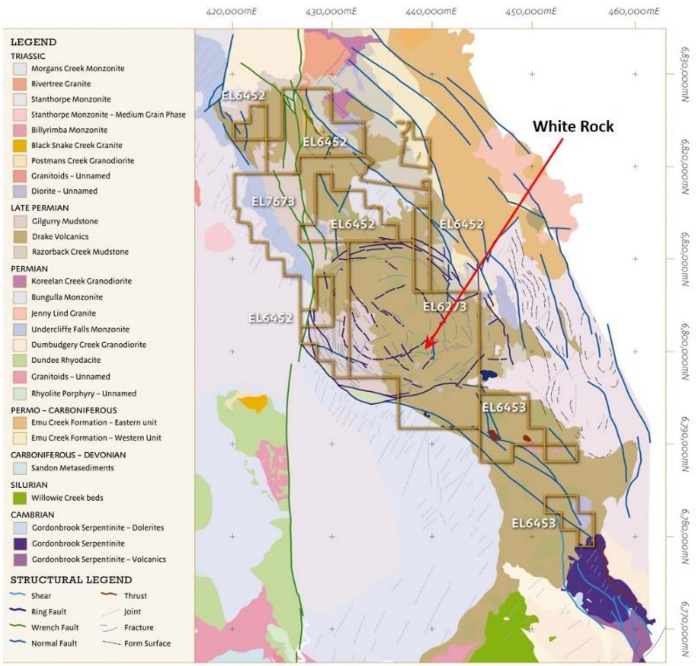




Mt Carrington project – White Rock

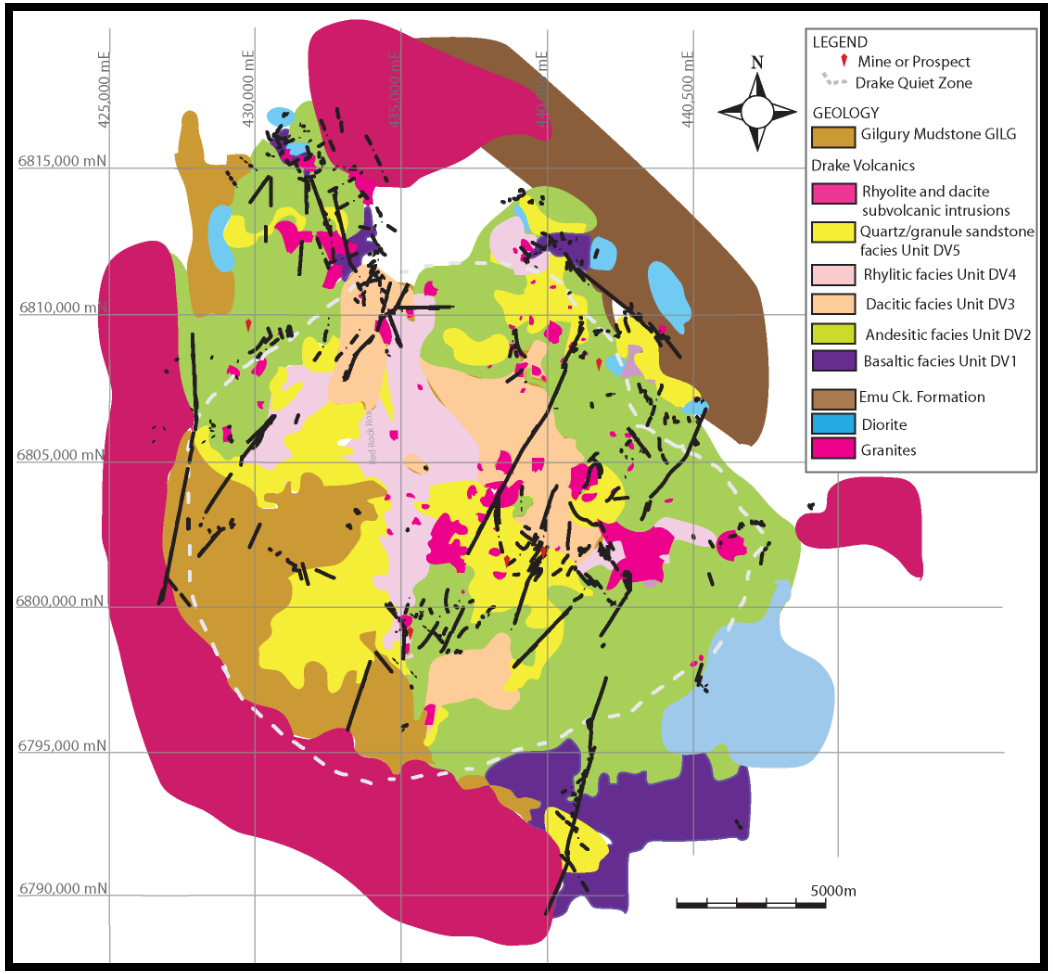
- Mt Carrington Project is 5 km from Drake in the southern New England Orogen
- Resources contained within eight near surface deposits
  - Four gold dominated (Red-Rock) and four silver dominated (White-Rock)
- PhD looking at the genesis of all of the deposits, and an honours project focused on White Rock
- Indicated and inferred resource estimates totalling 8.19 Moz Ag @ 58g/t





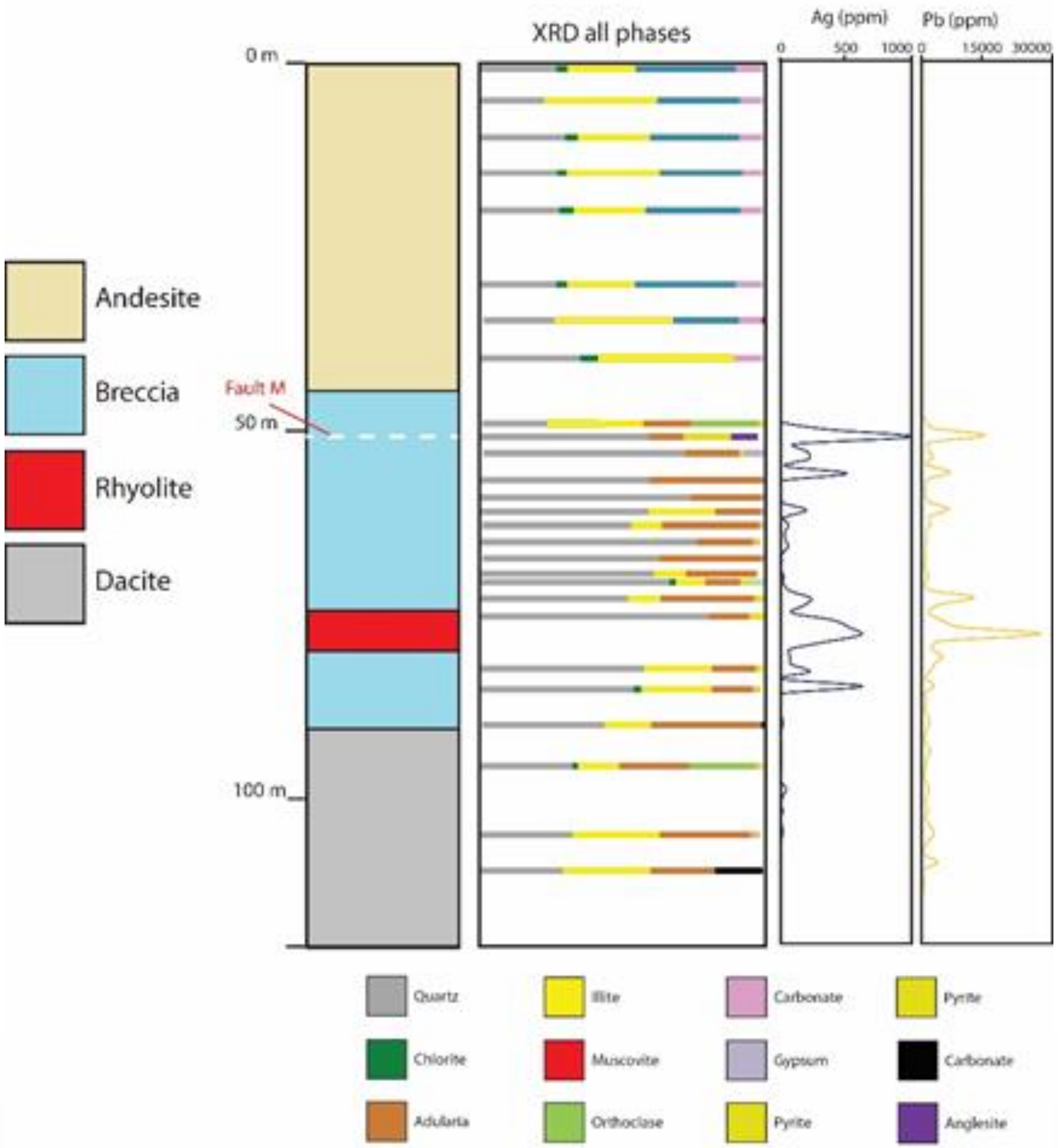
Mt Carrington project – White Rock

- Host sequence is the Permian Drake Volcanics
  - Acid to intermediate volcaniclastics intruded by contemporaneous dacite and rhyolite porphyries
  - Mineralisation within a collapsed volcanic caldera structure (Drake Quiet Zone)
  - Mineralisation styles include fissure veins, stockworks, breccias and stratbound disseminations

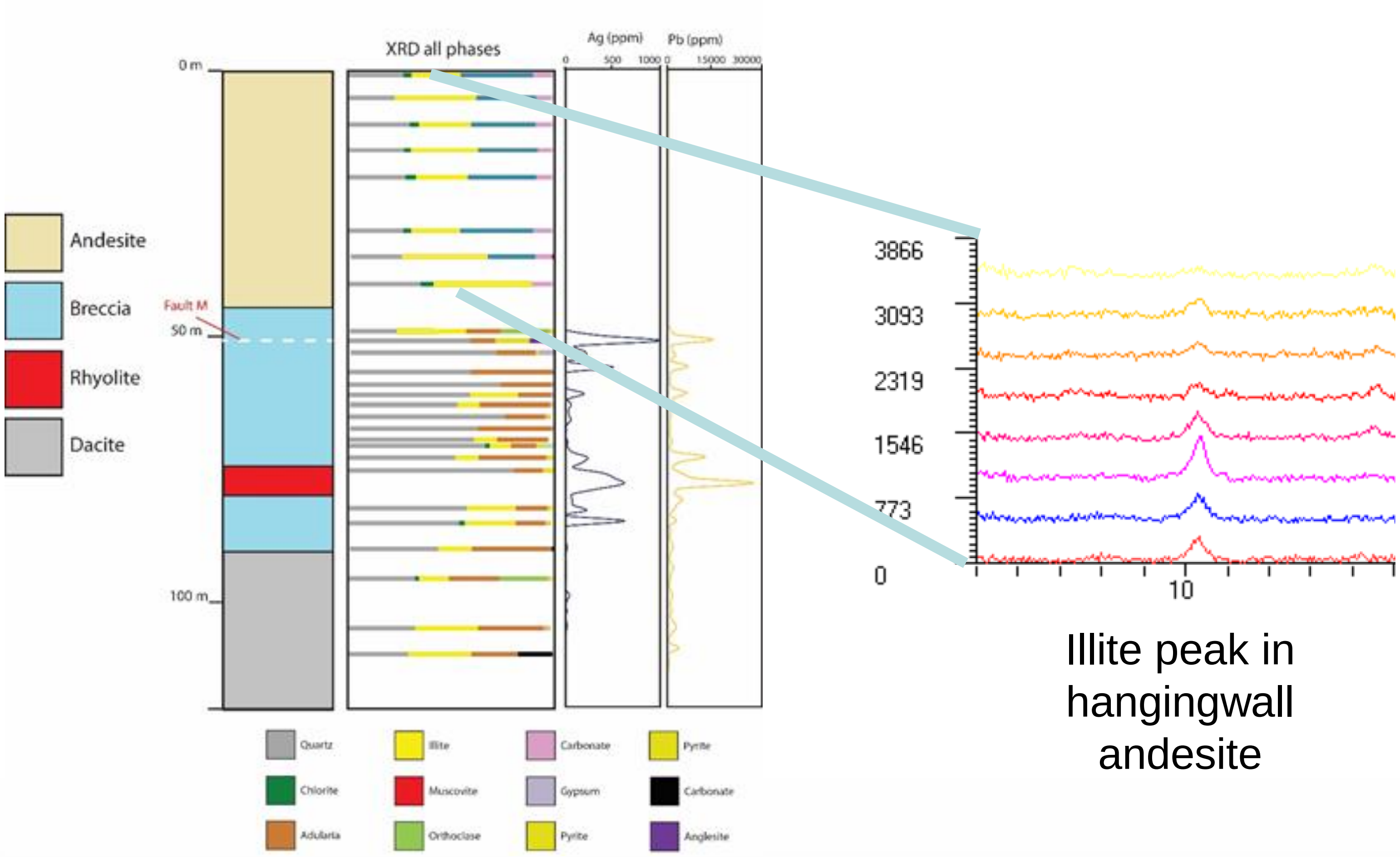


White Rock – lithology, alteration and mineralisation

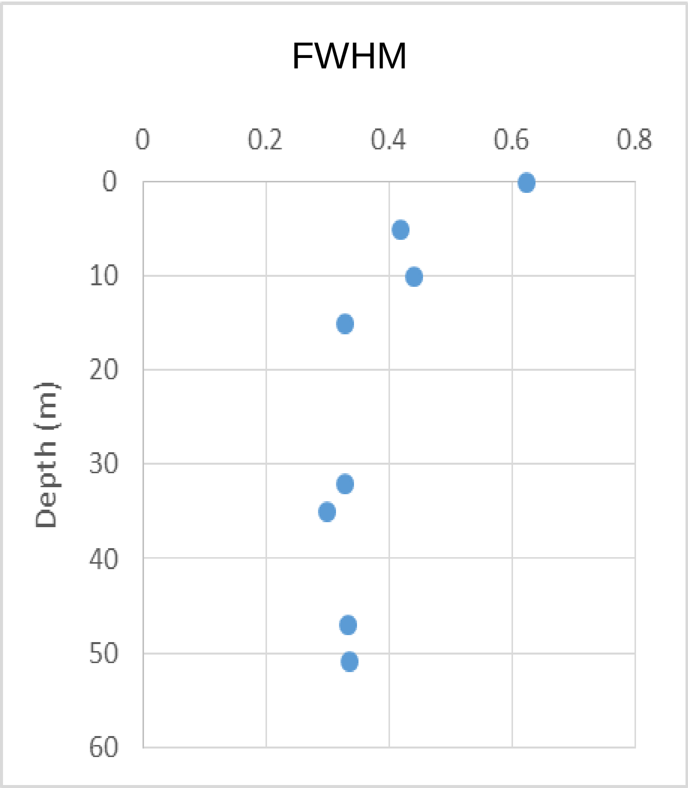
- Mineralisation confined to breccia and rhyolite units beneath fault
- Alteration within these units comprises quartz-adularia-illite
  - Highest grades associated with high quartz and adularia
- Above mineralisation the andesite hosts illite



White Rock – lithology, alteration and mineralisation



Illite peak in hangingwall andesite



Questions?