

# Integrated Spectral Mapping of Gold Related Alteration Mineral Footprints, Nanjilgardy Fault, WA.

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‘Promoting the Prospectivity of Western Australia’

# Acknowledgments

GSWA

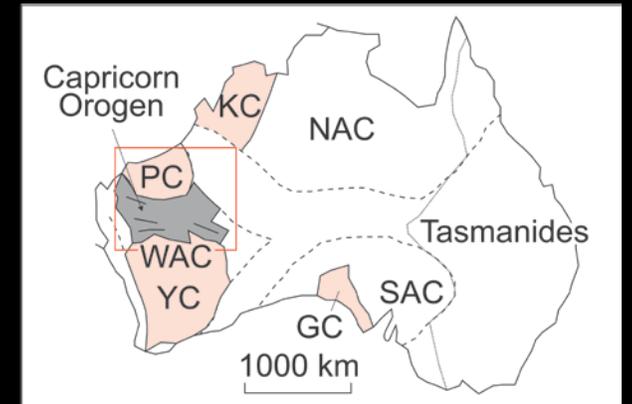
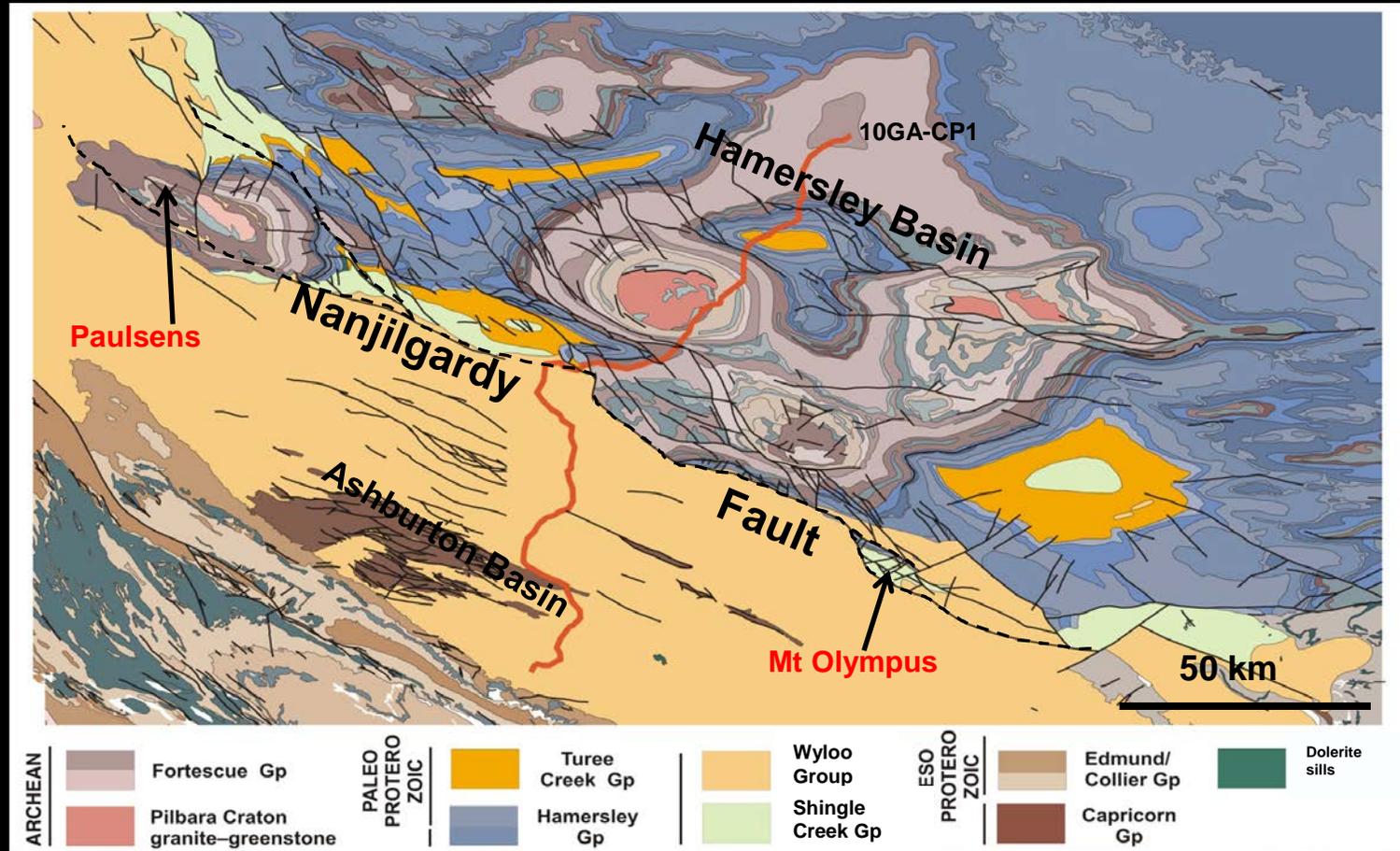
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# Geological setting: Capricorn Orogen



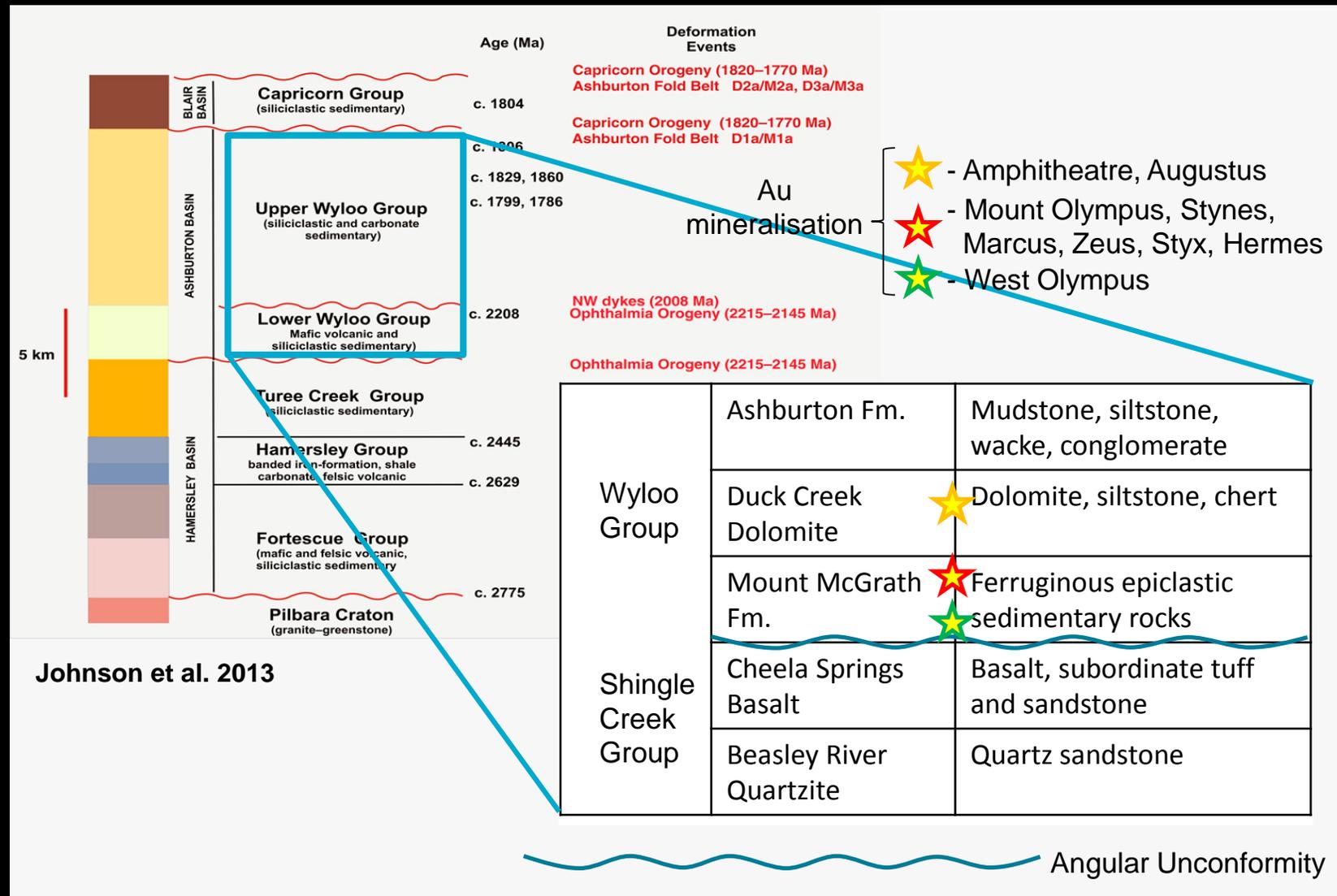
# Capricorn Orogen: General Stratigraphy

Au at Mt Olympus in meta-sediments of the McGrath Formation

- Duck Creek Dolomite
- Dated at 1740 Ma (xenotime analysis)

Carlin-style deposit

- Solid-solution, inclusions of Au in pyrite



Johnson et al., 2013 Australian Journal of Earth Sciences, 60, 681–705

# Alteration Mineralogy

Au-related to strong sulfide alteration and variously:

- Quartz or quartz-sericite
- Silica, sericite and carbonate

Other minerals? Sulfates, kaolin minerals

- Low-T, hydrothermal alteration

Strongly spectrally active:

- SWIR, 1.0–2.5  $\mu\text{m}$
- TIR, 6–14.5  $\mu\text{m}$



GSWA HyLogger-3. Photo from Lena Hancock

# Project Objectives

Opportunity to develop 3D mineral characterisation of potential structurally related, alteration footprints that may be associated with Au-mineralisation along the NF corridor

Integrate HyLogging-3™ and remotely sensed data (ASTER), within a validated mineralogical framework:

- Approach follows a ‘bottom-up’ methodology
- Adds value to GSWA’s precompetitive spectral data

Remote Sensing

Regional scale alteration patterns (ASTER, AEM, regolith geochem)

Local scale alteration patterns (ASTER, regolith geochem)

Deposit scale 3D-visualisation

Core-scale alteration mineralogy

Validation: XRD and Geochemistry

Proximal Sensing

HyLogging

# Hydrothermal Alteration: Mineral Indicators

Spectral parameters of 'indicator' mineral groups and examples of the associated geological environment

Two mineral groups used as indicators of hydrothermal alteration:

- Al-clay minerals (white mica, kaolinites)
- Sulphates (alunite, jarosite)

Parameter	Mineral Group	Geological environment	Active wavelength range [nm]
Advanced argillic alteration	Pyrophyllite	Porphyry	~ 2160
Advanced argillic alteration	Alunite	Epithermal	~ 1480, ~ 1760
(Advanced) argillic alteration	Kaolinit/Dickite	Epithermal	~ 2160/2180, ~ 2200
Tschermak exchange due to pH and/or T	White mica, Al-smectites	Hydrothermal (metamorphic?)	~ 2200

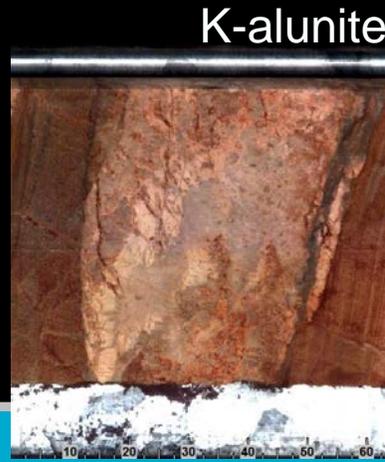
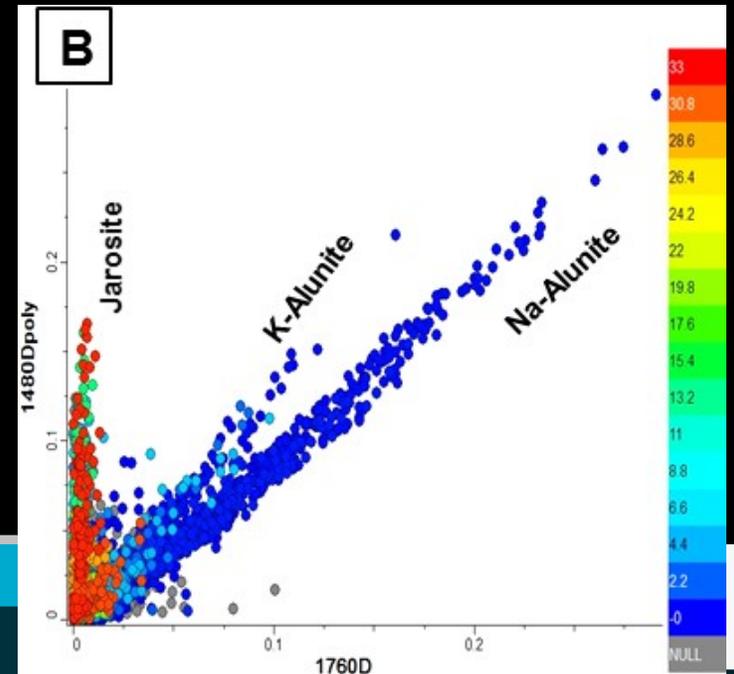
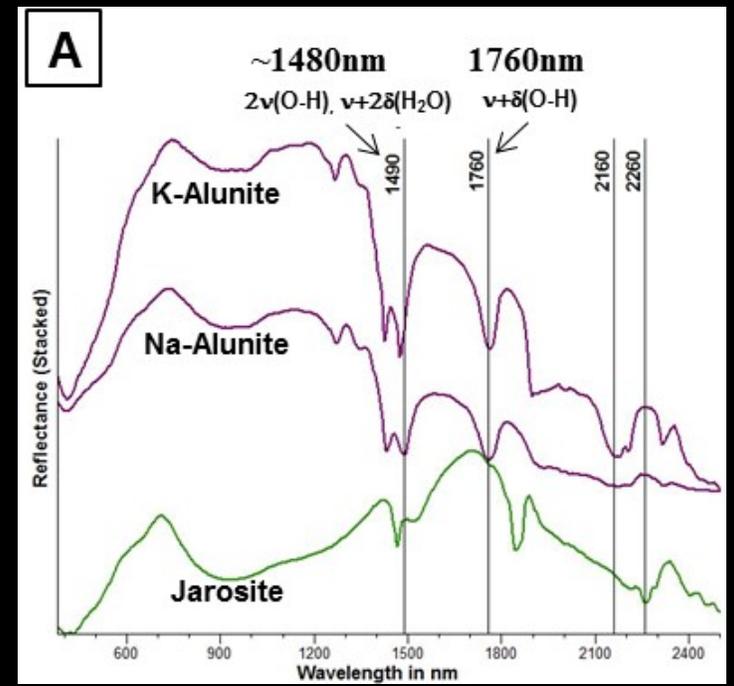
# HyLogging and Spectral Mineralogy

## Sulfates

- Alunite,  $KAl_3(SO_4)_2(OH)_6$
- Jarosite,  $KFe_3^{3+}(SO_4)_2(OH)_6$ 
  - Increasing T favours Na-alunite over K-alunite

## Absorption features are relatively unique

- Spectral separation of sulfate types
- In the core sulfate phases hard to distinguish



# Alteration Mineralogy vs. Au mineralisation (MOD4)

Siltstones interlayered with carbonates, dolomites and sandstones

Au in sandstone and siltstone

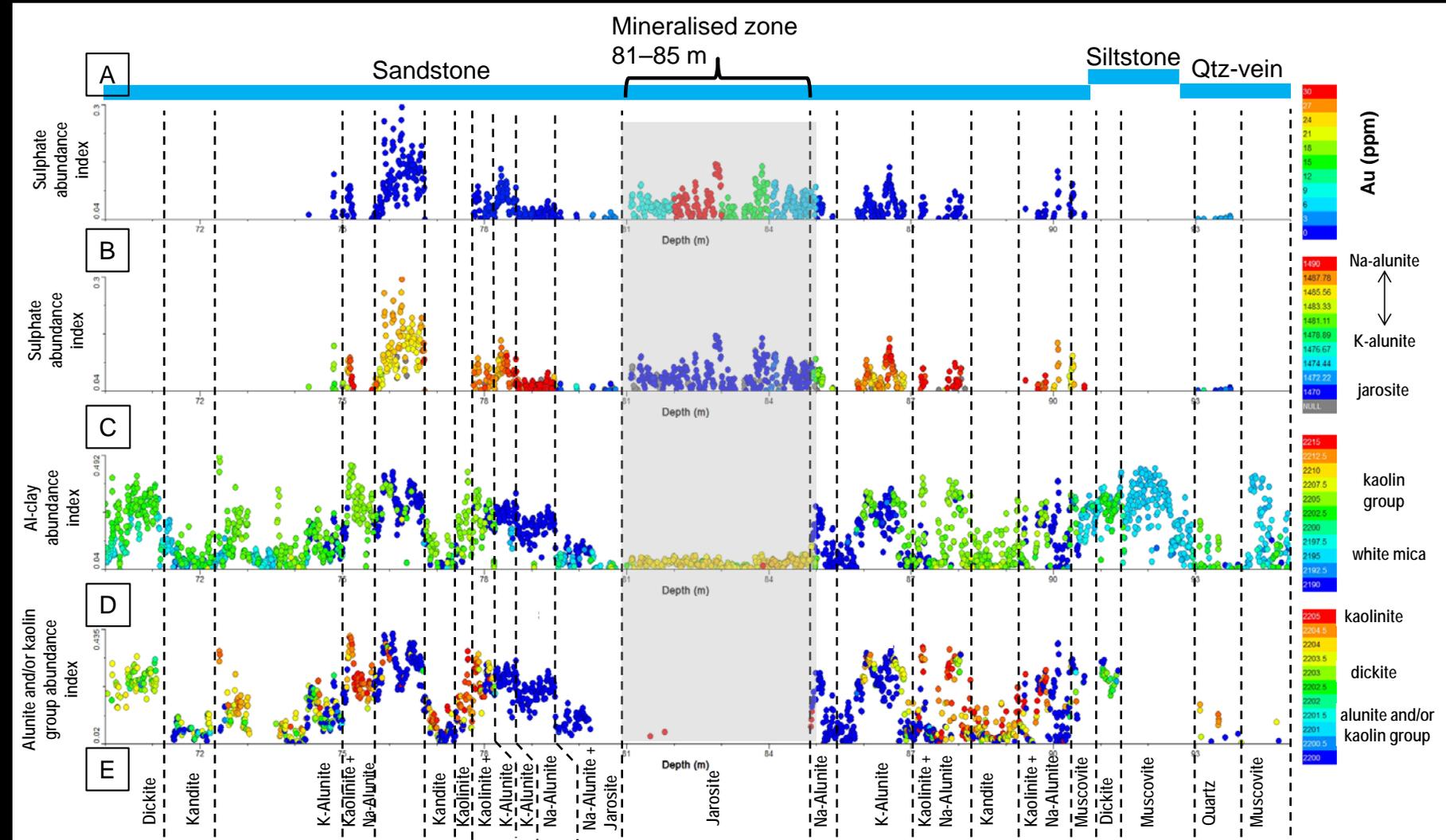
- 33 ppm @54 and 82 m

Jarosite (proximal) to Au mineralisation altered to Na/K-alunite

Kaolinite with alunite

More distally kaolinite replaced by dickite+mus

- No carbonate or chlorite detected
- No major changes in quartz abundance (TIR data)



MOD4: 190.6 m (11.7–202.3 m), above interval 70–95 m

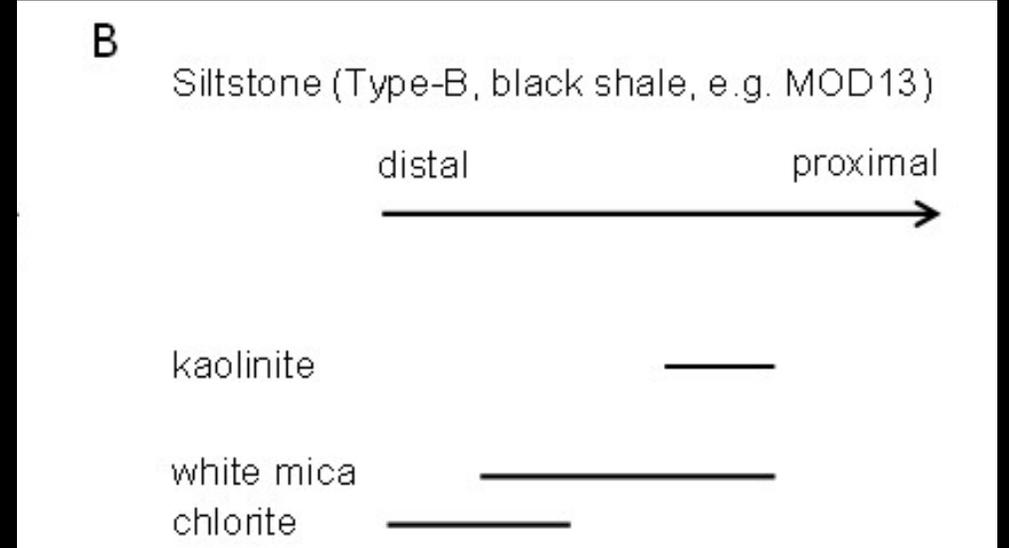
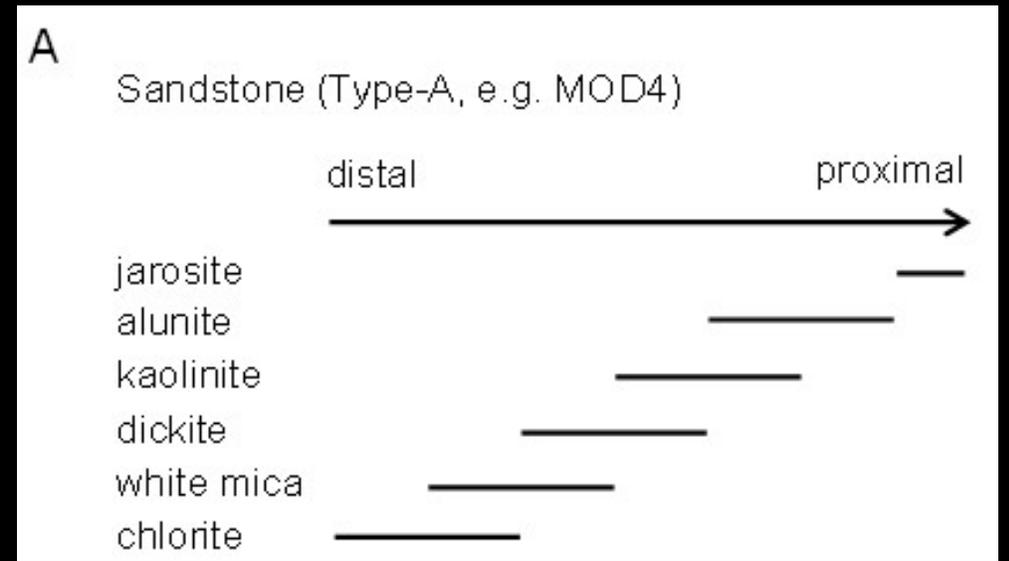
# Mineralisation Styles

Au-related mineral alteration patterns identified in common rock types at Mount Olympus

- Sandstone (Type-A, B)
- Siltstone (Bright/Black)
- Conglomerate

Potential hydrothermal minerals interpreted as:

- Na/K-alunite (proximally)
- Well-ordered kaolinite, dickite and pyrophyllite
  - (indicative of advanced argillic alteration)
- Muscovite
  - (indicative of phyllic alteration)
- Fe/Mg-chlorite and carbonate (distally)

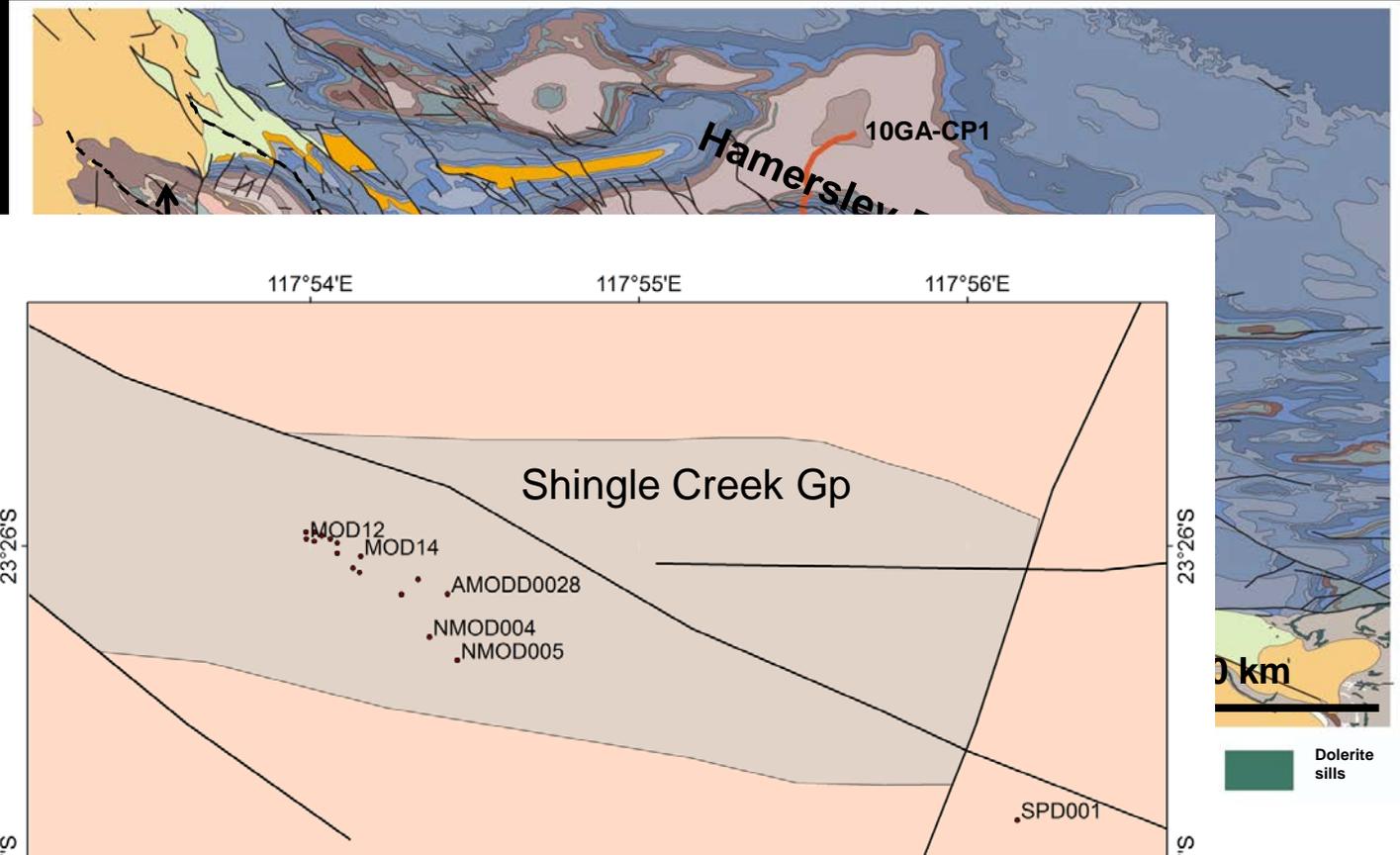


# Visualisation of Alteration Mineralogy

Deposit-scale alteration patterns

Only drill holes closest to Mt Olympus included

- 17 drill holes





# White-mica and chlorite visualisation

Al-poor white-mica proximal and shows a similar trend as Au and sulphate alteration

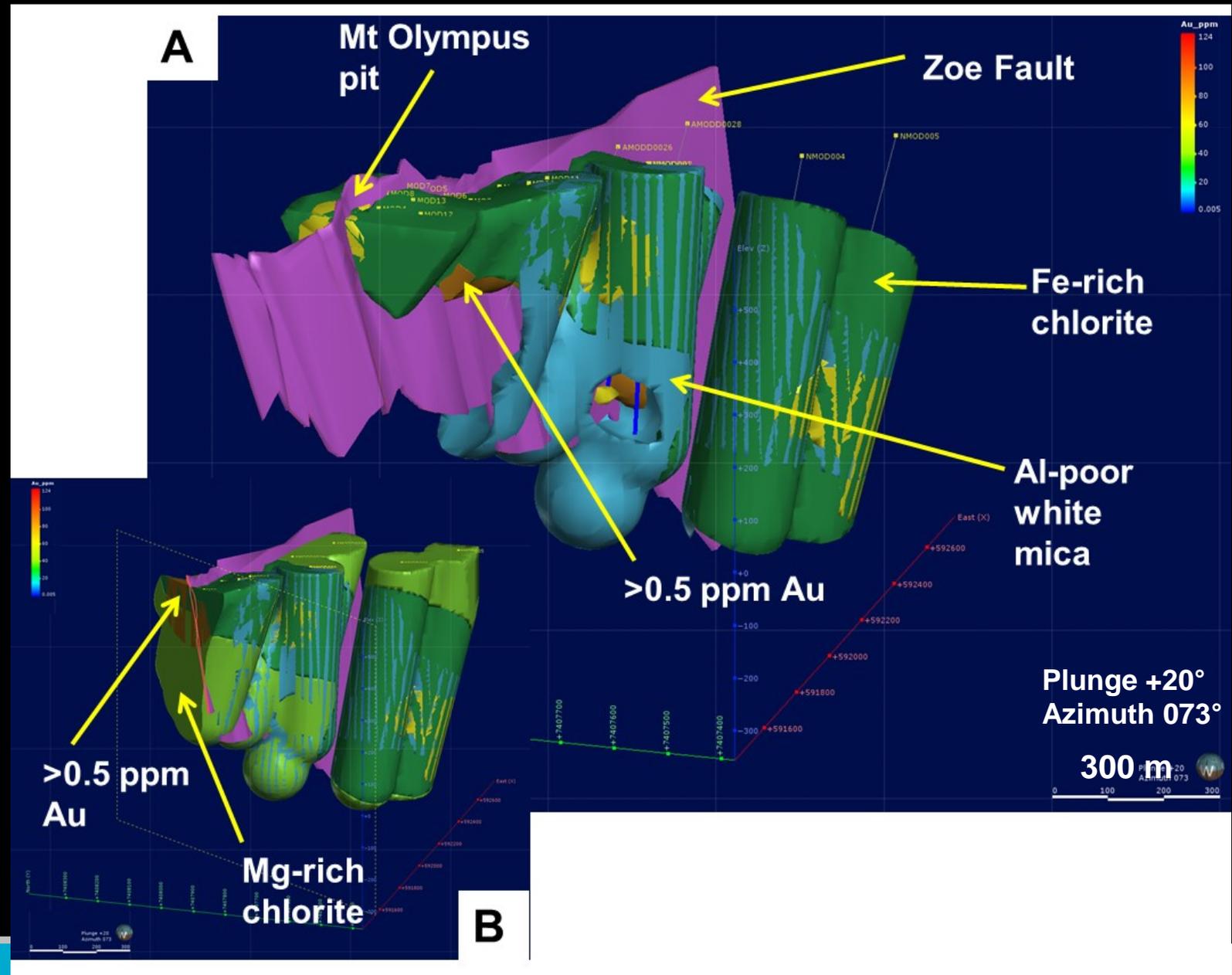
Al-rich white mica in Mt Olympus pit associated with main Au zone

Fe-rich chlorite 'envelopes' Al-poor white mica

Change to Mg-rich chlorite proximal to the largest zone of Au mineralisation

In the pit ore zone

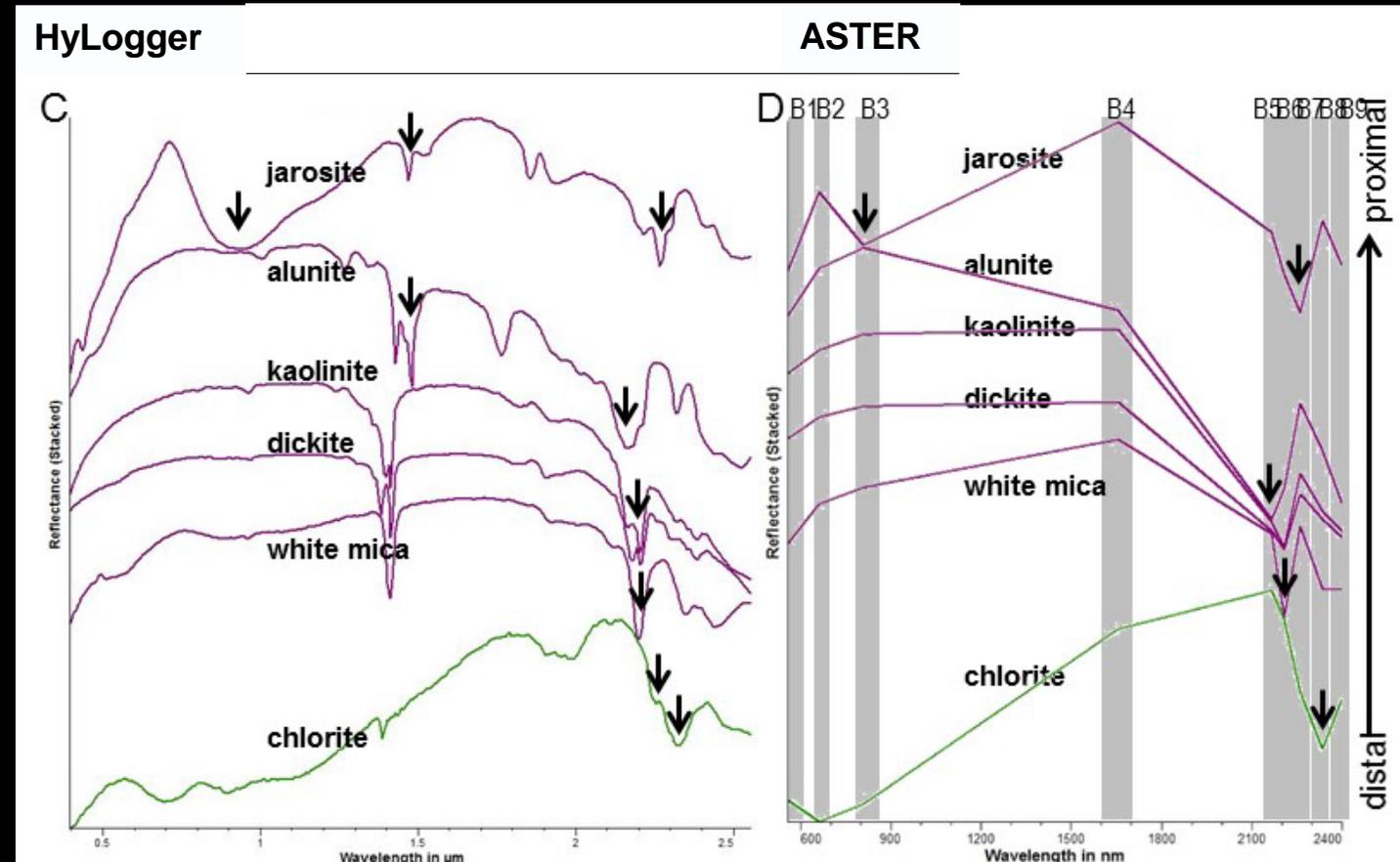
- Fe-rich chlorite in the upper part
- Underlying Mg-rich chlorite



# ASTER vs. HyLogger: Spectral Mineralogy

## Hyperspectral indicator minerals as ASTER products

- Diagnostic mineral features 'lost' in ASTER data
- 1480 nm alunite feature not detected
- Kaolin Group Index Product maps only 'Kaolinite/Alunite'
- Still 'track' white-mica and chlorite related features



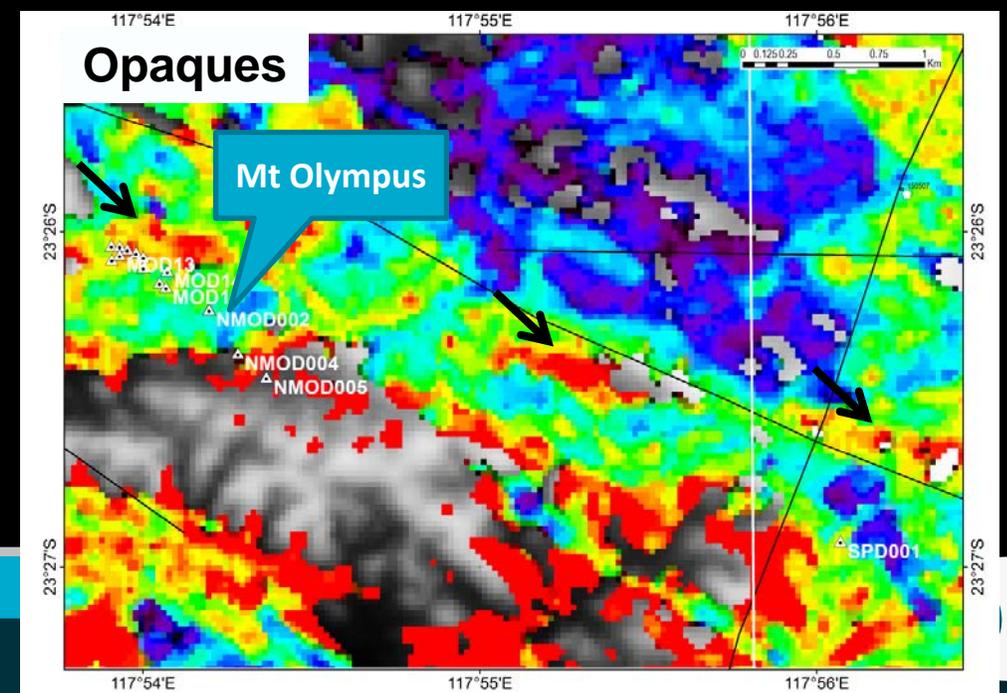
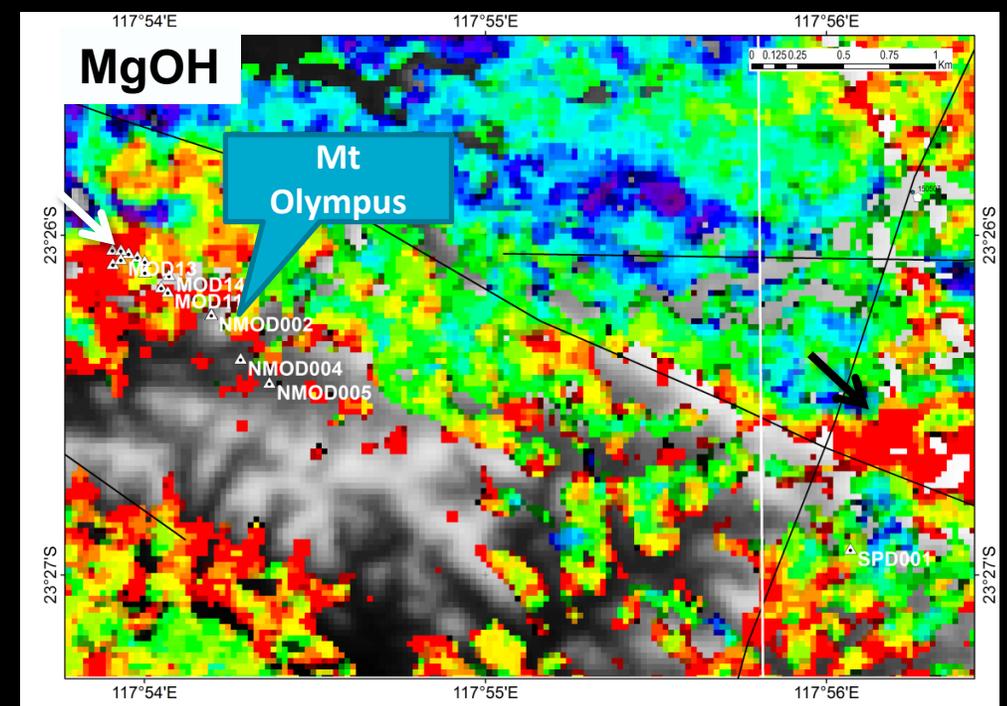
# ASTER Alteration Mapping

## Patterns in MgOH Group Content and Opaques Index

- Correlated with major structures around Mt Olympus
- Widespread, elevated MgOH content related to pervasive white mica+chlorite assemblages
- Close to joint/fault intersections (black arrow)

## Elevated Opaques Index values coincident to elevated MgOH values

- Potential occurrence of black shales, e.g., in MOD13



# ASTER vs. AEM

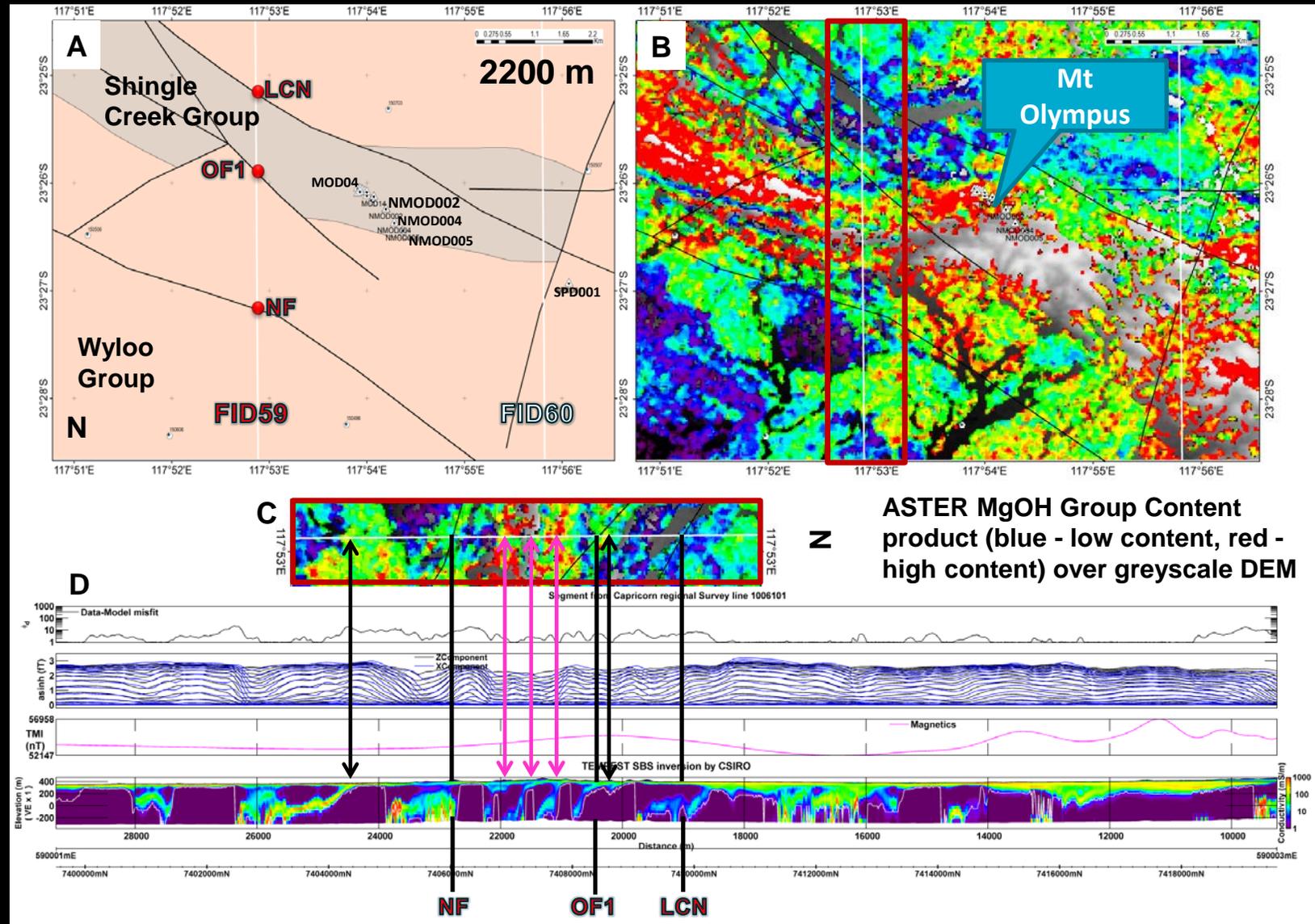
Correlating remotely sensed mineral patterns to deeper, sub-surface features

- Inversion modelling of AEM data
- FID59 Tempest line

No significant change in the MgOH Group Content along NF

- High conductivity domain (South) separated from low conductivity domain (North)

3 conductivity highs between OF1 and NF (pink arrows) continue East and West, mapped by MgOH Group Content Product



# ASTER vs. Regional Geochemistry

ASTER Silica Index, Ferric Oxide Content and AlOH Group showed coherent patterns related to distinct lithologies

South of NF, high Silica Index values may follow WNW-trending lithologies

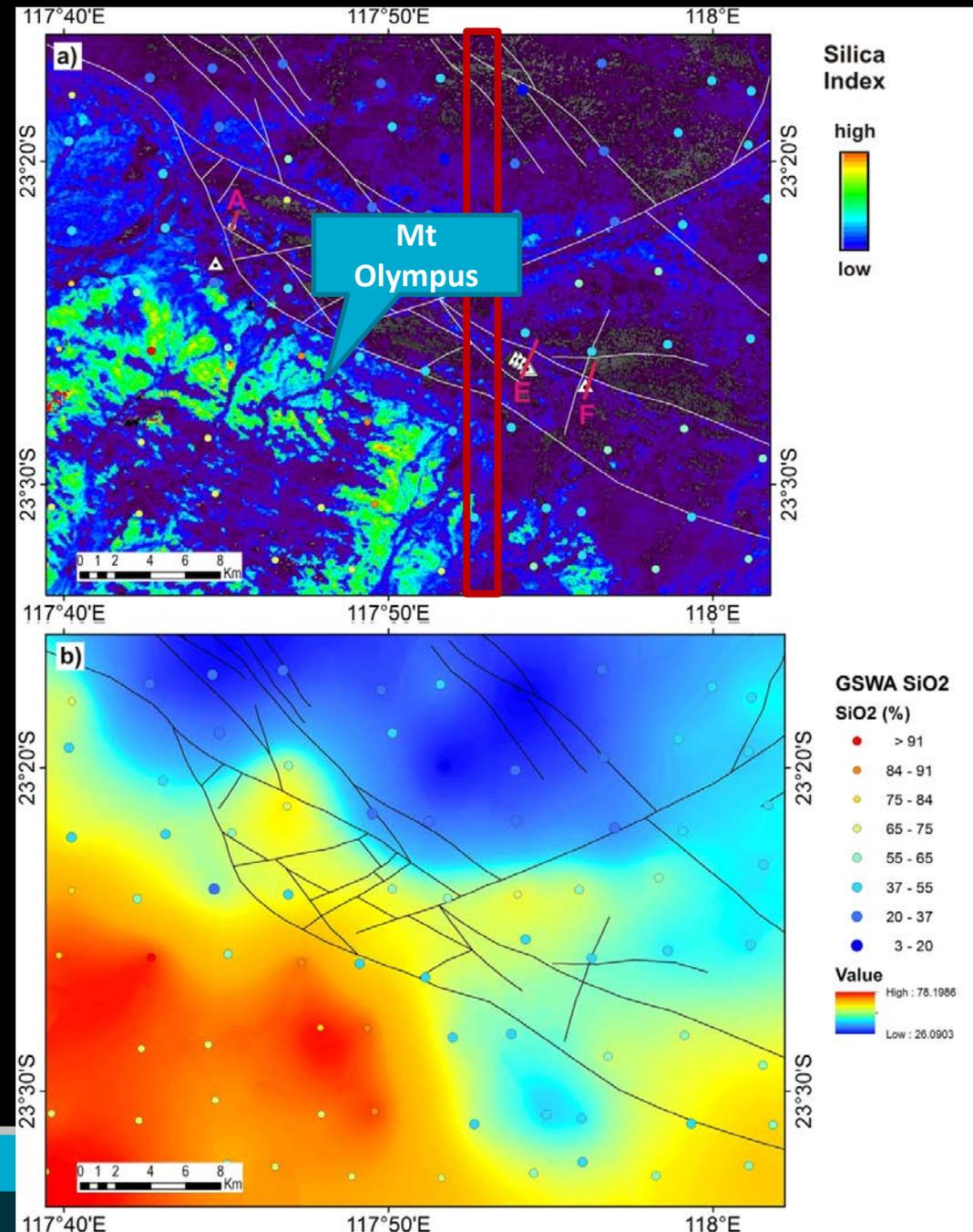
- Correlate with modelled high SiO<sub>2</sub> contents

Shingle Creek Grp, low/void of Silica Index

- Matches high MgOH/Carbonate abundances

North of NF (Hamersley Basin), low/void Silica Index values

- Correlates with modelled low SiO<sub>2</sub> contents



# Conclusions

HyLogger characterisation identified four Au-mineralisation alteration patterns

- Logged lithology and gold assay data
- Validation through XRD and compositional analyses

Potential hydrothermal alteration phases in common rock types along the Nanjilgardy Fault are:

- Na/K-alunite, kaolin (kaolinite, dickite), pyrophyllite, white mica and chlorite  
(proximal)  (distal)

New alteration mineralogy identified

- Sulfate-white mica-kaolin

# Conclusions

White mica and chlorite were widespread

- White mica has a characteristic hydrothermal spectral signature and occurs throughout alteration footprints for all mineralisation types

Chlorite abundance increased away from mineralisation

- Difficult to differentiate between regional metamorphic and later hydrothermal types

Kaolinite and dickite occurred proximally to all four mineralisation types

- Distribution restricted to certain intervals in drill cores

Jarosite probably formed during sulfide oxidation

# Conclusions

Identified small-scale hydrothermal mineral footprints (metre-decametre) in proximal (HyLogging) data

Some ASTER mineral products (MgOH Group Content), AEM data, mapped distinct, conductive, sub-surface geological domains

- Define structures (faults, lithological contacts, bedding-parallel shear zones) not previously mapped

Evidence for significant alteration zonation associated with NF not found in multispectral, remotely sensed (ASTER) data

- ASTER may not be sensitivity enough (spectrally/spatially) to detect small-scale alteration systems
- Future exploration programmes use available airborne, hyperspectral (AMS or Hymap) data or soon to be launched hyperspectral satellites (e.g. EnMAP) for detecting potential, small-scale alteration associated with large-scale structures, such as the Nanjilgardy Fault

*“Coffee time....”*

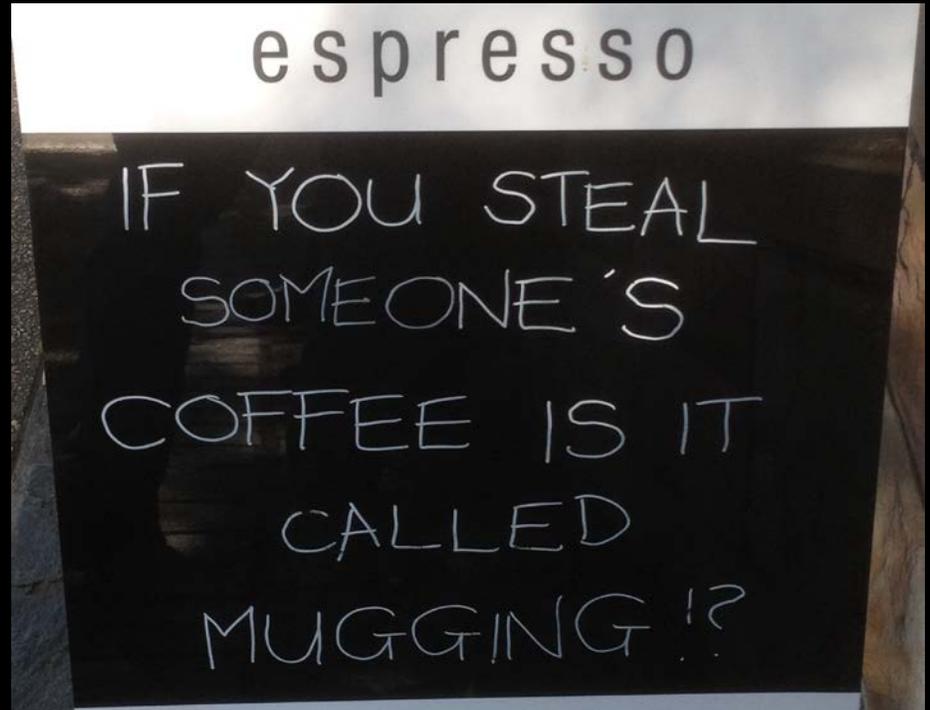
# Thank you

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# References

Johnson, S.P., Thorne, A.M., Tyler, I.M., Korsch, R.J., Kennett, B.L.N., Cutten, H.N., Goodwin, J., Blay, O., Blewett, R.S., Joly, A., Dentith, M.C., Aitken, A.R.A., Holzschuh, J., Salmon, M., Reading, A., Heinson, G., Boren, G., Ross, J., Costelloe, R.D. and Fomin, T. 2013. Crustal architecture of the Capricorn Orogen, Western Australia and associated metallogeny. *Australian Journal of Earth Sciences*, 60, 681–705.

Sener, A.K., Young, C., Groves, D.I., Krapez, B. and Fletcher, I.R. 2005. Major orogenic gold episode associated with Cordilleran-style tectonics related to the assembly of Palaeoproterozoic Australia? *Geology*, 33 (3), 225–228.

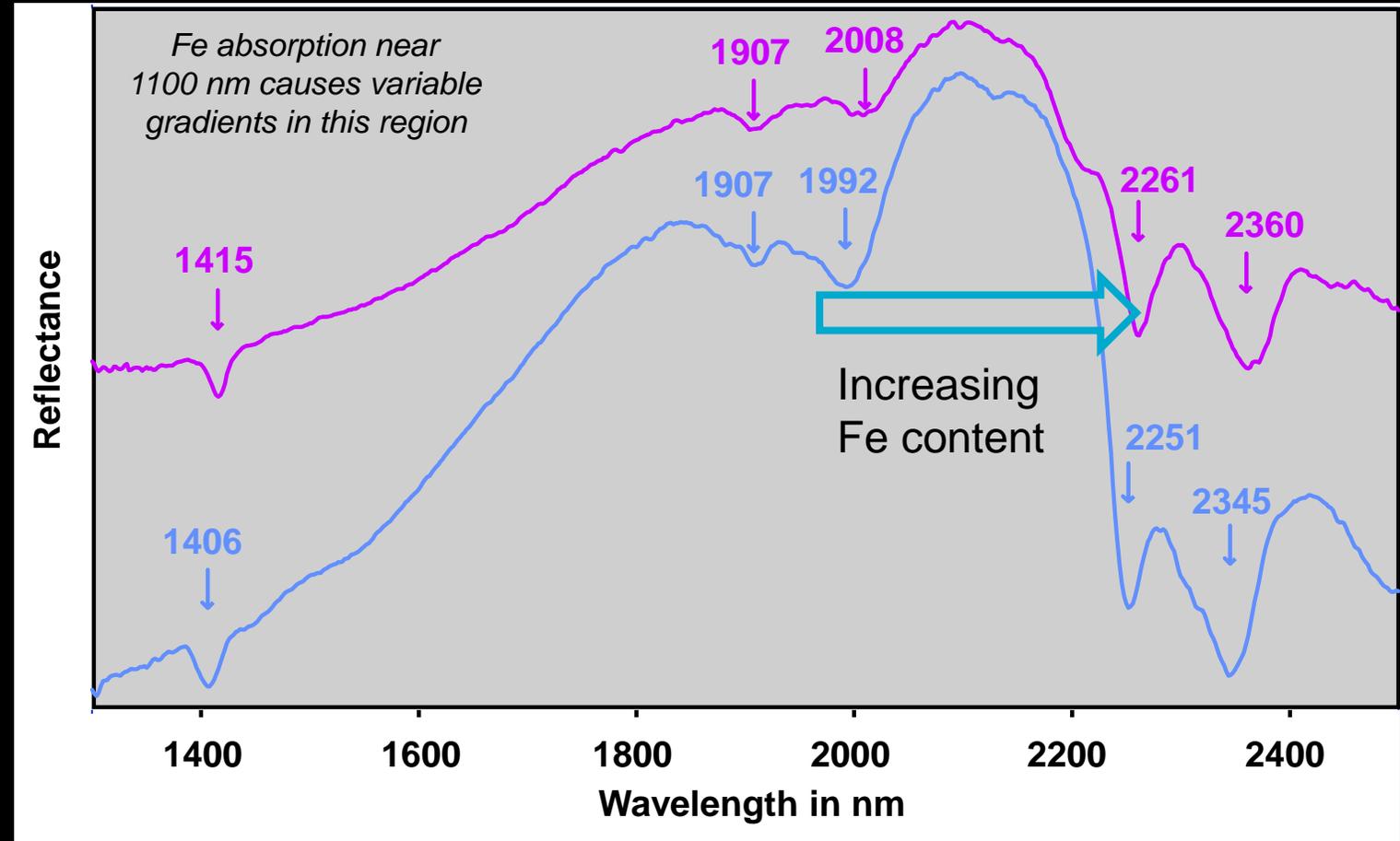
Tyler, I.M., Johnson, S.M., Thorne, A.M. and Cutten, H.N. 2011. Implications of the Capricorn deep seismic survey for mineral systems. *Capricorn Orogen seismic and magnetotelluric (MT) workshop 2011*, 115–120.

# Extra Slides

# Chlorite Spectral Chemistry

Changes in Fe:Mg ratio occur as a shift in the wavelength of the  $\approx 2250$  nm absorption feature

Chlorite absorption feature shifts to longer wavelengths as %Fe content increases



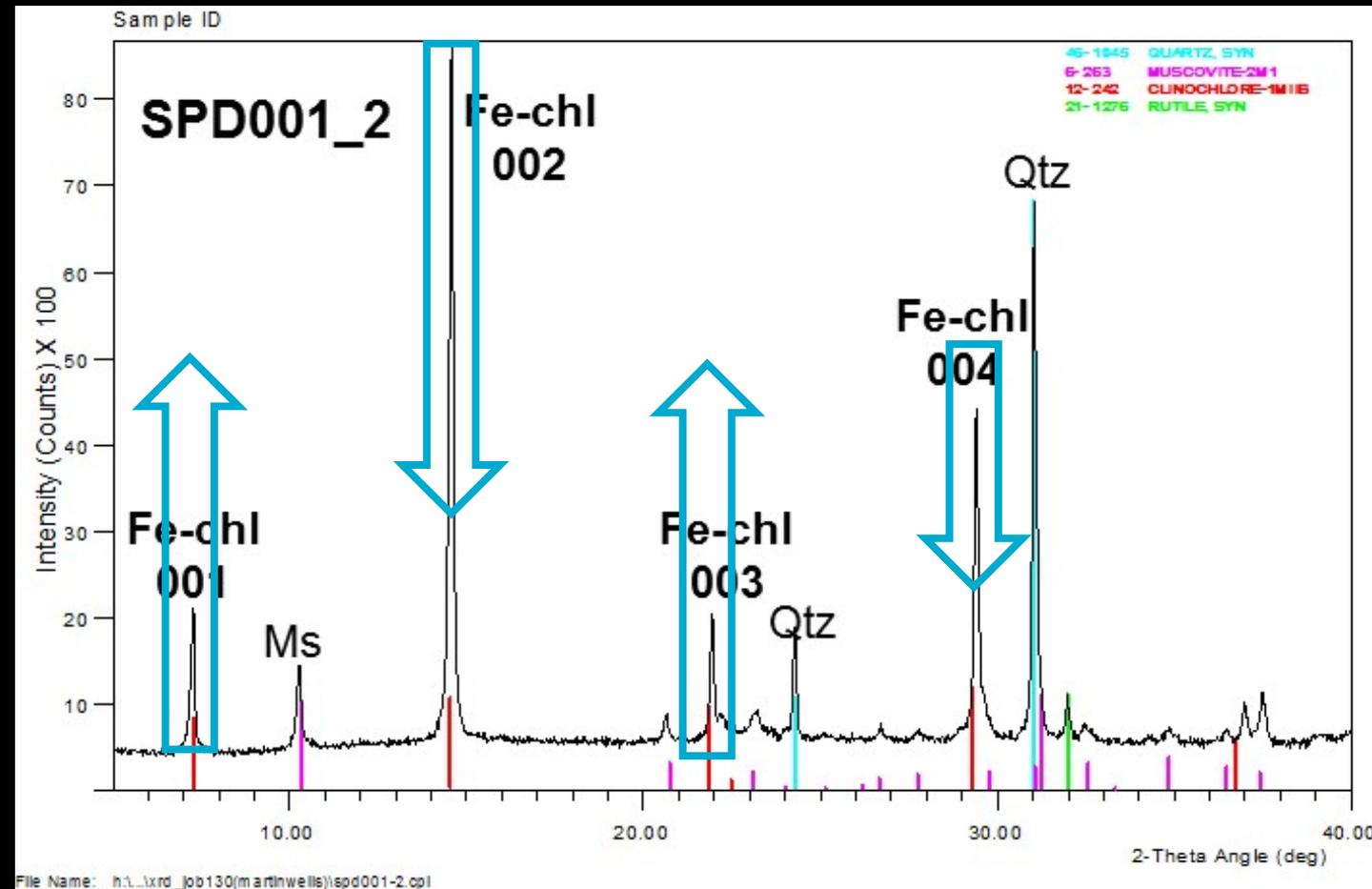
# Chlorite Chemistry: Spectral vs. XRD validation

## Influence of Fe substitution in chlorite

- Odd-numbered (001 and 003), basal peaks weaker (less intense)
- Even-numbered (002 and 004), basal peaks stronger

## With increasing Mg content

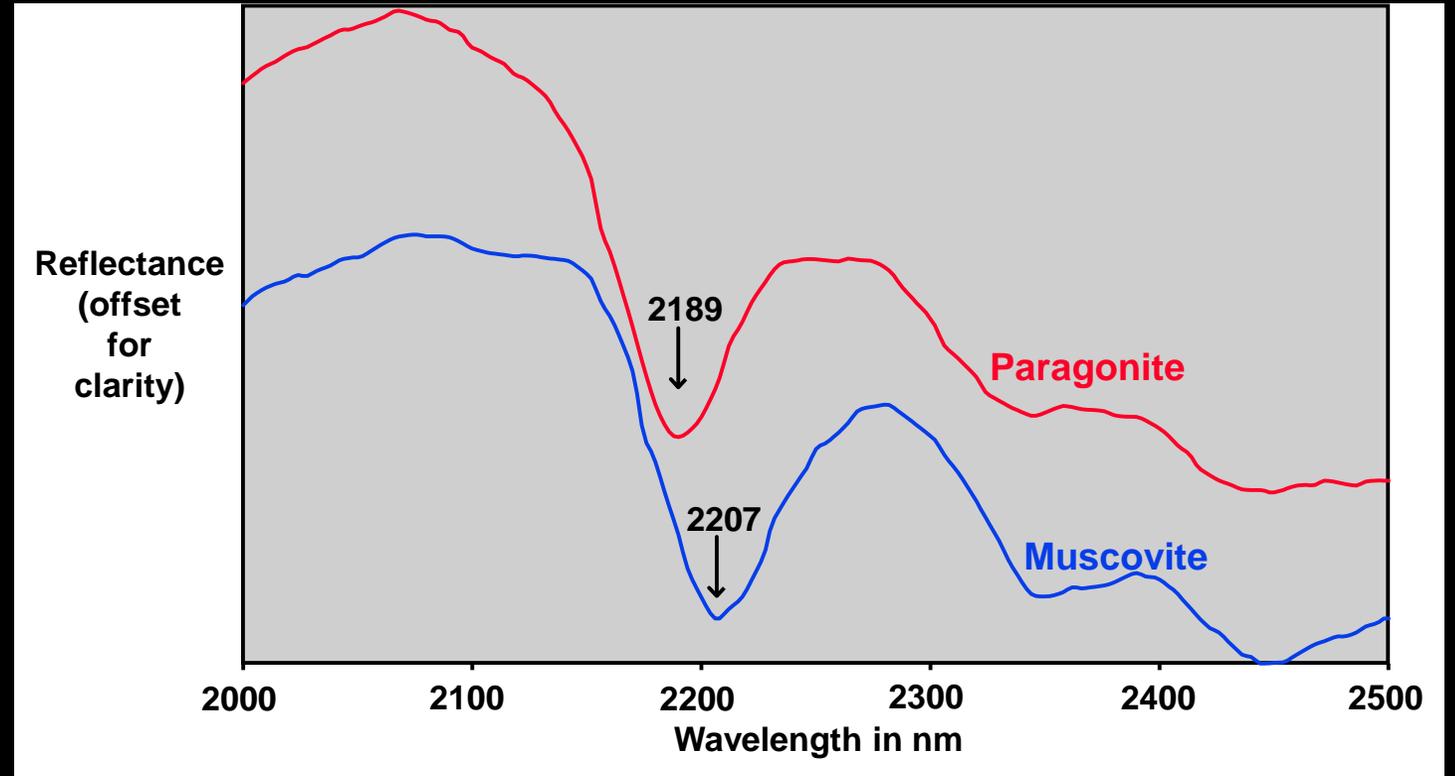
- odd-numbered peaks increase
- even-numbered peaks decrease in intensity



# Mica Chemistry: Spectral composition

Tschermak exchange in micas ( $\text{Al}^{\text{IV}}\text{Al}^{\text{VI}}\text{Si}^{\text{IV}}_{-1}(\text{Fe},\text{Mg})^{\text{VI}}_{-1}$ ) reflects hydrothermal fluid composition (e.g., T and pH conditions):

- muscovite = more acidic vs. phengite = less acidic
- muscovite = low-T recharge zones vs. phengite = high T hydrothermal fluids



Position of 2200 nm feature not related to Na-K exchange between paragonite-muscovite. Related more to decrease in  $\text{Al}^{\text{VI}}$  content with replacement by Mg/Fe:

- high-Al/low-Si micas (e.g. muscovite) to low-Al/high-Si micas (e.g. phengite)